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Computational Fluid Dynamics (CFD) Applications at the School of Architecture, University of Hawaii: Test Set-up & Prototyping of Natural Ventilation Enhancement Technologies

Task 7

Prepared For
Hawaii Natural Energy Institute

Prepared By
Sustainable Design & Consulting LLC, UH Environmental Research and Design Laboratory, UH Sea Grant College Program & HNEI

August 2015

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Project Phase 1- 7.B

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

11.2

FINAL

August 12, 2015

Prepared by:
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ERDL HNEI

Contract # N000-14-13-1-0463

Computational Fluid Dynamics (CFD) Applications at the School of Architecture, University of Hawaii

Project Phase 1 – 7.C

Task 7.C.1: Project Summary Report Phase 7.C (Phase 3)

Project Deliverable No. 11.2:

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- National Gypsum provided ten 2 feet by 4 feet 5/8 inch PCM board for test purposes. We greatly appreciate the support and would like to extend our special thanks to Mr. Michael Blades, Director, Product Development & Innovation, National Gypsum Company.

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Without the generous product support and technical guidance of these three companies the ERDL research team would have not been able to build the test set-up as it is in its final configuration (after shake down testing).

ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
clo	Clothing insulation
CFD	Computational Fluid Dynamics
ERDL	Environmental Design and Research Laboratory, University of Hawaii at Manoa
BRG	Gypsum Ceiling System
HIG	Hawaii Institute of Geophysics
HNEI	Hawaii Natural Energy Institute
HVAC	Heating, Ventilation, and Air Conditioning
met	Metabolic rate
NOAA	National Oceanic and Atmospheric Administration
OSHA	Occupational Safety & Health Administration
PCM	Phase Change Material
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied

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<u>APPENDICES</u>

EXECUTIVE SUMMARY

The present FINAL report on test set-up and prototyping of natural ventilation enhancement technologies is part of a Computational Fluid Dynamics (CFD) research program which is sponsored by the Hawaii Natural Energy Institute (HNEI). The research program endeavors to develop advanced building modeling skills at the Environmental Design and Research Laboratory (ERDL) of the School of Architecture, University of Hawaii at Manoa.

The present report, Project Deliverable 11 (e.g.11.2 FINAL), is part of Part 3 of the CFD research program. The objective of Part 3 of the research program is to investigate the use of CFD to predict occupant comfort in naturally ventilated spaces with comfort improving measures, and to provide validation of theoretical predictions with experimental studies.

The research introduces the concept of "comfort islands", which are technologies to increase thermal comfort at the occupant level in warm climates, while leaving the space basically naturally ventilated. These comfort islands lower the operative temperature in the space directly adjacent to the occupant by providing actively cooled radiant surfaces. In addition, the comfort islands have ceiling fans to lower the perceived temperature for the occupants. The research hypothesis of this research project suggests that the use of comfort islands has significant energy reductions of up to 70% compared to full space cooling and ventilation, in order to provide comfort in naturally ventilated spaces also during those times when natural ventilation alone cannot provide relieve from hot internal temperatures. The present research endeavors to verify that the basic concept of comfort islands is viable and provide experimental verification of certain heat transfer properties which are important for the overall thermal performance of radiant surfaces of comfort islands.

This FINAL report summarizes work that was performed to develop the scope of the experimental comfort investigations, including selection the test hardware, development of occupant surveys and design and install the experimental set-up in a room that serves as a temporary climate chamber. The experimental investigations of the comfort studies under Part 3 of the research program include the following types of investigations:

1. Comfort surveys: Surveys of occupants to determine the level of comfort and comfort improvement when the test person experiences different type of comfort improvement measures and a series of test parameters.

2. Convective and radiant heat transfer tests: Conducting tests of physical parameters to describe the convective and radiative heat transfer performance under different test parameter settings. These tests will be used to cross-check CFD simulations.

After considering other candidate rooms to conduct the experimental investigations, room HIG 204 was selected for the tests. Room HIG 204 is directly adjacent to the ERDL lab facilities in room HIG 205.

For the two types of experimental investigations, a test set-up had to be constructed to provide a temporary support structure for the installation of the ceiling fan, the radiant panels, the chilled water piping system and instrumentation cabling. It was decided early in the project that the radiant panels would be hung from the support structure and not installed on individual stands.

The use of radiant panels, which are operated inside a room without humidity adjustment, is an innovative approach for an energy efficient and localized comfort improvement without the need to condition the entire space. In typical applications of radiant cooling, absolute humidity is lowered to control dew point. The use of Phase Change Material (PCM) radiant panels was initially intended to provide additional benefits of heat storage to the concept of radiant cooling panels.

Scoping tests were conducted to determine the thermal characteristics of the PCM radiant panels and to verify the working conditions of the chilled water system design. The scoping tests showed that the working concept of chilled water system was adequate to provide chilled water quantities at the required quantities and temperatures. .

The scoping tests also revealed a thermal performance of the PCM radiant panels which yielded too high thermal differences between panel surfaces and chilled water temperatures. This indicated that the heat transfer between PCM panels and chilled water was not adequate for this set of investigations. The reason for the inadequate heat rejection performance of the PCM was identified as non-optimized fusion of PCM panels and heat transfer rails through which the chilled water flow occurred (the team glued the heat rejection aluminum rails to the back side of the PCM board). The low heat transfer rate between PCM board and chilled water flow was seen as a major problem for the comfort tests, where the main objective of the radiant surfaces is to provide sufficiently cold enough radiant panel temperatures, to improve comfort. The unique capacity of the PCM boards of offering a large thermal mass was thereby deemed secondary to the need to create low enough surface temperatures of the radiant panels.

For these reasons it was decided to use regular aluminum ceiling radiant panels for the experimental comfort tests in the climate chamber, in lieu of the PCM boards. The aluminum panels have thermal properties, such as small approach temperature and reaction time to cooling, which makes them a better choice to conduct the present tests.

It is planned, however, to utilize the PCM panels in future investigation. For future PCM applications, heat transfer performance could be optimized by the installation of the heat rejection part on the PCM under optimum manufacturing conditions, e.g. by the vendor and not the research team.

The efforts to optimize the thermal and hydraulic performance of the test set-up from the configuration used during the scoping test to the final successful shake down testing have been substantial. The improvements and fine-tuning of the chilled water generation and conveyance through the actively cooled radiant panels took several stages and iterations.

The installation and development of data acquisition procedures for more than 60 temperature, flow and other measurement / sensor points represented a major milestone for the team.

One of the challenges of operating the chilled water system is the need to manually operate the thermal and hydraulic system components, since an automated process control, which was planned at the beginning, was too complex for the scope and funding of the research project. The research team, however, has succeeded in keeping the test set-up in a thermal state for durations that are equal to the intended sittings of human test subjects. The team determined that the test set-up is ready for the experimental human comfort tests.

Since one of the main objectives of this research program was to provide educational opportunities to develop experimental work skills for students, we can only state that this objective has been successfully met.

PREFACE - HYPOTHESIS OF COMFORT ISLANDS AND OBJECTIVES OF EXPERIMENTAL INVESTIGATIONS

This section presents the hypothesis of significant energy savings for space conditioning through the use of "comfort islands", which can provide a level of occupant comfort in naturally ventilated spaces without the need to cool and ventilate the entire space by mechanical units. This section also describes the objective of Part 3 of the research project to verify the assumed thermal performance parameters of system components of "comfort islands" in order to verify the hypothesis.

A - Hypothesis of Comfort Islands and Anticipated Equipment Performance

The basic premise of "comfort islands" in the context of this investigation is that energy advantages of naturally ventilated spaces can be achieved, while satisfactory comfort is provided at the occupant level with the minimum amount of energy needs. Naturally ventilated spaces have the advantage to save significant amounts of energy in comparisons to energy intensive HVAC space conditioning. The disadvantage of naturally ventilated spaces is their lack of ability to provide a certain level of thermal comfort and ventilation at all times. Natural ventilation follows outdoor environmental thermal and humidity conditions, which can change significantly over time. Natural ventilation is dependent on a minimum wind movement which represents the driving force for space ventilation, and wind is by nature intermittent.

In order to give natural ventilation a more attractive appeal to building designers, comfort standards have been developed that take into account that occupants of naturally ventilated space react differently to thermal comfort conditions than occupants of fully conditioned spaces. The approach of "adaptive comfort" correlates the level of thermal discomfort a person can tolerate on the basis of the long term exposure of the occupant to either cold or warm weather. In essence, adaptive comfort defines that occupants living in a warm climate can tolerate higher internal operative temperatures than occupants who are used to colder climates. Adaptive comfort raises the allowable internal operative temperature while still staying within a prescribed range of occupant acceptance, i.e. 80% of 90% acceptance of internal conditions. Depending on the site and type of building, there are periods when thermal conditions in naturally ventilated spaces surpass temperatures that are deemed tolerable even under adaptive comfort standards. If periods outside the adaptive comfort zone are occurring too often the validity if the natural ventilation conditioning approach can be called into question. Therefore measures to assist the natural ventilation process providing a satisfactory basic comfort level all the time can add significant value to rely on natural ventilation.

The basic working scheme of "comfort islands" is providing additional, yet localized, thermal comfort mitigation measures. Rather than providing comfort throughout the entire space by means of energy intensive HVAC, comfort islands provide comfort to occupants where they carry out their work within the space. In essence, comfort islands provide comfort where is matters most, at the level of occupants.

Spaces with comfort islands combine advantages of conditioned and naturally ventilated spaces. They provide a certain level of comfort through energy efficient localized cooling, when natural ventilation alone cannot provide basic levels of comfort and space ventilation.

Figures A-1 through A-3 describe the basic thermal balance and working principle of three types of space conditioning. Table A-1 describes the parameters for heat and mass balance used in Figures A-1 through A-3.

Table A-1: Parameters used in Figures A-1 through A-3

Term ID	**Description**	**Heat flux**	
		sensible	latent
Q_{IN-ENV}	Heat intake through envelope; include solar gain through openings	Yes	No
Q_{IN-AIR}	Heat intake through air entering the space	Yes	Yes
$Q_{OUT-AIR}$	Heat discharged from space by air leaving the space	Yes	Yes
Q_{EQUIPM}	Internal heat gain from equipment;	Yes	No
$Q_{OCCUPNT}$	Internal heat gain from occupants	Yes	Yes
Q_{OUT}	Heat rejected from space by HVAC system; sensible and latent heat	Yes	Yes

Term ID	**Description**
Air_{IN}	Outside air entering the space
Air_{OUT}	Air leaving the space; or air discharged from space by mechanical ventilation

Figure A-1 illustrates the heat and mass balance of a generic naturally ventilated space. The indoor thermal conditions are determined by the exterior and interior heat gain and the ability of the air flow leaving the space to reject heat to the outside. The humidity inside the space is established by the humidity entering the space with the intake air and the internal humidity gain. Under steady state, the heat gain and loss as well as the mass flow entering and leaving the space is equal.

Figure A-2 illustrates the heat and mass balance of a generic space with full HVAC. The indoor thermal conditions, e.g. operative temperature, humidity and ventilation, are controlled by the HVAC system and these comfort conditions are kept within a predetermined range at all times. Under steady state the heat gain and loss as well as the mass flow entering and leaving the space has to equal.

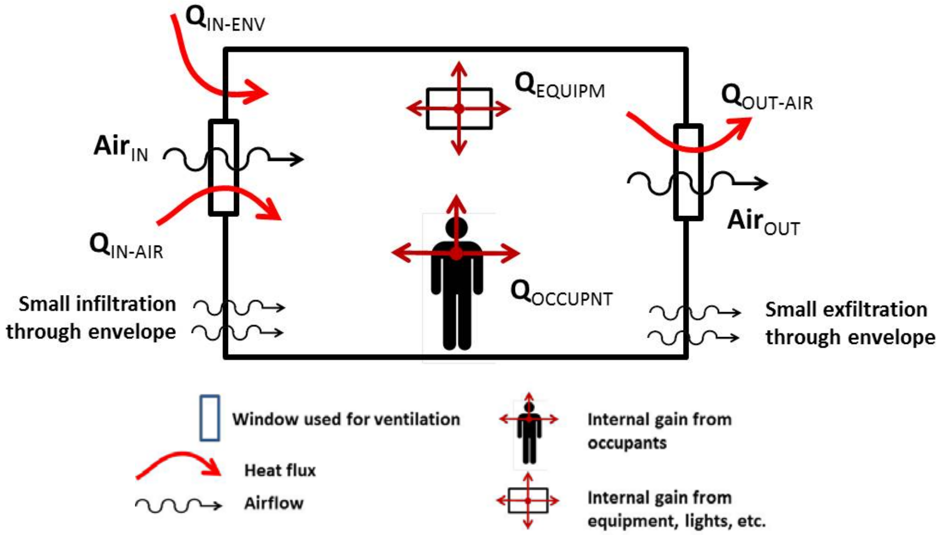

Figure A-1: Basic heat and mass balance of a generic naturally ventilated space

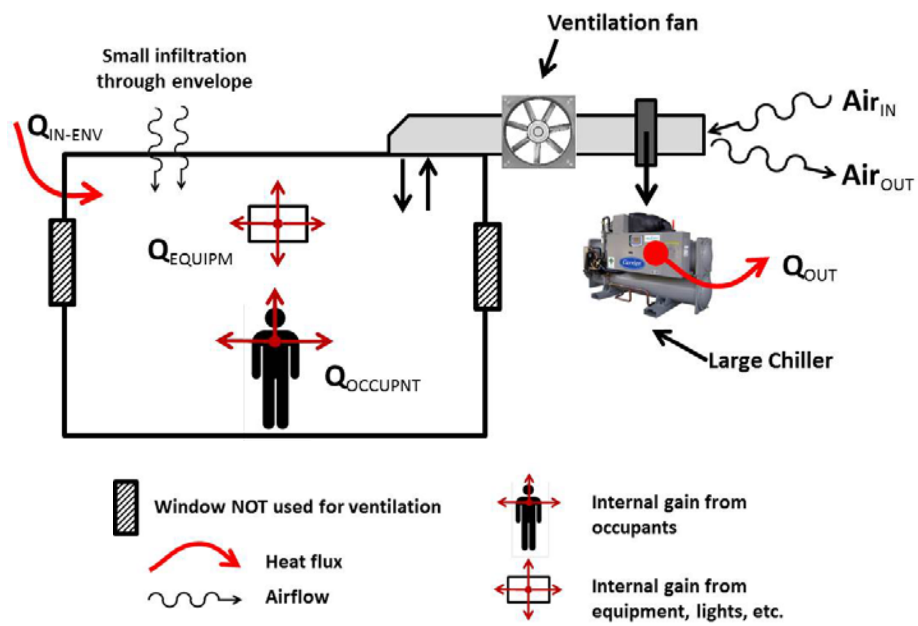

Figure A-2: Basic heat and mass balance of a generic space with full air conditioning

Figure A-3 illustrates the heat and mass balance of a generic space with comfort islands. The air temperature and humidity level in the entire space are similar to the naturally ventilated space, they are NOT controlled by a central HVAC system. In the depicted working scheme of Figure A-3 mechanical assist ventilation provides required outdoor air supply during periods of insufficient wind conditions and therefore insufficient natural ventilation rates. Ceiling fans provide increased air flow velocities over the occupants. The ceiling fans do not alter, however, the heat and mass balance of the entire space. The sole function of the ceiling fans is to lower the perceived ambient temperature of the occupants. The radiant cooling surfaces provide localized cooling and lower the operative temperatures at the occupant level.

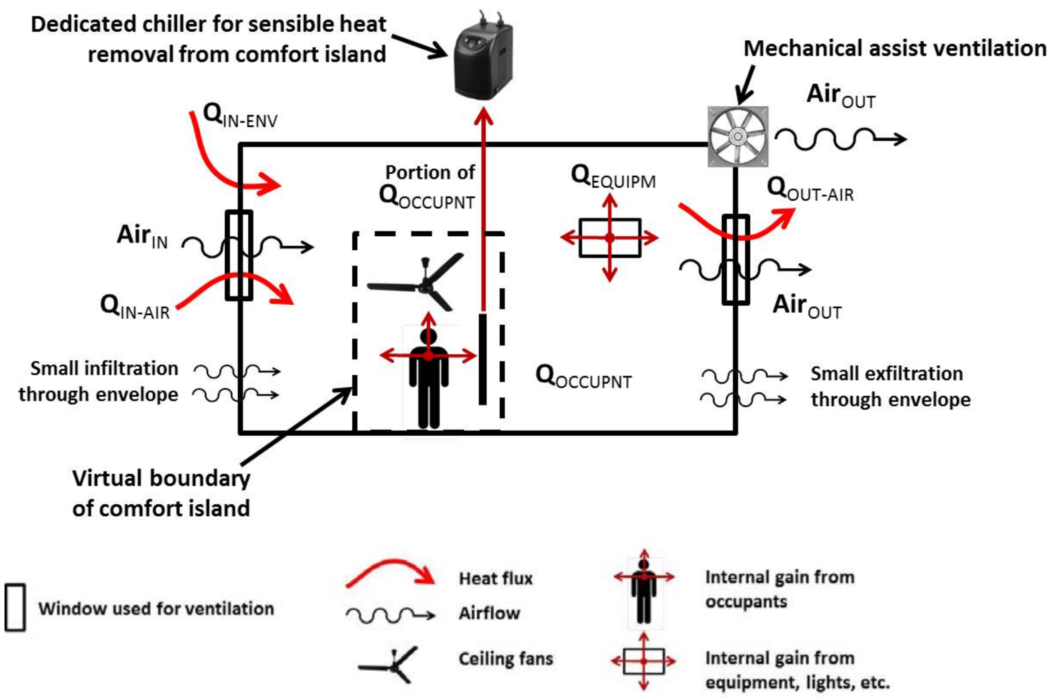

Figure A-3: Basic heat and mass balance of a generic space with comfort islands

The working schemes of the three types of space conditioning, e.g. natural ventilation, HVAC and naturally ventilated spaces with comfort islands is describes in Tables A-2 and A-3.

Table A-2: Comparison of working schemes of the three types of space conditioning

Type of space condition / properties that control thermal comfort	**Natural Ventilation**	**Full Space Conditioning**	**With Comfort Islands**
Control of air temperature in entire space	None; inside air temperatures is regulated by outside environmental conditions and internal loads.	Fully controlled; air temperature can be controlled by HVAC system.	Limited; inside air temperatures is regulated by outside environmental conditions and internal loads. (mechanical assist ventilation can mitigate some high internal temperatures)
Control of radiant temperatures in entire space	Very limited; inside radiant temperatures are regulated by convective heat transfer mechanisms; local elevated radiant temperatures from internal loads can be mitigated with effective internal ventilation pathways.	Fully controlled; inside radiant temperatures are regulated by convective heat transfer mechanisms	Limited; inside radiant temperatures are regulated by convective heat transfer mechanisms; local elevated radiant temperatures from internal loads can be mitigated with effective internal ventilation pathways (or mechanical assist ventilation)
Control of humidity levels in entire space	None; inside humidity level is regulated by outside environmental conditions and internal loads.	Fully controlled; air temperature can be controlled by HVAC system.	None; inside humidity level is regulated by outside environmental conditions and internal loads. (high internal humidity loads can be mitigated through increased air flow from mechanical assist ventilation).

Table A-2: Comparison of working schemes of the three types of space conditioning

Type of space condition / properties that control thermal comfort	Natural Ventilation	Full Space Conditioning	With Comfort Islands
Control of radiant temperatures at occupant level	None: inside air temperatures is regulated by outside environmental conditions and internal loads.	Fully controlled; air temperature can be controlled by HVAC system.	Controlled: Radiant temperatures at the occupant level lowered by actively cooled partition walls.

Table A-3: Comparison of comfort perceptions of the three types of space conditioning

Type of comfort perception and improvement measures	Natural Ventilation	Full Space Conditioning	With Comfort Islands
Thermal comfort perceptions by occupants	Occupant experience contact to natural environment through controlled openings; additional impacts from internal loads. Local variations of comfort due to changing ventilation efficiency.	Occupants are basically experiencing a controlled internal environment in the entire room provided by the HVAC systems. Localized difference in thermal comfort might occur due to uneven introduction of cold air.	Occupants are experiencing two levels of comfort; (1) the comfort level that is established in the entire room, and (2) comfort level that is established at the comfort islands.
Comfort improvement measures	The options are very limited since all space condition is all passive	The HVAC system can be optimized by appropriate settings at the space and occupant level.	Comfort conditions can be improved in two ways, (1) by providing sufficient ventilation levels at all time through the mechanical assist ventilation, and (2) through providing increased air flow over the occupants and lower surfaces close to the occupants

Table A-4 illustrates the energy performance of the three types of space conditioning. Generic assumptions of energy demands are considered for the assessment. It is obvious that the actual energy demand for space conditioning depends on site, technology and operation specific situations.

The energy demands of the four space conditioning depicted are relative to the full HVAC system, this means that 100% energy demand represents the full HVAC system energy demand. The distinction between “unit” and “overall” energy demand refers to the percentage required by the heat rejection or ventilation function and the total energy demand for all space condition functions, respectively.

<u>Type A - Naturally ventilated space:</u> There is no energy demand for space condition.

<u>Type B - HVAC conditioned space:</u> The following assumptions are used:

- 100 % of energy used for mechanical space ventilation represents 20% of total HVAC energy demand.
- 100 % of energy used for sensible cooling represents 48 % of total HVAC energy demand.
- 100 % of energy used for latent cooling represents 32% of total HVAC energy demand.

<u>Type C - Naturally ventilated space with Comfort Island:</u> It is assumed that 35% of the typical HVAC energy demand for sensible cooling is required; this equals 17% of total energy.

<u>Type D - Naturally ventilated space with Comfort Island – and mechanical assist ventilation:</u> In addition to the same 17% sensible cooling load, assumed for type C, 35% of the typical HVAC energy for ventilation is assumes. The 35% for space ventilation could be deduced from percentage of exceedance chart created by an internal CFD investigation.

The comparative assessment suggests that energy savings relative to full HVAC for naturally ventilated space with comfort island alone and with additional mechanical assist ventilation as an additional option could be significant and surpass **80% and 70%,** respectively.

Table A-4: Projected energy savings for different types of space ventilation and cooling

	Type of space conditioning and applied technology							
	A		B		C		D	
Description of energy service for function of conditioning	**Naturally ventilated space** Energy expenditures		**HVAC conditioned space** Energy expenditures		Naturally ventilated space with **comfort island** Energy expenditures		Naturally ventilated space with **comfort island – and mechanical assist ventilation** Energy expenditures	
	Unit %	Overall %	Unit %	Overall %	Unit %	Overall %	Unit %	Overall %
Energy demand on level of entire space:								
Energy for space ventilation	0%	0%	100%	**20%**	0%	0%	**35%**	7%
Energy for sensible heat removal	0%	0%	100%	**48%**	0%	0%	0%	0%
Energy for latent heat removal	0%	0%	100%	**32%**	0%	0%	0%	0%
Total energy demand on space level >>>		**0%**		**100%**		**0%**		**7%**
Energy demand on level of occupant:								
Energy for sensible heat removal	N/A	N/A	N/A	N/A	**35%**	17%	**35%**	17%
Energy for latent heat removal	N/A	N/A	N/A	N/A	0%	0%	0%	0%
Total energy demand on space level >>>		**0%**		**0%**		**17%**		**17%**
Total energy used to provide comfort in space >>>		**0%**		**100%**		**17%**		**24%**
Energy saved relative to full space conditioning >>>		**100%**		**0%**		**83%**		**76%**

Note:
Unit % of energy expenditures indicates that x% of energy has to be spend relative to this specific heat removal function.
Overall % of energy expenditures indicates that x% of energy has to be spend relative to the total energy.
All values are relative to the energy demands of a full space conditioning.

B - Objectives of Experimental Investigations

The main objective of the experimental investigations is to verify assumptions of system part performance relative to their heat rejection efficiency and their ability of achieving comfort levels.

Part 3 of the research program includes the installation and operation of certain prototypes of comfort improvement measures and assessment of their performance.

This FINAL report presents pertinent information about the following points:

1. Provide a brief review of the mechanisms under which comfort is provided to occupants and how it is measured in qualitative and quantitative ways.
2. Describe the scope of investigation carried out under Part 3 of the research program
3. Identify technology options that were investigated and selected for the prototype installation.
4. Describe the instrumentation and method of data acquisition used in the tests and measurements.
5. Describe the test site and design of the prototype installations
6. Present the preliminary test plan for testing physical performance parameters of the comfort measures. (Note: The test plan for the comfort studies with test subjects is still in a preliminary state and will be finalized before start of the human comfort tests).

SECTION 1 - APPROACH FOR PRESENT COMFORT STUDIES

This section provides a brief description about how comfort is experienced by building occupants and how the levels are quantified.

1.1 Basic Considerations of Human Thermal Comfort

Thermal discomfort is described as the absence of mechanisms that provide sufficient heat transfer to the environment. In a cold climate, this means that the human body loses more heat that can be created by metabolic activities. In a hot climate, this means that the human body cannot reject enough heat to keep the heat balance of the body within a preferable range. Since the investigations conducted under this research program are concerned with achieving thermal comfort in naturally ventilated spaces in a hot and humid climate, only mechanisms of heat rejection from the human body are considered.

In terms of heat energy, or heat as we refer it in the following, the human body constantly achieves equalization of its heat balance. A balanced heat condition is achieved if the sum of heat inflow, outflow and generation is zero. Figure 1.1.1 illustrates the simplified heat balance and also indicates average amounts of rate of heat that is generated by human body in the course of different physical activities. In the case of office work the heat output of humans is around 120 watts. This is an average thermal power output and predicted heat rates for different activities vary slightly.

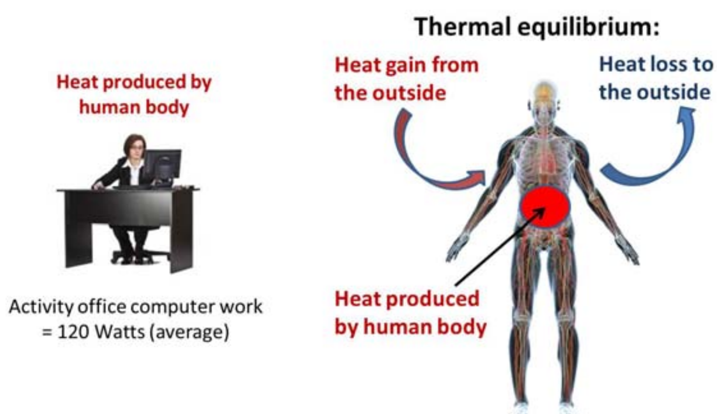

Figure 1.1.1: Heat generated by the human body and a basic illustration of thermal equilibrium

There are several mechanisms available to the human body to reject heat to the outside environment. This means that the human body has several physical processes available to regulate body temperature within an acceptable range. We consider four mechanisms since they are relevant to the mitigation measures that the project team has identified. The four mechanisms are illustrated in Figure 1.1.2 and are briefly summarized in the following.

In warm climates, the human body has to continuously lose (reject) body heat to the environment to maintain thermal equilibrium

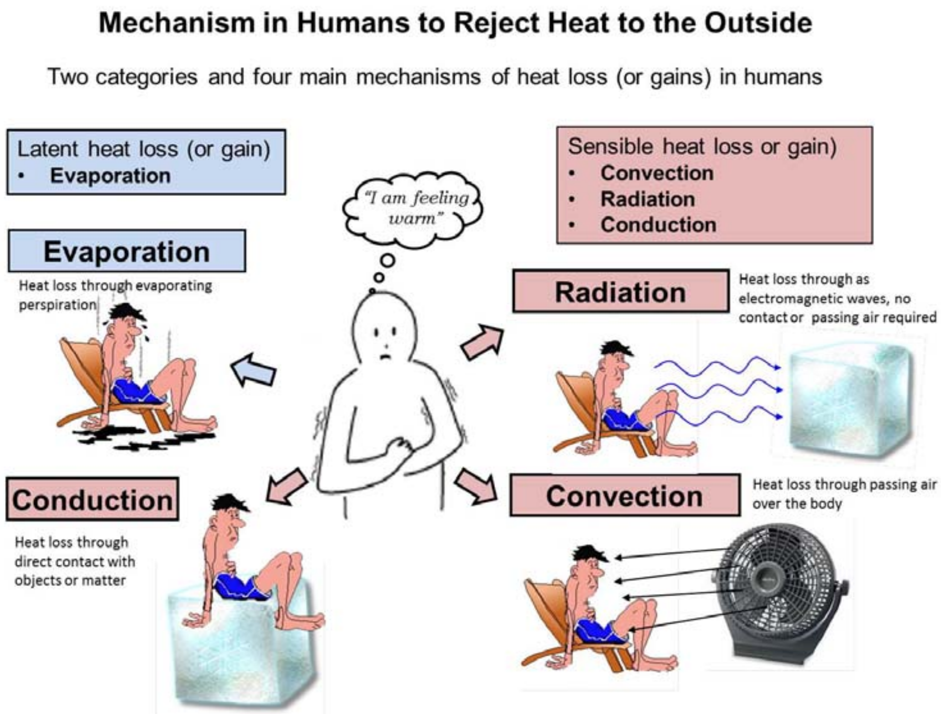

Figure 1.1.2: Two categories and four main mechanisms of how the human body loses heat to the outside environment:

The two main categories are <u>sensible and latent heat loss</u>. Sensible refers to changes in heat that we can "sense" such as measuring with a thermometer. This means the loss of heat energy goes hand-in-hand with a drop in temperature of an object that rejects heat. In latent heat loss the temperature of the object does not change since heat is used to create a phase change, e.g. evaporation of perspiration, or water, from the surface of the body.

Sensible heat loss mechanisms include convection, radiation and conduction and latent heat loss is evaporation. For all sensible heat loss processes the heat always flows from the warmer to the colder objects. The heat transfer rate is a function of the temperature difference between the body and the ambient air.

Sensible heat loss through convection: Under this process air is passing over the skin and heat is transferred to the passing air. The colder the air the more heat can be rejected from the body to the outside. The faster the air passes by the skin, even at the same air temperature, the more heat can be transferred, since the film resistance around the skin is reduced by the higher air speed.

Sensible heat loss through radiation: Under this process the body radiates heat energy to colder adjacent objects. The heat loss occurs through electromagnetic waves, the body basically “lights” up objects which have a lower surface temperature. The objects and body must be in line of sight to each other. The rate of heat radiated to objects depends on the value of temperature difference between the body and the receiving objects, the relative orientation of the body and object, and the size of the object. It is important to remember that radiative heat loss happens at the speed of light (e.g. the speed of electromagnetic waves).

Sensible heat loss through conduction: Under this process the body losses heat energy through direct contact with a colder object or matter, which can be solid, liquid or gaseous. The rate of heat energy exchanged between the body and colder objects depends on the temperature difference and the overall resistance of materials to the conduction of heat through it.

Latent heat loss through evaporation: Under this process the body losses heat energy through evaporating water on the skin. The rate of heat loss is dependent on the amount of water that is evaporated, which in turn is dependent on the relative humidity of the ambient air and other factors such as air speed over the skin. Increase air speed significantly increases the amount of evaporation.

The human body has the unique ability to use all heat transfer mechanisms in a combination that is most suitable, depending on the prevailing outside environmental conditions. There are many reasons why heat loss through touching cold objects or matters is not considered, and in conventional cooling technology only three heat transfer mechanisms are considered significant: **convection; radiation and evaporation**. There is a combination of heat transfer processes which have been identified for conditioned spaces that the human body prefers. Figure 1.1.3 illustrated the percentage of total in heat loss which is a “preferred” way to lose heat. The preferred combination in Figure 1.1.3 suggests that radiative heat loss is the most preferred process for humans to lose heat to the environment, followed by convection and evaporation.

It should be pointed out that the preferred combination of heat loss mechanisms presented in Figure 1.1.3 is guidance for establishing good cooling performance in conditioned spaces and not necessarily for naturally conditioned spaces. In naturally conditioned spaces and in humid climates the portion of heat rejection through evaporation is significantly higher that suggested in Figure 1.1.4.

In naturally ventilated spaces, no mechanical or other cooling processes take place that establish favorable internal environmental conditions. The air inside the space closely follows the conditions of the outside air, which has elevated temperatures and relative humidity levels. In the absence of conditioning and cooling the space with mechanical means, the preferred heat loss mechanisms suggested in Figure 1.1.3 cannot not be attained, and thus the overall heat loss uses a combination of heat transfer processes that are most effective under the conditions of natural ventilation. Figure 1.1.4 shows that at higher air temperatures, the primary heat loss mechanism shifts from sensible to latent heat loss. This means that at higher temperatures the body needs to reject heat energy more and more through perspiration. High humidity levels are impeding heat loss through evaporation. Higher air velocities of body can increase the amount of evaporation.

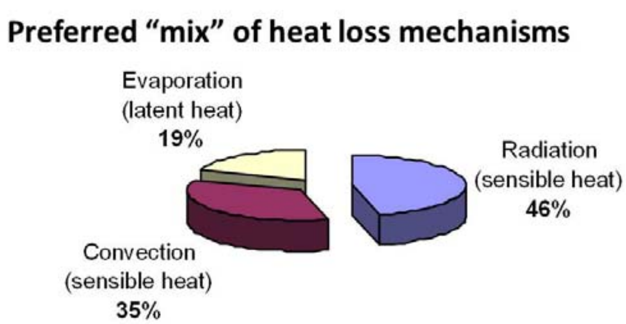

Figure 1.1.3: Average combination of convection, radiation and evaporation that is perceived as preferred by human beings (has been establish for conditioned spaces)

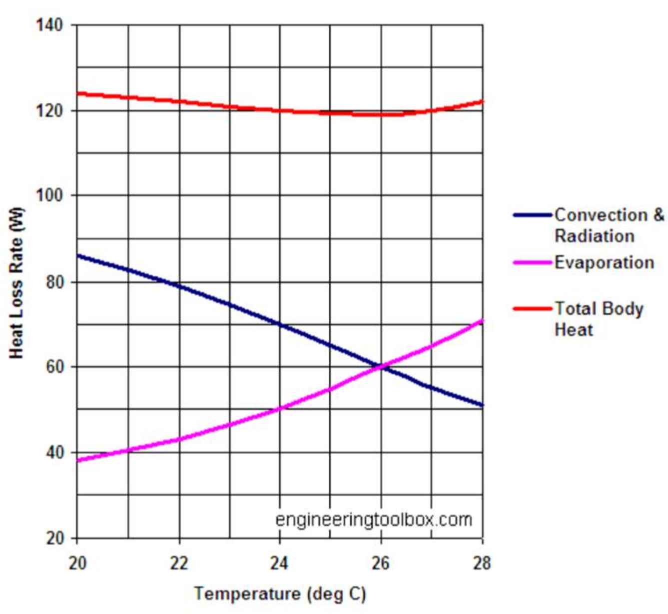

Figure 3.2.4: Contribution of sensible (convection and radiation) heat loss and latent heat loss (evaporation) to the total heat loss in humans. Note that above approximately 26°C (79F) the major portion of heat loss comes from evaporation *(source engineeringtollbox.com). These relationships have been developed for conditioned spaces.*

1.2 Standards to Quantify Comfort

The experience of thermal comfort happens on an individual level, and two occupants in a room with the same thermal conditions can feel different about whether it feels too warm or cold to them or if they do not perceive any thermal sensation at all. Standards have been developed to provide objective criteria of how a human will most likely experience thermal comfort. All of the relevant standards use six physics parameters that describe the predicted comfort level and provide a quantitative description. Figure 1.2.1 illustrates the six physical parameters. The parameters are furthermore discussed below in the following:

Air temperature: Air temperature regulates a significant portion of heat transfer processes since the driving force for sensible heat loss is the difference between the skin temperature and the ambient air temperature. Air temperature is measures by conventional dry bulb temperature.

Radiant temperature: This is the temperature of surfaces of objects to which the human body rejects heat through electromagnetic waves, e.g. through radiation. The total amount of heat that is lost through radiation from the human body is the sum of radiant heat loss to all relevant objects within the line of sight of the human body. In order to make things easier the term "mean radiant temperature" has been defined, which is the aggregated sum of radiant heat flux from objects that affect the body through radiant heat loss. The mean radiant temperature is measured through a so-called "globe thermometer".

Operative Temperature: Operative temperature is an expression that combines air and radiant temperature into one metric. Operative temperature is quantified as the weighted average of air and radiant temperature. When values of air and radiant temperatures do not deviate significantly, the operative temperature is the simple statistical mean of the air and radiant temperatures.

Metabolic rate: Metabolic rate, as it related to human comfort assessment, is the level of transformation of chemical energy into heat and mechanical work by metabolic activities within the human body. Metabolic rate is defines in "met" units, with 1 met being the rate generated by a person at rest. Tables are available that provide met units for different activities. Examples are sleep and light office work as 0.7 met and 1.2 met, respectively.

Clothing insulation: Clothing insulation is the amount of thermal insulation created by clothing worn by a person. The value of clothing insulation is expressed in "clo" unit and can be determined by adding the value of any particular clothing worn by a person.

Relative humidity: Relative humidity (RH) is expressed as the ratio of the amount of water vapor in the air to the amount of water vapor at saturation pressure of air at the specific temperature and pressure. Relative humidity has significance to human comfort in a range of processes, such as impeded ability to reject heat through evaporation at higher RH values to the feeling of itchiness and effects of respiratory system at very low RH values. RH is measured as a percentage.

Air speed: air speed is expressed as the average speed of air measured at points of reference. Higher air speed can lower the perceived temperature, enabling the set point in air conditioned spaces to be increased without the loss of comfort or raising acceptability limit for naturally ventilated spaces.

Human thermal comfort in internal spaces can be predicted statistically by using main comfort parameters and applying them to comfort standards. The result of predicted comfort suggests that a certain percentage of occupants will experience satisfaction with the thermal environment.

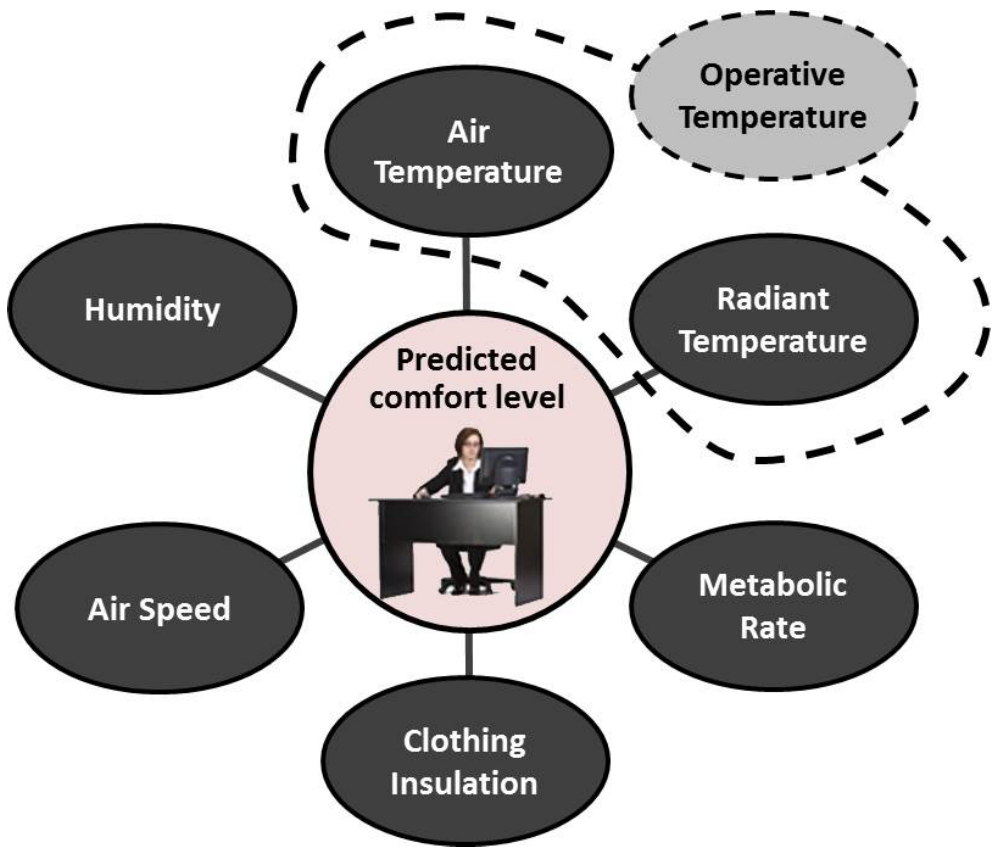

Figure 1.2.1: Main parameters to assess thermal comfort levels

1.3 Standards to Predict Occupant Comfort

Standard ASHRAE 55 is a recognized tool to assess comfort levels based on the main parameters presented. The standard applies to both conditioned and un-conditioned, naturally ventilated spaces.

In accordance with ASHRAE 55 compliance with the comfort standard can be demonstrated in two ways:

Option 1. Determining level of comfort through actual measurements, selective indoor and outdoor environmental conditions for up to 30 days before the date of comfort assessment and using the ASHRAE 55 comfort tool to determine whether the required 80% satisfactory rate has been achieved under the conditions.

Option 2. Determining level of comfort through surveys, if the comfort criteria have been satisfied.

Only Option 1 will be explained in the following paragraphs. Option 2 will be discusses in Section 4.5

<u>ASHRAE 55 comfort method:</u>

ASHRAE 55 includes two type of numerical assessment to determine level of comfort; (1) the PMV method which is typically used in conditioned spaces, and (2) adaptive comfort method which is used in naturally ventilated spaces.

(1) PMV method: The level of comfort can be assessed by determining the Predicted Mean Vote (PMV) index. The preferred method of calculating PMV is through use of the ASHRAE comfort wizard, a software application. For the present study the “CBE Thermal Comfort Tool for ASHRAE-55” is used to determine PMV. The Predicted Percentage Dissatisfied (PPD) for the general comfort is determined by an established correlation between PMV and PPD.
(2) Adaptive comfort method: ASHRAE 55 provides special considerations for spaces that are occupant-controlled naturally conditioned space. In these spaces thermal conditions can be controlled by occupants through opening and closing of windows. ASHRAE 55 suggests that that occupants' thermal responses in such spaces depend in part on the outdoor climate and may differ from thermal responses in buildings with centralized HVAC systems primarily because of the different thermal experiences, changes in clothing, availability of control, and shifts in occupant expectations.

The two comfort assessment methods (1) and (2) represent indoor environmental conditions at opposite sides of the spectrum. For conditions where the space has some form of mechanical conditioning, as in the case of the present set-up and the use of actively cooled radiant panels, ASHRAE 55 suggests does not give concise guidelines.

This AHRAE 55 adaptive comfort method applies under the following conditions:

- There is no mechanical cooling system installed that regulates the temperature and humidity in the space.
- Occupants' metabolic rates are between 1.0 and 1.3 met (met = metabolic rate; e.g. generic light office work has about 1.2 met, typing = 1.1 met; filing, standing = 1.4).
- Occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5-1.0 clo (clo = clothing unit, see explanation below).

The thermal insulation established by clothing is quantified with the "clo" unit. The effective insulation from clothing is the sum of all clothing items worn on the body. For the current thermal conditions in Room 301 the following generic clothing insulation is assumed: all underwear 0.05 clo, socks and shoes 0.04 clo, blouse = 0.12 clo, thin trousers (long) = 0.15, therefore 0.05+0.04+0.12+0.15 = 0.36 clo. The range of 0.5 to 1.0 is therefore conservative since 0.36 indicates less thermal insulation and therefore a higher ability to reject heat.

The ASHRAE 55 adaptive comfort method correlates the prevailing mean outdoor temperature to the operative temperature, both temperatures are determined as averaged temperatures over certain measurement cycles. The air speed in the space, determined by a weighted average of measurements at different heights, has a significant effect of the thermal comfort acceptance of occupants. The air speed refers to the movement of air over the body. Elevated air speed increases the heat transfer effectiveness in sensible and latent (e.g. evaporation) heat transfer processes. The ASHRAE 55 adaptive comfort method establishes two sets of operative temperature limits - one for 80% acceptability and one for 90% acceptability. The 80% acceptability limits are for typical applications and should be used primarily. It is acceptable to use the 90% acceptability limits when a higher standard of thermal comfort is desired. The acceptability of thermal comfort in Room 301 is determined by the 80% acceptability limits.

Figure 1.3.1 illustrates the application of the method by a fixed set of assumed prevailing mean outdoor temperature and internal operative temperature and varying air speeds. The figure indicates the resulting correlation by a red circular pointer. When the pointer is inside the colored band the condition complies with ASHRAE 55-210. The series of three images A, B and C in the figure show the dependency of thermal comfort sensation on the mean air speed. Higher air speed increases the allowable operative temperatures band, by pushing the colored compliance band upwards, and therefore results in compliances at higher operative temperatures. Figure 1.3.1 indicates that the temperature setting with a low airspeed of 59 foot per minute (fpm) does not comply with ASHRAE 55-210 standard, while conditions with higher air speed but the same temperature do comply.

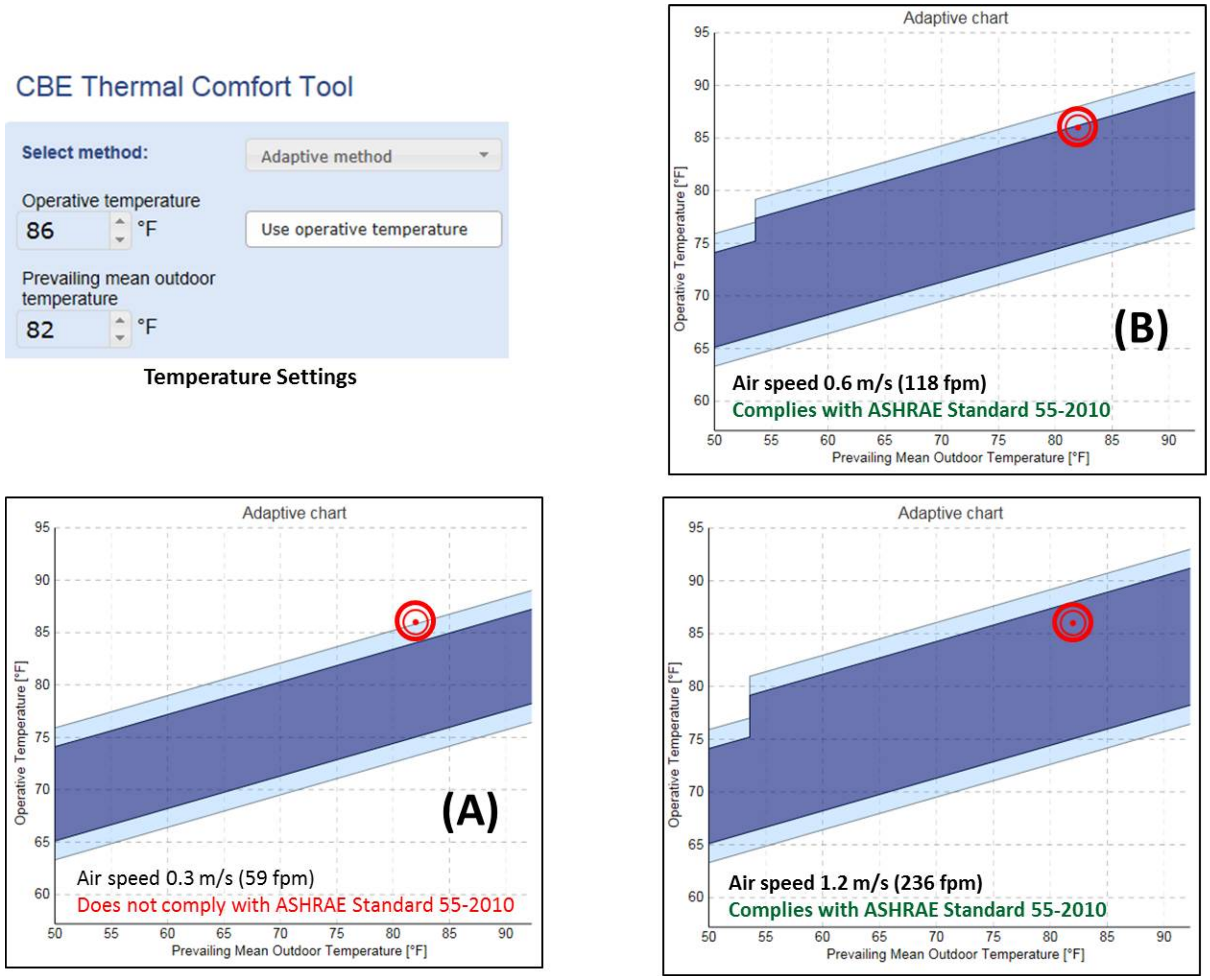

Figure 1.3.1: ASHRAE 55-2013 adaptive comfort method – dependency on air speed to achieve code compliance (CBE adaptive comfort assessment tool)

1.4 Using Heat Stress as Indicator for Level of Comfort

While ASHRAE 55 2013 uses relative humidity as one of the parameters to assess comfort, the optional Adaptive Comfort method for naturally ventilated spaces does NOT consider relative humidity effects. This is due to the fact that the Adaptive Comfort method delineated in ASHRAE 55 is a statistically derived predictive tool that addresses expected probability of thermal comfort based on the person's ability to adapt prevailing outside temperatures. The relative humidity level, however, has a significant effect on heat loss processes. Sweat does not evaporate as quickly when the air is moist as it does in a dry climate. Since evaporation of sweat from the skin is one of the main processes of heat loss from the human body at higher temperatures, high relative humidity levels reduce the natural cooling capacity. Evaporation rates are increased at higher air speeds across the skin. Therefore, at higher temperatures and relative humilities increased air speed is an effective measure to help humans to reject heat.

The **Heat Index** as an important thermal indicator that combines air temperature and relative humidity into a single value, the “apparent temperature.” The heat index indicates how hot it really feels when the effects of humidity are added to high temperatures. A heat index matrix has been established with categories ranging from “uncomfortable conditions” to situations when effects of heat and high relative humidity can lead to heat exhaustion or heatstroke. Figure 1.4.1 shows the heat index chart which is promulgated by the Oceanic and Atmospheric Administration (NOAA) National Weather Service website.

The NOAA heat index indication method was developed for a shade outdoor setting with light wind conditions. In cases where people are exposed to full sunlight the heat index has to be increases by 15 F or more. The heat index categories used by NOAA is also referenced by the Occupational Safety & Health Administration (OSHA). The NOAA and OSHA heat index categories are shown in Figures 1.4.2 and 1.4.3, respectively

HEAT INDEX °F (°C)

The heat index is an accurate measure of how hot it really feels when the affects of humidity are added to high temperature.

	RELATIVE HUMIDITY (%)												
Temp.	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
110 (47)	136 (58)												
108 (43)	130 (54)	137 (58)											
106 (41)	124 (51)	130 (54)	137 (58)										
104 (40)	119 (48)	124 (51)	131 (55)	137 (58)									
102 (39)	114 (46)	119 (48)	124 (51)	130 (54)	137 (58)								
100 (38)	109 (43)	114 (46)	118 (48)	124 (51)	129 (54)	136 (58)							
98 (37)	105 (41)	109 (43)	113 (45)	117 (47)	123 (51)	128 (53)	134 (57)						
96 (36)	101 (38)	104 (40)	108 (42)	112 (44)	116 (47)	121 (49)	126 (52)	132 (56)					
94 (34)	97 (36)	100 (38)	103 (39)	106 (41)	110 (43)	114 (46)	119 (48)	124 (51)	129 (54)	135 (57)			
92 (33)	94 (34)	96 (36)	99 (37)	101 (38)	105 (41)	108 (42)	112 (44)	116 (47)	121 (49)	126 (52)	131 (55)		
90 (32)	91 (33)	93 (34)	95 (35)	97 (36)	100 (38)	103 (39)	106 (41)	109 (43)	113 (45)	117 (47)	122 (50)	127 (53)	132 (56)
88 (31)	88 (31)	89 (32)	91 (33)	93 (34)	95 (35)	98 (37)	100 (38)	103 (39)	106 (41)	110 (43)	113 (45)	117 (47)	121 (49)
86 (30)	85 (29)	87 (31)	88 (31)	89 (32)	91 (33)	93 (34)	95 (35)	97 (36)	100 (38)	102 (39)	105 (41)	108 (42)	112 (44)
84 (29)	83 (28)	84 (29)	85 (29)	86 (30)	88 (31)	89 (32)	90 (32)	92 (33)	94 (34)	96 (36)	98 (37)	100 (38)	103 (39)
82 (28)	81 (27)	82 (28)	83 (28)	84 (29)	84 (29)	85 (29)	86 (30)	88 (31)	89 (32)	90 (32)	91 (33)	93 (34)	95 (35)
80 (27)	80 (27)	80 (27)	81 (27)	81 (27)	82 (28)	82 (28)	83 (28)	84 (29)	84 (29)	85 (29)	86 (30)	86 (30)	87 (31)

Figure 1.4.1: Heat Index Chart published on NOAA Weather Service website

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Category	Heat Index	Possible heat disorders for people in high risk groups
Extreme Danger	130°F or higher (54°C or higher)	Heat stroke or sunstroke likely.
Danger	105 - 129°F (41 - 54°C)	Sunstroke, muscle cramps, and/or heat exhaustion likely. Heatstroke possible with prolonged exposure and/or physical activity.
Extreme Caution	90 - 105°F (32 - 41°C)	Sunstroke, muscle cramps, and/or heat exhaustion possible with prolonged exposure and/or physical activity.
Caution	80 - 90°F (27 - 32°C)	Fatigue possible with prolonged exposure and/or physical activity.

Figure 1.4.2: Heat Index Chart published on NOAA Weather Service website

Heat Index	Risk Level	Protective Measures
Less than 91°F	Lower (Caution)	Basic heat safety and planning
91°F to 103°F	Moderate	Implement precautions and heighten awareness
103°F to 115°F	High	Additional precautions to protect workers
Greater than 115°F	Very High to Extreme	Triggers even more aggressive protective measures

Figure 1.4.3: Heat Index Chart definitions published by OSHA

1.5. Mechanisms to Increase Thermal Comfort in Natural Ventilation Considered

The term naturally ventilated spaces needs perhaps a bit more clarification. Naturally ventilated spaces are such that primarily rely in natural driving forces to ventilate spaces and lack mechanical means of cooling the entire space. Naturally ventilated spaces are open to the environment and are not sealed. This means that no sensible and latent heat is extracted from the intake air. Naturally ventilated spaces can have, however, mechanical means to change conditions in the room, but these changes in condition exclude cooling and reducing the humidity under normal way of operation. Air that is introduced to naturally ventilated spaces basically retains the temperature and absolute humidity.

Three mechanisms to change conditions in naturally ventilated spaces in order to increase comfort have been identified for this research project:

1. **Comfort measure 1:** Provide mechanical ventilation when natural ventilation driving forces are insufficient: Supplying sufficient outside air to naturally ventilated spaces can at times not be guaranteed, since wind and buoyancy driving forces depend on favorable external conditions. These driving forces are intermittent. During periods of insufficient environmental driving ventilation forces (e.g. sufficient pressure differentials) the mechanical ventilation provides the pressure difference to move air through the spaces. In this case we refer to the mechanical systems as a mechanical “assist” ventilation system.

   The importance of sufficient ventilation is code compliance and the supply of sufficient outside air is required under applicable standards, such as ASHRAE 62.1, which are often adopted as local building performance codes. The second importance of introducing sufficient outside air is to expel internal heat gain to the environment and therefore avoid temperature rises in the space due to internal heat sources.

2. **Comfort measure 2:** Provide increase air velocities over the occupant body: The purpose of increasing air speed over the occupant body is the individual cooling effect. Increased air velocities decrease the boundary layer thickness over the skin, and therefore reduce the heat transfer film resistance, which in turn stimulates convective heat loss from the body. In addition, increase air velocity increases the amount of evaporation and therefore latent cooling.

   Providing increase air velocities over the body has no effect on the ventilation performance. It is not a measure that acts on the level of the entire space. The effects are localized and they affect the thermal comfort perception of only those occupants which are directly exposed to the increased air velocities.

3. **Comfort measure 3:** Provide radiant cooling to lower the operative temperature: The operating temperature can be lowered by providing cooling surfaces which are lower than the ambient room temperatures. The cooling effect is different from radiant cooling in conventional radiant cooling applications, where the radiant cooling surfaces remove most of the sensible load from the entire space. In the application for this research the cooling surfaces are acting only locally, and provide limited radiant cooling to occupants and not the entire space.

One important feature of the type of radiant cooling is that the space will not be dehumidified as it is required for conventional radiant cooling. This fact creates opportunities and challenges. Opportunities are created by not dehumidifying the air in the space, which means not lowering the humidity levels in the intake air and removing internal humidity sources. Dehumidification typically represents a large portion of overall energy demands in hot and humid climates. Challenges are encountered by the need to keep the radiant surfaces as well as the chilled water supply conduits about dew point, or otherwise risk condensation.

1.6 Technology Innovations Investigated Under Part 3 of Project

The comfort enhancing measures 1 and 2, discussed in Section 1.5, namely increased air velocities of the occupants and rejecting internal heat gain through ventilation can be regarded as conventional measures. They have been used for a long time, well before mechanical cooling became widespread, although their use has become less dominant in modern building designs.

The third comfort enhancing measure, discussed in Section 1.5, is an innovative technology and this research project will test the basic proof of concept. The challenge, as was already pointed out, is that the radiant surfaces need to remain well above the dew point or having the risk of condensation on below dew-point surfaces or at least elevated relative humidity levels close to the cold surfaces.

As an additional innovation the use of Phase Change Material (PCM) radiant panels was planned for this research study. PCM boards could potentially offer interesting energy saving options for naturally ventilated spaces. The PCM panel has high heat storage capacities due to the latent heat change of encapsulated phase-change material. This makes it possible to use nighttime flushing to “precool” spaces with colder air during the nights. Because of technical difficulties the investigation into PCM panels were not carried out under the present research. The ERDL team still believes that PCM panels could be an important part of energy savings in buildings, especially those that are missing sizeable thermal mass construction.

A further innovation will be the combination of comfort enhancing measures. ASHRAE 55 stipulates that the combination of different radiant and air temperatures and the resulting temperature differential has effects on the effectiveness of increased air velocity as cooling strategies.

1.7 Comfort Measures that will be Tested in Part 3 of Project

Project Phase 3 will use a comfort "chamber" to **test two technologies** which have significant potential to improve comfort levels in naturally ventilated building in warm climate. These two technologies are:

1. **Install a ceiling fan** to provide a range of locally increased air velocities. The ceiling fan will have a range of air velocities and will have the capacity to provide a "gentle shower" at low fan speed or more intensive air movements at stronger fan speeds.
2. Install **radiant cooling panels** that are actively cooled to a range of temperatures.

The effect of mechanical ventilation cannot be tested in the comfort chamber since elevated temperatures and humidity levels will be established in the chamber.

1.8 Type of Comfort Investigation

The comfort investigation will include the following qualitative and quantitative types of measurements:

<u>Comfort surveys:</u> The level of comfort will be assessed in occupant comfort surveys. The level of comfort is a subjective experience, and occupants react differently to the same environmental conditions in spaces. The comfort surveys will provide data for statistical analysis of the perceived level of comfort from a sample group. The surveys are qualitative descriptions of comfort improvements created by the technologies used in these tests.

<u>Measuring comfort relevant physical properties for PMV:</u> Physical properties, such as air temperature, mean radiant temperature, air velocity and humidity will be measures for analysis of the so-called Predicted Mean Vote (PMV). PMV is a recognized thermal comfort model that correlates physical properties in the space and the occupant to the predicted thermal comfort experience.

<u>Measuring physical properties for CFD validation:</u> A main objective of the Project Phase 3 is the application of CFD thermal and air flow simulations to study the physical performance of the comfort improvement measures.

1.9 Validation of CFD Comfort Simulations

CFD simulations will be conducted to investigate the performance of the comfort improvement measures. The goal of the study is to achieve a correlation of physical properties of the space and measures the level of comfort obtained through surveys and PMV.

The CFD will be validated with actual measurements of air temperature, mean radiant temperature, humidity and air velocity due to ceiling fan operation. The measurements for CFD validation will be conducted during times when no comfort survey test will be conducted.

SECTION 2 – DESCRIPTION OF THE TEST SITE

2.1 Candidate Spaces for the Comfort Investigations

For preparation of the tests for Phase 3 several candidate test spaces were under consideration to complete the planned scope of the investigations. The following candidate test spaces were considered:

Sinclair Room 301: The ERDL team was tasked to perform a comfort study and develop strategies to improve the comfort in the currently naturally ventilated space. The ERDL team installed mechanical assist ventilation systems that were comprised of two large fan units, both with two 6,500 cfm propeller type fans. The investigation for Room 301 included the study of mechanical assists ventilation and their contribution to control space heat balance. The studies also included the installation of a ceiling fan for one office cubicle, which functioned as a “test cubicle”. It was also planned to install the radiant cooling panels in the test cubicle, but the planned installation could not be realized.

HIG 411: The room HIG 411 was considered as a test space since it offered an office setting with the space to accommodate two desks, one with the installed comfort improvement measures, the other as a normal “baseline” desk, without comfort improvement. The room could not be acquired as the test site.

HIG 204: The room HIG 204 is located next to the office in HIG 205 which is used by the ERDL field measurement team. HIG 204 is a room that has no windows and has been used as storage space and overflow office. **The room HIG 204 was selected to be the test site.**

2.2 Description of the Selected Test Site

Room HIG 204 is a windowless space that has a door to the exterior. The room dimensions and the room configurations prior to the test are depicted in Figures 2.2.1 and 2.2.2. The room was rearranged to make space for two test desks with textile covered partitions as room dividers. The layout of the test site is shown in Figure 2.2.2.

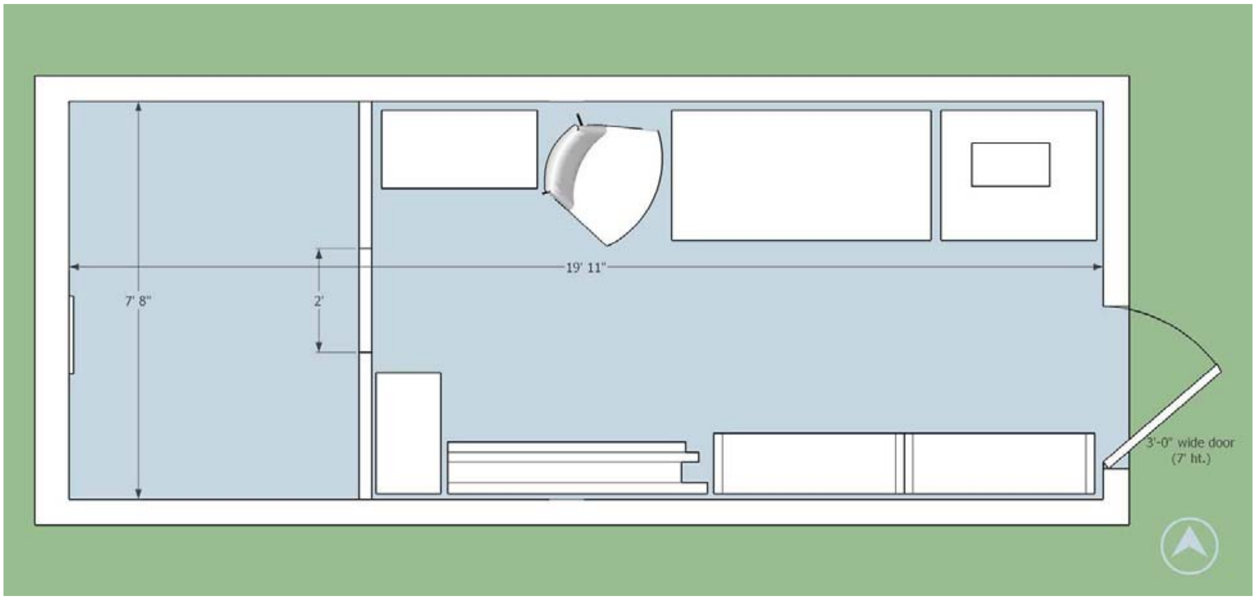


Figure 2.2.1: Dimensions and room configuration of Room HIG 204 prior to tests

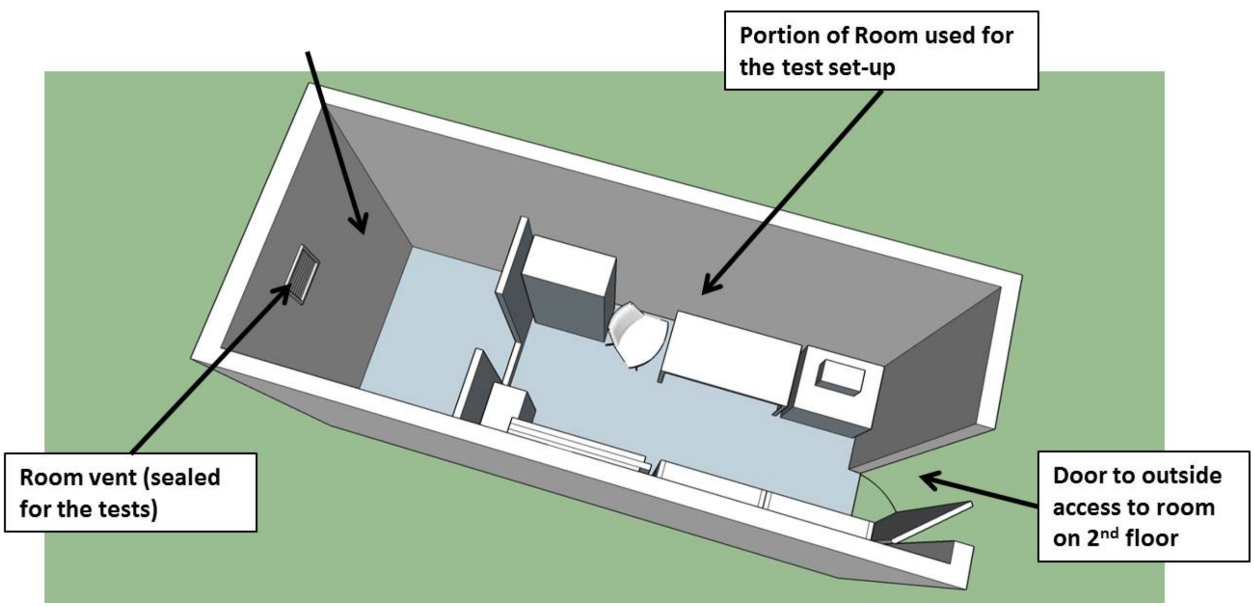


Figure 2.2.2: Room configuration of Room HIG 204 prior to tests

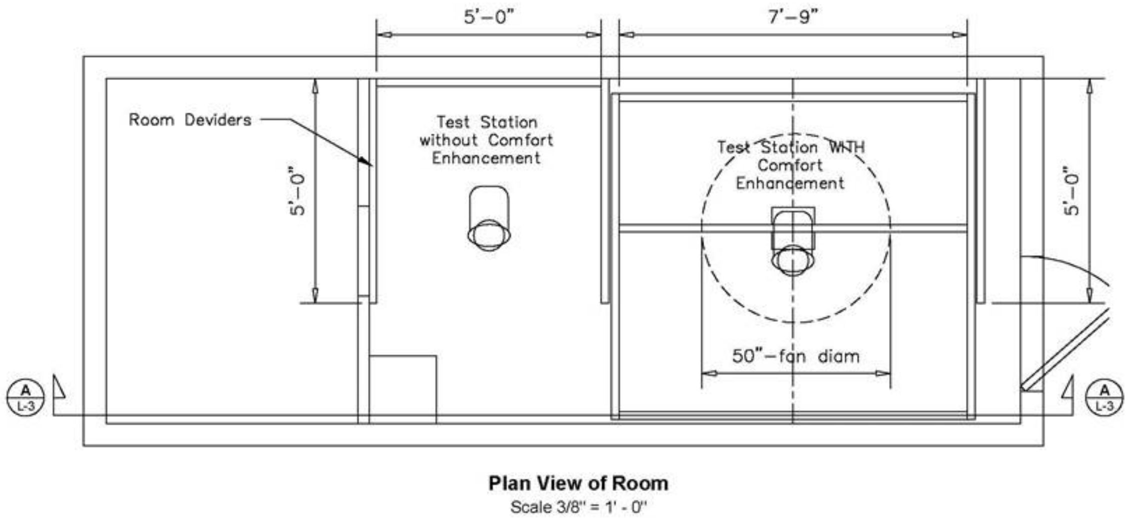


Figure 2.2.3: Layout of the test set-up in HIG 204 (the full size image is presented in Appendix A)

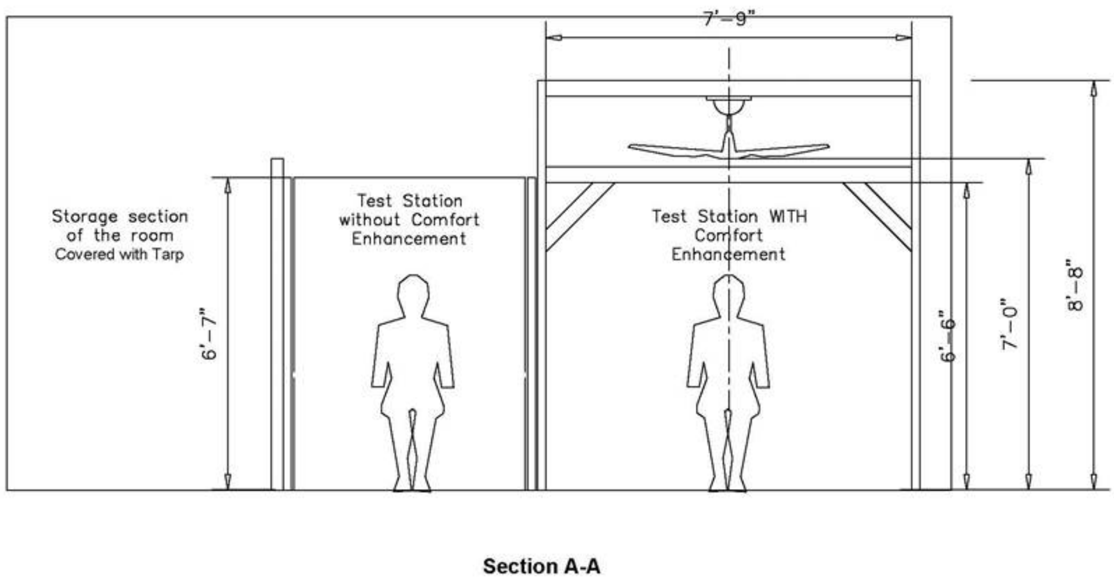


Figure 2.2.4: Layout of the test set-up in HIG 204 – Section A-A (the full size image is presented in Appendix A)

There will be two desks in Room HIG 204. Desk One is the "baseline desk" which has no comfort improvement measures. Desk Two is equipped with a wooden structure that will support the various comfort improvement measures. Since the comfort measures will be tested in different configurations, the wooden support structure provides flexible structural support for the measures.

2.3 Wooden Support Structure for Test Set-up

The wooden support structure is depicted in Figures 2.3.1 through 2.3.x. The full size figures of the wooden support structure is presented in **Appendix A**

The main purpose of the wooded structure is to provide support for the comfort improvement measures.

- The **ceiling fan** will be installed on a cross beam of the wooden structure and the ceiling fan will be moveable along the cross beam. This provide the flexibility to move the ceiling fan, which is important since the test desk will also be moved to establish certain distances to the cooling panels.
- The **radiant cooling** panels will be hung from the horizontal beams. The height and location of the cooling panels can be easily adjusted by the support wires and by moving the support cross beams, respectively.
- The chilled water piping systems will be installed on the wooden structure by means of simple pipe hangers.

2.4 Chilled Water Supply System.

The actively cooled radiant panels were connected to a supply and return piping systems. The pipes are connected to a chiller and a circulation pump that are located outside of the room. Provisions will be made to facilitate removal of air pockets from the chilled water supply.

2.5 Heating and Humidification to Attain Desired Room Temperatures and Humilities

Electric heaters will be used to hold the climate test chamber (e.g. room HIG 204) at a certain temperature. Humidity will be introduced into the room air by a suitable vaporizer.

SECTION 3 –SCOPING TESTS

This section describes a series of initial scoping tests which were conducted to determine the heat transfer performance of two radiant panel configurations, the ThermoCore Phase Change Material (PCM) panel and the Barcol aluminum panel, which are referred to as PCM panel and radiant panel, respectively. Scoping tests with both panel types were performed to determine heat transfer performance of panels and determine if the chilled water loop of the test set-up could serve the required chilled water temperatures to establish low panel surface temperatures.

3.1 Description of the Two Types of Radiant Panels Used in the Scoping Tests

The two panel configurations are shows in the following Figures 3.1.1 and 3.1.5.

PCM panel assembly: A heat transfer device had to be attached to the PCM board in order reject the heat from the PCM panel to the chilled water. It was opted to utilize a Gypsum Ceiling System (BRG) provided by Barcol as the heat rejection device. The BRG consisted of 4-inch wide aluminum plates with an attached meander of 10 mm copper tubing. The connection between aluminum attached the copper tubing was such to allow effective heat transfer between the aluminum plates and the copper tubing. Figure 3.1.1 shows the working principle of the PCM board. By mixing PCM granular material into the gypsum plaster the resulting PCM-gypsum board attains significantly larger specific heat capacity than normal (e.g. without PCM) gypsum boards.

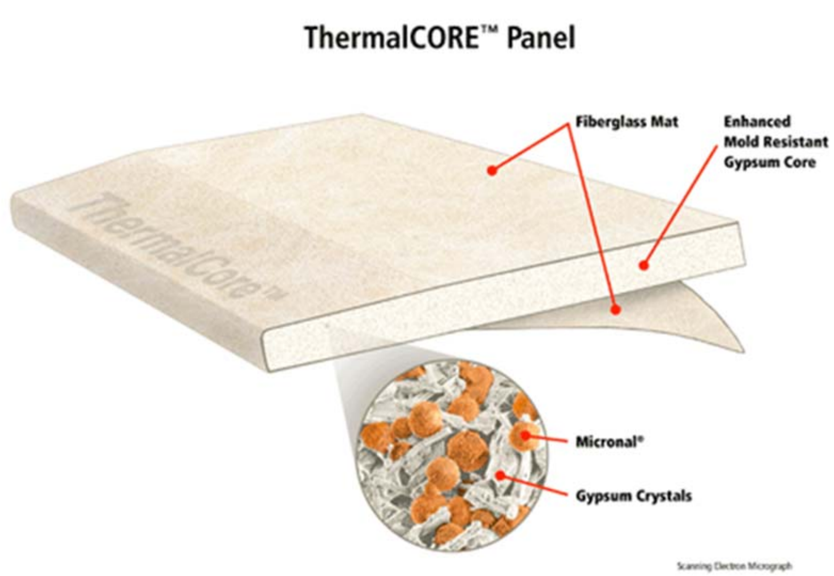


Figure 3.1.1: Phase Change material (PCM) gypsum board.

Note: the PCM boards were provided by National Gypsum. They are not yet commercially available.

Figure 3.1.2 shows the Gypsum Ceiling System (BRG) heat rejection assembly. The chilled water is conveyed through the copper tubing, thereby removing heat from the four aluminum plates. Figure 3.1.3 depicts the attachment of the copper tubing to the aluminum plates. As can be seen the copper tubing is embedded in an extruded channel which establishes a tight fit and provides for good heat transfer performance.

Figure 3.1.2: Gypsum Ceiling System (BRG) heat rejection assembly

Note: the BRG assembly used in the scoping test was not painted and the fourth aluminum plate was removed to fit the PCM board.

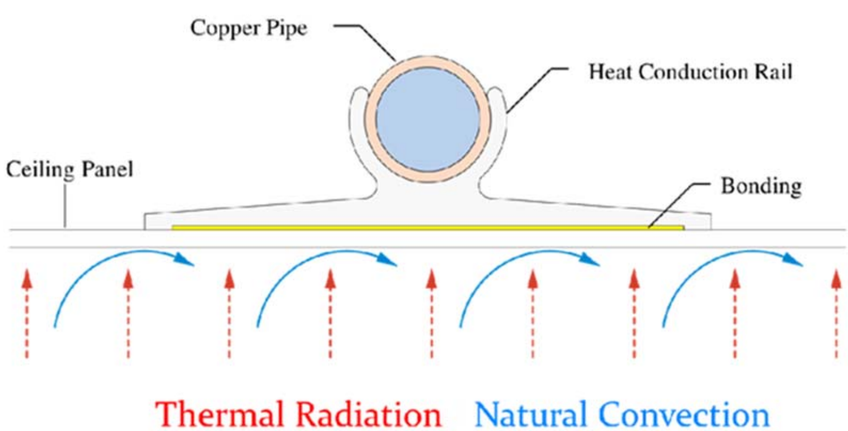


Figure 3.1. 3: Connection of copper tubing to aluminum plates of the BRG

Figure 3.1.4 shows the completed PCM panel assembly comprised of PCM board and the BRG. The PCM board has attached to the BRD by gluing the BRG to the surface of the PCM board. The BRG systems came with self-adhesive rails. In Figure 3.1.4 the PCM is the white board inside. The BRG is shown with three aluminum panels, where one aluminum plate was removed to fit the BRG to the PCM board dimensions. In order to provide structural strength, the PCM was mounted on a wooden frame. A 1.5 inch Styrofoam insulation was added to the back of the PCM board, e.g. on the side of the BRG, in order to minimize unwanted heat transfer to the PCM board.

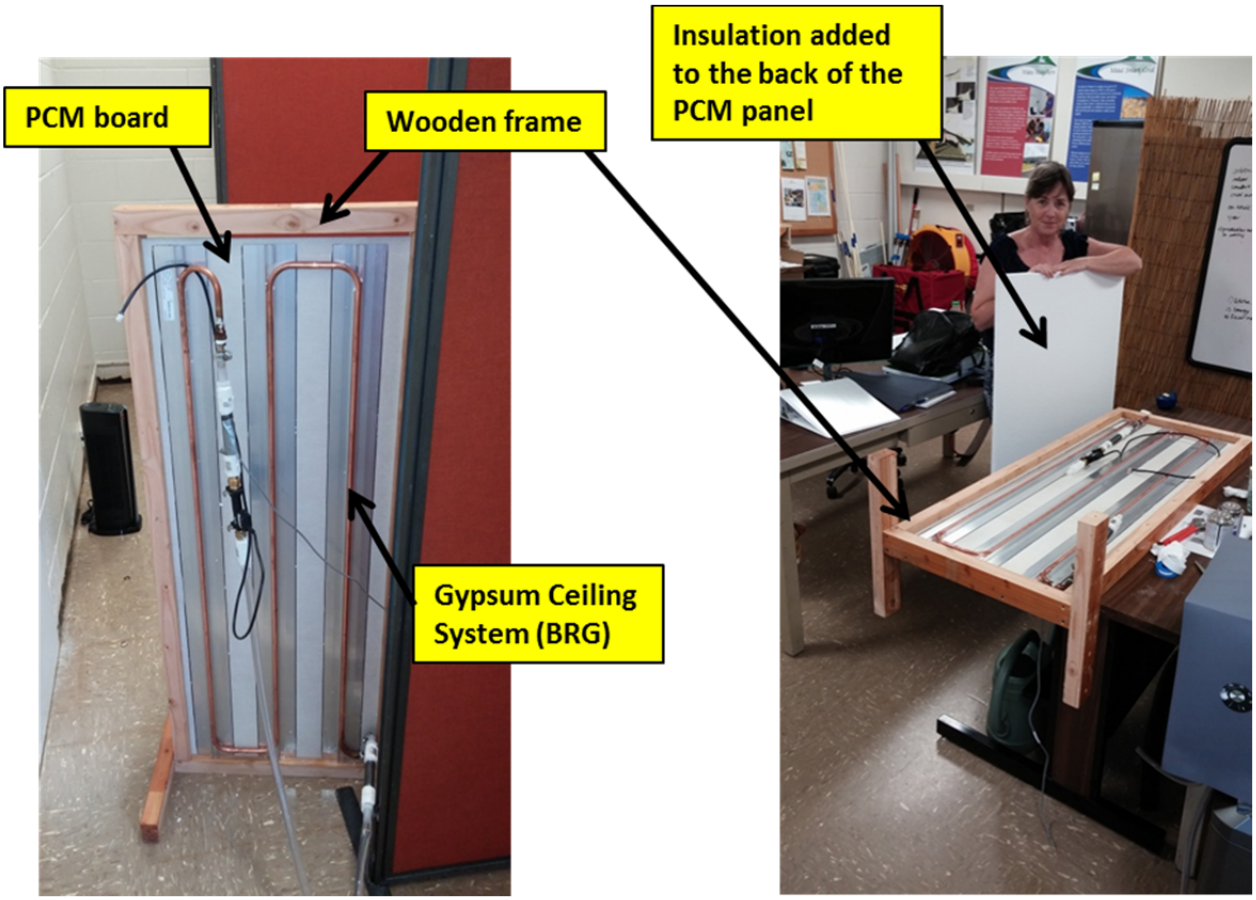


Figure 3.1.4: Completed PCM panel assembly. Note: This PCM panel assembly was used only in the scoping test

<u>Aluminum radiant (ceiling) panels:</u> Figure 3.1.5 shows the radiant panel provided by Barcol USA. These types of panels are commercially available and have been installed in numerous radiant ceiling cooling applications.

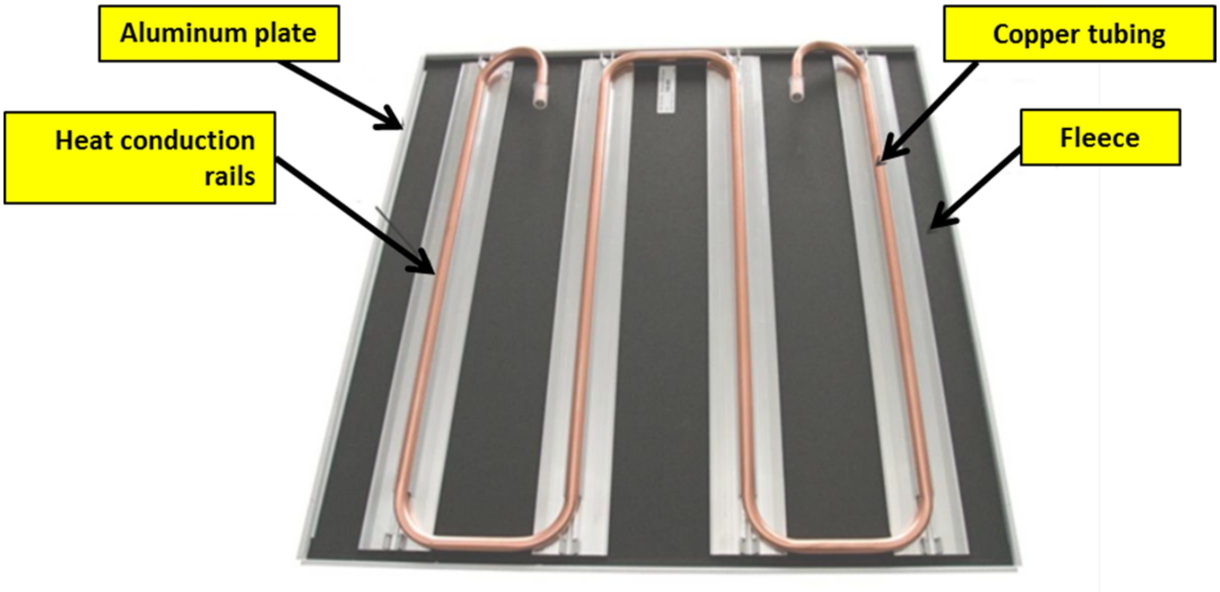


Figure 3.1.5: Radiant panel
Note: Panel is show from the back side; for the test a 1.5 inch Styrofoam insulation was added

3.2 Description and Results of Scoping Tests

The scoping tests included the following tasks:

Chilled water loop shake down testing:

- Determine the process to fill the chilled water system with water (and be able to expel all air in the system) and run the chilled water loop successfully. (the flow schematic of the initial scoping tests is presented in Figure 3.1.6)
- Calibrate the flowmeter
- Obtain experimental experience in installing fixed and flexible tubing components

Thermal performance of radiant panels:

- Assess the thermal response of the two types of radiant panels,
- Determine the approach temperature between radiant panel surface and the chilled water supply temperatures.

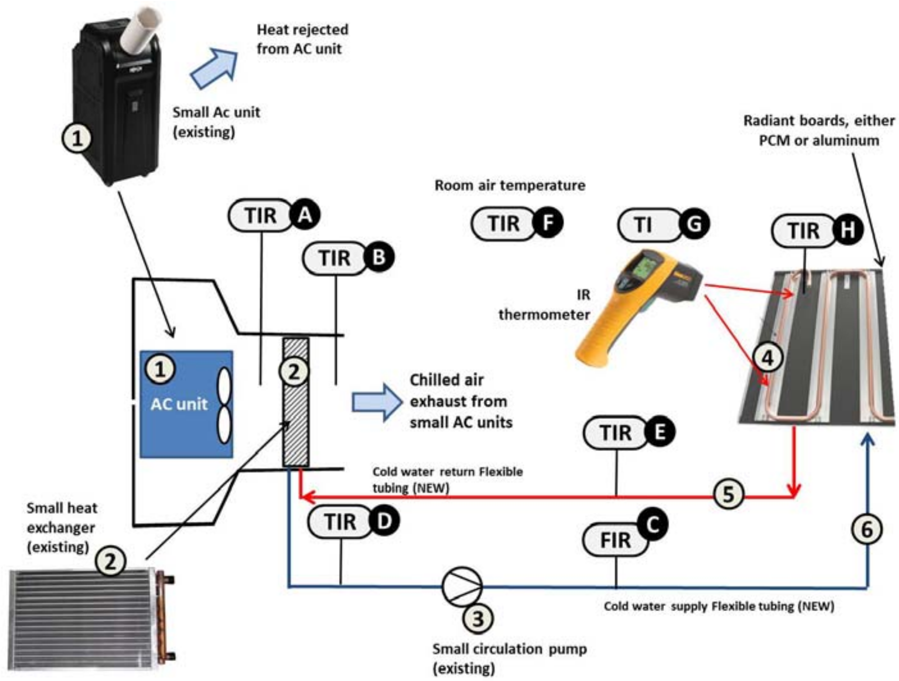


Figure 3.1.6:
Basic process diagram of the system used in the scoping tests

Note: The instruemtnation and data acquisition points are indicated in the figure.

The scoping test included the following steps:

- Attach the radiant panel to the chilled water supply and fill completely with water, removing all the bubbles and air pockets
- Leave the panel inside the heated room so that the panel can acquire the ambient room temperature
- Record the panel surface temperature and the chilled water supply temperature.
- Run the chilled water supply and record temperatures as a function of time.

Figure 3.1.7 shows the temperature response of the PCM board to cooling with chilled water. The temperature response shown in Figure 3.1.7 indicates that the smallest temperature difference between the chilled water and the PCM panel surface is between 7 F and 8 F. Figure 3.1.8 shows temperature response of the radiant panels. The temperature response shown in Figure 3.1.8 indicate he smallest temperature difference between the chilled water and the PCM panel surface is between 1.5 F and 2 F.

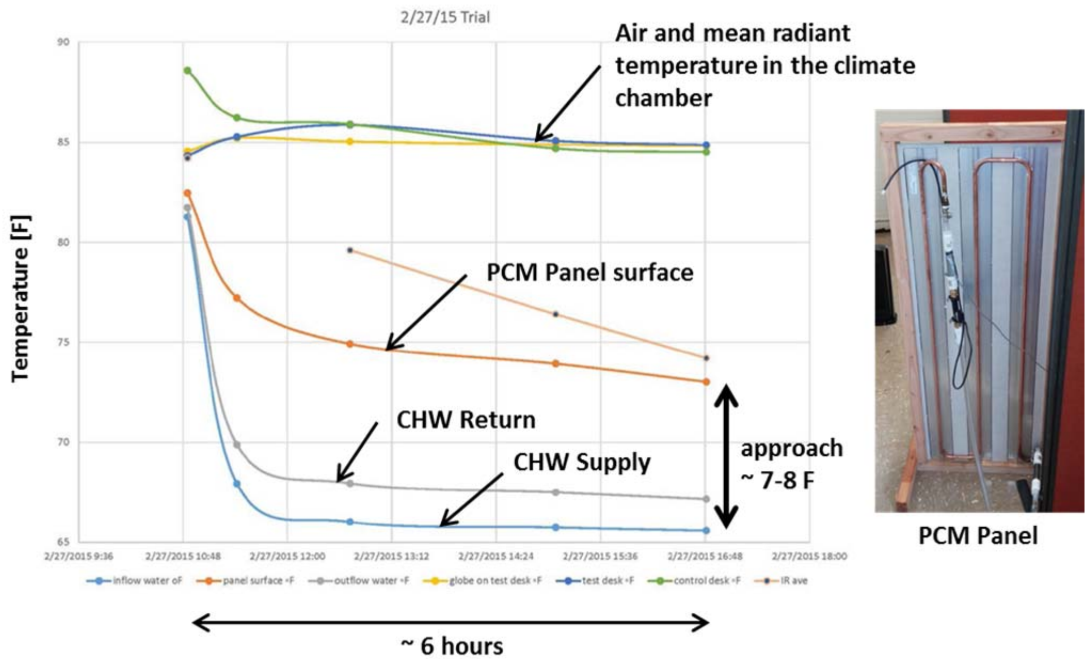


Figure 3.1.7: Thermal response of PCM panel during scoping tests

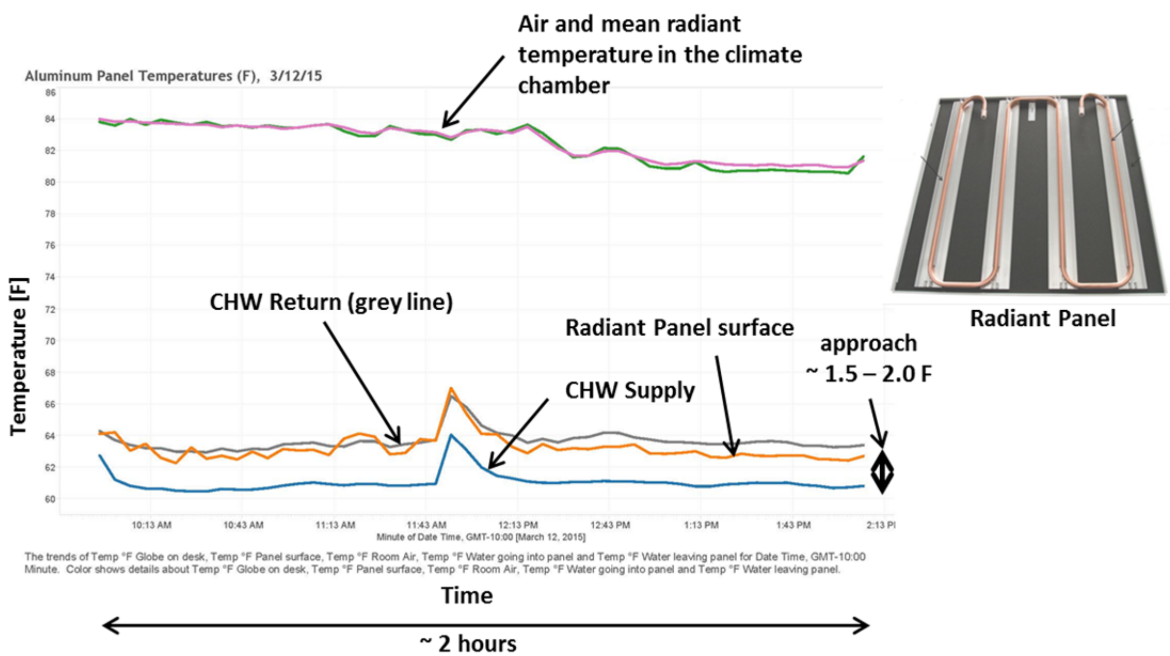


Figure 3.1.8: Thermal response of Barcol radiant (aluminum) panel during scoping tests

Table 3.1.1: Thermal performance of the two types of panels test in the scoping tests

Type of radiant panel	Approach temperature(**) [F]	Chilled water temperature	
		Supply [F]	Return [F]
PCM board	**7.0 – 8.0**	**65.5**	**67.5**
Barcol radiant ceiling panel	**1.5 – 2.0**	**64.0**	**66.0**

Note: Approach temperature is the difference between CHW supply and panel surface temperature

3.3 Conclusions of Scoping Tests

- The working scheme of chilled water generation by using a chilled air (AC-unit) coupled with an air-to-water heat exchanger and distribution systems worked satisfactorily. Care was taken to avoid buckling of the flexible hoses where flexible hoses and fixed piping fittings connect.
- Condensation could be observed when the chilled water temperatures were noticeably below the dew point. While some small quantities of condensed water is not a significant concern to the operation of the test set-up, the fact that very low chilled water temperatures would be needed to cool the PCM was a significant concern and decision point to select other boards for the test.
- The temperature difference between chilled water supply and surface of the PCM panel is in the range of 7 to 8F. This is a significant temperature difference and it implies that the chilled water would have to be significantly below the dew point in order to bring the panel surface temperature to a temperature slightly above dew. **Therefore it was decided to use all metal aluminum radiant panels as radiant surfaces in lieu of the PCM panels.**

SECTION 4 – PROTOTYPES AND SUPPORT SYSTEMS

Section 4 presents the test set-up configuration including comfort enhancing equipment and support systems as it is at the time of completion of shake down testing. In the course of optimizing the test set-up the research team incorporated numerous improvements. In this section only the final configuration of the test set-up is presented. A photo documentation of the test set-up is presented in Appendix E.

This section provides information about the function, selection, procurement process, and specifications of the prototype equipment and the required support systems.

A. Prototype equipment:
   - A. 1 Ceiling fan (high performance fans)
   - A. 2 Actively cooled radiant surfaces (e.g. radiant panels)

B. Support equipment:
   - B. 1 Chilled water system
   - B. 2 Heating and Humidification

4.1 Prototype equipment – Ceiling fan

The ceiling fan used in the test set-up is a Haiku fan provided by Big Ass Solutions.

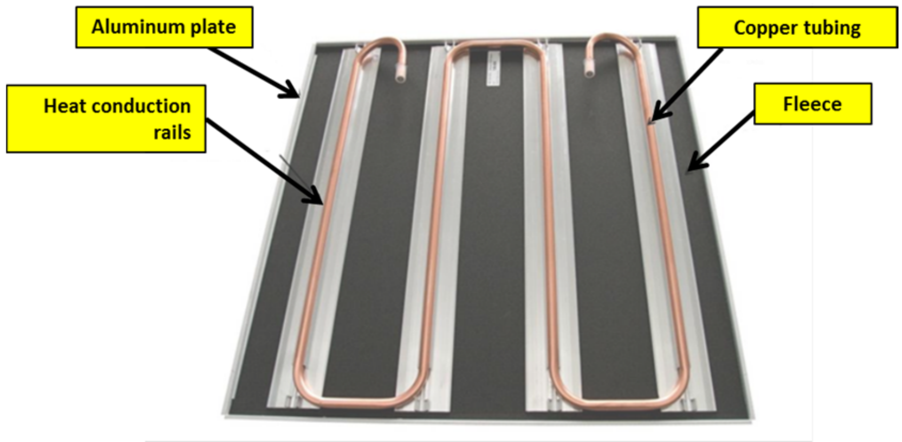
Equipment function / process	**Description**
Function	• Provide a good control of air flow • Have a well distributed air flow • Outstanding energy demand (e.g. low energy consuming fan that would be installed for the purpose of energy efficient comfort measures)
Overall description and procurement.	• The Haiku fan is a very low energy consumption fan with high performance foils. A MOU was executed with Big Ass Fan (BAF) Company Inc., the manufacturer of the Haiku.
Specifications	The fan has the following main performance characteristics: • Quiet operating fan on high speed • Patented "self-balancing" system • Remote control included • 6 speeds and reverse function • Energy efficient DC-motor • SenseME™ technology to adjust fan speed to room conditions • Optimized 3d-aerofoil blades for even airflow

Equipment function / process	Description
	The full specification of the Haiku is provided at the following link: **http://www.bigassfans.com/products/haiku/**
Haiku product photo – Big Ass Fans	

4.2 Prototype Equipment – Barcol Radiant Panels

Barcol radiant panels were selected as the radiant surfaces.

Equipment function / process	Description
Function	• The Barcol radiant panel is an "off-the-shelf" product which can be readily installed at the test site to achieve radiant cooling capacity. • The radiant panel has a good thermal performance with a minimum of approach temperatures between chilled water and panel surface • The response time of the radiant panel to thermal changes is fast because of a high panel thermal conductivity.
Specifications	The specifications are included in Appendix B.More specification can be accessed at **http://barcolairusa.com/Radiant-Ceilings.php** Ceiling System by Steel Ceilings Inc., System: 15/16'' T-Grid, Lay-In, Square edge, Standard Leg, Material: 0.040" Aluminum, Surface: Global white polyester powder coat, Perforation: B Pattern (*holes to be approx. 1.5 mm in diameter and 3mm apart*), panels are 2' x 4'.

Equipment function / process	Description
BARCOL-AIR Barcol-Air Radiant Ceiling (BRC) Product picture (annotated by the authors)	

4.3 Support Equipment - Chilled water system – Working process

Selecting and procuring the chilled water system included several options and vendors. The chilled water system has the following elements (instrumentation is not included at this point):

- Chiller unit (AC unit)
- Air-to-water heat exchanger
- Chilled water piping and valves
- Chilled water pump

Figure 4.3.1 shows a basic schematic of the chilled water systems as it was designed at the start of the shake down testing.

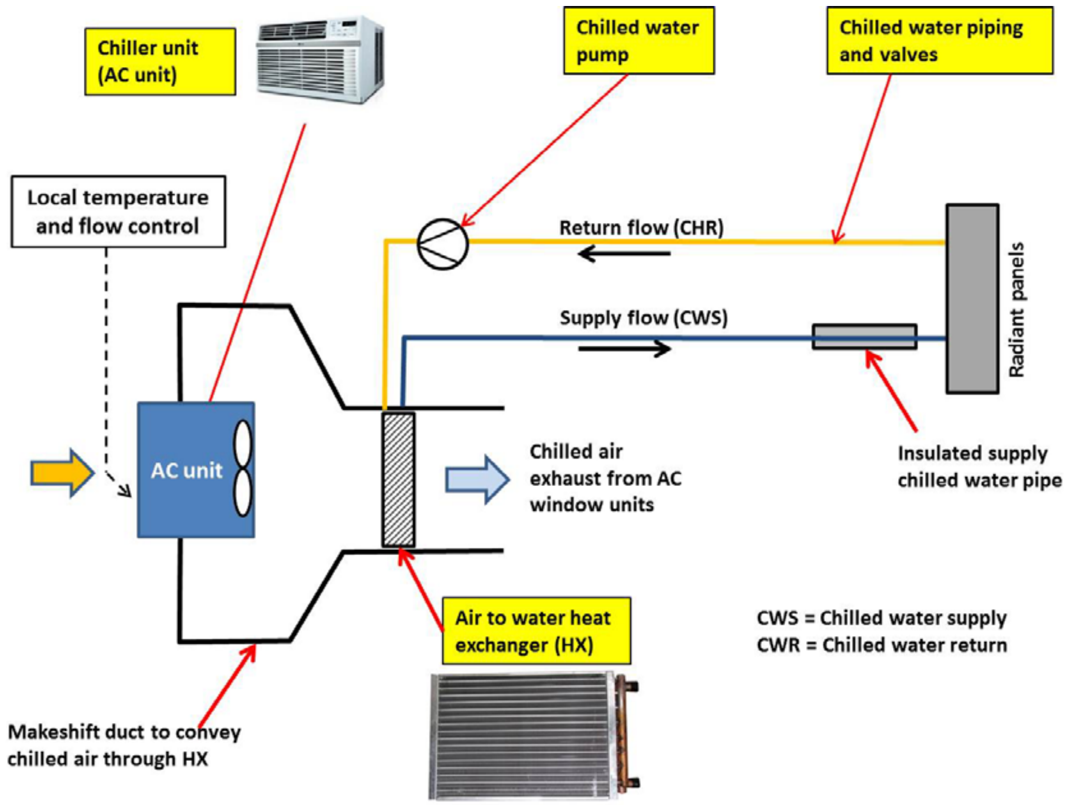


Figure 4.3.1: Schematics of the initial chilled water system (at the start of the shake down testing)

The following system optimizations were added to improve the system performance:

- Separating the chilled water system into **primary and secondary chilled water loop**. The primary chilled water loop rejects heat from chilled water loop by means of chiller units (e.g. AC-unit).
- A **chilled water reservoir**, e.g. a commercially available 40 gal cooler, is added to the chilled water system. The chilled water reservoir allowed a more precise temperature and flow control of the chilled water supply.
- **Re-circulating** the chilled air discharge of the heat exchanger and directing it towards the AC-unit intake. It was found that the heat removal by the chilled air was not as effective as anticipated. As a result of optimization trials, a re-direction of the exhaust air from the heat exchanger back to the Ac-unit intake was installed, which increased the cooling performance of the system significantly.

- The chilled water generation unit (AC-unit, chilled water reservoir and pumps) was placed on a movable wooden platform that allowed the research team to move the unit in and out of room 205.

Figure 4.3.2 shows the basic flow diagram of the optimized chilled water system, which will be used in the actual tests.

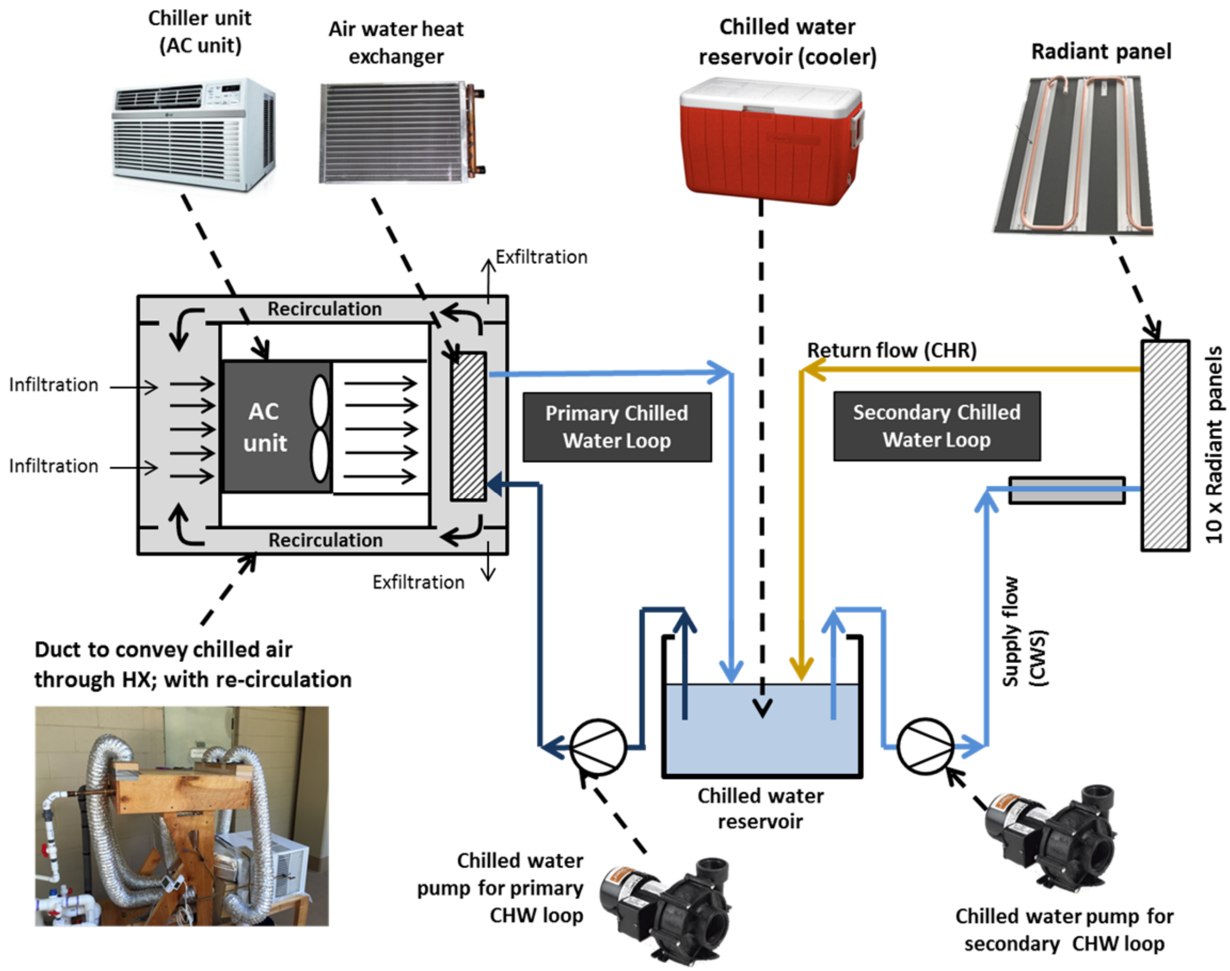
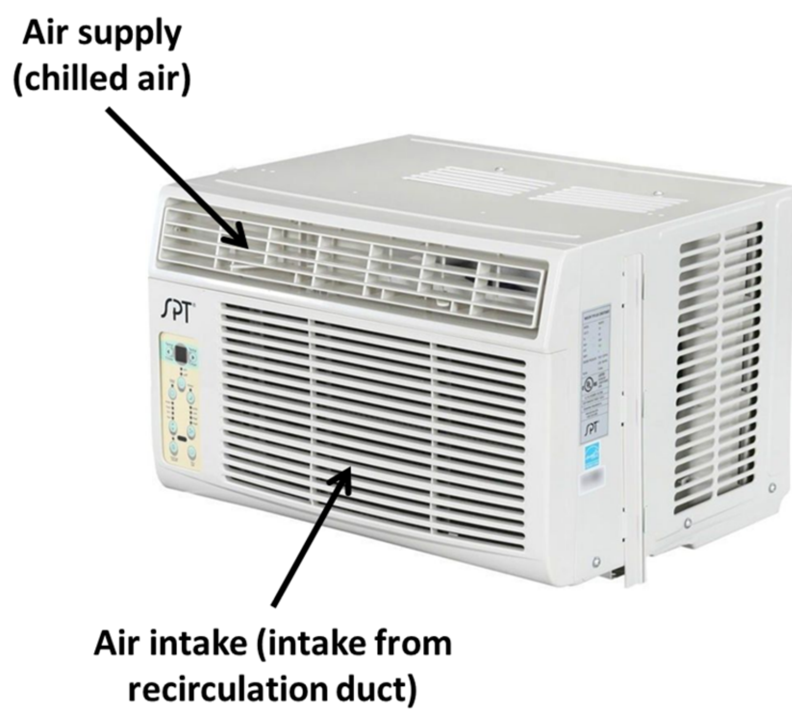


Figure 4.3.2: Basic flow diagram of the chilled water system configuration that will be used in the experimental testing

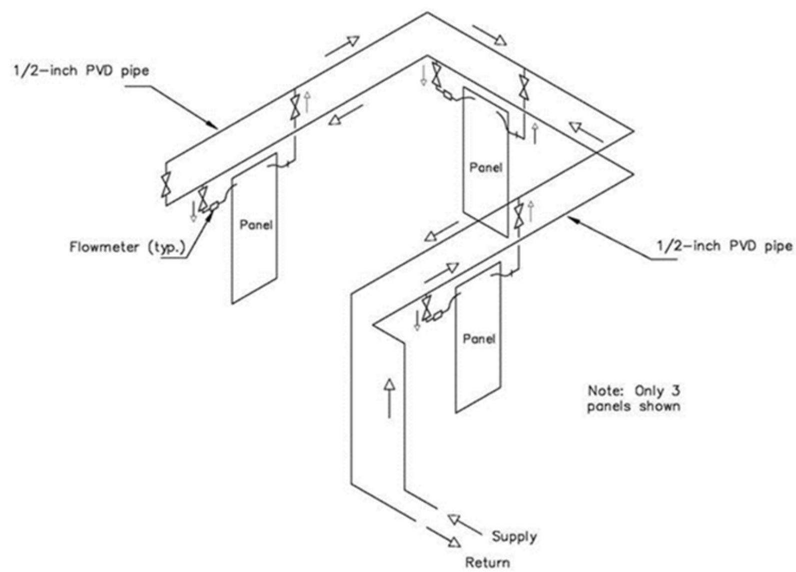
4.4 Support Equipment - Chilled water system - Chiller unit (AC unit)

Equipment function / process	Description
Function	• Provide chilled water at the temperature and quantity that is required to achieve the test objectives. • Provide a flexible yet robust working process to build and operate the chilling capacity • Use a conventional AC window unit incorporated into a chilled air duct to provide chilled air to the air-to-water heat exchanger
Selection process	A surplus window unit was used
Specifications	Kenmore, Model 253.70121 12,000 BTU, 60 Hz, 1 Ph
Produkt Image, Kenmore	

4.5 Support Equipment - Chilled water system – Air-to-water Heat Exchanger

Equipment function / process	**Description**
Function	• Transfer heat from the chilled air to the chilled water
Selection process	The commercial small air to water heat exchanger was selected; the typical application for the heat exchanger is to transfer heat from flue gases to water for heating purposes. The application in the test set-up was different since the temperature differentials between the gas and water were significantly lower than in applications for which the heat exchanger is typically used. Therefore the product specification of the heat exchanger does not exactly apply to this test configuration.
Procurement process	The small heat exchanger was procured
Specifications	Brent Industries LLC, part# HWC-20X20, see **Appendix C**
Product image, Brent Industries	

4.6 Support Equipment - Chilled Water System –Piping

Equipment function / process	**Description**
Function	• Convey the chilled water from the chiller unit to the radiant panels • Provide a flexible way to convey and distribute the chilled water supply and return
Selection process	The chilled water piping system consists of ½ inch PVC piping, flexible hosing, valves and fittings. All piping components are standard products.
Procurement process	PVC piping, flexible hosing, valves and fittings will be purchased either locally or ordered online
Specifications	Standard product specifications apply.
Illustrations	The following figure shows systematics of the chilled water piping system. Not all panels are shown. More information is provided in technical drawings shown in **Appendix A and D**  **PVC Piping - Isometric** Scale N/A

4.7 Support Equipment - Chilled water system –Pumps

Two types of pumps were used: (1) a small submersible pump to fill the chilled water system and (2) an inline pump to convey the chilled water through the piping system.

Equipment function / process	**Description of small submersible pump**
Function	• Provide hydraulic energy to convey the chilled water through the heat exchanger of the primary cooling loop • Fill the chilled water system (radiant panels and piping) and purge air out of the system
Selection process	The chilled water pump was selected based on their nameplate capacity
Procurement process	The chilled water pump has been purchased
Specifications	Specification are provided on **Appendix C**
Image of chilled water pump, Little Giant pumps	

4.8 Support Equipment – Space Heater

Equipment function / process	Description
Function	Provide heating to the room air for establishing the warm temperatures that are used in the comfort climate chamber
Selection process	The heater was selected online as a regular space heater with easy operation.
Procurement process	Two (2) space heater have been purchased
Specifications	Vornado ATH1 whole room tower heater, automatic climate control 2 heat settings (750W or 1500W) and 2 fan settings (Auto or Continuous)
Product image, Vornado	

SECTION 5 - INSTRUMENTATION AND P&I DIAGRAMS

The range of instrumentation and types of measurement procedures used in this project were as follows:

1. Air temperature in room
2. Relative Humidity in room
3. Contact temperature (for chilled water pipe and panel surface temperature)
4. Flow sensor - for chilled water flow
5. IR temperature probe – for assessment of surface radiant temperatures of objects
6. Hot wire anemometer – to measure air velocities generated by the ceiling fan
7. Hand held anemometer – to make spot checks for air velocities
8. Carbon dioxide level to detect ventilation needs of the climate chamber

Table 5.1 shows the type of measurement procedure used in the test set-up. Table 5.2 shows the types of instruments are being used.

Table 5.1: Type of measurements used

I.D. equipment	Function of measurements	Number of sensors required
A	Air temperature measurement; measures temperature of chilled air **upstream** of the heat exchanger	1
B	Air temperature measurement; measures temperature of chilled air **downstream** of the heat exchanger	1
C	Flow rate of chilled water measurement; measures flow rate chilled water supply flow	10 (one for each of the planned 10 panels)
D	Chilled water temperature measurement; measures cold water air temperature in the **SUPPLY** piping	1
E	Chilled water temperature measurement; measures cold water air temperature in the **RETURN** piping	1
F	Air temperature measurement; measures air temperature in the room air	2
G	Air humidity measurement; measures relative humidity levels in the room air	2

I.D. equipment	Function of measurements	Number of sensors required
H	Radiant panel surface temperature measurements; measures surface temperature of panel through contact sensor	10 (one for each of the planned 10 panels)
I	Radiant panel surface temperature measurements; measures surface temperature of panel through IR thermometer	1
J	Air flow measurements; measures air velocities due to ceiling fan with anemometer	8
K	Air flow measurements; measures air velocities due to ceiling fan with hand held flow sensor	1
L	Carbon dioxide levels measurements; measures Carbon dioxide levels in the room air	1
M	Chilled water temperature measurement; measures cold water air temperature in the Cooler that serves as container. Min / Max Temp. switching	1
N	Mean radiant temperature measurement;	5

Table 5.2: Type of instruments used

I.D. equipment	Function of Instrumentation	Product name
A	Air temperature measurement	Onset HOBO UX-100-023
B	Air temperature measurement	Onset HOBO UX-100-023
C	Flow rate of chilled water measurement	Grundfos VFS 1-20 vortex flow sensor
D	Chilled water temperature measurement	Onset HOBO UX120-006M equipped with Onset TMC6-HE (flat stainless steel tip)
E	Chilled water temperature measurement	Onset HOBO UX120-006M equipped with Onset TMC6-HE (flat stainless steel tip)
F	Air temperature measurement	Onset HOBO UX-100-023
G	Air humidity measurement	Onset HOBO UX-100-023
H	Radiant panel surface temperature measurements	Onset HOBO UX120-006M equipped with Onset TMC6-HE (flat stainless steel tip)
I	Radiant panel surface temperature measurements with IR sensor	Flir b50 camera
J	Air flow measurements;	Accusense F900 hot wire anemometers equipped with the XS blade and signals were acquired with a National Instruments UBB-6341 USB device and a laptop equipped with National Instruments Signal Express software. Data processing was completed using a Python script.
K	Air flow measurements; hand held instrument	Graywolf Hand held Anemometer AS-201, Graywolf Sensing Solutions,
L	Carbon dioxide levels measurements	Telaire 7001 (signal was acquired by an Onset HOBO UX120-006M)
M	Min / Max Temp. switching	Johnson Controls electronic temperature controller A419ABG-3C
N	Mean radiant temperature measurement;	Onset TMC20-HD temperature probe incased in a 40-mm celluloid globe (table tennis ball) spray-painted matt black.

Figures 5.1 through 5.5 show P&I diagrams with instrumentation used for the experimental set-up.

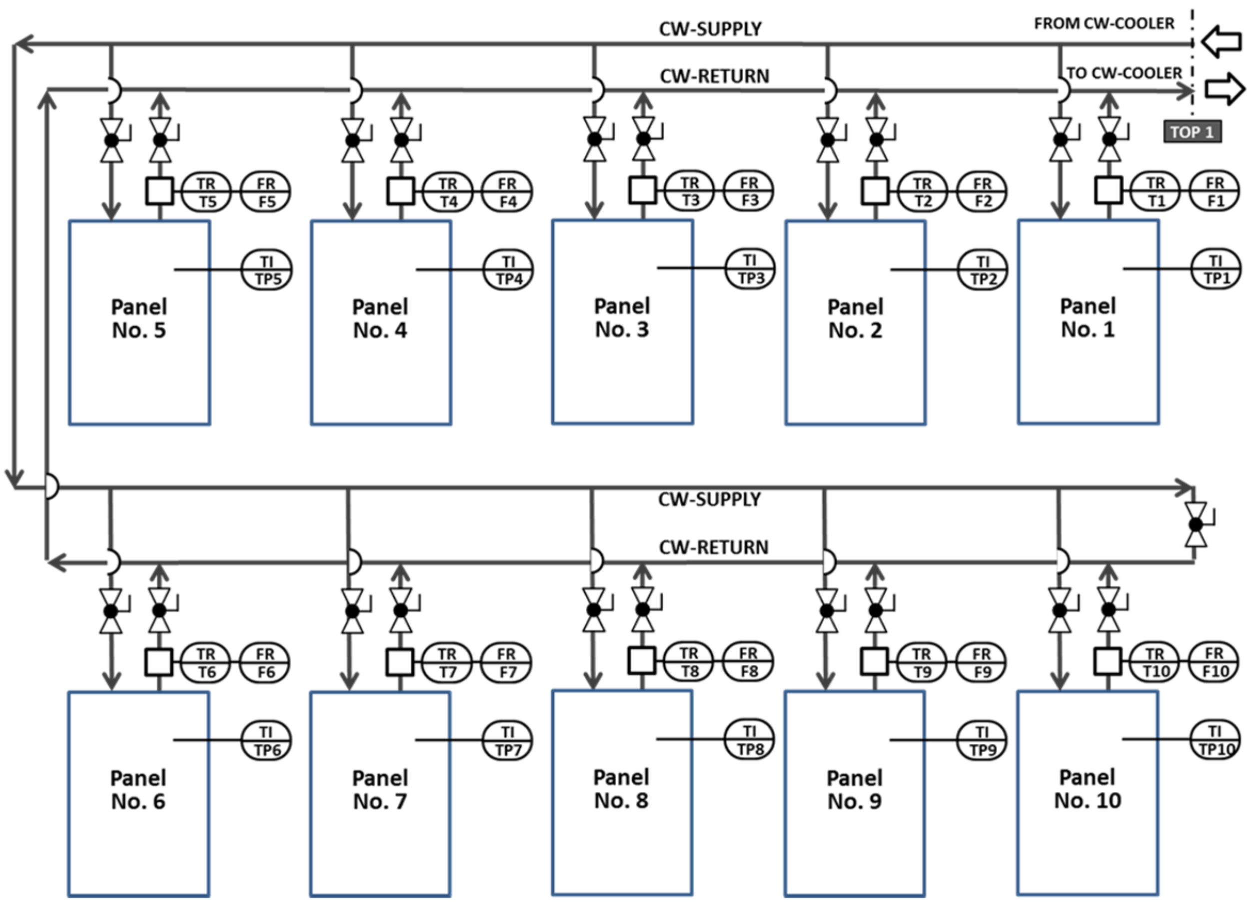


Figure 5.1: Piping & Instrumentation Diagram (P&I D) for the Test Station – Sheet 1 - Radiant panels in the test station with Chilled Water system (the full size diagram is presented in Appendix D)

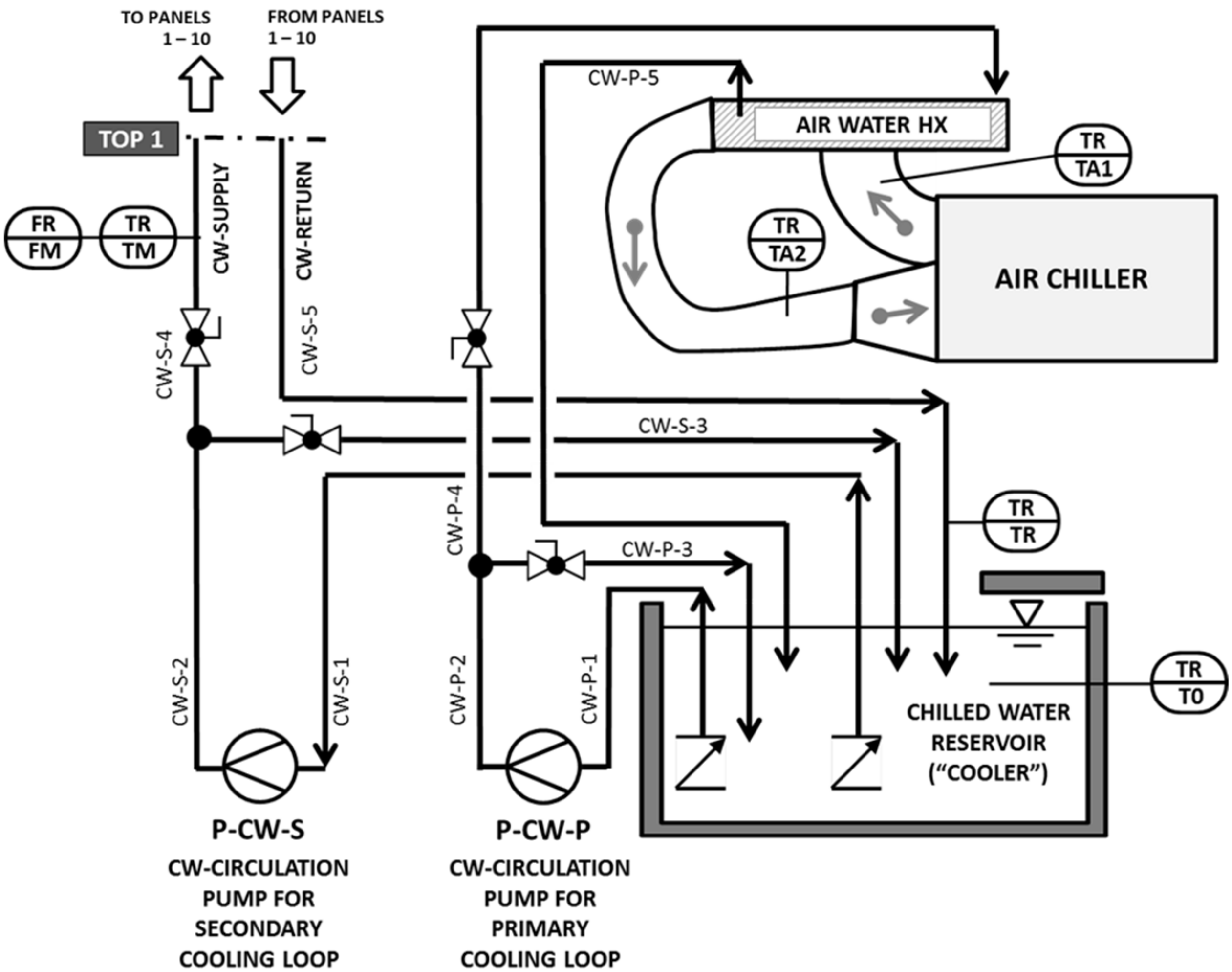


Figure 5.2: Piping & Instrumentation Diagram (P&I D) for the Test Station – Sheet 2 - Chilled Water (CW) generation plant (the full size diagram is presented in Appendix D)

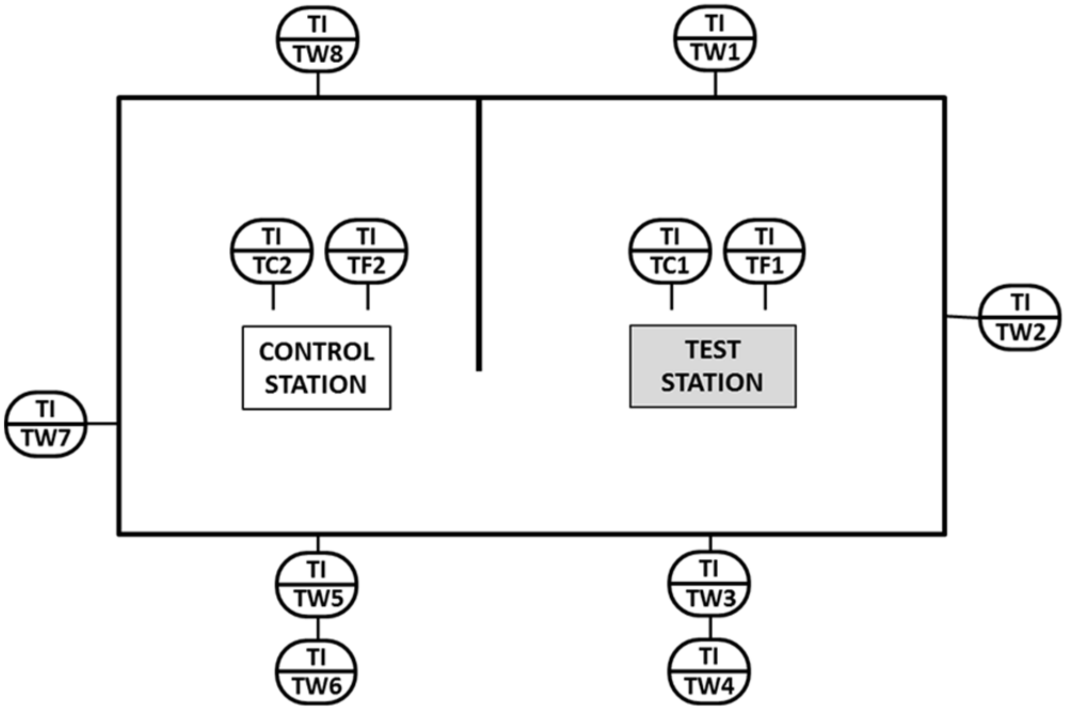


Figure 5.3: Piping & Instrumentation Diagram (P&I D) for the Test Station – Sheet 3 - IR measurement of radiant temperature on walls, ceiling and floor (the full size diagram is presented in Appendix D)

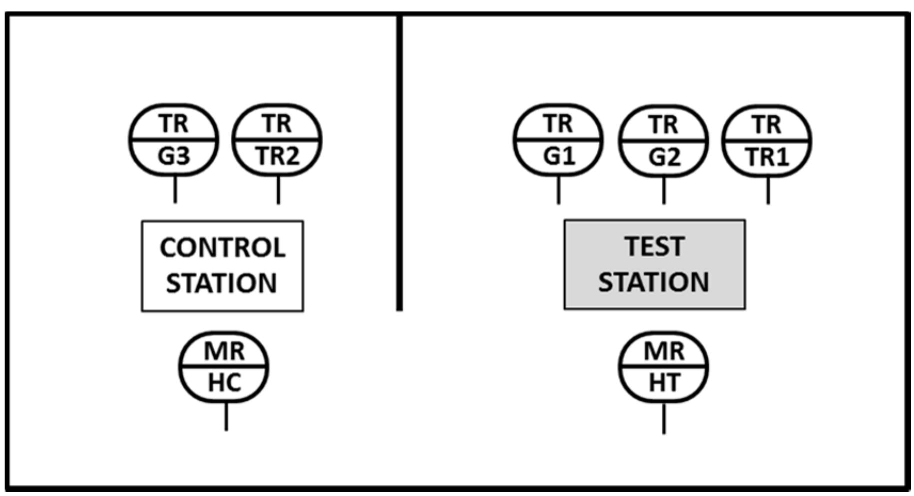


Figure 5.4: Piping & Instrumentation Diagram (P&I D) for the Test Station – Sheet 4 - Recorded temperature and humidity measurements in test and control stations (the full size diagram is presented in Appendix D)

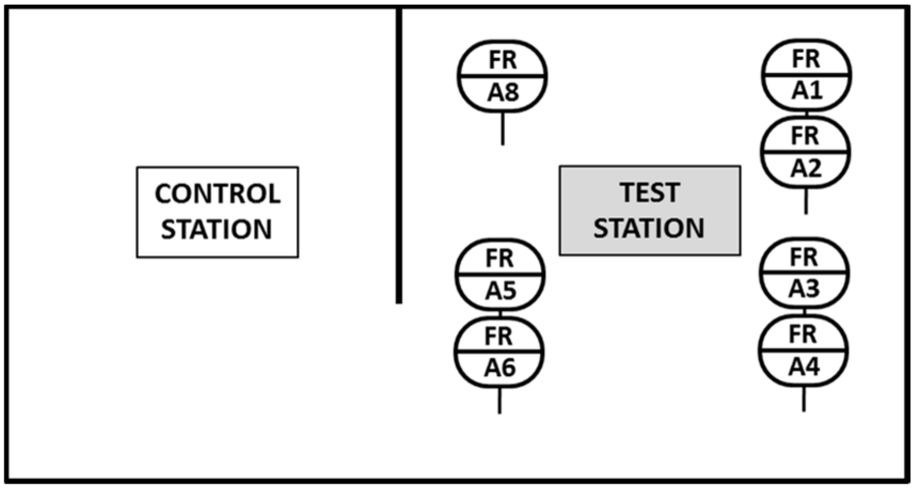


Figure 5.5: Piping & Instrumentation Diagram (P&I D) for the Test Station – Sheet 5 - Anemometers used in validation tests in test station (the full size diagram is presented in Appendix D)

Note (*)

Definition of Instrumentation in P&I D

First letter: Measured variable

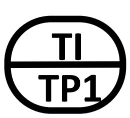
F	Flow
T	Temperature
M	Humidity

Second letter Passive Function

R	Recording
I	Indicating

Identifier in P&I D:

Example:



First letter : T = Temperature measured

Second letter: R = Recorded

Identifier in P&I D: Identifier for Data Acquisition & processing

	P&I Diagram				Data Acquisition & processing		
Run No.	Shown in Diagram sheet No.	Identifier in P&I D see Note (*)	First letter see Note (*) Measured variable	Second letter see Note (*) Passive Function	units	Physical parameter measured	**Sensor ID** is used for the data acquisition and processing
1	5	A1	F	R	m/s	air speed	Anem_1
2	5	A2	F	R	m/s	air speed	Anem_2
3	5	A3	F	R	m/s	air speed	Anem_3
4	5	A4	F	R	m/s	air speed	Anem_4
5	5	A5	F	R	m/s	air speed	Anem_5
6	5	A6	F	R	m/s	air speed	Anem_6
7	5	A7	F	R	m/s	air speed	Anem_7
8	5	A8	F	R	m/s	air speed	Anem_8
9	3	TC1	T	I	F	temperature	C1
10	3	TC2	T	I	F	temperature	C2
11	3	TF1	T	I	F	temperature	F1
12	3	TF2	T	I	F	temperature	F2
13	1	F1	F	R	l/min	water flow	Flow_1
14	1	F10	F	R	l/min	water flow	Flow_10
15	1	F2	F	R	l/min	water flow	Flow_2
16	1	F3	F	R	l/min	water flow	Flow_3
17	1	F4	F	R	l/min	water flow	Flow_4
18	1	F5	F	R	l/min	water flow	Flow_5
19	1	F6	F	R	l/min	water flow	Flow_6
20	1	F7	F	R	l/min	water flow	Flow_7
21	1	F8	F	R	l/min	water flow	Flow_8
22	1	F9	F	R	l/min	water flow	Flow_9
23	2	FM	F	R	l/min	water flow	Flow_Main
24	4	G1	T	R	F	globe temp	Globe_1_test
25	4	G2	T	R	F	globe temp	Globe_2_test
26	4	G3	T	R	F	globe temp	Globe_3_control
27	4	HC	M	R	%	relative humidit	Humidity_control
28	4	HT	M	R	%	relative humidit	Humidity_test
29	1	TP1	T	I	F	temperature	P1
30	1	TP10	T	I	F	temperature	P10
31	1	TP2	T	I	F	temperature	P2
32	1	TP3	T	I	F	temperature	P3
33	1	TP4	T	I	F	temperature	P4
34	1	TP5	T	I	F	temperature	P5
35	1	TP6	T	I	F	temperature	P6
36	1	TP7	T	I	F	temperature	P7
37	1	TP8	T	I	F	temperature	P8
38	1	TP9	T	I	F	temperature	P9
39	4	TR1	T	R	F	temperature	RoomTemp_test
40	4	TR2	T	R	F	temperature	RoomTemp_control
41	2	TA1	T	R	F	temperature	Temp_AC
42	2	TA2	T	R	F	temperature	Temp_ACreturn
43	2	T0	T	R	F	temperature	Temp_cooler
44	1	T1	T	R	F	temperature	Temperature_1
45	1	T10	T	R	F	temperature	Temperature_10
46	1	T2	T	R	F	temperature	Temperature_2
47	1	T3	T	R	F	temperature	Temperature_3
48	1	T4	T	R	F	temperature	Temperature_4
49	1	T5	T	R	F	temperature	Temperature_5
50	1	T6	T	R	F	temperature	Temperature_6
51	1	T7	T	R	F	temperature	Temperature_7
52	1	T8	T	R	F	temperature	Temperature_8
53	1	T9	T	R	F	temperature	Temperature_9
54	2	TM	T	R	F	temperature	Temperature_Main
55	2	TR	T	R	F	temperature	Temperature_Return
56	3	TW1	T	I	F	temperature	W1
57	3	TW2	T	I	F	temperature	W2
58	3	TW1	T	I	F	temperature	W3
59	3	TW1	T	I	F	temperature	W4
60	3	TW1	T	I	F	temperature	W5
61	3	TW1	T	I	F	temperature	W6
62	3	TW1	T	I	F	temperature	W7
63	3	TW1	T	I	F	temperature	W8

Figure 5.5:
Table of instrumentation referenced in the P&I D (sheets 1 through 5)
(the full size figure is presented in Appendix D)

SECTION 6 – TYPES OF EXPERIMENTAL INVESTIGATIONS PLANNED FOR THE COMFORT TEST PROGRAM

The following type of experimental investigations will be performed:

1. **Comfort surveys:** Comfort surveys will be performed with a group of occupants under varying air temperature, humidity and air speed conditions.
2. **CFD validation tests:** Measurements of a range of thermal and air flow conditions will be performed at the test set-up. Selected data will be used for validation of the CFD results. Measurements will be conducted for environmental conditions that are established in the CFD investigations.

SECTION 7 – PRELIMINARY HUMAN COMFORT TEST PLANS

This section presents the preliminary scope of the human comfort tests. The final test plan will implemented at the start of the actual comfort tests.

Comfort Surveys will be conducted with a group of approximately 20 to 30 people. It is planned to enroll UHM students as volunteers to report on their comfort experience under various thermal conditions established in room HIG 204.

The specifics of the comfort tests will be finalized. At this point the following survey guidelines are planned:

- Assemble a group of people that represents a good mix of gender and age. Add other qualifiers, if deemed necessary.
- Ask the test people to participate for **two** sittings, with online surveys and/or hand out written survey forms.
- One “sitting” period for one person will typically consist of seven consecutive sequence:

Sequence NO.	Activities of test person	Function of sequence in test	duration [min]
1	Test person arrives at HIG 205 and remains seated at a dedicated chair	Acclimation	10
2	Test person moves to the control station and is engaged in specific and assigned reading activity	Experience comfort conditions at the **Control** Station of the Test set-up	12
3	Test person leaves control station and returns to HIG 205 and remains seated at a dedicated chair	Re- Acclimation	8
4	Test person moves to the test station and is engaged in specific and assigned reading activity; **Test Condition A** is active	Experience comfort conditions at the **Test** Station of the Test set-up under Test Condition A	12
5	Test person moves to the test station and is engaged in specific and assigned reading activity; **Test Condition B** is active	Experience comfort conditions at the **Test** Station of the Test set-up under Test Condition B	12
6	Test person leaves test station and returns to HIG 205; person is asked to record his/her comfort experience and provide other	De-briefing of test person	5
7	Test person receives certificate of attendance (or small gift) of attendance (might be used for credits at classes)	certification & appreciation gift	1
		sum of all sequences	**60**

The following are the preliminary test parameters:

- One (1) scenario of the radiant panel configuration.
- Use two (1) temperatures and humidity settings
- Use two (2) fan speeds; low and medium

Preliminary "Test conditions" during the planned two sittings:

Sitting 1: High temperature and humidity setting (TBD)

Test Condition A: Radiant panels are NOT actively cooled
Ceiling fan speed "LOW"
Test Condition B: Radiant panels are NOT actively cooled
Ceiling fan speed "MEDIUM"

Sitting 2: High temperature and humidity setting (TBD)

Test Condition A: Radiant panels are actively cooled
Ceiling fan OFF
Test Condition B: Radiant panels are actively cooled
Ceiling fan speed "LOW"

This preliminary test plan remains subject to change. The sequence and the detailed format of comfort tests will be decided shortly before the test runs. The preliminary comfort survey is presented in Appendix F.

Tests of physical parameters:

Thermal and air flow experiments will be conducted to allow for selective validation of convective and/or radiative heat transfer performance on the test set-up. Fort these experiments NO human test person will be on the test space.

The test plan will be presented in Project Deliverable 14 of this research program.

APPENDICES

There are the following appendices attached to this FINAL report:

APPENDIX A: TEST SET-UP IN HIG 204

APPENDIX B: INFORMATION ABOUT THE PROTOTYPE COMFORT EQUIPMENT

APPENDIX C: SELECTED INFORMATION ABOUT THE SUPPORT EQUIPMENT

APPENDIX D: P&I D DIAGRAM AND INSTRUMENTATION LIST

APPENDIX E: PHOTO DOCUMENTATION OF THE TEST SET-UP

APPENDIX F: OCCUPANT COMFORT SURVEY FORM

APPENDIX A:

TEST SET-UP IN HIG 204

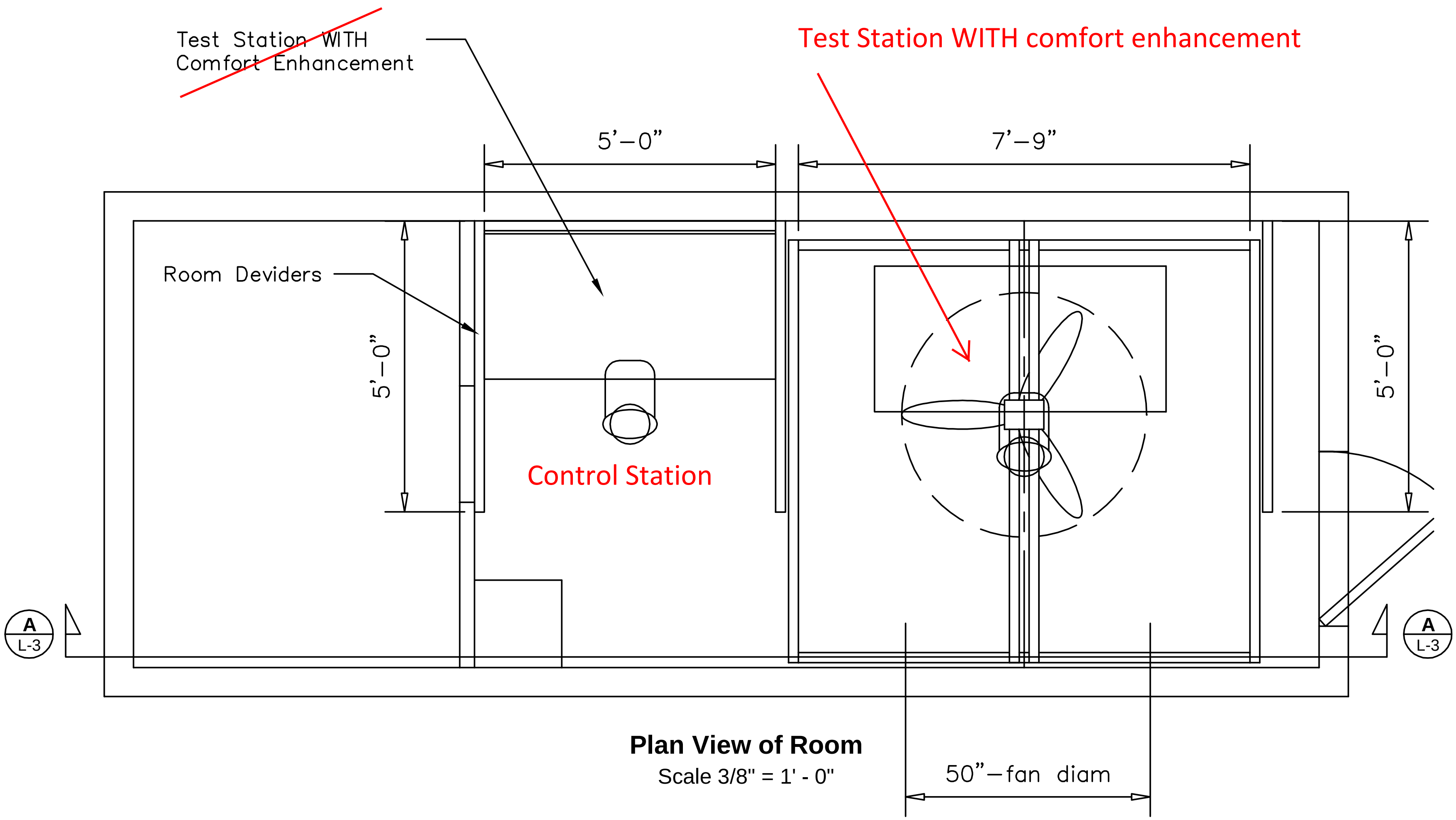
Note: There have been several modifications made from the initial test set-up design. For the sake of clarity and brevity, the changes are listed on the applicable pages of Appendix A.

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies

Test set up in HIG 204 - Design Concept Rev. A

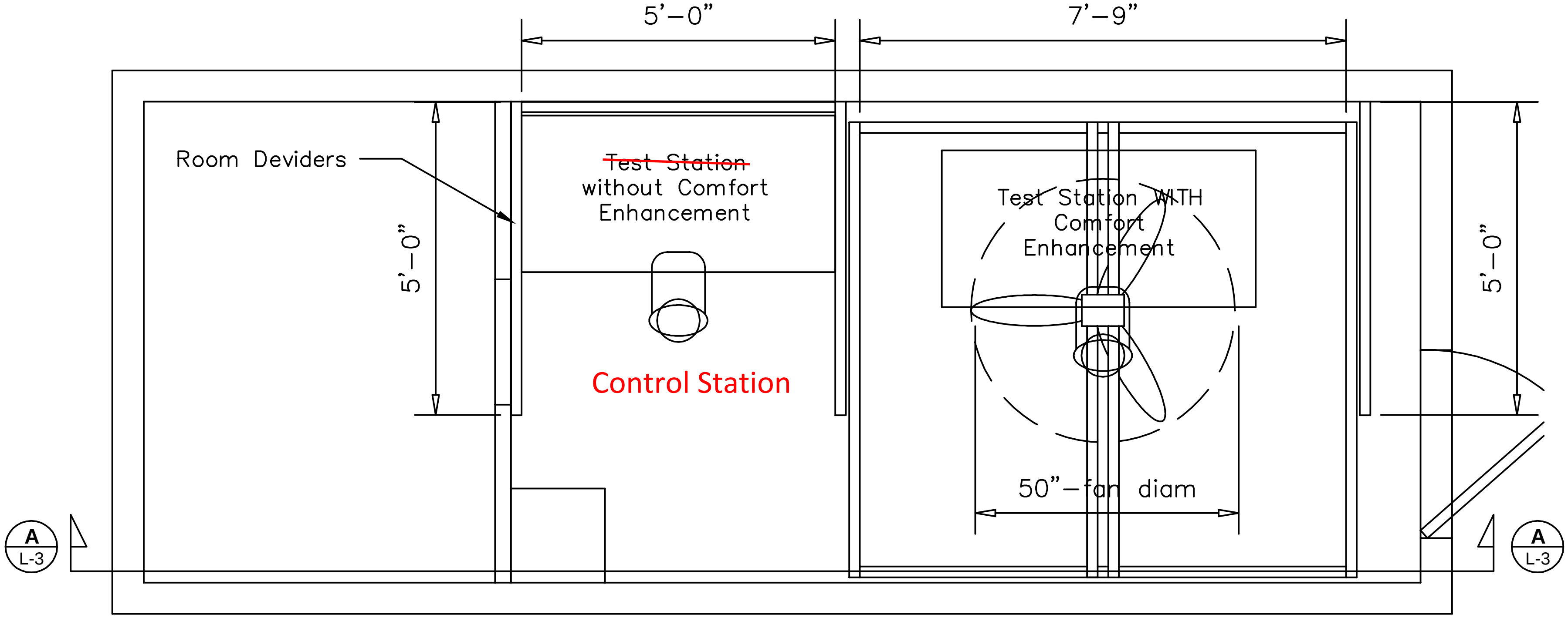
Index page   March 13, 2105

There are several changes to the original design made by the team. The design / installation changes are indicated by comments



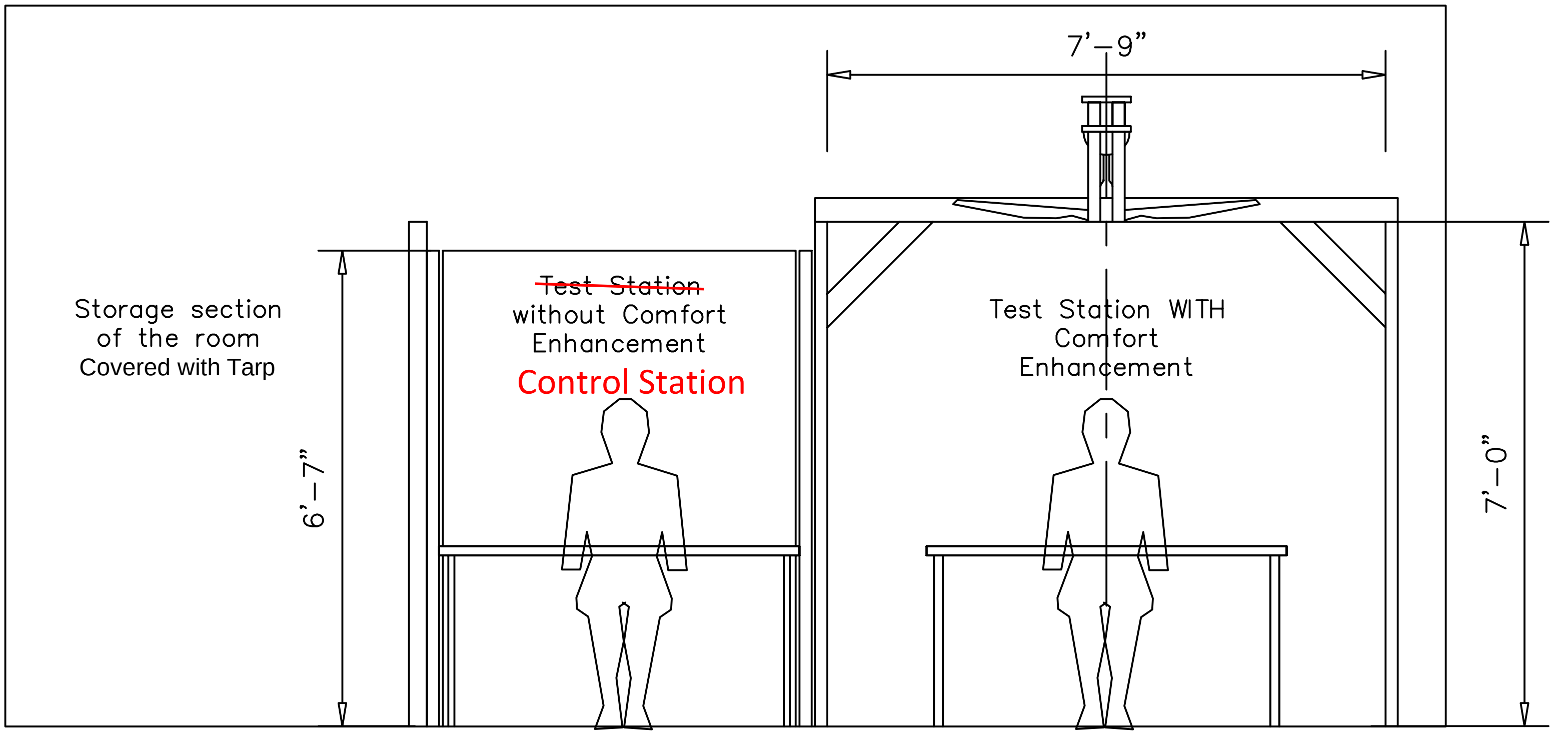
Plan View of Room
Scale 3/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Layout of room with test workstations
	Sheet No : L-2 Date : March 13, 2015 Drawn: MZ



Plan View of Room
Scale 3/8" = 1' - 0"

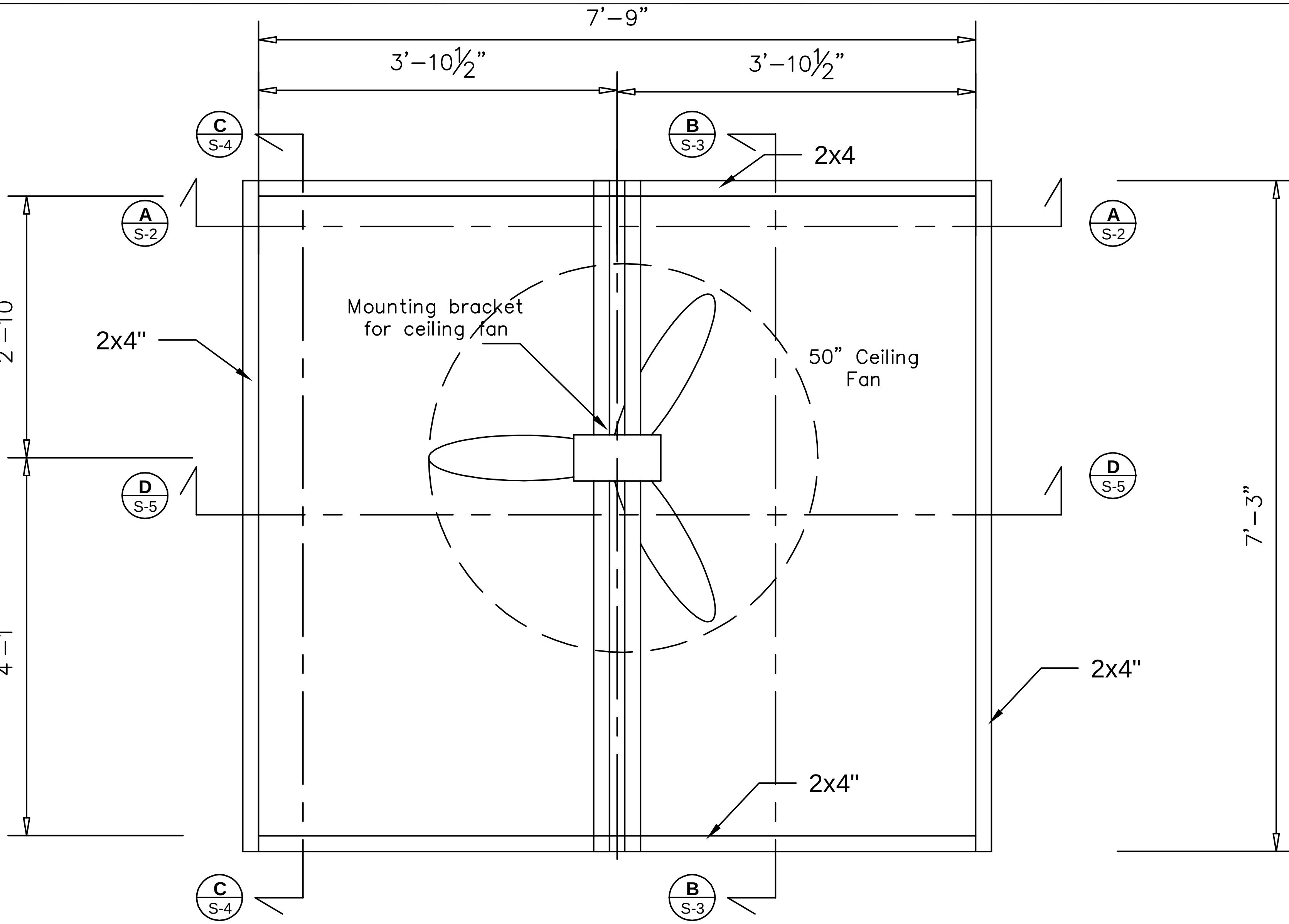
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Layout of room with test workstations
	Sheet No : L-2 | Date : March 13, 2015 | Drawn: MZ



Section A-A

Scale 3/8" = 1' - 0"

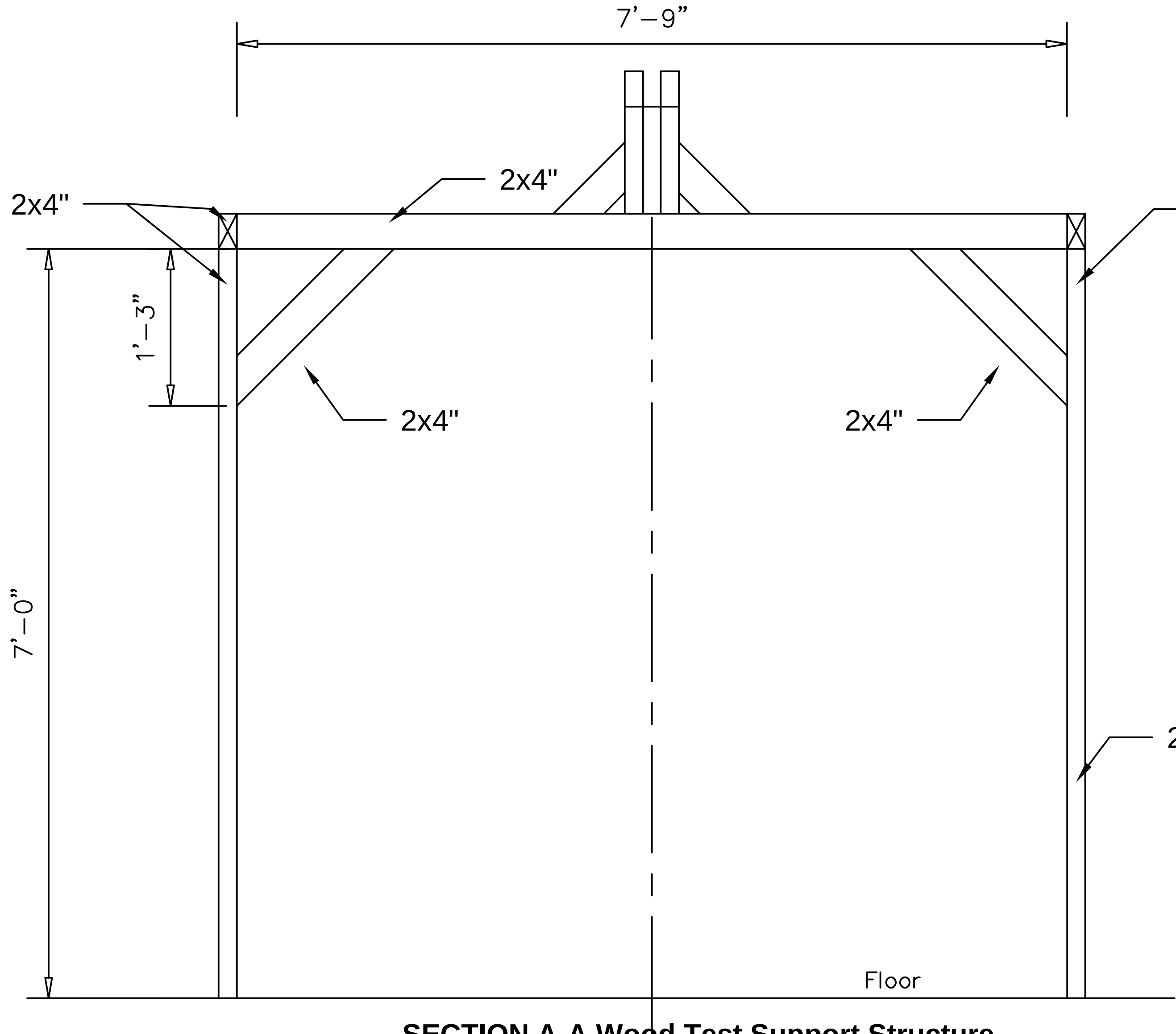
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Layout of room with test workstations - Sections		
	Sheet No : L-3	Date : March 13, 2015	Drawn: MZ



Plan View of Wood Test Support Structure

Scale 5/8" = 1' - 0"

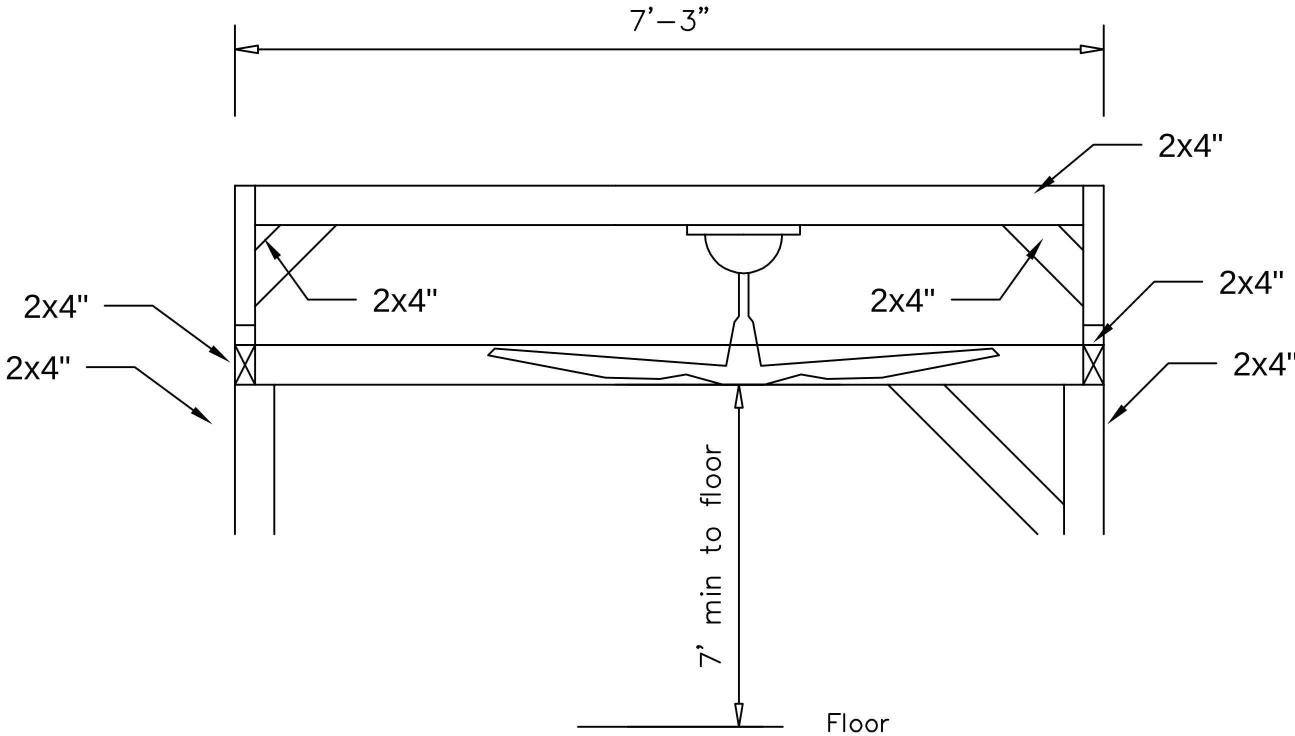
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Wood Test Support Structure - Plan View		
	Sheet No : S-1	Date : March 13, 2015	Drawn: MZ



SECTION A-A Wood Test Support Structure

Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Wood Test Support Structure - Section B-B		
	Sheet No : S-2	Date : March 13, 2015	Drawn: MZ



SECTION B-B Wood Test Support Structure

Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Wood Test Support Structure - Section B-B		
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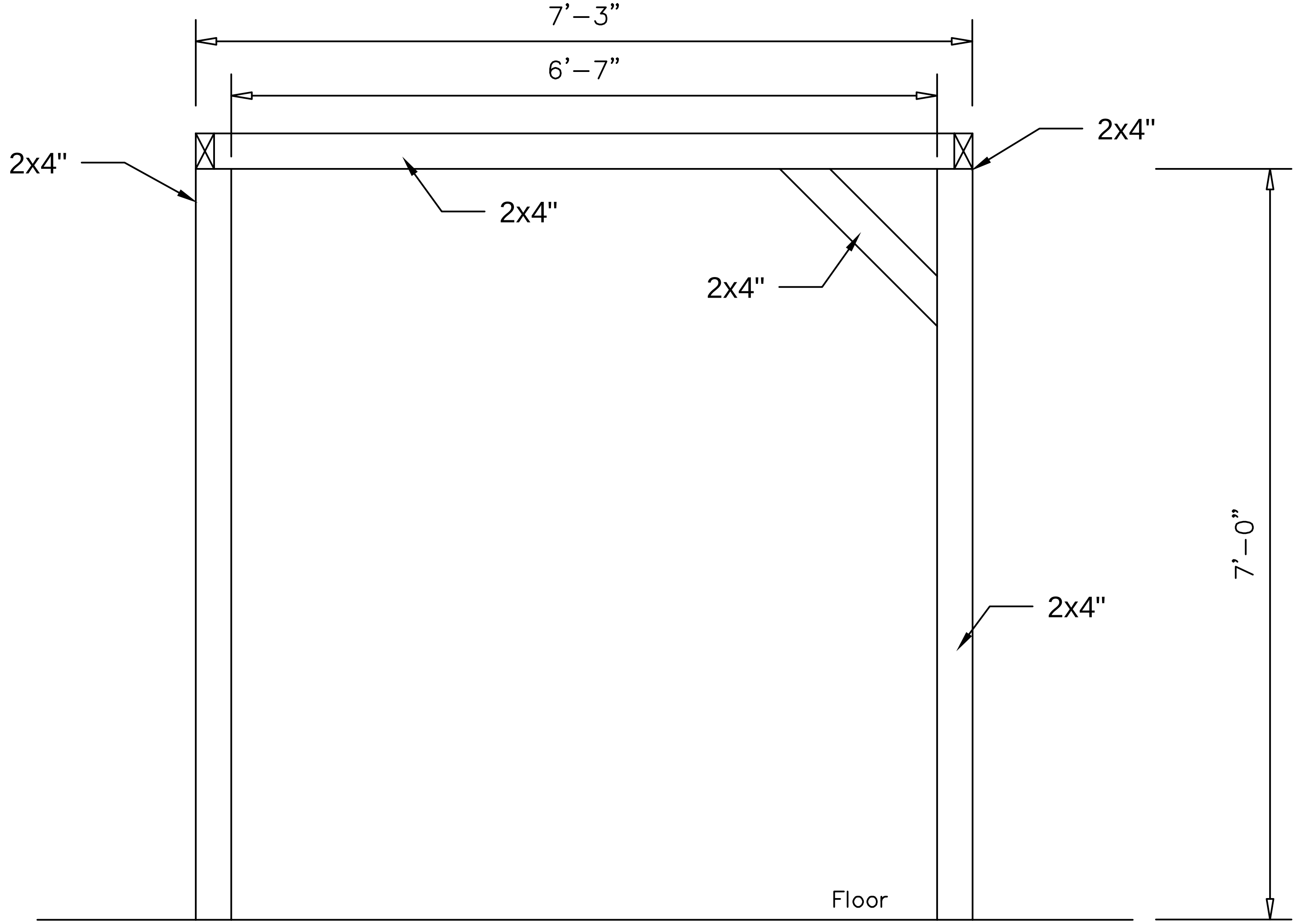
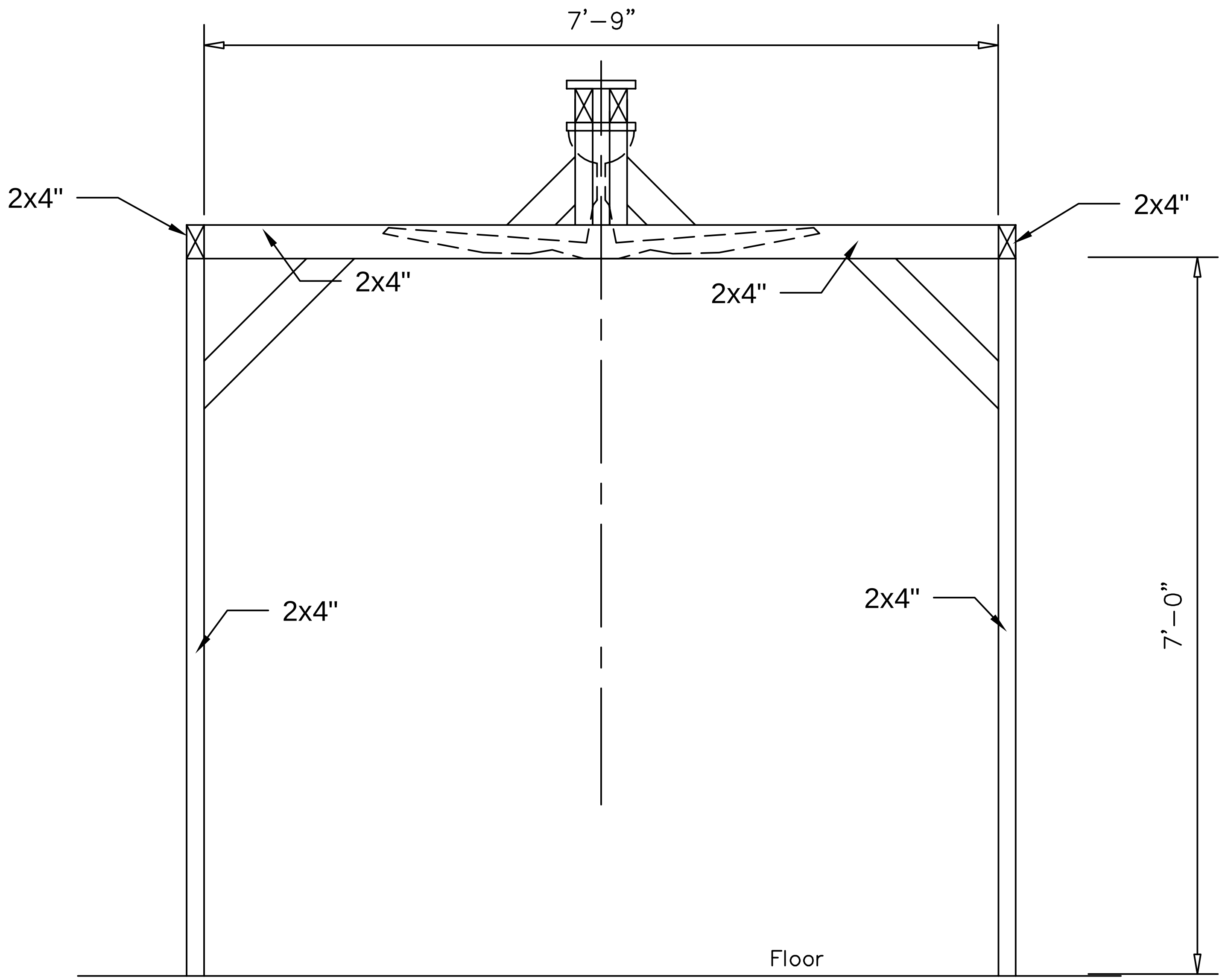


SECTION C-C Wood Test Support Structure
Scale 5/8" = 1' - 0"

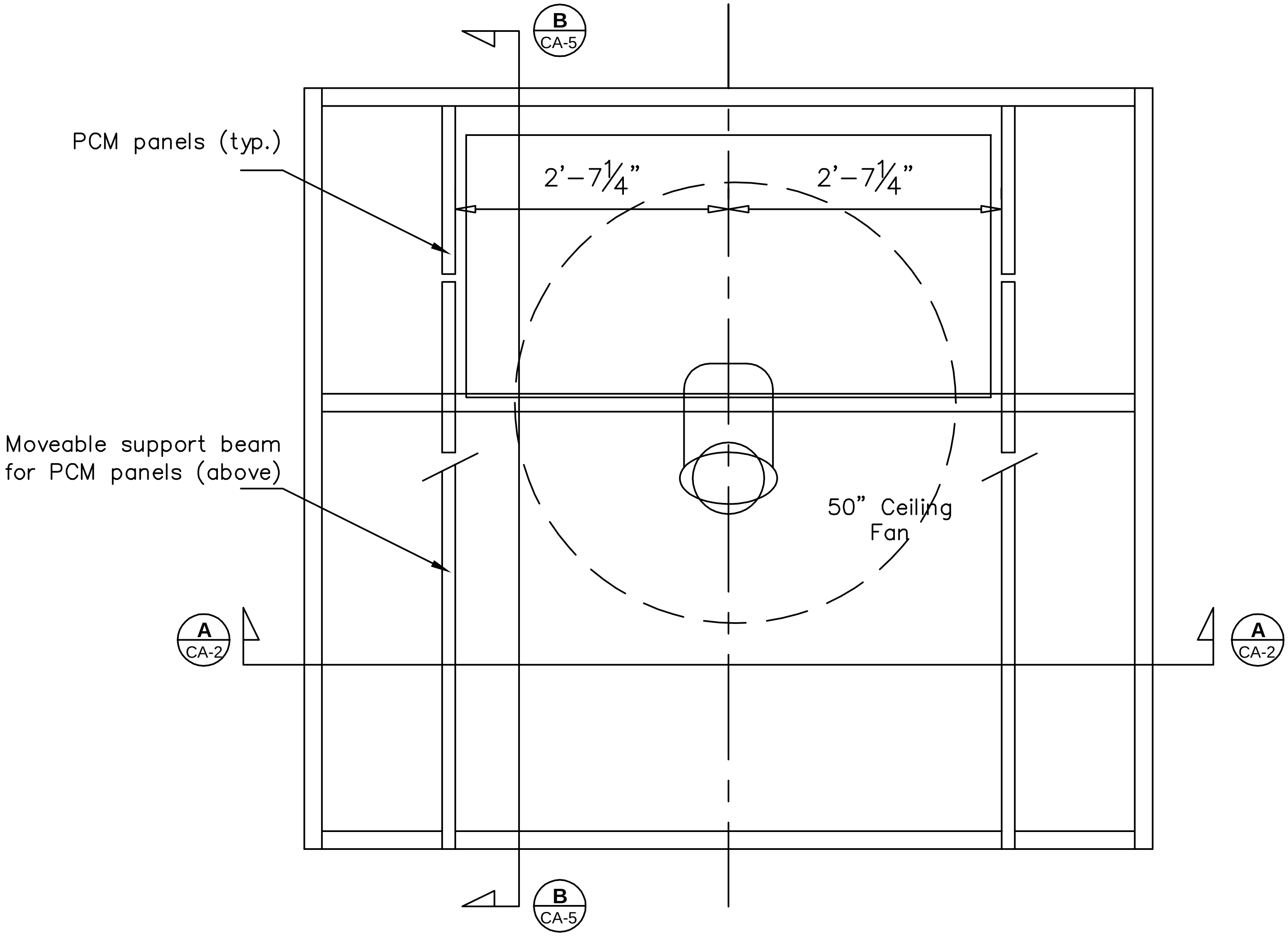
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Wood Test Support Structure - Section C-C
	Sheet No : S-4 / Date : March 13, 2015 / Drawn: MZ



SECTION D-D Wood Test Support Structure

Scale 5/8" = 1' - 0"

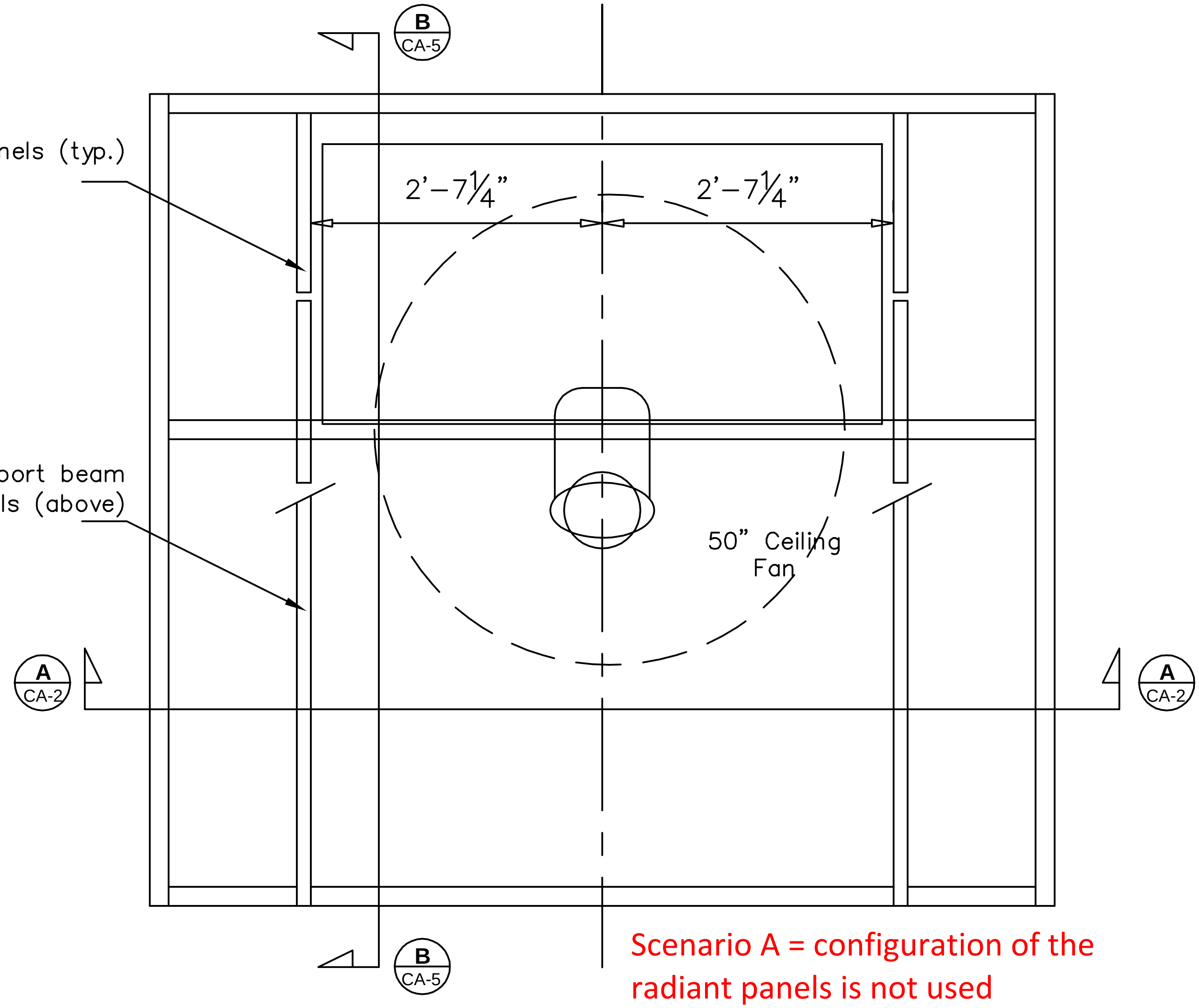
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Wood Test Support Structure - Section D-D
	Sheet No : S-5 | Date : March 13, 2015 | Drawn: MZ



Test Structure - Comfort Set Up - Scenario A

Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario A - Plan View
	Sheet No : CA-1 | Date : March 13, 2015 | Drawn: MZ

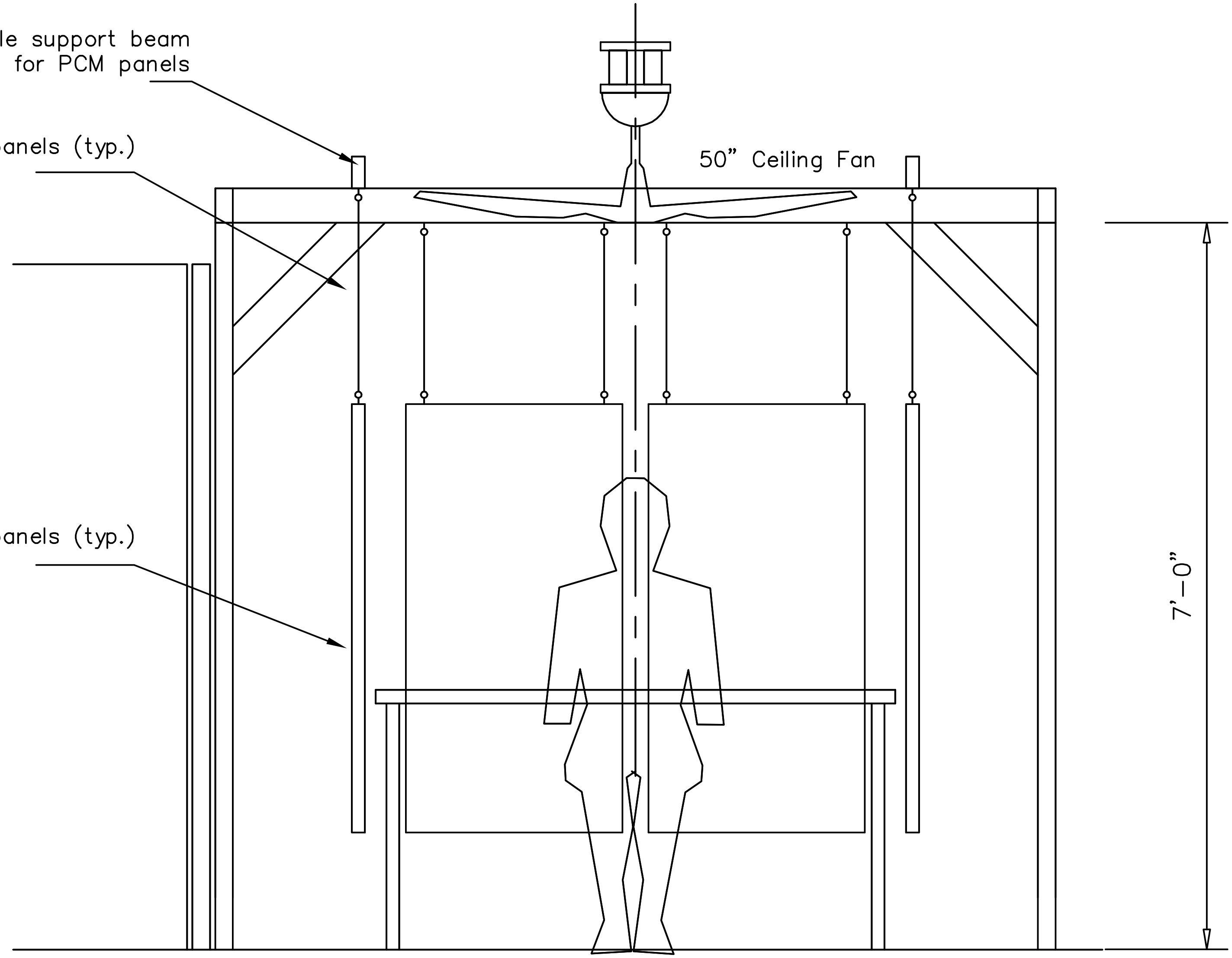


Scenario A = configuration of the radiant panels is not used

Test Structure - Comfort Set Up - Scenario A

Scale 5/8" = 1' - 0"

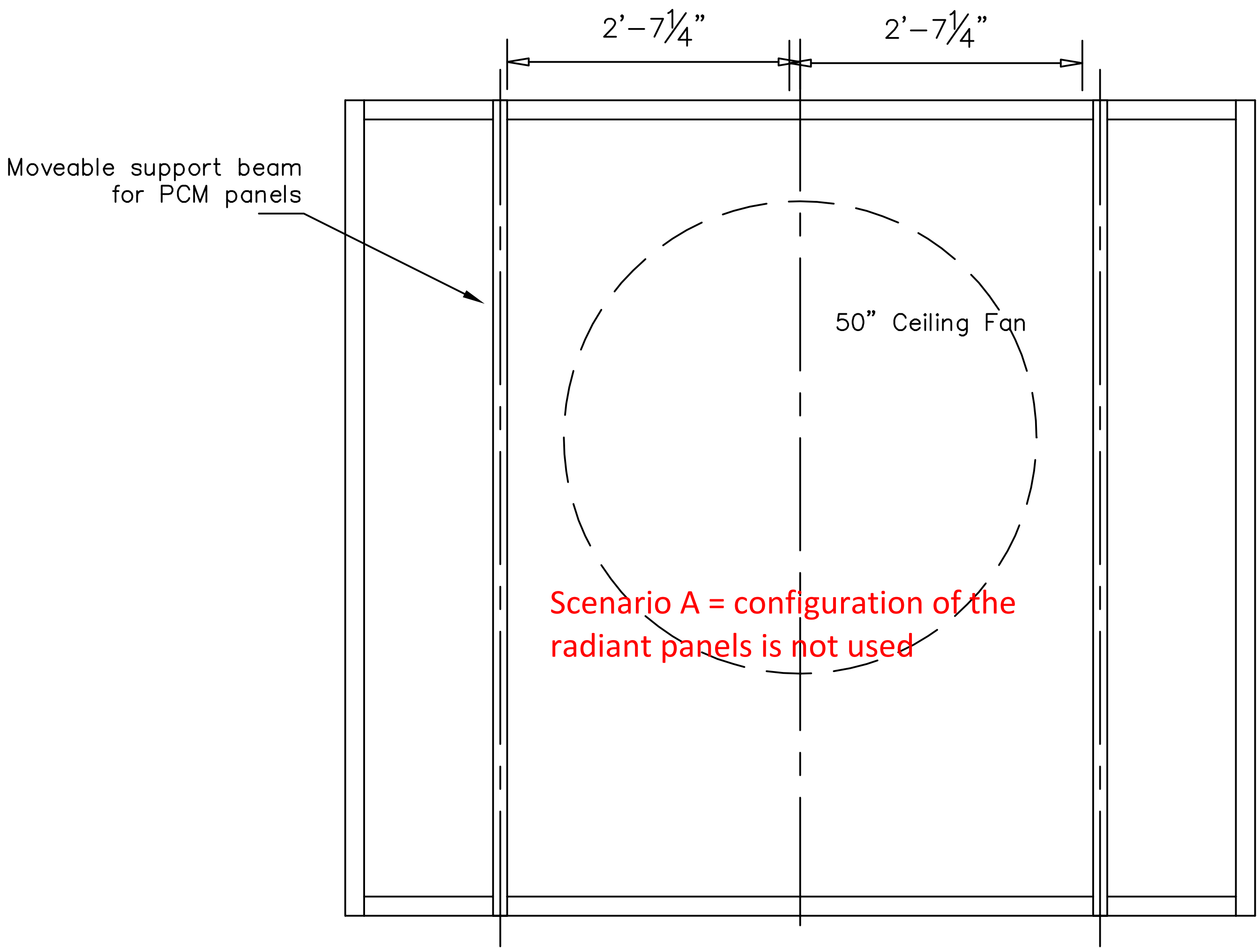
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario A - Plan View
	Sheet No : CA-1	Date : March 13, 2015	Drawn: MZ



Test Structure - Comfort Set Up - Scenario A -
SECTION A_A
Scale 5/8" = 1' - 0"

Scenario A = configuration of the radiant panels is not used

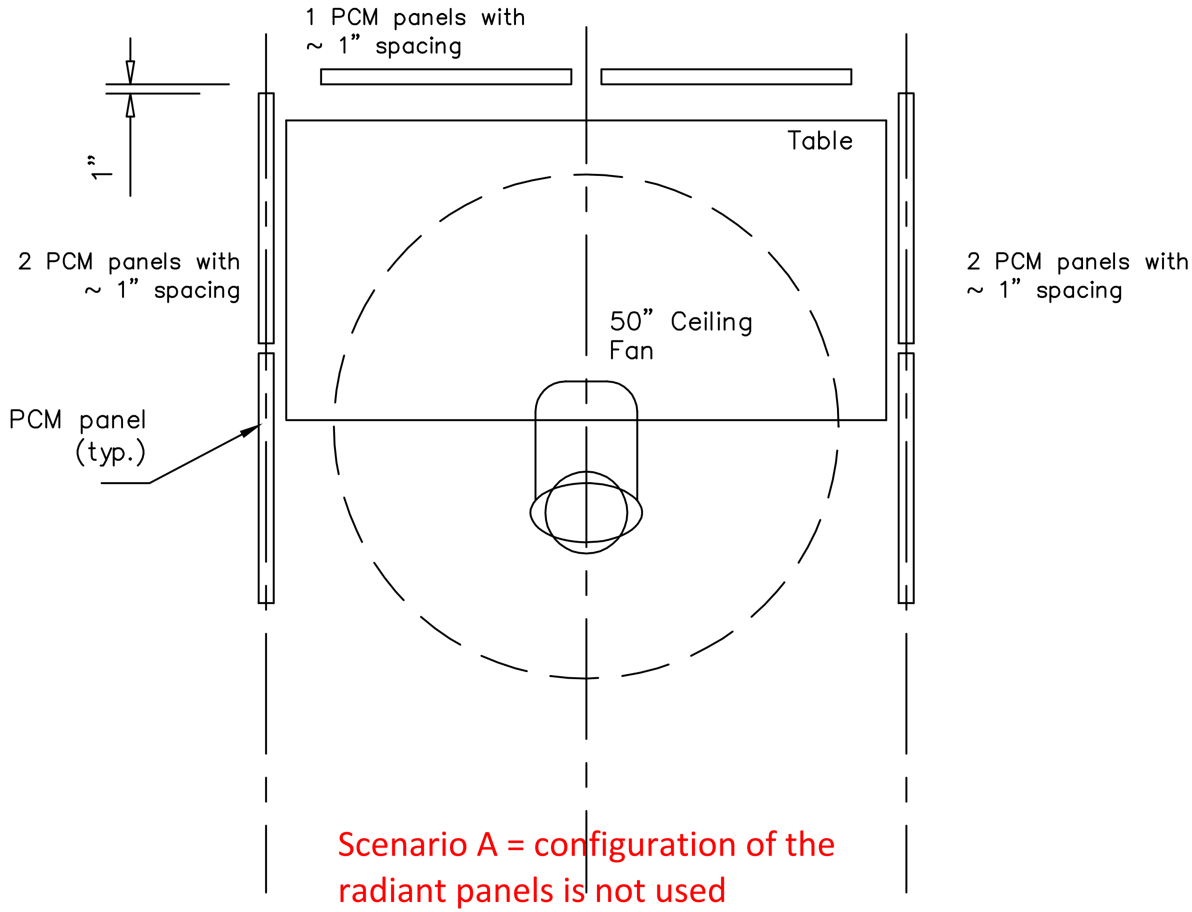
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario A - Section A-A
	Sheet No : CA-2 | Date : March 13, 2015 | Drawn: MZ



Test Structure - Comfort Set Up - Scenario A -
Structure without PCM panels

Scale 5/8" = 1' - 0"

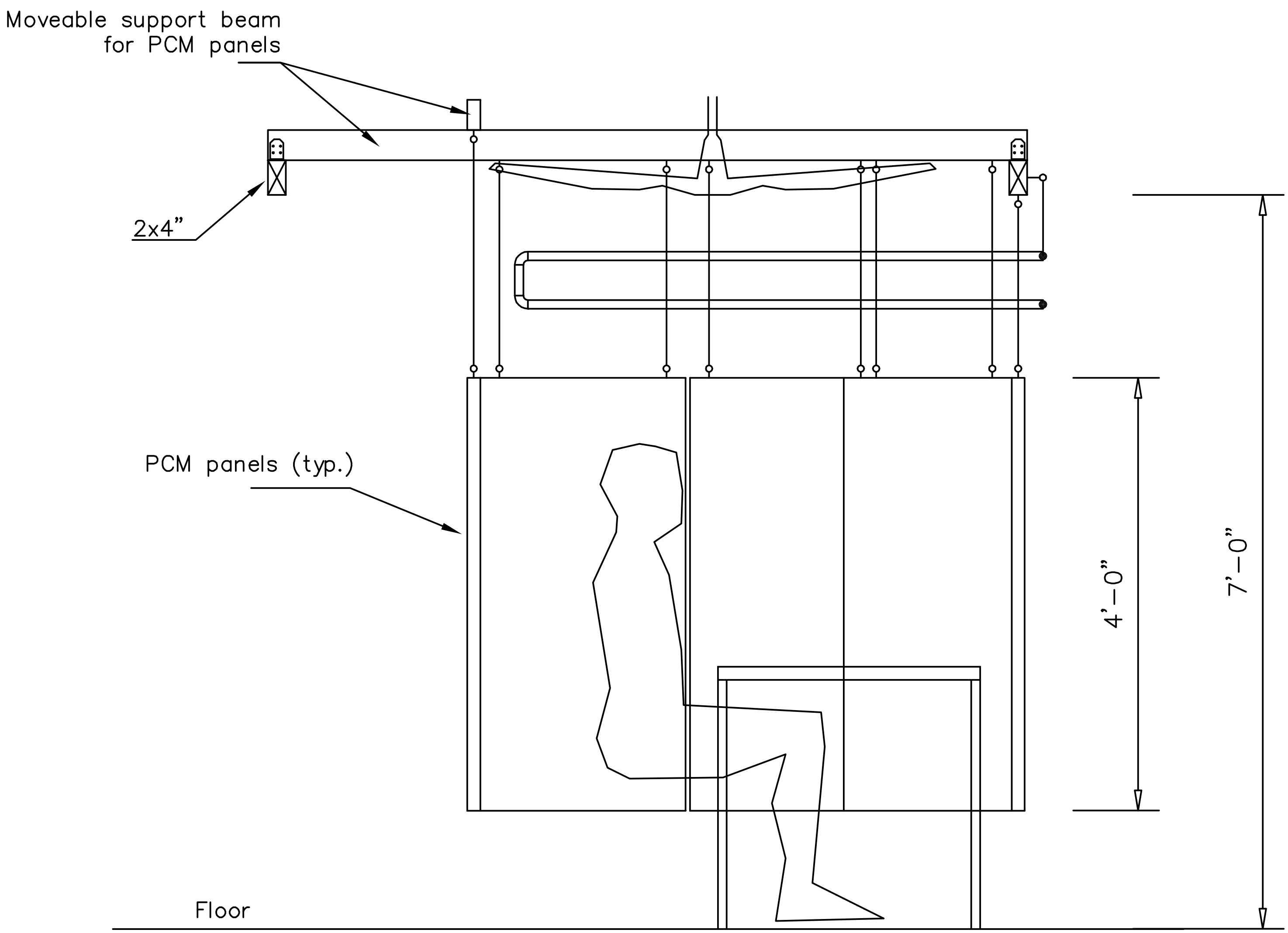
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario A - Layout	
	Sheet No : CA-3	Date : March 13, 2015	Drawn: MZ



Test Structure - Comfort Set Up - Scenario A -
Layout without Structure

Scale 5/8" = 1' - 0"

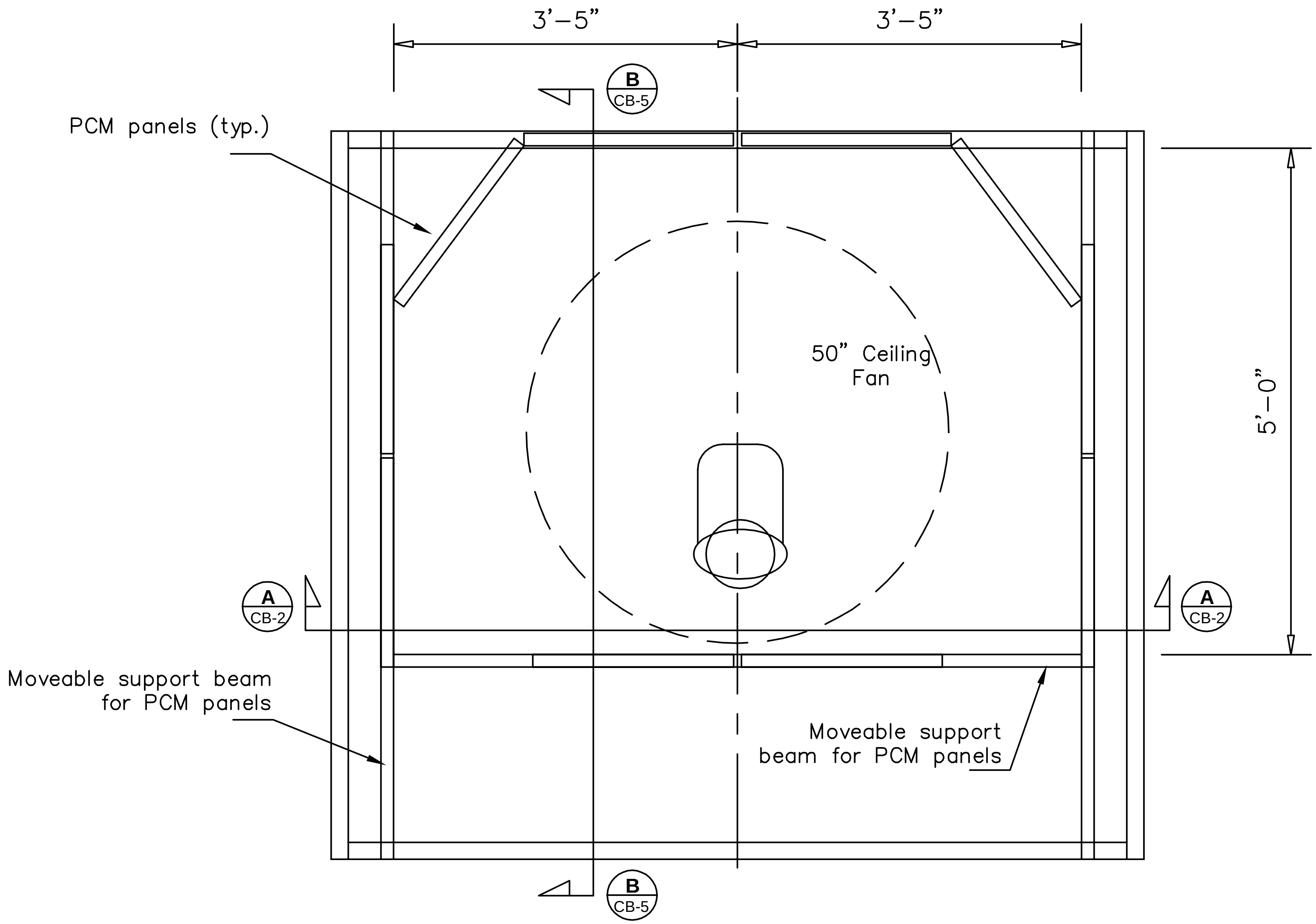
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario A - Layout
	Sheet No : CA-4 | Date : March 13, 2015 | Drawn: MZ



Test Structure - Comfort Set Up - Scenario B -
SECTION B-B

Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario B - Section B-B
	Sheet No : CB-5 | Date : March 13, 2015 | Drawn: MZ



Test Structure - Comfort Set Up - ScenarioB

Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario B - Plan View
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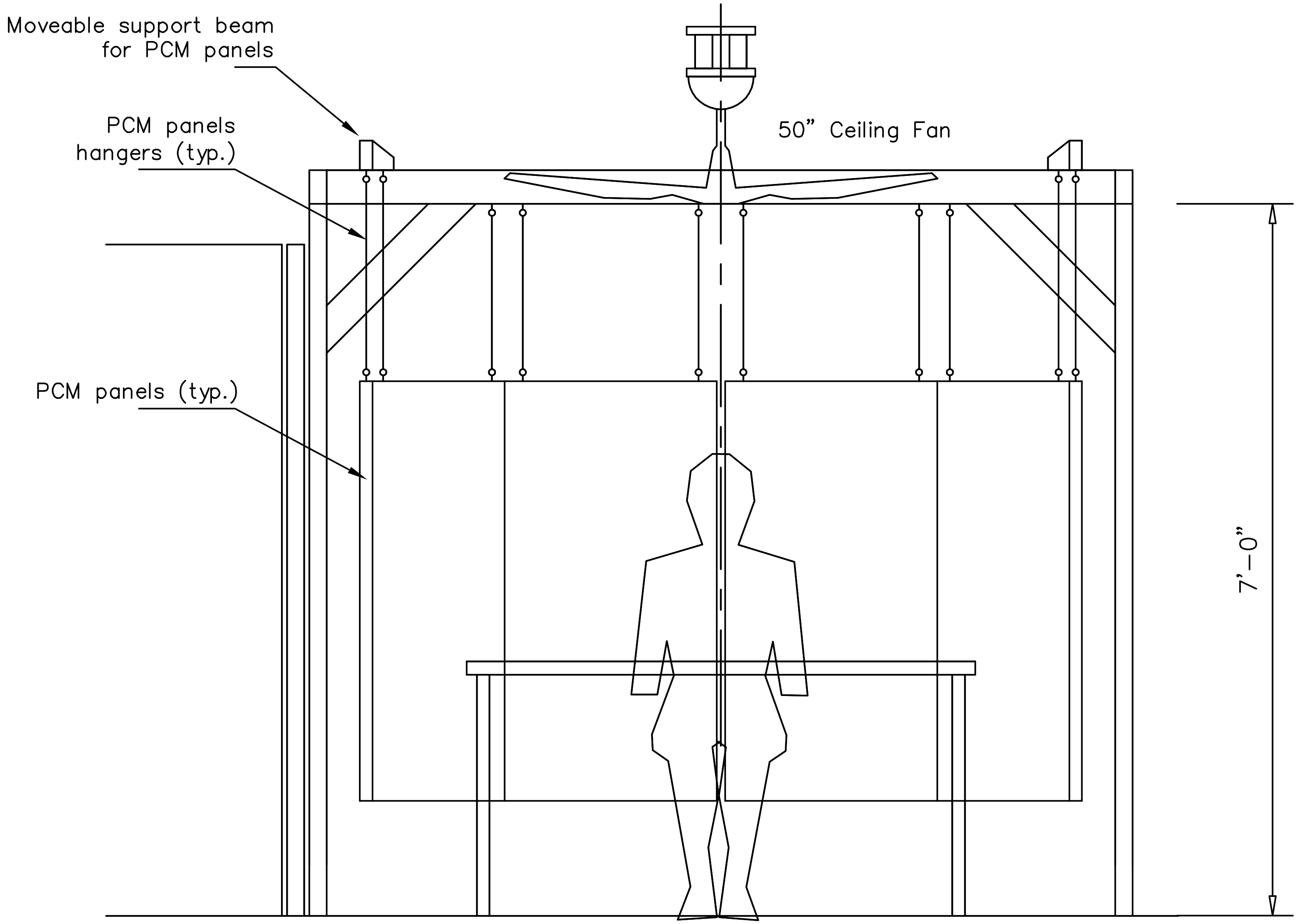
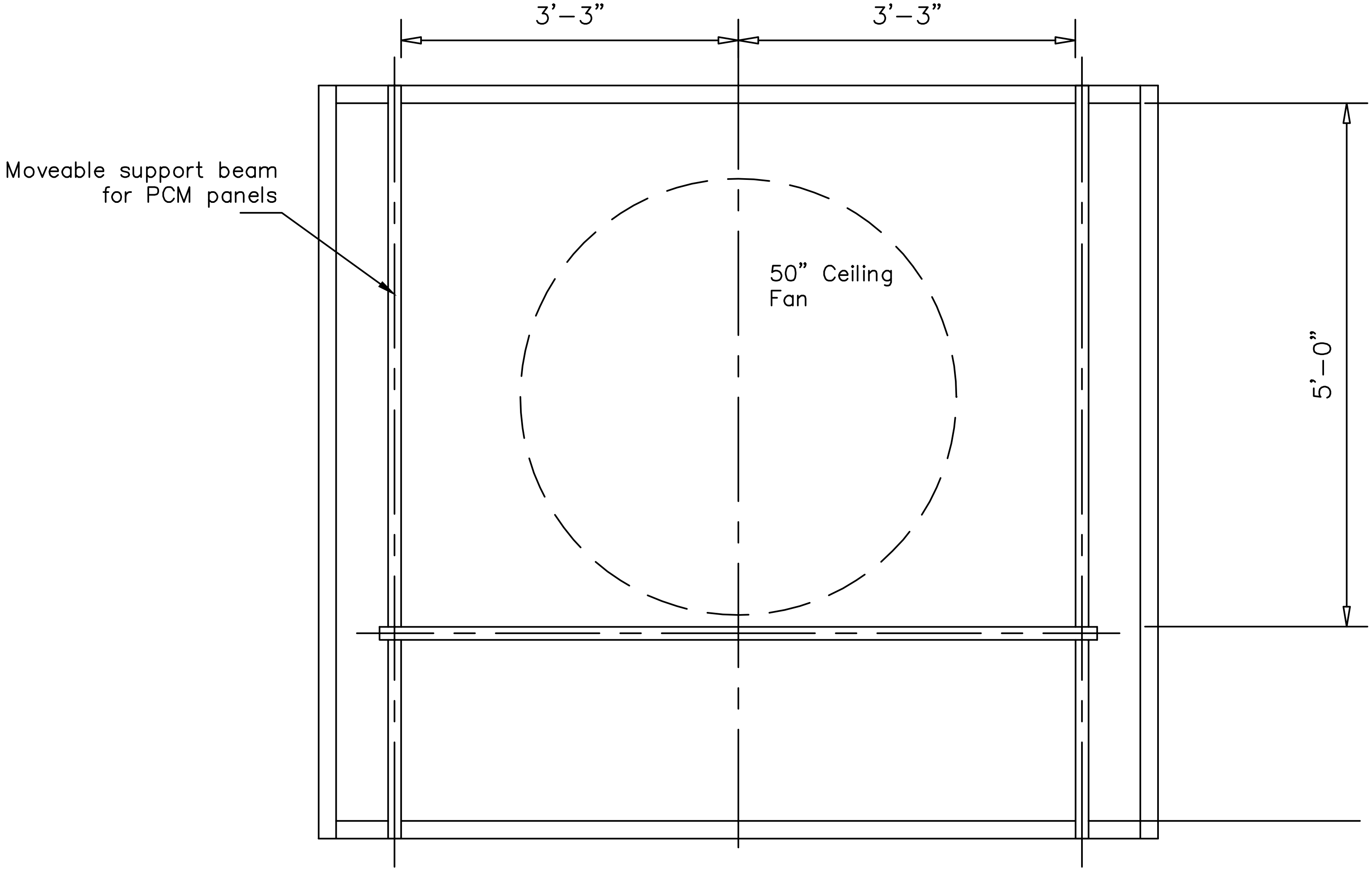


Test Structure - Comfort Set Up - Scenario B -
SECTION A_A
Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies

Test set up in HIG 205 - Design Concept
Test Structure - Comfort Set Up - Scenario A - Section B-B

Sheet No : CB-2 | Date : March 13, 2015 | Drawn: MZ



Test Structure - Comfort Set Up - Scenario B -
Structure without PCM panels

Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario B - Layout
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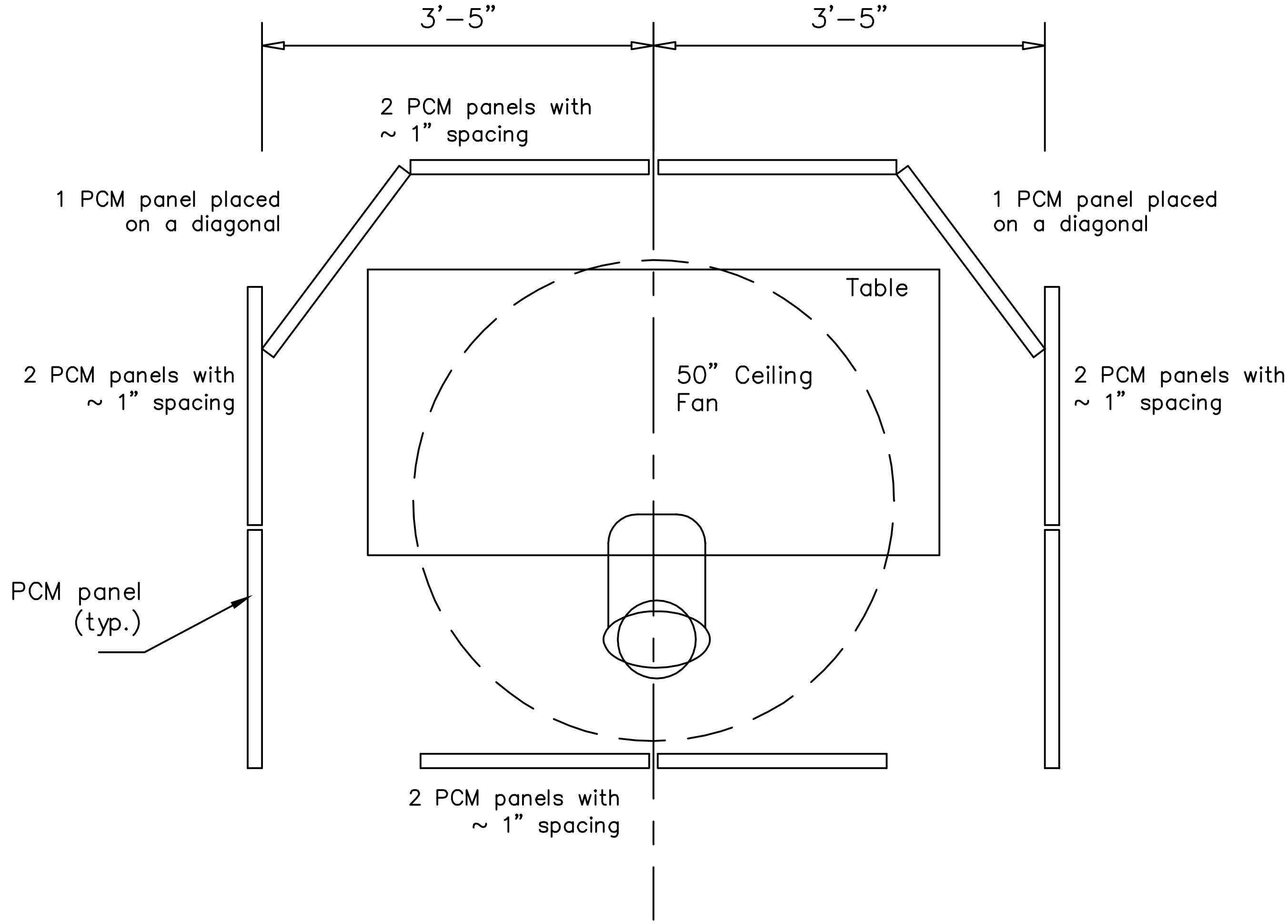
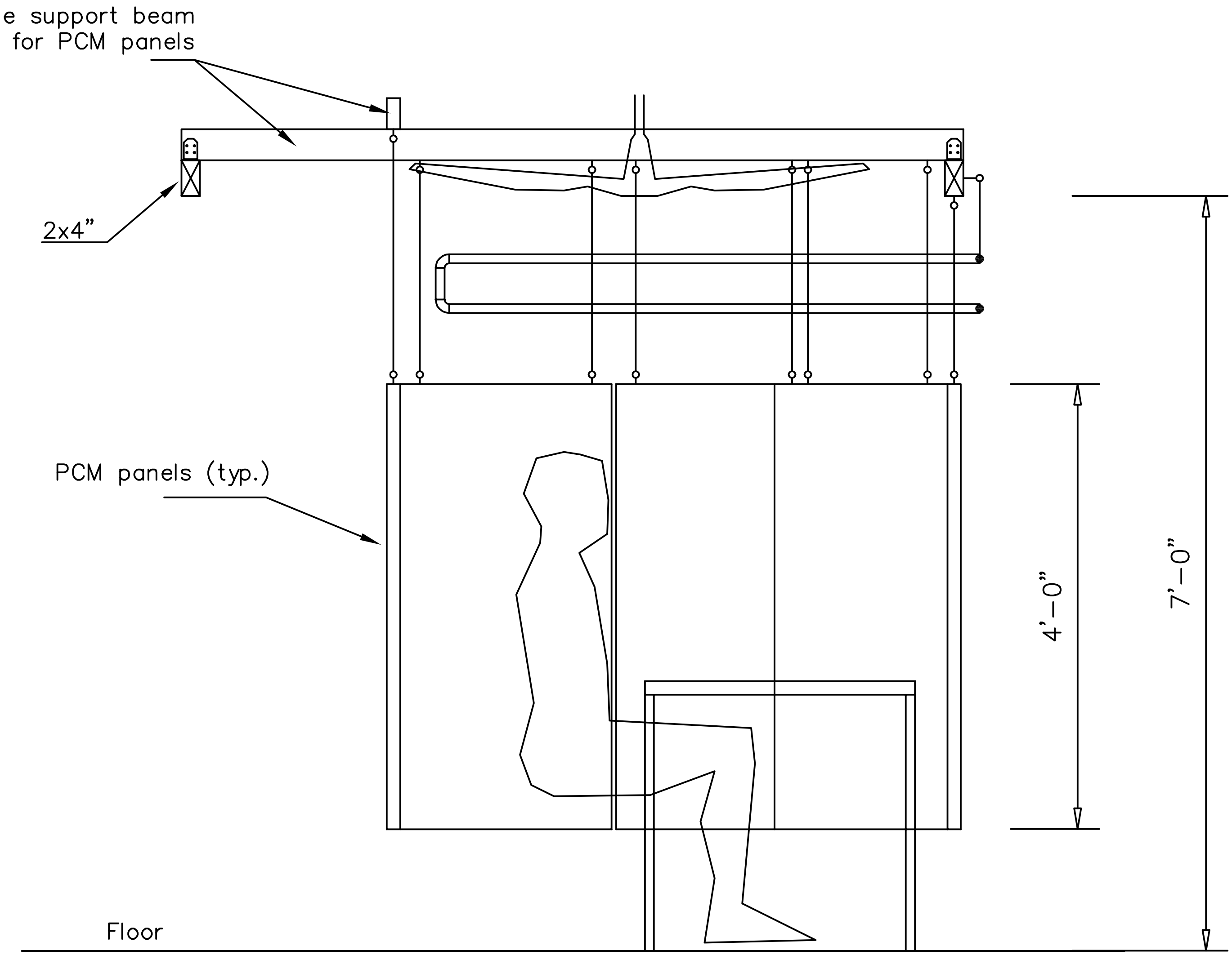


Test Structure - Comfort Set Up - Scenario B -
Layout without Structure

Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario B - Layout
	Sheet No : CB-4 · Date : March 13, 2015 · Drawn: MZ



Test Structure - Comfort Set Up - Scenario B -
SECTION B-B

Scale 5/8" = 1' - 0"

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - Scenario B - Section B-B
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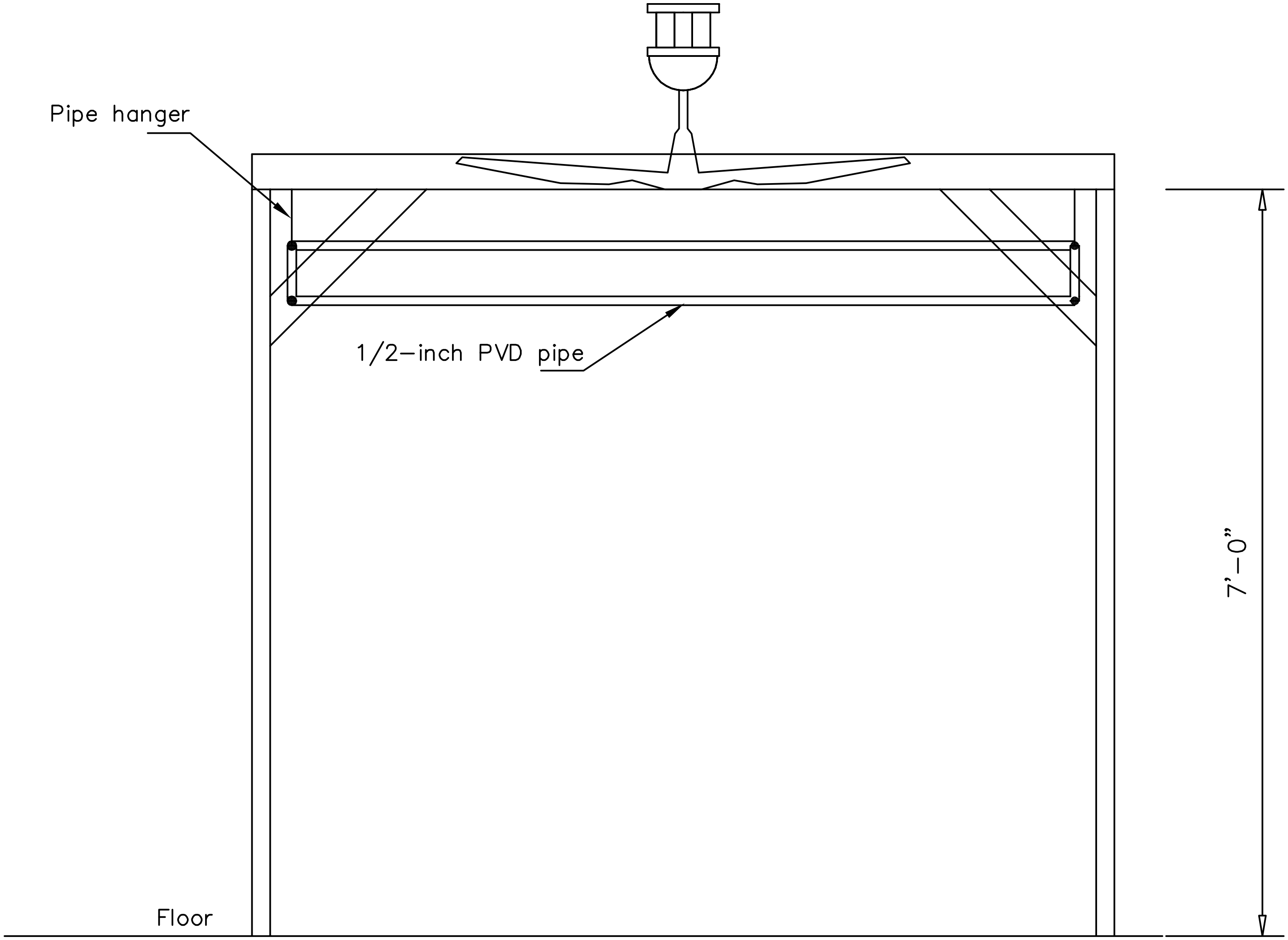
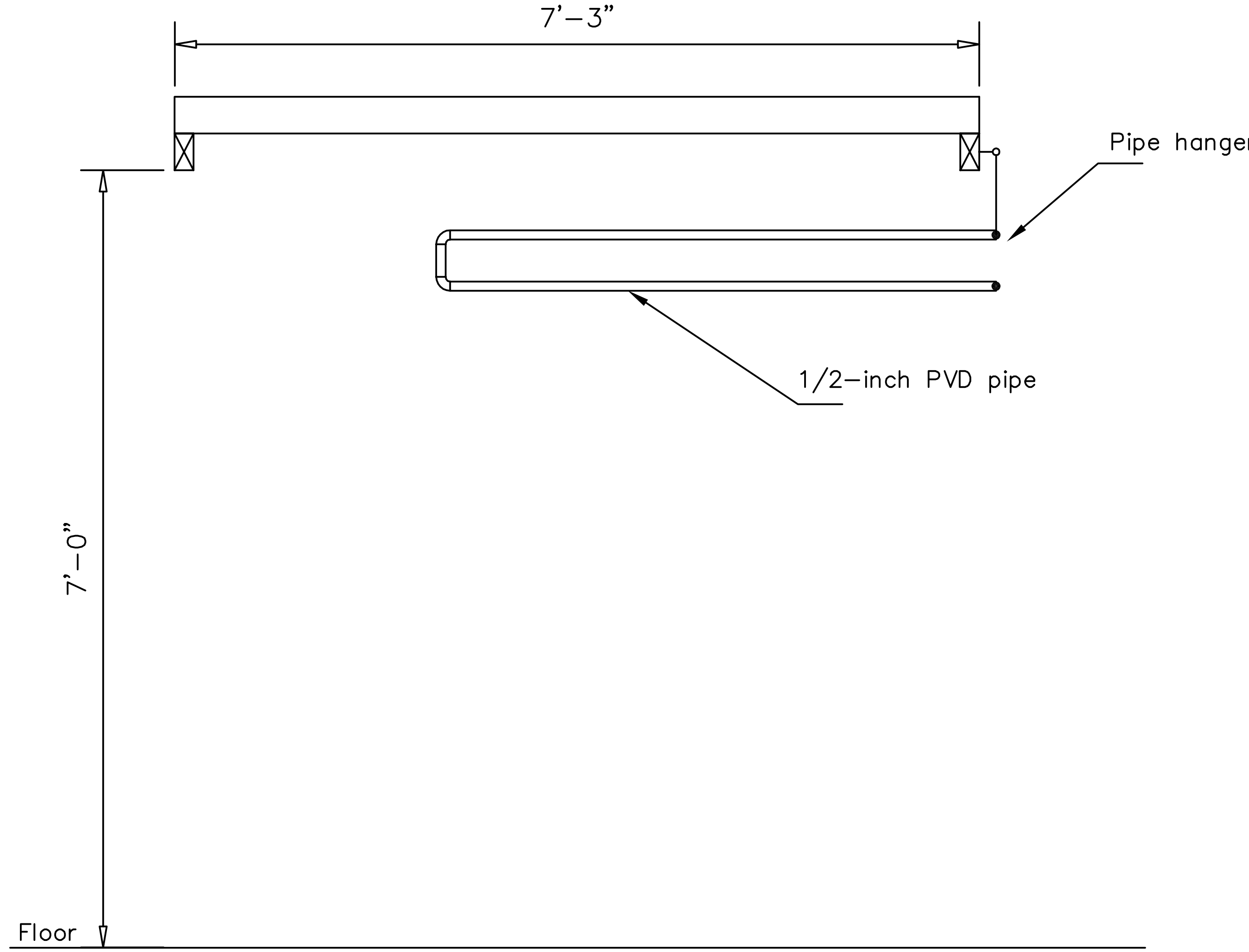


PVC Piping SECTION A-A

Scale 5/8" = 1' - 0"

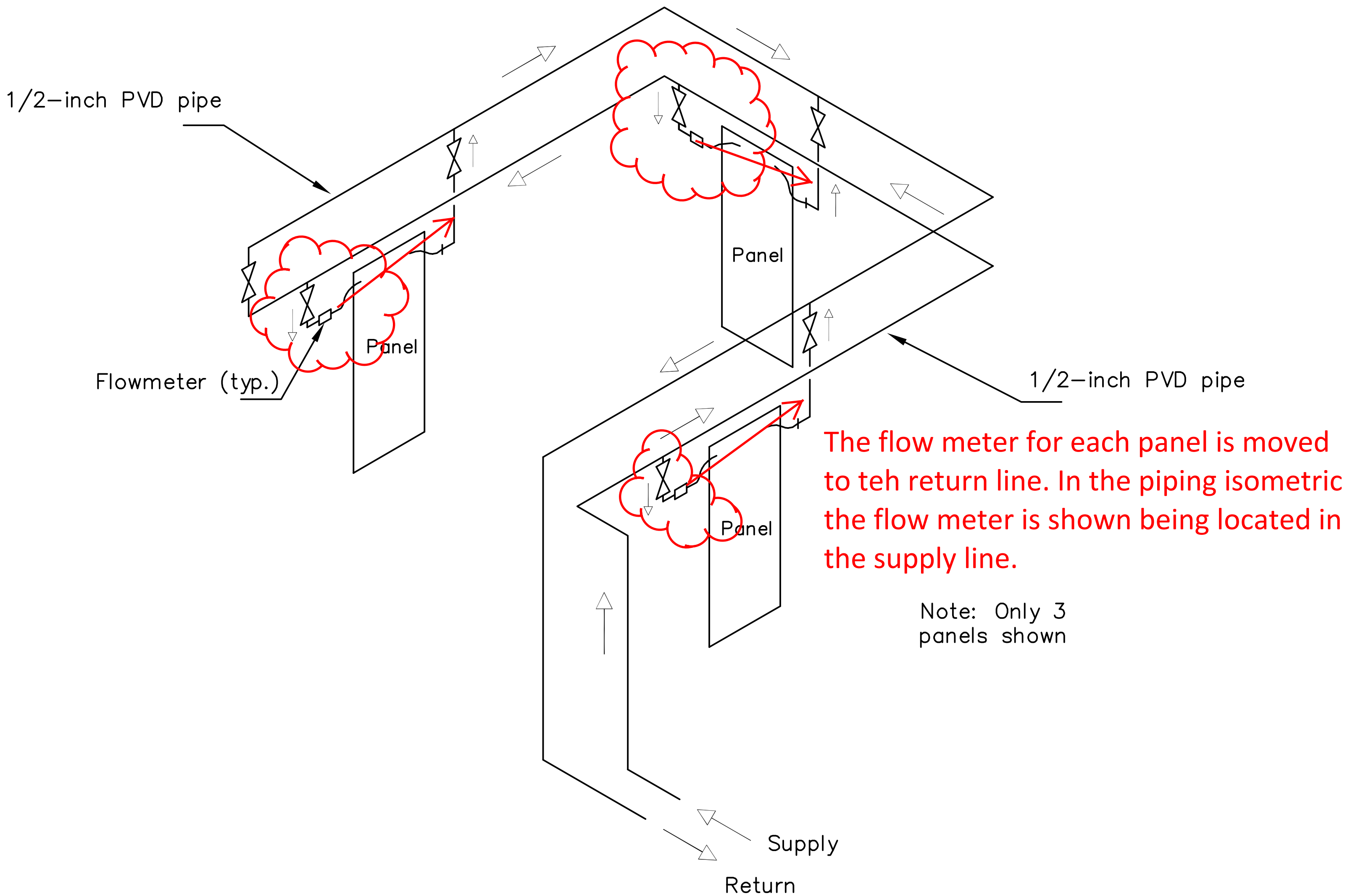
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - PVC Piping		
	Sheet No : P-1	Date : March 13, 2015	Drawn: MZ



PVC Piping SECTION B-B

Scale 5/8" = 1' - 0"

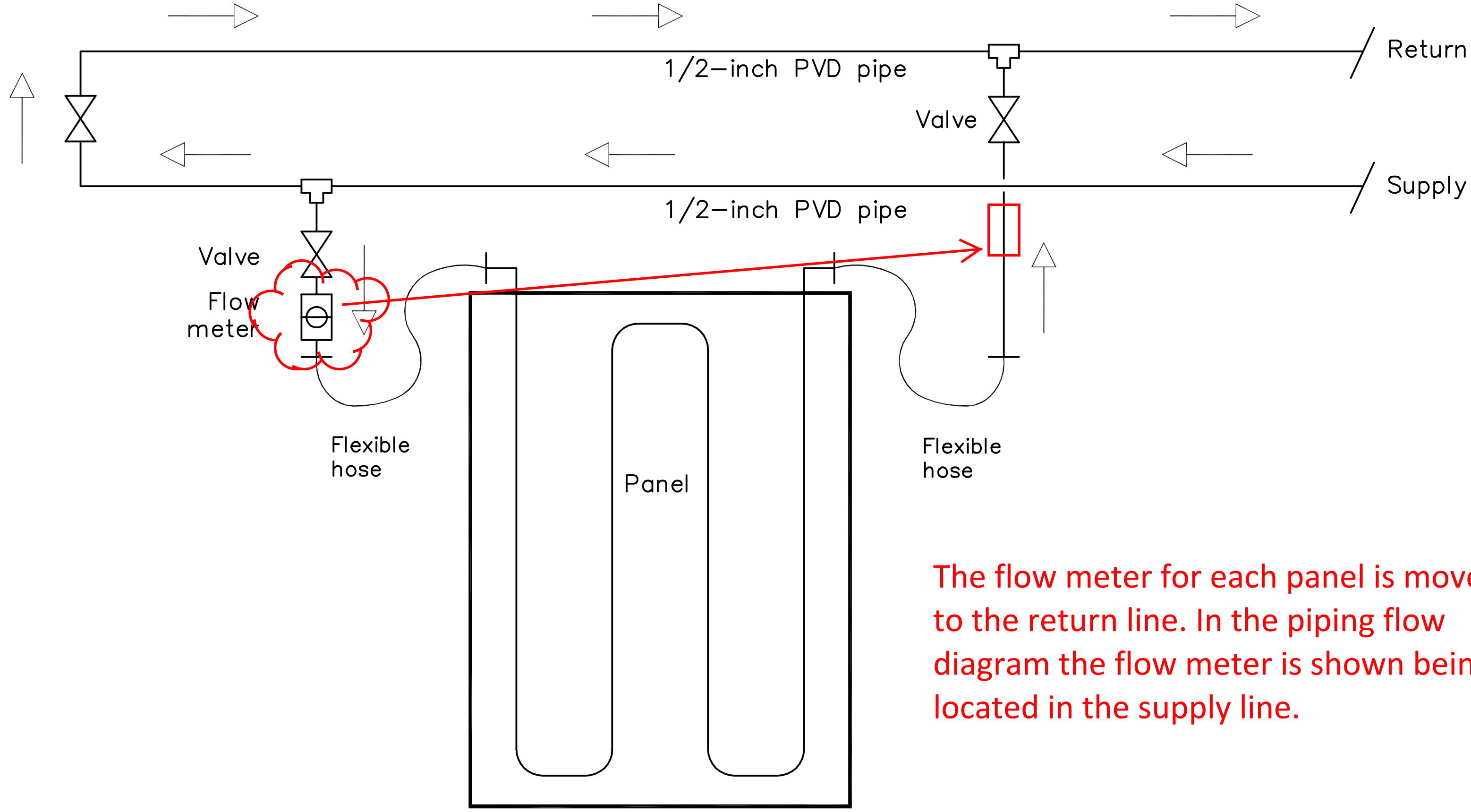
PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - PVC Piping		
	Sheet No : P-2	Date : March 13, 2015	Drawn: MZ



PVC Piping - Isometric

Scale N/A

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - PVC Piping		
	Sheet No : P-3	Date : March 13, 2015	Drawn: MZ



The flow meter for each panel is moved to the return line. In the piping flow diagram the flow meter is shown being located in the supply line.

PVC Piping - Flow Diagram

Scale N/A

PROJECT PHASE 3 - 7.c: Occupant comfort simulation and verification - active comfort technologies	Test set up in HIG 205 - Design Concept Test Structure - Comfort Set Up - PVC Piping
	Sheet No : P-4 | Date : March 13, 2015 | Drawn: MZ

APPENDIX B:

INFORMATION ABOUT THE PROTOTYPE COMFORT EQUIPMENT

Product information of the ceiling fan Haiku 52:

Haiku 52 with SenseME Technology

What a Smart Ass™ Fan

The world's first smart fan is now even smarter. Haiku® with SenseME™ monitors temperature conditions and adjusts the fan speed to keep you comfortable, automatically. When you change the speed via an easy-to-use smartphone app or the supplied remote, SenseME remembers your comfort preferences for the future.

Haiku with SenseME works with the Nest Learning Thermostat™ to help you reduce air conditioning use in the summer and heating use in the winter without sacrificing comfort, which means serious savings year-round. Now that's a Smart Ass fan.

SenseME App Features

Motion Sensor
Detects when you enter or leave a room, turning the fan and LED light on and off automatically

Smart Mode
Learns your comfort preferences, automatically adjusting the speed to what you find comfortable

Whoosh® Mode
Silently mimics a natural breeze to make you feel up to 40% cooler

Sleep Mode
Provides customized comfort for your bedroom all night long so you don't wake up freezing or sweating

Scheduling
Set precise schedules for all of Haiku's unique control modes

Wi-Fi
Control your fan manually with the smartphone app and enjoy new features via over-the-air updates

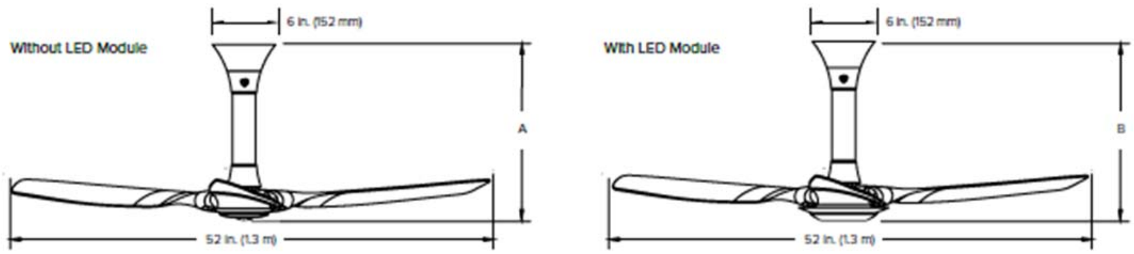
(877) 244-3267 | BIGASSFANS.COM

06-02-2015

BIGASS FANS

Product information of the ceiling fan Haiku 52:

Haiku 52 with SenseME | TECHNICAL SPECIFICATIONS



Technical Specifications		
Model	Haiku Matrix Composite Standard Mount	
Model number	K3127-A2-XX-XX-02-C[1]	
Fan diameter	52 in. (1.3 m)	
Fan height (A)	16.9 in. (429.3 mm)	
Fan height (B)	17.4 in. (442 mm)	
Hanging weight	14 lb (6 kg)[2]	
Motor and assembly finishes	Black or white	
Airfoil material	Matrix Composite	
Airfoil finishes	Black or White	
Number of airfoils	3	
Motor type	EC motor with digital inverter drive	
Power factor	>0.92	
Number of fan speeds	7	
Operating voltage and frequency	100–125 VAC / 200–240 VAC, 1 Φ, 50–60 Hz	
IP rating	X2	
RPM (min/max)	49/201 RPM	
Amps (min/max)	0.0478/0.2696 A	
Watts (min/max)	2.41/31.94 W	
Controller	Smartphone app[3]; IR remote supplied	
Optional LED	16 dimmable light settings	
Operational temperature range	32 to 104°F (0 to 40°C)	
Operational humidity range	20–90% non-condensing	
Environment	Indoor or covered outdoor use[4]	
Warranty (Residential)[5]	Motor	Limited Lifetime in the US and Canada
	All other components	1 year in the US and Canada
Warranty (Commercial)[5]	Motor	2 years in the US and Canada
	All other components	1 year in the US and Canada

Accessories

Standard Remote

Optional LED Module

Airfoil Finishes

Sensors	
Environmental sensors	Ambient temperature, surface temperature and relative humidity
Motion	Passive infrared
Communication radio	Embedded Wi-Fi chip

Product information about the Barcol radiant panels:

The product information is presented in the Barcol brochure which is shown on the following pages.

APPENDIX C:

SELECTED INFORMATION ABOUT THE SUPPORT EQUIPMENT

Air to water heat exchanger

Brent Industries LLC, part# HWC-20X20

Product Description

This unit is Water to Air Heat Exchanger for use in your hot air plenum of your existing forced air furnace. This unit is most commonly used in conjunction with an outside wood furnace to transfer heat into your existing forced air system. It can also be used with any other source of hot water such as a boiler to create hot air. This exchanger is for use with ANY outdoor wood stove. And also features quality aluminum fins with seamless copper tubes. Our coils are packaged the best possible way to minimize shipping damage. The coils fit snuggly in the boxes to minimize movement within the box. There are strips of Styrofoam all the way around the manifold to prevent damage if dropped. The entire coil is packaged in a double wall, cardboard box. These are also packaged with metal port protectors over the inlet/outlet ports to protect them from shipping damage.

Product Data:
Finned Area: 20" x 20"
Overall Dimensions: 20-1/4" x 22" x 3-1/2" THICK
Overall Dimensions (including Copper Manifold): 20-1/4" x 25-1/2" x 3-1/2" THICK
Rows of Tubes: 3 (3/8" Seamless Copper)
Inlet/Outlet: 1" Copper Sweat
Rating: 175 psig/350°F
Fin Spacing: 12/inch

Product Performance:
145,172 BTU with 180°F Entering Water Temp., 15 GPM and 2200 CFM (air flow)

We do our best to offer a high quality product that will not be damaged during shipping and you will not have to return due to manufacturers defects such as leaking. We stand behind the exchangers with a LIMITED LIFETIME WARRANTY AGAINST MANUFACTURERS DEFECTS. A free copy of the written warranty is available upon request to our email address.

Chilled water pumps:

Out-of-Pond
WG Pumps

Little GIANT®

OPWG-29/46

Features

- Thermally protected, enclosed, fan cooled, permanent split capacitor motor
- 8', 115V power cord (pre-wired for 115V operation)
- 2" FNPT intake and 1-1/2" FNPT discharge ports
- Motors are enclosed for excellent protection and weather resistance
- Low power consumption
- For larger systems, plumb two or more units in parallel to economically multiply the flow

Construction

- Volute — Corrosion-resistant thermoplastic
- Volute Cover — Corrosion-resistant thermoplastic
- Impeller — Glass-filled Noryl®
- Shaft Seal — Carbon/Ceramic

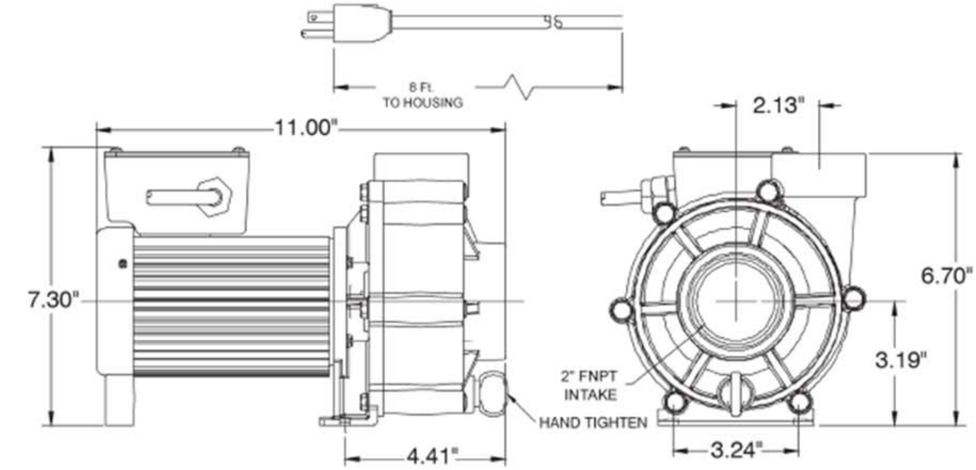
Cost-Saving Efficiency
The Little Giant Professional Series of pumps produce a maximum flow rate with minimal electrical consumption. The dollars saved from reduced operating costs can pay for the pump in a matter of months.

Safety
The Professional Series are end suction centrifugal pumps, designed to be located on the perimeter of the pond. This eliminates the need for wading into the pond to service the pump or pump intake filter. By locating the pump outside of the pond, you also greatly reduce the chance of electrical shock.

Reliability
The Professional Series was designed with the professional in mind. Built tough, the pump housings are injection-molded of corrosion-resistant thermoplastics, and are mounted to custom-built motors. Each Professional Series pump is thoroughly tested prior to shipment. When properly installed, your pump is designed to provide years of dependable, reliable service.

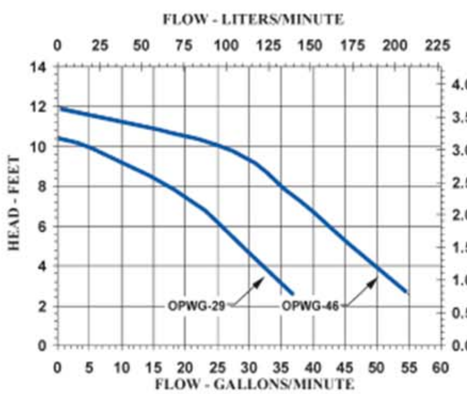
Quiet Operation
Install these pumps wherever you desire. The Professional Series was designed for water gardening, not industrial applications, generating noise levels equivalent to a small electrical fan at 52 dB.

OPWG-29/46



Specifications

Model No.	Item No.	Listings	Discharge Size	Intake Size	HP	Volts	Hertz	Amps	Watts	Performance (GPM @ Head) 2.5'	5'	7.5'	10'	Shut Off Feet	PSI	Power Cord (ft.)	Weight (lbs.)	Height (in.)	Length (in.)	Width (in.)
OPWG-29	566020	UL/CSA	1-1/2" FNPT	2" FNPT	1/8	115	60	1.1/.6	137	37	29	20	5	11	4.8	8	9.12	7.00	10.5	6.80
OPWG-46	566021	UL/CSA	1-1/2" FNPT	2" FNPT	1/8	115	60	1.3/.8	174	55	46	37	26	12	5.2	8	9.14	7.00	10.5	6.80



Replacement Parts

166200	Impeller OPWG-29
166201	Impeller OPWG-46
166205	Bracket
166207	Volute
166209	Drain Plug with O-Ring
924041	O-Ring, Volute
926045	Seal Assembly, Ceramic/Carbon

Little GIANT.
PO Box 12010 • Oklahoma City, OK 73157
Phone: 800.701.7894 • Fax: 800.701.8046
E-mail: customerservice@littlegiant.com

www.LittleGiant.com

Form 995171 — 09/2007

APPENDIX D:
INSTRUMENTATION

Appendix D presents process and instrumentation information, including Process & Instrumentation Diagrams (P&I D) as well as product sheets of selected instrumentation. The following information is presented hereafter:

A. Process and Instrumentation Diagrams (P&I D) and supporting identification of for all instrumentation and measurement points.

B. Definition of the IR temperature measurement points on the walls and floors of the test and control station.

C. Data sheets for selected instruments and measurement procedures:

  C. 1. National Instruments NI X Series Multifunction Data Acquisition (only cover sheet included)

  C. 2. FLIR B50 Thermal Imaging Camera

  C. 3. Degree Controls, F900 Series Air Velocity and Air Temperature Sensors

  C. 4. VFS 1-20 Vortex Flowsensor standard, 1-20 l/min

  C. 5. ONSET HOBO® UX100 Loggers

  C. 6. ONSET HOBO UX120 4-Channel Analog Logger

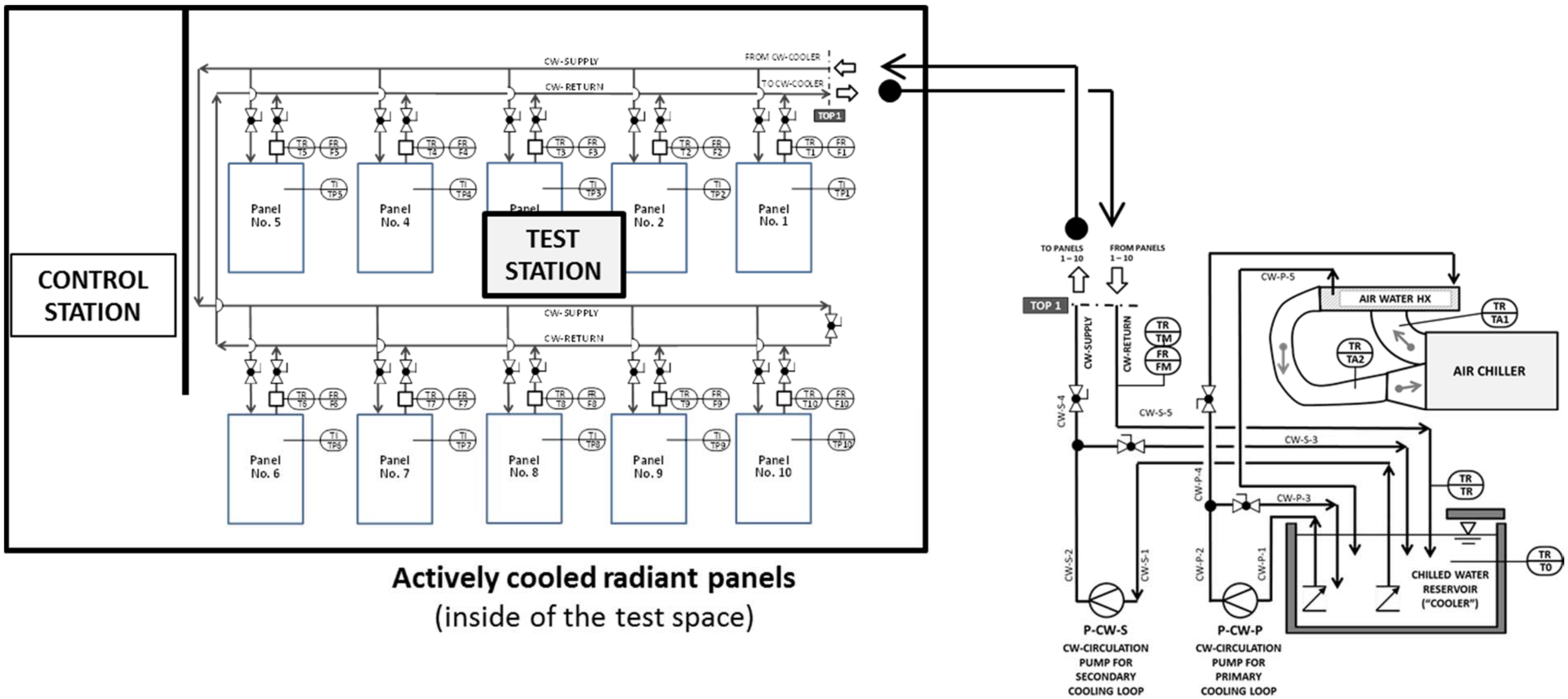
  C. 7. Graywolf Hand held Anemometer AS-201, Graywolf Sensing Solutions

D. D. Python Scripts for Data Processing

A. Process and Instrumentation Diagrams(P&I D) and supporting identification of for all instrumentation and measurement points.

APPENDIX D

Piping and Instrumentation Diagrams (P&I D) of the Test Set-up



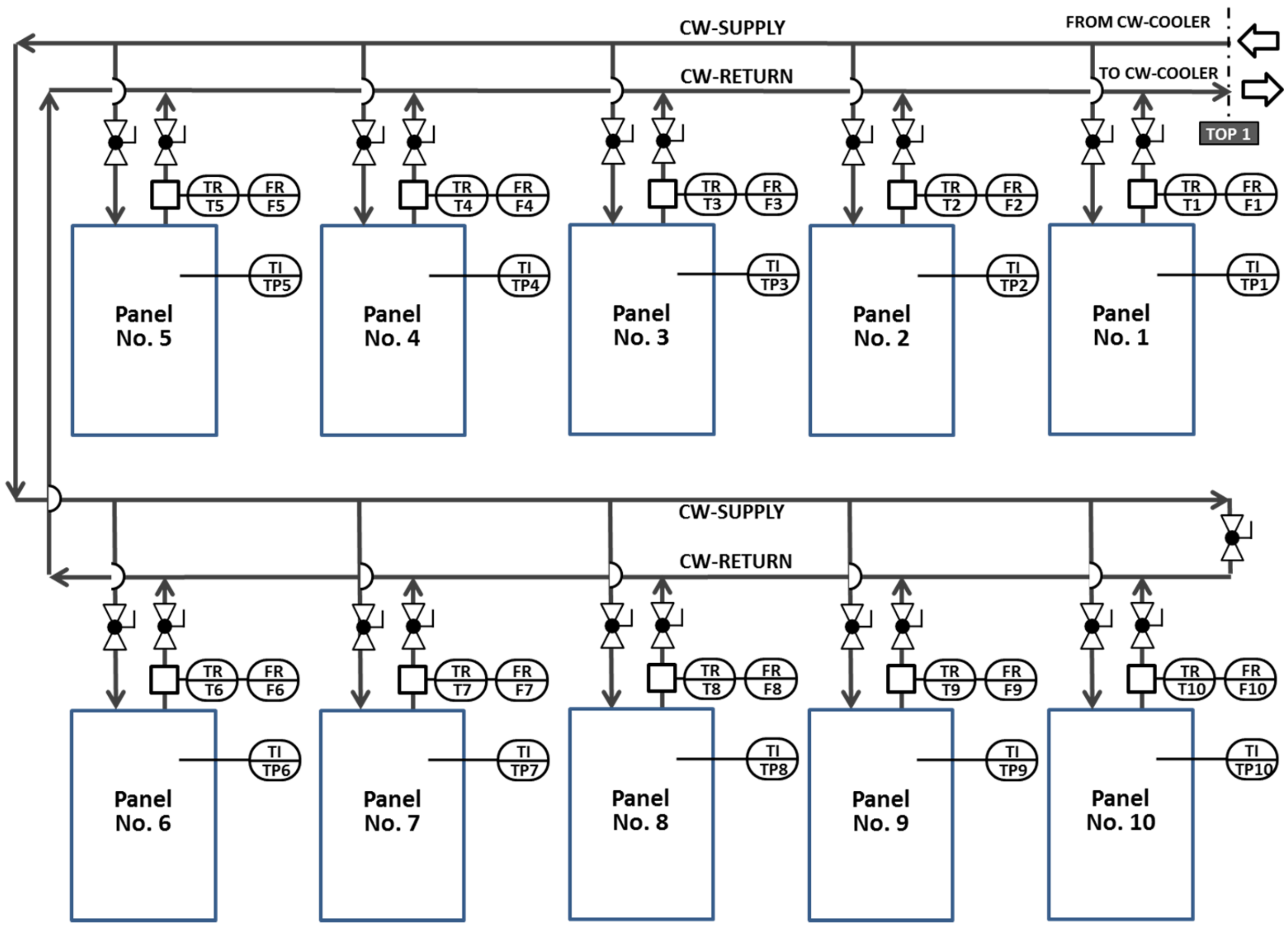
Actively cooled radiant panels
(inside of the test space)

Chilled water generation
(outside of the test station)

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix D: Piping and Instrumentation diagrams

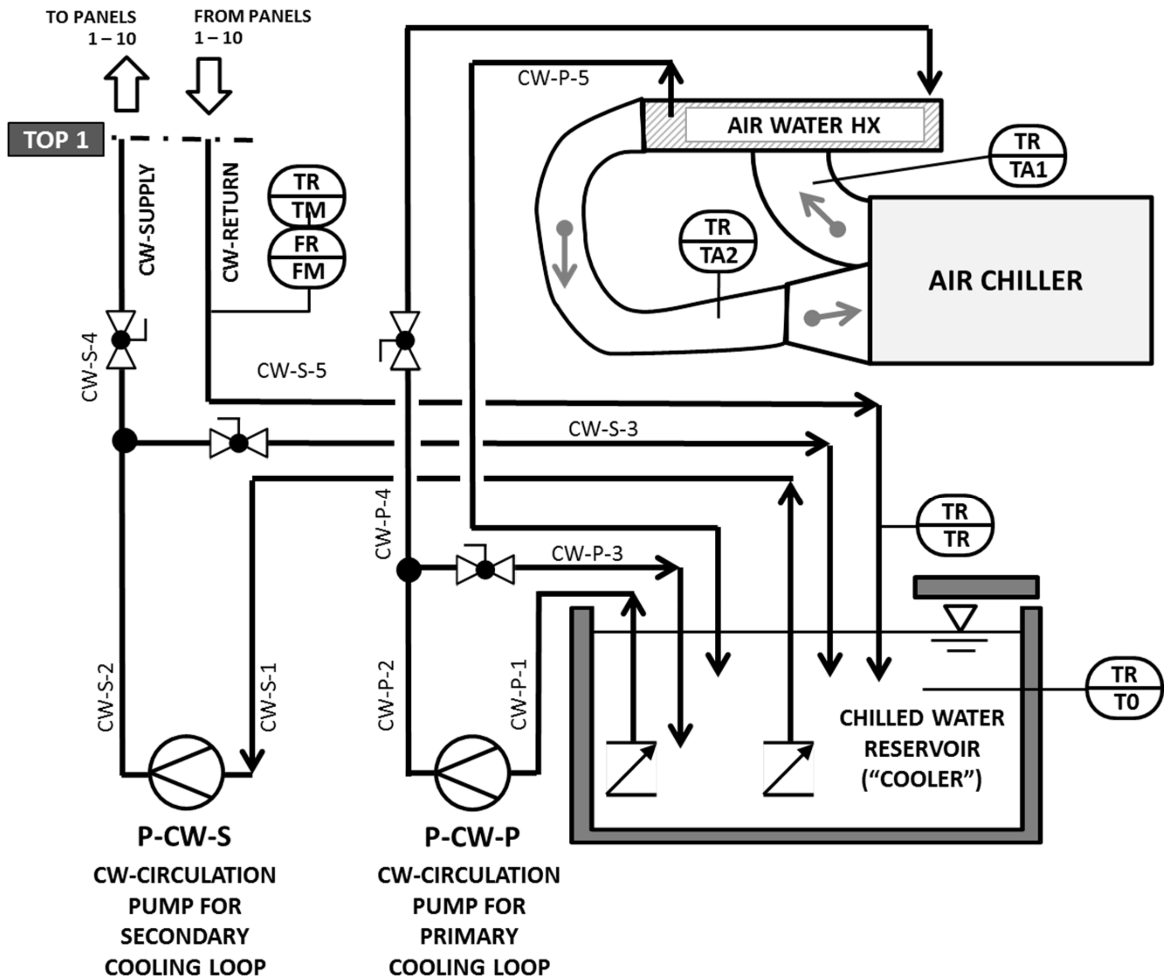
Figure A-1: Overview of the process diagrams of the test set-up



Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 1**

Radiant panels in the test station with Chilled Water system

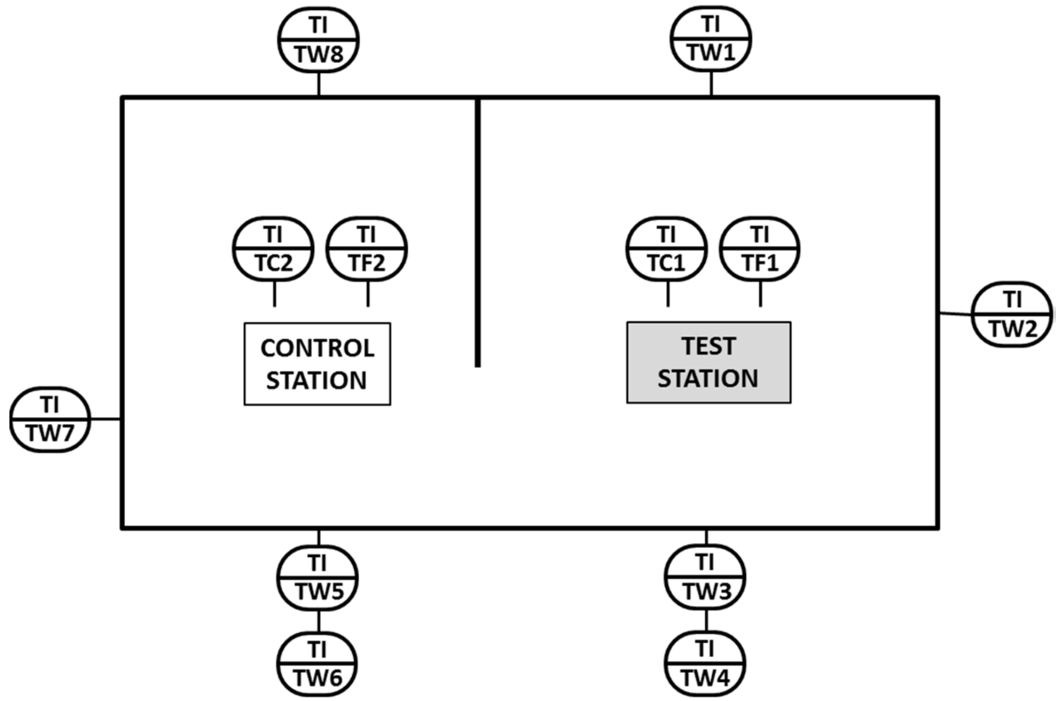
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES	**Appendix D:** Piping and Instrumentation diagrams	**Figure A-2:** Overview of the process diagrams of the test set-up



Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 2**

Chilled Water (CW) generation plant

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES	**Appendix D:** Piping and Instrumentation diagrams	**Figure A-3:** Chilled Water (CW) generation plant



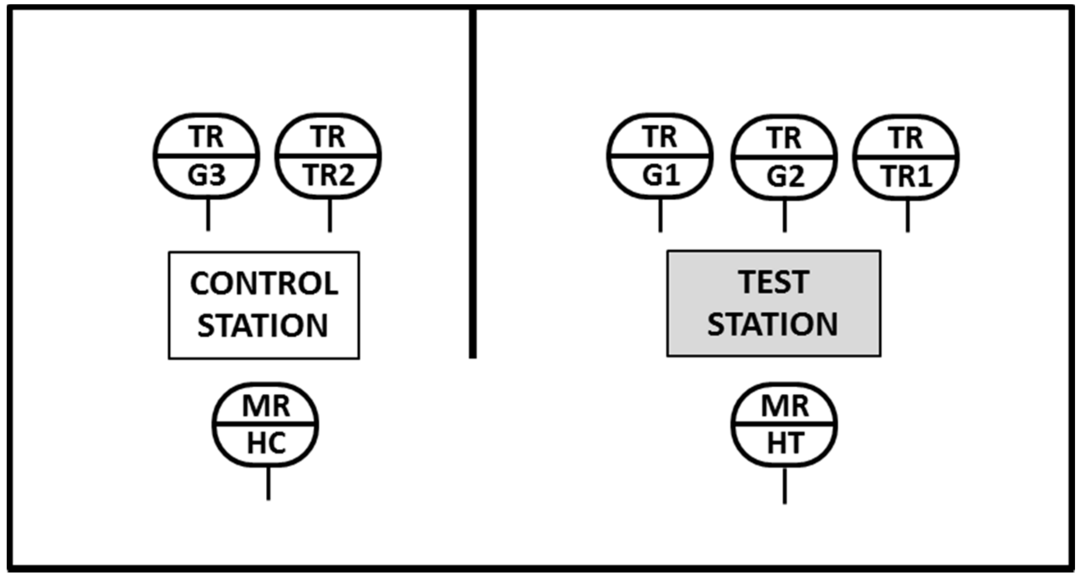
Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 3**

IR measurement of radiant temperature on walls, ceiling and floor

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix D: Piping and Instrumentation diagrams

Figure A-4: IR measurement of radiant temperature on walls, ceiling and floor



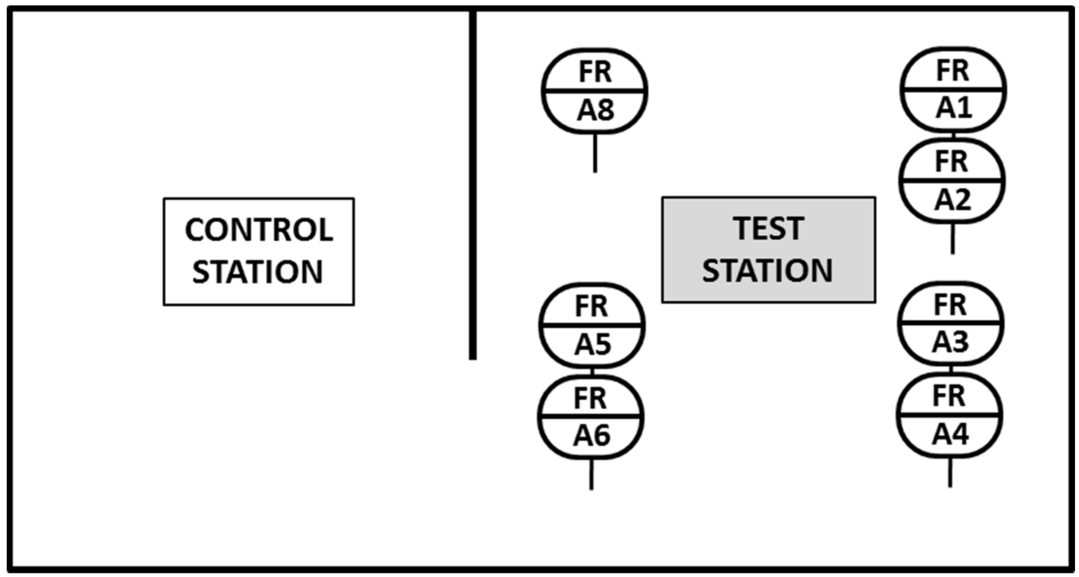
Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 4**

Recorded temperature and humidity measurements in test and control stations

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix D: Piping and Instrumentation diagrams

Figure A-5: Recorded temperature and humidity measurements in test and control stations



Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 5**

Anemometers used in validation tests in test station

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix D: Piping and Instrumentation diagrams

Figure A-6: Anemometers used in validation tests in test station

No.	Sensor ID.	Listed in P & D diagrams				Units reported	Description of type of measurements
		Sheet No.	Identifier	Measured variable	Passive Function		
1	Anem_1	5	A1	F	R	m/s	Measurement of air flow field below the ceiling fan
2	Anem_2	5	A2	F	R	m/s	Measurement of air flow field below the ceiling fan
3	Anem_3	5	A3	F	R	m/s	Measurement of air flow field below the ceiling fan
4	Anem_4	5	A4	F	R	m/s	Measurement of air flow field below the ceiling fan
5	Anem_5	5	A5	F	R	m/s	Measurement of air flow field below the ceiling fan
6	Anem_6	5	A6	F	R	m/s	Measurement of air flow field below the ceiling fan
7	Anem_7	5	A7	F	R	m/s	Measurement of air flow field below the ceiling fan
8	Anem_8	5	A8	F	R	m/s	Measurement of air flow field below the ceiling fan
9	C1	3	TC1	T	I	F	IR measurement of ceiling in test space (use target C1)
10	C2	3	TC2	T	I	F	IR measurement of ceiling in control space (use target C2)
11	F1	3	TF1	T	I	F	IR measurement of floor in test space (use target F1)
12	F2	3	TF2	T	I	F	IR measurement of floor in control space (use target F2)
13	Flow_1	1	F1	F	R	l/min	Flow measurement of CW exiting panel 1
14	Flow_10	1	F10	F	R	l/min	Flow measurement of CW exiting panel 10
15	Flow_2	1	F2	F	R	l/min	Flow measurement of CW exiting panel 2
16	Flow_3	1	F3	F	R	l/min	Flow measurement of CW exiting panel 3
17	Flow_4	1	F4	F	R	l/min	Flow measurement of CW exiting panel 4
18	Flow_5	1	F5	F	R	l/min	Flow measurement of CW exiting panel 5
19	Flow_6	1	F6	F	R	l/min	Flow measurement of CW exiting panel 6
20	Flow_7	1	F7	F	R	l/min	Flow measurement of CW exiting panel 7
21	Flow_8	1	F8	F	R	l/min	Flow measurement of CW exiting panel 8
22	Flow_9	1	F9	F	R	l/min	Flow measurement of CW exiting panel 9
23	Flow_Main	2	FM	F	R	l/min	Flow measurement of CW in main supply line to test space
24	Globe_1_test	4	G1	T	R	F	Measurement of globe thermometer in tests space (large globe thermometer)
25	Globe_2_test	4	G2	T	R	F	Measurement of globe thermometer in tests space (small globe thermometer)

Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 6**

List of sensors / data acquisition: Part 1

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix D: Piping and Instrumentation diagrams

Figure A-7: List of sensors / data acquisition: Part 1

No.	Sensor ID.	Listed in P & D diagrams				Units reported	Description of type of measurements
		Sheet No.	Identifier	Measured variable	Passive Function		
26	Globe_3_control	4	G3	T	R	F	Measurement of globe thermometer in control space (small globe thermometer)
27	Humidity_control	4	HC	M	R	% RH	Measurement of relative humidity in control space
28	Humidity_test	4	HT	M	R	% RH	Measurement of relative humidity in test space
29	P1	1	TP1	T	I	F	IR measurement of surface temperature of panel 1
30	P10	1	TP10	T	I	F	IR measurement of surface temperature of panel 10
31	P2	1	TP2	T	I	F	IR measurement of surface temperature of panel 2
32	P3	1	TP3	T	I	F	IR measurement of surface temperature of panel 3
33	P4	1	TP4	T	I	F	IR measurement of surface temperature of panel 4
34	P5	1	TP5	T	I	F	IR measurement of surface temperature of panel 5
35	P6	1	TP6	T	I	F	IR measurement of surface temperature of panel 6
36	P7	1	TP7	T	I	F	IR measurement of surface temperature of panel 7
37	P8	1	TP8	T	I	F	IR measurement of surface temperature of panel 8
38	P9	1	TP9	T	I	F	IR measurement of surface temperature of panel 9
39	RoomTemp_test	4	TR1	T	R	F	Air temperature measurement in test space
40	RoomTemp_control	4	TR2	T	R	F	Air temperature measurement in control space
41	Temp_AC	2	TA1	T	R	F	Chilled air temperature measurement downstream of HX
42	Temp_ACreturn	2	TA2	T	R	F	Chilled air temperature measurement upstream of HX
43	Temp_cooler	2	T0	T	R	F	Measurement of chilled water in cooler
44	Temperature_1	1	T1	T	R	F	Measurement of chilled water exiting panel 1
45	Temperature_10	1	T10	T	R	F	Measurement of chilled water exiting panel 10
46	Temperature_2	1	T2	T	R	F	Measurement of chilled water exiting panel 2
47	Temperature_3	1	T3	T	R	F	Measurement of chilled water exiting panel 3
48	Temperature_4	1	T4	T	R	F	Measurement of chilled water exiting panel 4
49	Temperature_5	1	T5	T	R	F	Measurement of chilled water exiting panel 5
50	Temperature_6	1	T6	T	R	F	Measurement of chilled water exiting panel 6
51	Temperature_7	1	T7	T	R	F	Measurement of chilled water exiting panel 7
52	Temperature_8	1	T8	T	R	F	Measurement of chilled water exiting panel 8

Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 7**

List of sensors / data acquisition: Part 2

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix D: Piping and Instrumentation diagrams

Figure A-8: List of sensors / data acquisition: Part 2

No.	Sensor ID.	Listed in P & D diagrams				Units reported	Description of type of measurements
		Sheet No.	Identifier	Measured variable	Passive Function		
53	Temperature_9	1	T9	T	R	F	Measurement of chilled water exiting panel 9
54	Temperature_Main	2	TM	T	R	F	Measurement of chilled water supply to panels 1 through 10
55	Temperature_Return	2	TR	T	R	F	Measurement of chilled water return from panels 1 through 10 (measured just upstream of pipe terminus in cooler)
56	W1	3	TW1	T	I	F	IR temperature measurement of wall (wall target 1)
57	W2	3	TW2	T	I	F	IR temperature measurement of wall (wall target 2)
58	W3	3	TW3	T	I	F	IR temperature measurement of wall (wall target 3)
59	W4	3	TW4	T	I	F	IR temperature measurement of wall (wall target 4)
60	W5	3	TW5	T	I	F	IR temperature measurement of wall (wall target 5)
61	W6	3	TW6	T	I	F	IR temperature measurement of wall (wall target 6)
62	W7	3	TW7	T	I	F	IR temperature measurement of wall (wall target 7)
63	W8	3	TW8	T	I	F	IR temperature measurement of wall (wall target 8)

Note (*)

Definition of Instrumentation in P&I D

First letter: Measured variable

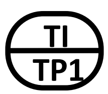
F Flow
T Temperature
M Humidity

Second letter Passive Function

R Recording
I Indicating

Identifier in P&I D:

Example:



First letter : T = Temperature measured
Second letter: R = Recorded
Identifier in P&I D: Identifier for Data Acquisition & processing

Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 8**

List of sensors / data acquisition: Part 3

TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix D: Piping and Instrumentation diagrams

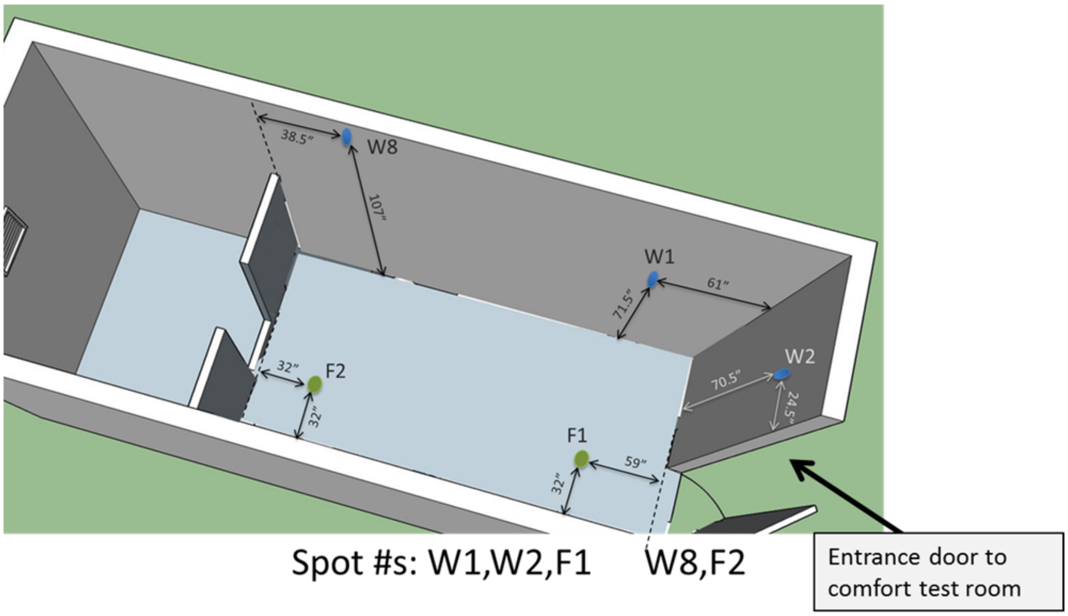
Figure A-9: List of sensors / data acquisition: Part 3

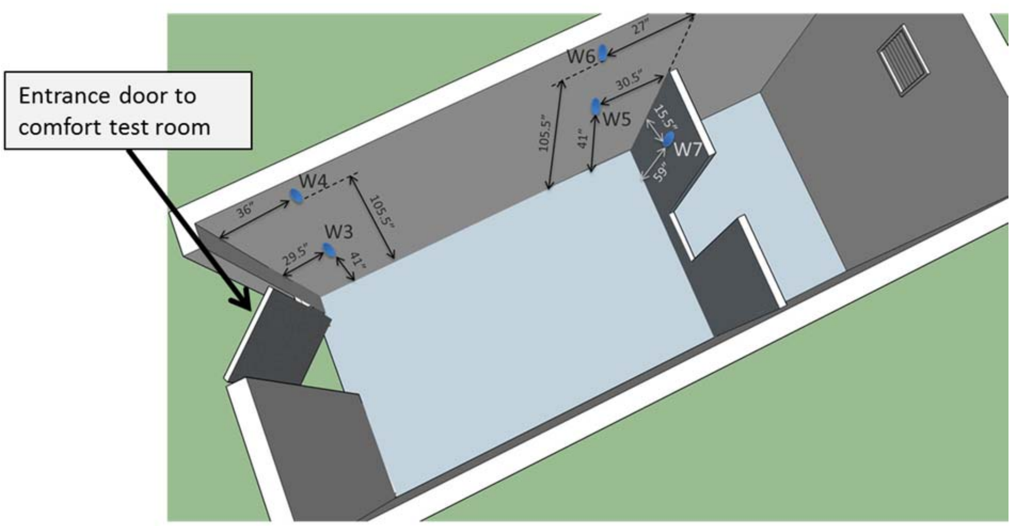
Pipe Number	Size [inch]	From	To	Description
Primary cooling loop – Primary Chilled Water (CW)				
CW-P-1	1.5	Cooler	P-CW-P	Suction line from cooler to CW pump of primary CW loop
CW-P-2	1.5	P-CW-P	CW-P-3	Pressure line to junction of CW-P-3
CW-P-3	1.5	CW-P-2	Cooler	By-pass line back to cooler
CW-P-4	0.5	CW-P-3	Air water HX	Supply line to heat exchanger (HX)
CW-P-5	0.5	Air water HX	Cooler	Return line from heat exchanger (HX) to Cooler
Secondary cooling loop – Secondary Chilled Water (CW)				
CW-S-1	1.5	Cooler	P-CW-S	Suction line from cooler to CW pump of secondary CW loop
CW-S-2	1.5	P-CW-S	CW-S-3	Pressure line to junction of CW-S-3
CW-S-3	1.5	CW-S-2	Cooler	By-pass line back to cooler
CW-S-4	0.5	CW-S-3	Panels in test room	Supply line to radiant panels 1 through 10
CW-S-5	0.5	Panels in test room	Cooler	Return line from radiant panels 1 through 10

Piping & Instrumentation Diagram (P&I D) for the Test Station – **Sheet 9**

List of pipes

B. Definition of the IR temperature measurement points on the walls and floors of the test and control station.





Spot #s: W3,W4 W5,W6,W7

C. 1. National Instruments NI X Series Multifunction Data Acquisition (only cover sheet included)

NATIONAL INSTRUMENTS

Technical Sales
United States
(866) 531-6285
info@ni.com

Requirements and Compatibility | Ordering Information | Detailed Specifications | Pinouts/Front Panel Connections

For user manuals and dimensional drawings, visit the product page resources tab on ni.com

Last Revised: 2012-03-22 17:23:27.0

NI X Series Multifunction Data Acquisition

Overview

NI X Series devices for USB, PCI Express, and PXI Express are the most advanced data acquisition devices ever designed by National Instruments. They feature significant improvements in onboard timing and triggering and optimizations for use with multicore PCs. X Series devices integrate high-performance analog, digital, and counter/timer functionality onto a single device, making them well-suited for a broad range of applications, from basic data logging to control and test automation.

Back to Top

Requirements and Compatibility

OS Information	Driver Information	Software Compatibility
PharLap	NI-DAQmx	ANSI C/C++
Real-Time OS		LabVIEW
Windows 7		LabVIEW Real-Time Module
Windows 7 64-bit		LabWindows/CVI
Windows Vista x64/x86		Measurement Studio
Windows XP		SignalExpress
		Visual Basic
		Visual Studio .NET

Back to Top

C. 2. FLIR B50 Thermal Imaging Camera

FLIR

FLIR b-Series

FLIR b50

FLIR b50 a lightweight, competent infrared camera. Li Ion batteries allow work for 5 hours without interruption of charging. The FLIR LED lights make it possible to work even in dark environments. Insulation alarm and Dew point alarm are perfect in a building site. The visual 2.3 Mpixel digital camera and three step Fusion Picture in Picture functionality helps produce radiometric JPEG images in a professional way. FLIR QuickReport™ software makes it possible to analyze IR and visual pictures captured in field back in the office.

- *IR resolution 140 x 140 pixels*
- *Digital camera 1536 x 1536 pixels*
- *Lightweight 600 g*
- *Laser Pointer*
- *Copy to USB*
- *Fusion (3 steps Picture in Picture)*
- *5 hours battery*
- *LED lights*
- *21 languages*
- *Dew point & Insulation alarm*
- *NETD 90 mK*

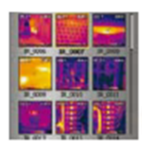
FLIR b50 Features

- **Digital Camera** — 2.3 Megapixels with built-in LED lights provides sharp images regardless of lighting conditions
- **Picture in Picture (PiP)** — Displays resizable IR image super-imposed over a digital image
- **Wide Temperature Range** — Measures from -20 °C to +120 °C targeting building applications
- **± 2% Accuracy** — Reliable temperature measurement
- **Insulation alarm** — Shows the insulation performance of the building structure
- **Dew point alarm** — Alerts you to the areas where there is a risk of condensation
- **Thumbnail Image Gallery** — Allows quick search of stored images
- **Laser Pointer** — Pinpoints the hot spot on the IR image with the real physical target
- **Micro SD Card** — Stores more than 2000 radiometric JPEG images

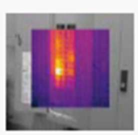
140 x 140 pixel resolution

Fusion (3 steps PiP)

Built-in LED lights



Thumbnail Image Gallery



Fusion (3 steps Picture in Picture)

Allows for easier identification and interpretation of infrared images. This advanced technology enhances the value of an infrared image by allowing you to overlay it directly over the corresponding visible image. This functionality combines the benefits of both the infrared image and visual picture at the push of a button.

FLIR b50 Specifications

Imaging and optical data	
Field of view (FOV) / Minimum focus distance	25° × 25° / 0.10 m (0.33 ft.)
Spatial resolution (IFOV)	3.12 mrad
Thermal sensitivity/NETD	<0.09 °C (<0.16 °F) @ +25 °C (+77 °F) / 90 mK
Image frequency	9 Hz
Focus	Manual
Focal Plane Array (FPA) / Spectral range	Uncooled microbolometer / 7.5–13 µm
IR resolution	140 × 140 pixels
Image presentation	
Display	Built-in 3.5 in. LCD, 256k colors, 240 × 320 pixels
Image modes	IR image, visual image, Picture in Picture, thumbnail gallery
Picture in Picture	IR area (in three steps) on visual image
Measurement	
Object temperature range	–20 to +120°C (–4 to +248°F)
Accuracy	±2°C (±3.6°F) or ±2% of reading
Measurement analysis	
Spotmeter	Center spot
Area	1 box with min./max.
Emissivity correction	Variable from 0.1 to 1.0 or selected from list of materials
Reflected apparent temperature correction	Automatic, based on input of reflected temperature
Isotherm	1 with above/below
Dew point alarm	Yes
Insulation alarm	Yes
Set-up	
Menu commands	Palettes (Black and White, Iron and Rainbow), image adjustment (auto/ manual)
Set-up commands	Local adaptation of units, language, date and time formats; automatic shutdown, display intensity
Storage of images	
Image storage	Standard JPEG, including measurement data, on memory card
Digital camera	
Built-in digital camera	2.3 Mpixels (1536 × 1536 pixels), and two LED lights
Digital camera, focus	Minimum focus distance 0.4 m (1.3 ft.)

Laser pointer	
Laser	Semiconductor AlGaInP diode laser, Class 2
Data communication interfaces	
Interfaces	USB-mini, USB-A
Power system	
Battery	Li Ion (field replaceable), 5 hours operating time
Charging system	In camera, AC adapter, 2-bay charger or 12 V from a vehicle
Power management	Automatic shutdown (user selectable)
AC operation	AC adapter, 90–260 VAC, 50/60 Hz, 12 V output to camera
Environmental data	
Operating temperature range	–15 to +50 °C (+5 to +122°F)
Storage temperature range	–40 to +70 °C (–40 to +158°F)
Humidity (operating and storage)	IEC 68-2-30/24 h 95% relative humidity +25 °C to +40 °C (+77°F to +104°F)
Encapsulation	IP 54 (IEC 60529)
Bump	25 g (IEC 60068-2-29)
Vibration	2 g (IEC 60068-2-6)
Physical data	
Camera weight, incl. battery	0.60 kg (1.32 lb)
Camera size (L × W × H)	235 × 81 × 175 mm (9.3 × 3.2 × 6.9 in.)
Scope of delivery	
Packaging, contents: Hard transport case, Infrared camera with lens, Battery, Calibration certificate, FLIR QuickReport™ PC software CD-ROM, Memory card with adapter, Power supply, Printed Getting Started Guide, USB cable, User documentation CD-ROM, Warranty extension card or Registration card	
Optional software	
FLIR Reporter Standard/ Professional	A powerful yet easy-to-use tool to generate comprehensive and professional infrared inspection reports.
FLIR BuildIR™	A powerful yet easy-to-use software designed to visualise and quantify building related issues

Applications

Building: Water and mildew in wall

Building: Heat Loss

Electrical: Hot Fuses

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FLIR

www.flir.com/thg

C. 3. Degree Controls, F900 Series Air Velocity and Air Temperature Sensors

degreeC

CAMBRIDGE ACCUSENSE **F900 Series Air Velocity and Air Temperature Sensors**

applications

- HVAC
- Industrial Processes
- Automotive
- Air f ltration Systems
- Electronics Enclosures, and
- Critical Containment Areas
- Biological Safety Cabinets
- Fume Hoods
- Clean Rooms

features

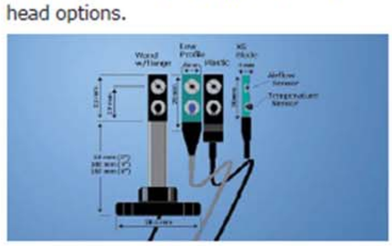
- Measures air & inert gas velocity and temperature
- Standard f ow ranges between 0.15-10 m/s (approximately 30-2000 fpm)
- Temperature measurements from 0-70°C
- Digital UART Interface
- Linear 0-4 VDC airf ow output from 0 to full-scale
- Wide voltage supply: 7-13VDC
- Temperature-compensated from 15-35°C
- Ideal for ducted or open airf ow applications
- Available in multiple sensor heads
- Wide acceptance angle (±30°)

about

The F900 Airf ow Sensor is designed to measure the velocity and temperature of airf ows in applications such as HVAC, industrial processes, automotive, air f ltration systems, electronics enclosures, and critical containment areas such as biological safety cabinets, fume hoods, and clean rooms.

With standard airf ow sensing ranges from 0.15-2 m/s (30-400 fpm) to 0.15-10 m/s (30-2000 fpm), the Series F900 offers unparalleled price to performance, compact size, reliability with resistance to mechanical shock and vibration.

The F900 series has a linear 0-4V output and a digital 5v UART output depending on the model. The F900 is easy to install and operate. An adjustable mounting bracket is included with the sensor. In addition, the F900 can be ordered with any of the AccuSense remote sensing head options.



degreeC DEGREE CONTROLS, INC.

Engineered Airflow. Intelligent Cooling. www.degreec.com • sales@degreec.com

18 Meadowbrook Drive, Milford, NH 03055 • TEL: 603-672-8900 or 1-877-DEGREEC • FAX: 603-672-9565

F900 Series Air Velocity and Air Temperature Sensors

F900 Series Air Velocity and Air Temperature Sensors

airflow measurement

Air Velocity

Temperature compensation range: 15-35°C (60-95°F):
Accuracy: ±5% of reading or ±0.05m/s (10fpm)
±10% of reading or ±0.05m/s (10fpm)
Repeatability: ±1% of reading

Airf ow Temperature

Measurement range: 0-70°C (32-158°F)
Measurement Accuracy[1]: ±1°C (1.8°F)
Resolution: ±0.1°C

Temperature Compensation Range: The F900 is a thermal airf ow sensor; it is sensitive to changes in air density and indicates velocity with reference to a set of standard conditions (25°C (77°F), 760mmHg (101.325kPa), and 0%RH). The F900 has been designed so that when used over the stated temperature compensation range, the sensor indicates very close to actual air velocity and minimal compensation is only required to account for changes in barometric pressure or altitude. Changes in relative humidity have a minimal impact and can usually be ignored.

[1] Above 0.5m/s (100fpm), ±1.5°C (2.7°F) below 0.5m/s (100fpm).

temperature measurement

Range 0-70°C (50-140°F)	Available on 5v UART output only
Accuracy ±1°C above 1 m/s (196 fpm) ±1.5°C below 1 m/s (196 fpm)	Resolution is ±0.1°C

electrical specifications

Supply Voltage 7-13 VDC	Warm-up Time <5 seconds
Supply Current 40-75 mA	Operating Temperature 0 – 70°C (32-158°F)
Response Time 1.5 seconds	Storage Temperature −10 to 100°C
Output is linearized 0-4.0 vdc, which equals 0 to full scale of calibrated range (airf ow only).	

mechanical specifications

Dimensions	100 mm long X 12 mm diameter for standard unit, 91 mm X 12 mm for long tube with remote sensor heads
Vibration	Up to 25 G's
Acceptance Angles	Standard, rod w/f ange, plastic heads are ±30°, low-prof le is ±45°, XS blade is ±60° from perpendicular

connection specifications

Pin 1 Black	Supply Return
Pin 2 Red	Supply 7-13 VDC
Pin 3 White	Analog Airf ow Output (0-4Vout) for calibrated range, up to 4.095V beyond calibrated range.
Pin 4 Orange	Digital serial output - 19200 BPS, 5v UART level, 8 bit, 1 stop bit
Pin 5 Yellow	Digital serial input – 19200 BPS, 5v UART levels, 8 bit, 1 stop bit -
Connector	Molex#22-01-2057 or equivalent

part number scheme

F900 - V - A - B - S - L

V =
Velocity Range
N = 0.15 - 2 m/s
O = 0.15 – 5 m/s
P = 0.15 - 10 m/s

A =
Accuracy Specification
5 = Greater of 5% of reading or ±0.05 m/s or 1% full-scale
10 = Greater of 10% of reading or ±0.05 m/s or 1% full-scale

B =
Body Type
0 = Standard (Default) – short tube
1 = Long tube (for remote sensor heads)

S =
Sensor Head Type (for B =1 ONLY)
0 = Plastic
1 = Low Prof le
2 = 50 mm (2") SS wand /w f ange
4 = 100 mm (4") SS wand /w f ange
6 = 150mm (6") SS wand /w f ange
9 = XS Blade

L =
Sensor Cable Length (for B =1 ONLY)
2 = 2 m

User Manual available at www.degreeC.com

degreeC DEGREE CONTROLS, INC.
Engineered Airflow. Intelligent Cooling.
www.degreec.com • sales@degreec.com
18 Meadowbrook Drive, Milford, NH 03055 • TEL: 603-672-8900 or 1-877-DEGREEC • FAX: 603-672-9565

C. 4. VFS 1-20 Vortex Flowsensor standard, 1-20 l/min

GRUNDFOS **DATA SHEET**

VFS 1-20

Vortex Flowsensor standard, 1-20 l/min

TM03 8208 0807

Fig. 1 VFS 1-20 sensor

Technical overview

Grundfos Direct Sensors™, type VFS, is a series of combined flow- and temperature sensors (two-in-one) based on the principle of vortex shedding behind a bluff body. The VFS sensors are designed for high-volume production and are fully compatible with wet, aggressive media. The VFS sensor utilises MEMS sensing technology in combination with a novel packaging concept using corrosion-resistant coating on the MEMS sensor element. This makes the VFS sensor very robust and ideal for high-volume OEM applications. VFS sensors are available for flow ranges of 1-12, 1.3-20, 2-40, 5-100, 10-200 and 20-400 l/min.

Applications

- thermal management in solar heating systems
- industrial process flow control
- flow rate detection for pump controls
- monitoring of pumps, valves and filters
- cooling and temperature control
- domestic hot-water systems
- heat metering (solar - heat pumps).

Features

- flow ranges: 1-12, 1.3-20, 2-40, 5-100, 10-200 and 20-400 l/min.
- based on vortex shedding
- voltage output (ratiometric, ideal for use with microprocessor and PLC)
- compact and robust design
- approved for potable water: WRAS, KTW, W270, ACS.

Benefits

- no moving parts
- flow and temperature sensor in one package (two-in-one sensor)
- fast temperature response (direct media contact)
- compatible with wet, aggressive media
- cost-effective and robust construction.

Specifications

Flow	
Measuring range	1.3 to 20 l/min
Accuracy (±1σ), 0 to 100 °C	±1.5 % FS
Response time (63.2 %)	< 1s
Resolution	0.1 l/min
Temperature	
Measuring range	0 to 100 °C
Accuracy (±1σ), 25 to 80 °C	±1 °C
Accuracy (±1σ), 0 to 100 °C	±2 °C
Response time (63.2 % at 50 % FS flow)	< 1s
Resolution	0.5 °C
Media and environment	
Media types	The sensor is compatible with liquids (kinematic viscosity ≤ 2 mm^2/s)
Media temperature (operation)	0 to 100 °C
Media temperature (peak)	−25 to 120 °C
Ambient air temp. (operation)	−25 to 60 °C
Ambient air temp. (peak)	−55 to 90 °C
Humidity	0 - 95 % (relative), non-condensing
System burst pressure	> 16 bar
Electrical data	
Power supply	5 V DC (± 5 %). Grounding of the sensor supply is recommended (PELV)
Output signals	Ratiometric
Flow signal	0.35 - 3.5 V (Zero at 0.35 V)
Temperature signal	0.5 - 3.5 V
Power consumption	< 50 mW
Load impedance	> 10 kΩ
Sensor materials	
Sensing element	Silicon-based MEMS sensor
Seal (sensor to housing)	EPDM rubber
Housing	Composites (PPS, PA66)
Flow pipe	PPA 40-GF
Wetted materials	Corrosion-resistant coating EPDM, PPS, PPA 40-GF
Environmental standards	
Enclosure class	IP44 (Not overmoulded IP20)
Temperature cycling	IEC 68-2-14
Vibration (non-destructive)	20 - 2000 Hz, 10G, 4h
Electromagnetic compatibility	EN 61326-1
Dimensions	
Sensing element	47 x 40 x 20 mm, see drawing
Flow pipe	82 x 39 x 25 mm

If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

BE > THINK > INNOVATE >

GRUNDFOS

BE › THINK › INNOVATE ›

Being responsible is our foundation
Thinking ahead makes it possible
Innovation is the essence

Dimensions (in mm)

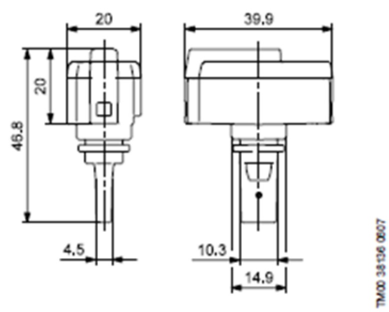


Fig. 2 Dimensional sketches of sensing element

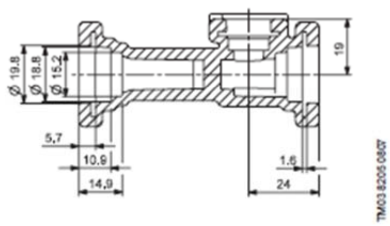


Fig. 3 Dimensional sketch of flow pipe

Type key

The sensor is labelled with a type designation.

96xxxxxx - XX - XXX XXXXX

- Product number
- Revision
- Production year and week
- Consecutive number

For more information, see http://www.grundfos.com/directsensors.

Electrical connections

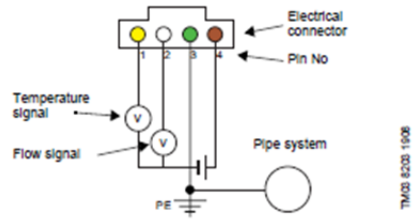


Fig. 4 Electrical connections

Pin configuration		Colour
1	Temperature signal (0.5 to 3.5 V relative to pin 3)	Yellow
2	Flow signal (0.5 to 3.5 V relative to pin 3)	White
3	GND (0 V)	Green
4	Power supply (+5V DC), PELV	Brown

Power supply requirements

- 5 Vdc
- separated from hazardous live circuitry by double or reinforced insulation
- power limitation:150 VA; current limitation: 8 A.

Sensor output signals

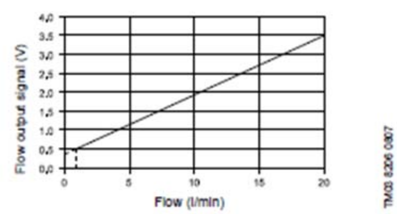


Fig. 5 Flow response

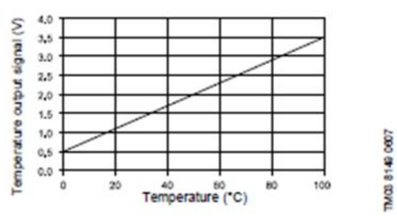


Fig. 6 Temperature response

96702082 1008	GB
Repl. 96702082 0108	

Subject to alterations.

Grundfos Sensor A/S
Poul Due Jensens Vej 7. DK-8850 Bjerringbro. Denmark
Telephone: +45 87 50 14 00

www.grundfos.com/directsensors

GRUNDFOS

C. 5. ONSET HOBO® UX100 Loggers

onset
HOBO® Data Loggers

HOBO® UX100 Loggers

Next-generation family of temperature and humidity data loggers

The HOBO UX100 Series is Onset's next-generation family of data loggers for tracking temperature and relative humidity in indoor environments.

HOBO UX100 Series offer a dramatic price/performance advantage over competitive products by delivering higher accuracy, larger measurement capacity, and more LCD display features to make environmental data collection faster and easier than ever. The loggers provide a variety of features to reduce deployment time, and offer new logging modes for recording and displaying more detailed data without extensive post-processing or memory use.

Supported Measurements:
Temperature, Relative Humidity, Dew Point, Thermocouple

Key Advantages:

- Easy-to-view LCD display
- Large memory capacity
- Flexible mounting options
- Visual high & low alarm thresholds
- New Burst and Statistics logging modes
- User-replaceable RH sensors
- Temp, humidity, and thermocouple models available

Minimum System Requirements:

Common Features of HOBO UX100 Series Loggers

*USB cable included with software

For complete information and accessories, please visit: **www.onsetcomp.com**

Part number	UX100-001 (Temp)	UX100-003 (Temp/RH)	UX100-011 (Temp/RH)	UX100-023 (Ext Temp/RH)
Memory	84,650 measurements			
Sampling Rate	1 second to 18 hours, user-selectable			
Battery Life	1 year typical with logging rate of 1 minute and sampling interval of 15 seconds or greater, user-replaceable, CR2032			
Dimensions	3.66 x 5.94 x 1.52 cm (1.44 x 2.34 x 0.6 in.)	3.66 x 8.48 x 1.52 cm (1.44 x 3.34 x 0.6 in.)		
Temperature				
Range	-20° to 70°C (-4° to 158°F)			
Accuracy	±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F)			
Resolution	0.024°C at 25°C (0.04°F at 77°F)			
Response Time (airflow of 1 m/s (2.2mph))	8 minutes to 90%	4 minutes to 90%		6 minutes to 90%
Relative Humidity				
Range	n/a	15% to 95%	1% to 95%	
Accuracy	n/a	±3.5% from 25% to 85%	±2.5% from 10% to 90%	
Resolution	n/a	0.07% at 25°C (77°F)	0.05% at 25°C (77°F)	
Response Time (airflow of 1 m/s (2.2mph))	n/a	43 seconds to 90%	11 seconds to 90%	5 minutes to 90%
CE compliant	Yes			

Part number	**UX100-014M** (Thermocouple)		
Memory	208,076 measurements		
Sampling Rate	1 second to 18 hours, user-selectable		
Battery Life	1 year, typical with logging rate of 1 minute and sampling interval of 15 seconds or greater, user-replaceable, CR2032		
Dimensions	3.66 x 8.48 x 1.52 cm (1.44 x 3.34 x 0.6 in.)		
Operating Range	Logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing)		
Thermocouple (probes sold separately)	**Range**	**Accuracy**	**Resolution**
Type J	-210° to 760°C (-346° to 1,400°F)	±0.6°C (±1.08°F) ± thermocouple probe accuracy	0.03°C (0.06°F)
Type K	-260° to 1,370°C (-436° to 2,498°F)	±0.7°C (±1.26°F) ± thermocouple probe accuracy	0.04°C (0.07°F)
Type T	-260° to 400°C (-436° to 752°F)	±0.6°C (±1.08°F) ± thermocouple probe accuracy	0.02°C (0.03°F)
Type E	-260° to 950°C (-436° to 1,742°F)	±0.6°C (±1.08°F) ± thermocouple probe accuracy	0.03°C at (0.05°F)
Type R	-50° to 1,550°C (-58° to 2,822°F)	±2.2°C (±3.96°F) ± thermocouple probe accuracy	0.08°C (0.15°F)
Type S	-50° to 1,720°C (-58° to 3,128°F)	±2.2°C (±3.96°F) ± thermocouple probe accuracy	0.08°C (0.15°F)
Type B	550° to 1,820°C (1,022° to 3,308°F)	±2.5°C (±4.5°F) ± thermocouple probe accuracy	0.1°C (0.18F)
Type N	-260° to 1,300°C (-436° to 2,372°F)	±1.0°C (±1.8°F) ± thermocouple probe accuracy	0.06°C (0.11°F)

Contact Us

Sales (8am to 5pm ET, Monday through Friday)
- Email sales@onsetcomp.com
- Call 1-508-759-9500
- In U.S. toll free 1-800-564-4377
- Fax 1-508-759-9100

Technical Support (8am to 8pm ET, Monday through Friday)
- Contact Product Support onsetcomp.com/support/contact
- Call 1-508-759-9500
- In U.S. toll free 1-877-564-4377

Onset Computer Corporation
470 MacArthur Boulevard
Bourne, MA 02532

C.6. ONSET HOBO UX120 4-Channel Analog Logger

HOBO UX120 4-Channel Analog Logger

Flexible, Accurate, 4-channel Analog Logger

The HOBO UX120-006M Analog Logger is a high-performance, LCD display data logger for building performance monitoring applications.

As Onset's highest-accuracy data logger, it provides twice the accuracy of previous models, a deployment-friendly LCD, and flexible support up to four external sensors for measuring temperature, current, CO_2, voltage, and more.

Supported Measurements: Temperature, 4-20mA, AC Current, AC Voltage, Air Velocity, Carbon Dioxide, Compressed Air Flow, DC Current, DC Voltage, Gauge Pressure, Kilowatts, Volatile Organic Compound (sensors sold separately)

Minimum System Requirements:

Software USB cable*

Key Advantages:

- Twice the accuracy over previous models
- 16-bit resolution
- Flexible support for a wide range of external sensors
- LCD confirms logger operation and displays near real-time measurement data
- Provides minimum, maximum, average, and standard deviation logging options
- On-screen alarms notify you when a sensor reading exceeds set thresholds
- Stores 1.9 million measurements for longer deployments between offloads

▸ For complete information and accessories, please visit: **www.onsetcomp.com**

Part number	**UX120-006M** (4-Channel Analog)
Memory	1.9 Million
Logging Rate	1 second to 18 hours, user selectable
Logging Modes	Normal, Burst, Statistics
Memory Modes	Wrap when full or stop when full
Time Accuracy	±1 minute per month at 25°C (77°F)
Battery Life	1 year typical with logging rate of 1 minute and sampling interval of 15 seconds or greater, user replaceable, 2 AAA
Dimensions	10.8 x 5.41 x 2.54 cm (4.25 x 2.13 x 1 in.)
Operating Range	Logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing)
Accuracy	±0.1 mV ±0.1% of reading
CE Compliant	Yes

C.7 Graywolf Hand held Anemometer AS-201, Graywolf Sensing Solutions

D. Python Scripts for Data Processing

The "driver.py" script calls up the other two scripts. The "NISignalExpressUtility.py" script converts the proprietary TDMS file format to CSV format, calibration, and reshaping. The "GrundfosUtility.py" script converts the voltage signal to flowrate (l/min) and temperature (F). To process anemometer data, the final line in "driver.py" is disabled by putting a # at the front of it so it will not call up the "GrundfosUtility.py" script.

"driver.py"

```
import NISignalExpressUtility
import os
from GrundfosUtility import convert_output
from DataFiles import __data__
from ConvertedCSVs import __converted__
from ReshapedCSVs import __reshaped__
from CalibratedCSVs import __calibrated__
from Output import __output__

data_location = os.path.dirname(os.path.abspath(__data__.__file__))
converted_location = os.path.dirname(os.path.abspath(__converted__.__file__))
reshaped_location = os.path.dirname(os.path.abspath(__reshaped__.__file__))
calibrated_location =
os.path.dirname(os.path.abspath(__calibrated__.__file__))
output_location =os.path.dirname(os.path.abspath(__output__.__file__))

print "data: ", data_location
print "converted: ", converted_location
print "reshaped: ", reshaped_location
print "calibrated: ", calibrated_location
print "output: ", output_location

data_folders_locations = []
for folder_name in os.listdir(data_location):
    if ".py" not in folder_name:
        data_folders_locations.append(os.path.join(data_location,
folder_name))
#        print data_folders_locations

for data_folders in data_folders_locations:
    print data_folders
    NIExtract = NISignalExpressUtility.NISignalExpressUtility(\
        data_folders, converted_location,\
```

```
        reshaped_location, calibrated_location)
    NIExtract.convert_to_csv()
    NIExtract.reshape_csv()
    NIExtract.calibrate_output()

#Enable only if the the collected data is from Grundfos VFS 1-20 sensor
convert_output(calibrated_location, output_location)
```

“NISignalExpressUtility.py”

```
#-------------------
# Author: Christian A. Damo
# file name: NISignalExpressUtility.py
# rev. by: Reed Shinsato
# rev. date: 2014-07-11
#------------------
#
# Patch Notes: Cleaned up class
#
#------------------
"""
    This script convertes .tdms files from NISignalExpress into .csv files.
    Then, it pushes the .csv files to a server with a specified ip.
"""

# Import Libraries
from nptdms import TdmsFile
import os
import datetime
import csv

#dictionary for tacking on a sensor name & location to a corresponding port
notes = {'ai0':"Temperature_1",
         'ai1':"Flow_1",}

# Create Classes
class GroupChannel:
    """
        This class holds the group and channel names from a metafile.
    """
    def __init__(self, meta_filename):
        print
        self._channel_type = ""
        self._start_time = datetime.datetime.now()
        self._meta_filename = meta_filename
        self._group_name = ""
        self._channel_names = []
        self.__get_group_name(self._meta_filename)
        # self.__str__()

    def __str__(self):
        print "\nCalling GroupChannels __str__()"
```

```
        print "Type: ", self._channel_type
        print "Start: ", self._start_time
        print "Group Name: ", self._group_name
        print "Channel Names: \n\n", self._channel_names

    def __get_start_and_names(self, meta_filename, temp_names):
        """
            This function stores the start time and channel names
        """
        # Check the meta_file for " ", which is the line of the channel
names.
        # Check the meta_file for "Log start time", which holds the start
time.
        meta_file = open(meta_filename)
        for line in meta_file:
            if line[0] == " ":
                 temp_names.append(line)
            if "Log start time" in line:
                self._start_time =
self.__start_convert_to_datetime_object(line)
        meta_file.close()

    def __start_convert_to_datetime_object(self, line):
        """
            This function turns the given line into a datetime object.
        """
        # Find each element of the given line
        # Turn the elements into a datetime object
        # Return the datetime object
        line = line.split(" ")
        date = line[3]
        date = date.split("/")
        year = int(date[2])
        day = int(date[1])
        month = int(date[0])
        time = line[4]
        time = time[:-1]
        time = time.split(":")
        hour = int(time[0])
        minute = int(time[1])
        second = time[2].split(".")
        second = int(second[0])
        begin_time = datetime.datetime(year, month, day, hour, minute,
second)
```

```
        return begin_time

    def __get_group_name(self, meta_filename):
        """
            This functions determines the group_name
        """
        # Get the start time and channel names
        # Determine the timestamp
        # Store the channel names
        # Determine the data type
        # Create the group name
        temp_names = []
        self.__get_start_and_names(meta_filename, temp_names)
        for line in temp_names:
            temp_line = line.split("-")
            timestamp = temp_line[0]
            timestamp = timestamp[5: -1]
            channel_name = temp_line[-1]
            channel_name = channel_name[1: -1]
            self._channel_names.append(channel_name)
            data_type = temp_line[1]
            data_type = data_type[1: -1]
            self._channel_type = data_type
            self._group_name = (timestamp + " - " + data_type +
                                " - " + "All Data")

    def return_group_name(self):
        """
            This function returns the group name.
        """
        # Retunr group_name
        return self._group_name

    def return_channel_names(self):
        """
            This function returns the channel names.
        """
        # Return channel_names
        return self._channel_names

    def return_start_time(self):
        """
            This function returns the start time.
        """
```

```
        # Return start_time
        return self._start_time

class NISignalExpressUtility:
    def __init__(self, data_location = os.path.dirname(\
        os.path.abspath(__file__)), csv_location = os.path.dirname(\
        os.path.abspath(__file__)), reshaped_location = os.path.dirname(\
        os.path.abspath(__file__)), calibrated_location = os.path.dirname(\
        os.path.abspath(__file__))):
        self._data_location = data_location
        self._csv_location = csv_location
        self._reshaped_location = reshaped_location
        self._calibrated_location = calibrated_location
        self._meta_voltage_filename = (os.path.join(self._data_location,\
            "Voltage_meta.txt"))
        self._meta_current_filename = (os.path.join(self._data_location,\
            "Current_meta.txt"))
        self._tdms_voltage_filename = (os.path.join(self._data_location,\
            "Voltage.tdms"))
        self._tdms_current_filename = (os.path.join(self._data_location,\
            "Current.tdms"))
        self._channel_names = []
        self._tdms_filenames = []
        self._GroupChannels = []
        self._tdms_to_csv_filename = str(os.path.split(data_location)[-1]) +\
            "_converted.csv"
        self._reshaped_filename = str(os.path.split(data_location)[-1]) +\
            "_reshaped.csv"
        self._converted_to_csv = False

    def __check_for_group_channels(self, tdms_filename, tdms_filenames,\
            meta_filename, channel_names, GroupChannels):
        """
            This function creates the GroupChannels.
        """
        # Create a tdms object
        # Create a GroupChannel object
        # Add to the list of channel_names
        # Add to the list of tdms_filenames
        # Add to the list of GroupChannels
        tdms_file = TdmsFile(tdms_filename)
        TypeGroupChannel = GroupChannel(meta_filename)
        type_channel_names = TypeGroupChannel.return_channel_names()
        channel_names.append(type_channel_names)
```

```
        tdms_filenames.append(tdms_file)
        GroupChannels.append(TypeGroupChannel)

    def __tdms_to_csv_file(self, channel_names, tdms_filenames,
                           GroupChannels):
        """
            This function will convert .tdms files into .csv files
        """
        # Get the data from the .tdms file
        #    Create a channel object from a tdms object
        #    Get the data from the channel
        #    Get the time from the channel
        # Clean up the channel_names to be a single array
        # Save the data into the output file
        #    Save the timestamp using delta from the start_time
        #    Save the data in a row relative to the channel_id column

        datas = []
        times = []
        for channel_names_index in range(0, len(channel_names)):
            for channel_name in channel_names[channel_names_index]:
                channel = (tdms_filenames[channel_names_index].
              object(GroupChannels[channel_names_index].
              return_group_name(), channel_name))
                data = channel.data
                datas.append(data)
                times = channel.time_track()

        temp_channel_names = []
        for channel_names_index in range(len(channel_names)):
            for name in channel_names[channel_names_index]:
                temp_channel_names.append(name)

        channel_names = []
        channel_names = temp_channel_names


        converted_file = open(os.path.join(self._csv_location,\
            self._tdms_to_csv_filename),"wb")
        writer = csv.writer(converted_file)

        new_row = list(channel_names)
        new_row.insert(0, "timestamp")
        writer.writerow(new_row)
```

```
        #iterates through each time element
        for times_index in range(len(times)):
            #created delta object
            delta = datetime.timedelta(seconds = times[times_index] + 1)
            #creates the actual printed time
            current_time = GroupChannels[0].return_start_time() + delta
            #creates new line with time as element 0
            new_row = [current_time]
            #iterating through the datas list
            for datas_index in range(len(datas)):
                data = datas[datas_index][times_index]
                new_row.append(data)
            writer.writerow(new_row)
            #print new_row
            #print len(new_row)
            #raw_input("Press Enter to continue...")
        converted_file.close()


    def reshape_csv(self):
        """
            This function reshapes the data to a specific table format.
        """
        # Find the correct input file
        # Create an output file
        # Write the header
        # Clean up the channel_names
        # Write the output row with the correct format
        #    Add time to the output row
        #        Add the channel_names to the row
        #        Add the data to the row
        #        Write the row with [time, channel_names, data]
        if self._converted_to_csv == True:
            channel_names = list(self._channel_names)
            input_file = (open(os.path.join(self._csv_location,\
                self._tdms_to_csv_filename), "r"))
            reader = csv.reader(input_file)

            reshaped_file = (open(os.path.join(self._reshaped_location,\
                self._reshaped_filename), "wb"))
            writer = csv.writer(reshaped_file)

            reader.next()
```

```
            new_row = ["datetime", "position", "value"]
            writer.writerow(new_row)

            temp_channel_names = []
            for channel_names_index in range(len(channel_names)):
                for names in channel_names[channel_names_index]:
                    temp_channel_names.append(names)
            channel_names = []
            channel_names = temp_channel_names
            new_channel_names = []
            for name in channel_names:
                name = name.split("_")
                name = name[1]
                new_channel_names.append(name)

            for row in reader:
                current_time = row[0]
                row = row[1:]
                for new_channel_names_index in range(len(new_channel_names)):
                    new_row = []
                    new_row.append(current_time)

new_row.append(new_channel_names[new_channel_names_index])
                    new_row.append(float(row[new_channel_names_index]))
                    writer.writerow(new_row)

            input_file.close()
            reshaped_file.close()

    def convert_to_csv(self):
        """
            This function extracts the tdms data to the correct format.
        """
        # Check for voltage and current group channels
        # Convert the tdms files to csv
        # Reshape the csv files to the correct format
        files_found_voltage = True
        files_found_current = True
        try:
            self.__check_for_group_channels(self._tdms_voltage_filename,\
                self._tdms_filenames, self._meta_voltage_filename,\
                self._channel_names, self._GroupChannels)
        except:
            print "Note: No Voltage Files"
```

```
            files_found_voltage = False
        try:
            self.__check_for_group_channels(self._tdms_current_filename,\
                self._tdms_filenames, self._meta_current_filename,\
                self._channel_names, self._GroupChannels)
        except:
            print "Note: No Current Files"
            files_found_current = False

        if files_found_current == True or files_found_voltage == True:
            self.__tdms_to_csv_file(self._channel_names,
self._tdms_filenames,\
                self._GroupChannels)
            self._converted_to_csv =  True

    def add_calibration(self, sensor_id, premultiplier,
                        preoffset, multiplier, offset):
        """
            This function adds a calibration to NICalibrate.csv.
        """
        # Open the calibration file
        # Check if the sensor_id is in the calibration file
        # Delete the calibration for the sensor_id
        # if it is in the calibration file
        # Append the new calibration to the calibration file
        calibration_filename = "NICalibrate.csv"
        delete_id = False
        sensor = str(sensor_id)
        with open(calibration_filename, "r") as calibration_file:
            for row in csv.reader(calibration_file):
                if sensor in row:
                    delete_id = True

        if delete_id == True:
            self.delete_calibration(sensor_id)

        with open(calibration_filename, "a") as calibration_file:
            row = (str(sensor_id) + "," +\
                   str(premultiplier) + "," +\
                   str(preoffset) + "," +\
                   str(multiplier) + "," +\
                   str(offset) + "\n")
            calibration_file.write(row)
```

```
def delete_calibration(self, sensor_id):
    """
        This function deletes a calibration from NICalibrate.csv.
    """
    # Copy NICalibrate.csv into a temp.csv
    # skipping the sensor_id to be deleted
    # Delete the old calibration file NICalibrate.csv
    # Rename temp.csv into the new calibration file NICalibrate.csv
    calibration_filename = "NISignalExpressCalibrate.csv"
    temp_filename = "temp.csv"
    sensor = str(sensor_id)
    with open(temp_filename, "wb") as temp_file:
        with open(calibration_filename, "r") as calibration_file:
            for row in csv.reader(calibration_file):
                if sensor not in row:
                    csv.writer(temp_file).writerow(row)

    os.remove(calibration_filename)
    os.rename(temp_filename, calibration_filename)


def __calibrate_value(self, sensor_id, value):
    """
        This function calibrates the value of the senor_id.
    """
    # Open the calibration file
    # Check if the sensor_id of the calibration file
    # to determine the multipliers and offsets
    # Return the value with calibration
    calibration_filename = "NISignalExpressCalibrate.csv"
    calibration_file = open(calibration_filename, "r")
    reader = csv.reader(calibration_file)

    value = float(value)

    premultiplier = 1.0
    preoffset = 0.0
    multiplier = 1.0
    offset = 0.0

    row = reader.next()
    for row in reader:
        if row[0] == str(sensor_id):
```

```
                premultiplier = float(row[1])
                preoffset = float(row[2])
                multiplier = float(row[3])
                offset = float(row[4])

        value = multiplier * ((premultiplier * value) + preoffset) + offset

        calibration_file.close()
        return value

    def clean_folder(self, folder_location):
        """
            This function deletes all the output files created.
        """
        folder_files_list = os.listdir(folder_location)

        for folder_files in folder_files_list:
            if ".py" not in folder_files:
                try:
                    os.remove(os.path.join(folder_location, folder_files))
                except:
                    pass

    def calibrate_output(self):
        """
            This function calibrates the output for given callibrations.
        """
        # Find the correct input file
        # Create a output file for the calibrated values
        # Write the header row
        # Go through each input row and callibrate the value of the row
        # Write the callibrated row to the output file

        input_file = (open(os.path.join(self._reshaped_location,\
            self._reshaped_filename), "r"))
        reader = csv.reader(input_file)

        output_filename = str(self._reshaped_filename).replace(".csv",\
            "_calibrated.csv")
        output_file = (open(os.path.join(self._calibrated_location,\
            output_filename), "wb"))
        writer = csv.writer(output_file)

        new_row = reader.next()
```

```
        writer.writerow(new_row)

        for row in reader:
            value = self.__calibrate_value(row[1], row[2])
            new_row = [row[0], row[1], round(value,5), notes[row[1]]]
            writer.writerow(new_row)

        input_file.close()
        output_file.close()
```

"GrundfosUtility.py"

```
import copy
import csv
import os

"""
Engineering Notes:

[#1] VFS 1-20 @port_assignments
=============================================================================
===
ai0 : temperature sensor
ai1 : flow sensor

Input File
=============================================================================
===
Datetime Stamp, Sensor ID, Value, Comments

Output File
=============================================================================
===
Datetime Stamp, Sensor ID, Value, Comments, Converted Value
"""

def convert_flow(voltage):
    """
    Input(s):
    @voltage: (int/float) The output voltage from the Grundfos sensor

    Returns: (float) The flow rate in l/min
```

```
    Notes:
    Computes the l/min:
        flow_rate = 6.6522 x output_voltage - 2.5396

    This equation was derived from experiments to measure the accuracy of the
    sensor, which can be located as an Excel spreadsheet in the data sheet
    folder

    The ideal equation provided by the company is:
        flow_rate = (187/30) x voltage - (109/60)
    """
    return 6.6522*float(voltage)-2.5396

def convert_temperature(voltage):
    """
    Input(s):
    @voltage: (int/float) The output voltage from the Grundfos sensor

    Returns: (float) The temperature in Fahrenheit

    Notes:
    Computes the ideal temperature:
        temperature = (100/3) x output_voltage - (100/6)
    """
    return celsius_fahrenheit((100.0/3.0)*float(voltage)-(100.0/6.0))

def celsius_fahrenheit(temperature):
    """
    Input(s):
    @temperature: (int/float) Temperature in Celsius

    Returns: (float) The temperature in Fahrenheit

    Notes:
    Converts from Celsius to Fahrenheit
        F = (9/5) x C + 32
    """
    return (9.0/5.0)*temperature+32.0

def convert_output(input_location, output_location):
    """
    Input(s):
    @input_location: (string) input direction path
    @output_location: (string) output direction path
```

```
    Returns: Nothing, however it will generate a CSV with the tag '_output'

    Notes:
    Takes a CSV with data collected from a Grundfos VFS sensor and converts
the
    voltage data to something that is usable for research
    """
    print "Input:\t", input_location
    print "Output:\t", output_location
    print "\nStarting conversion...\n"
    error_count = 0
    data_count = 0
    for item in os.listdir(input_location):
        item_target = item.split(".")
        #Target the extension of the file name
        extension_target = item_target[len(item_target)-1]
        if extension_target == "CSV" or extension_target == "csv":
            print "Input File:\t", item
            output = ""
            #Create output file name
            for part in item_target:
                #Reconstruct the file name
                if part != extension_target:
                    output = output + part
                #Insert the output tag and finalize the file name
                else:
                    output = output + "_output." + extension_target
            print "Output File:\t", output
            #Generate a path to the output file
            output_path = os.path.join(output_location, output)
            with open(output_path, "wb") as output_file:
                output_writer = csv.writer(output_file)
                #Generate a path to the input file
                item_path = os.path.join(input_location, item)
                with open(item_path, "r") as item_file:
                    item_reader = csv.reader(item_file)
                    #Skip the header
                    item_reader.next()
                    for row in item_reader:
                        output_buffer = []
                        output_buffer = copy.deepcopy(row)

                        #Edit following list when adding more sensors
```

```
#========================================================
                        #[#1] VFS 1-20 temperature sensor
                        if row[1] == "ai0":
                            output_buffer.append(convert_temperature(row[2]))
                        #[#1] VFS 1-20 Flow sensor
                        elif row[1] == "ai1":
                            output_buffer.append(convert_flow(row[2]))
                        else:
                            #Increment error count
                            error_count = error_count + 1
                            continue

#======================================@port_assignments

                        data_count = data_count + 1
                        output_writer.writerow(output_buffer)
    print "\nConversion completed...\n"
    print "Number of data points: ", data_count
    print "Number of errors: ", error_count
```

APPENDIX E

PHOTGRAPHIC DOCUMENTATION OF THE TEST SET-UP

APPENDIX E:

Picture documentation of the test set-up

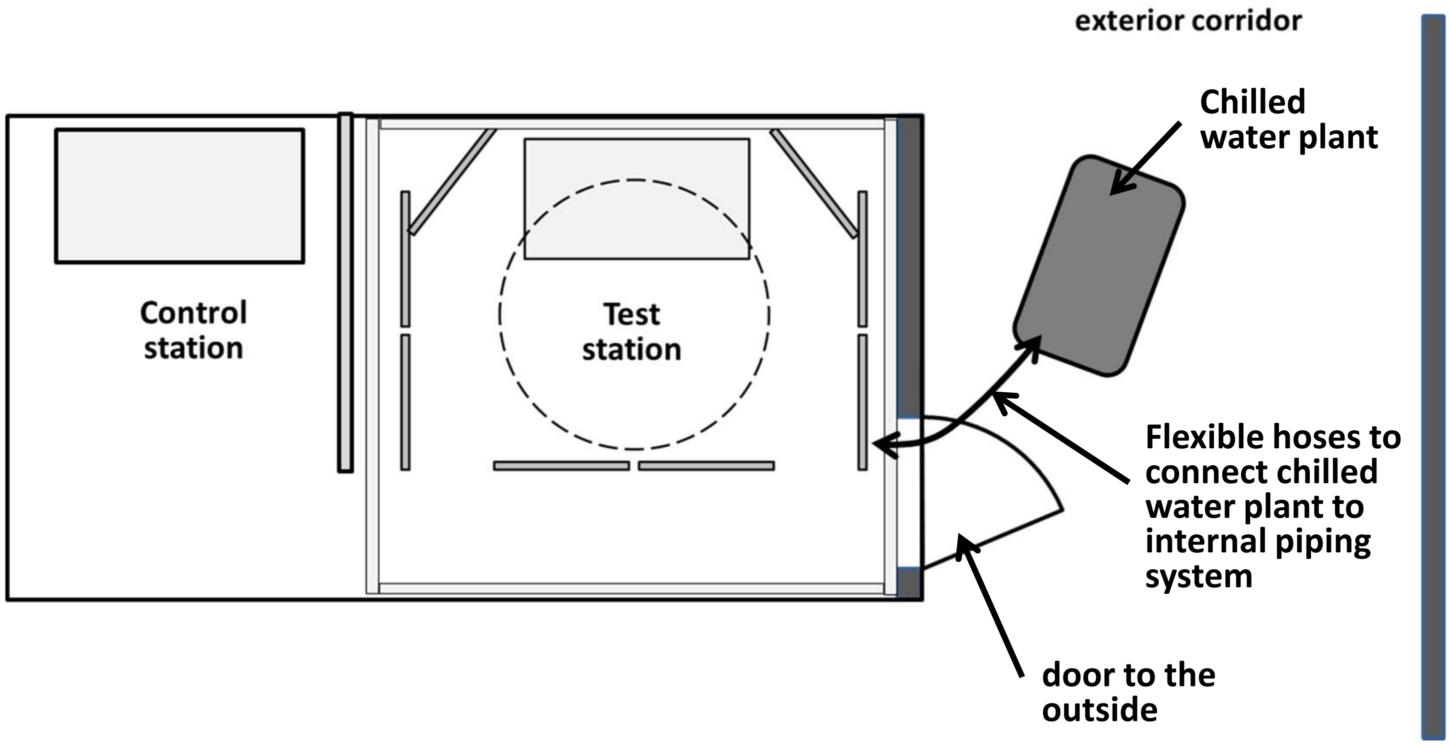


Photo documentation of the Test Station

Layout pf the test set-up

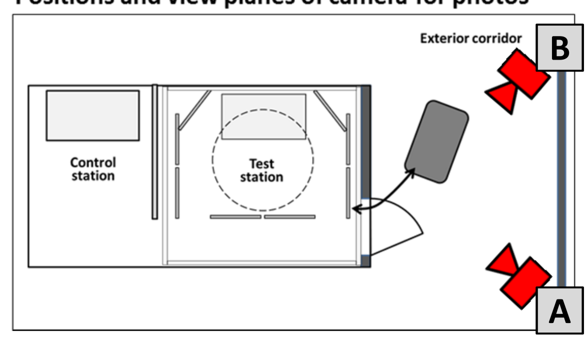
Figure E-1: Layout of the test and control

Photo A

Photo B

Photos A and B show the chilled water generation plant which is positioned on the exterior corridor during operating. When not operating the chilled water plant is stored inside the test station.

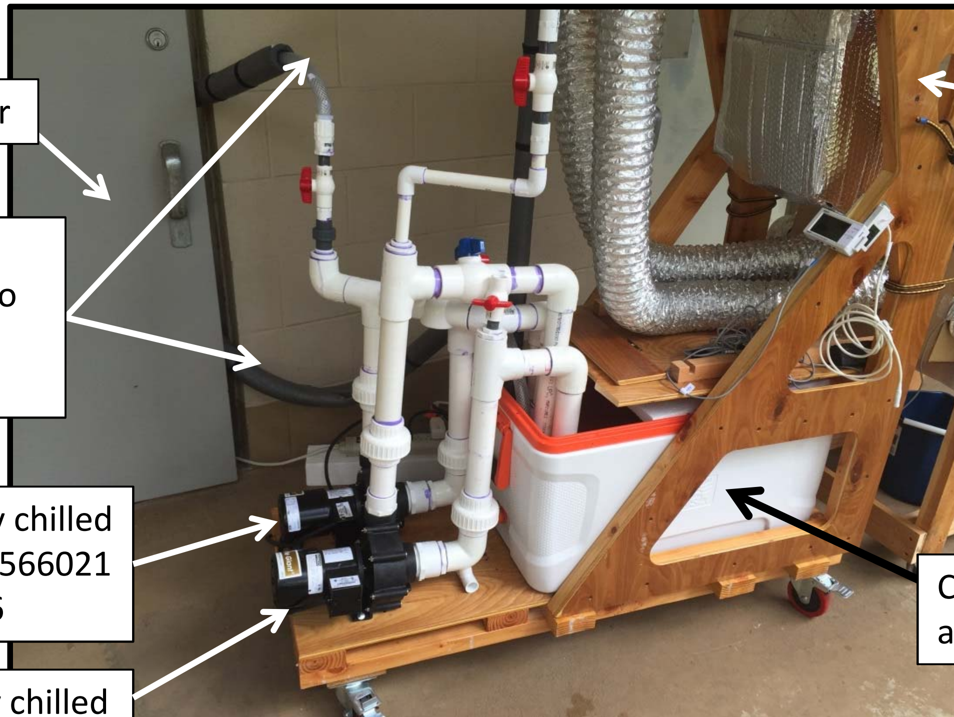
Positions and view planes of camera for photos



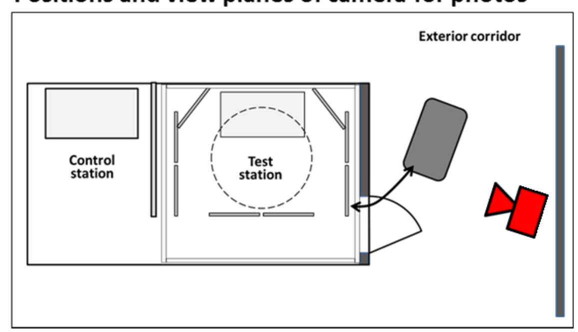
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

Figure E-2: Chilled water (CW) generation plant, location in exterior corridor



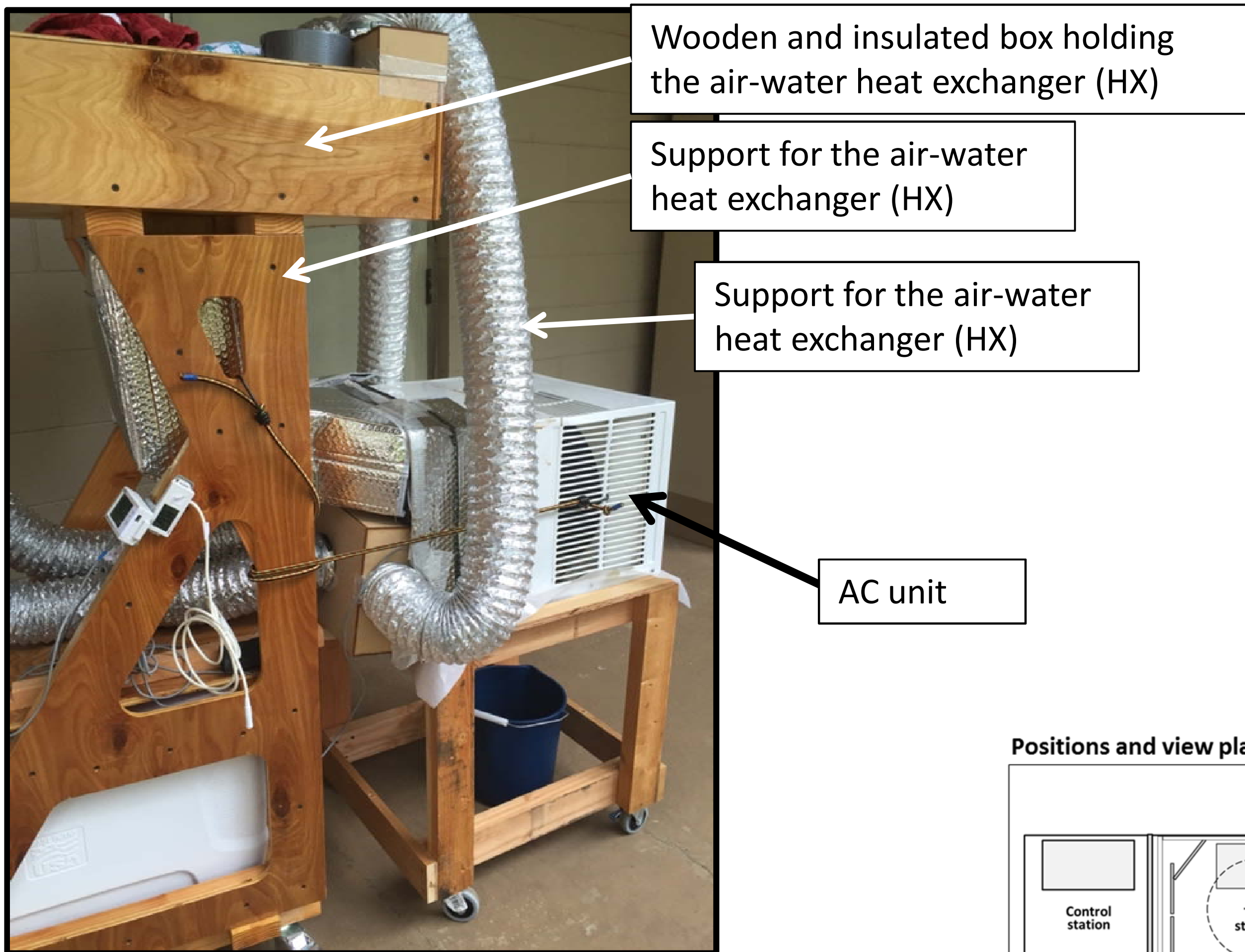
Positions and view planes of camera for photos



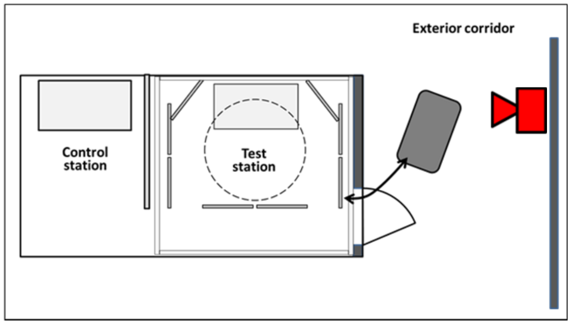
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

Figure E-3: Chilled water (CW) generation plant, details



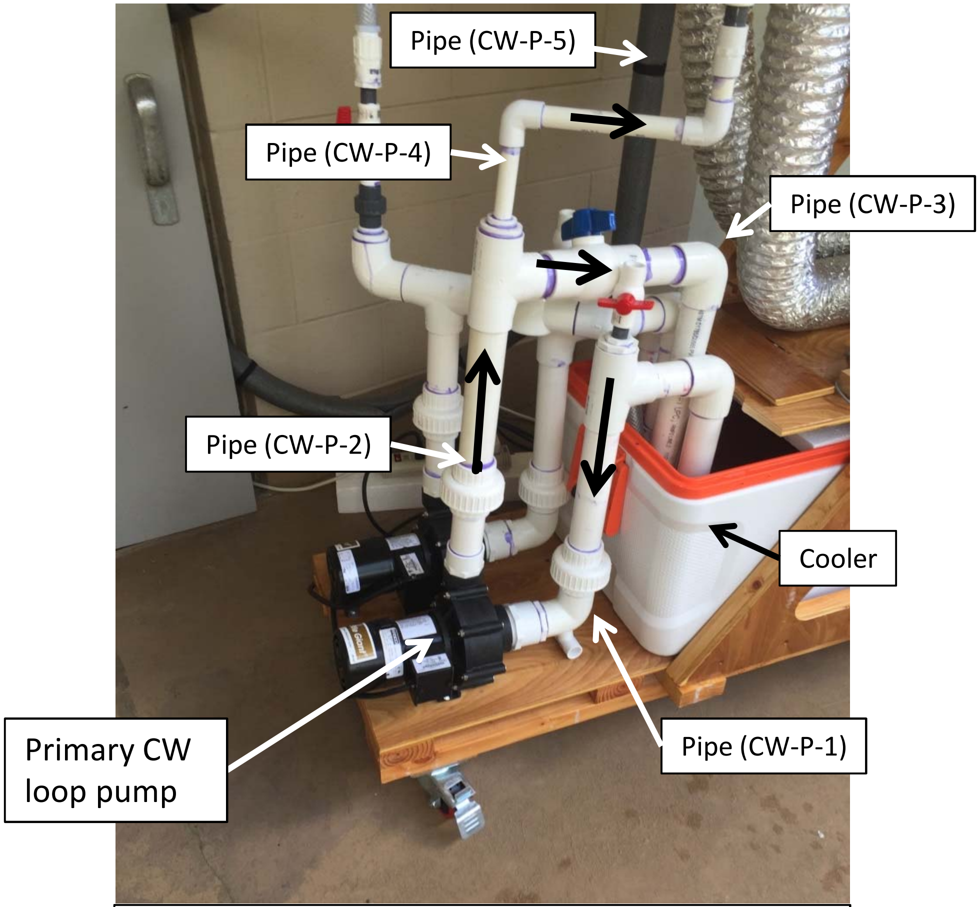
Positions and view planes of camera for photos



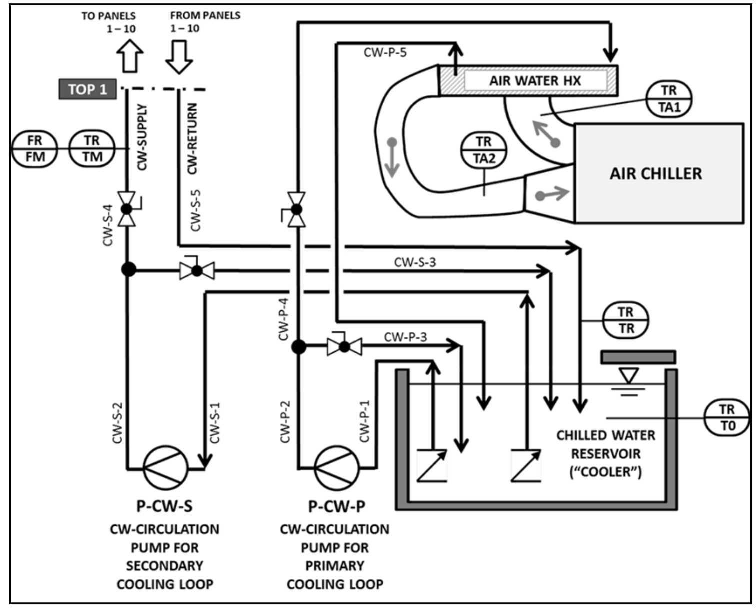
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

Figure E-4: Chilled water (CW) generation plant, details

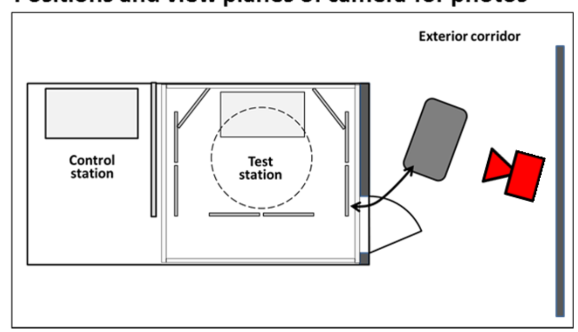


Piping of the CW plant - Primary CW loop



P&I D sheet 2 of Appendix D:

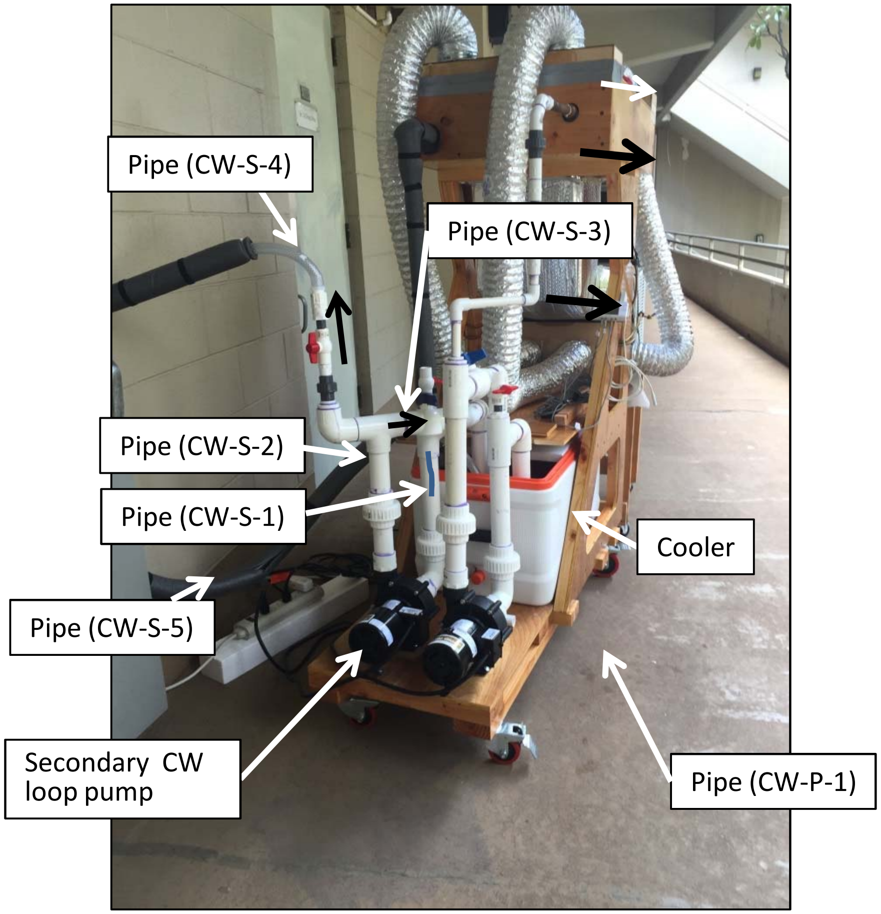
Positions and view planes of camera for photos



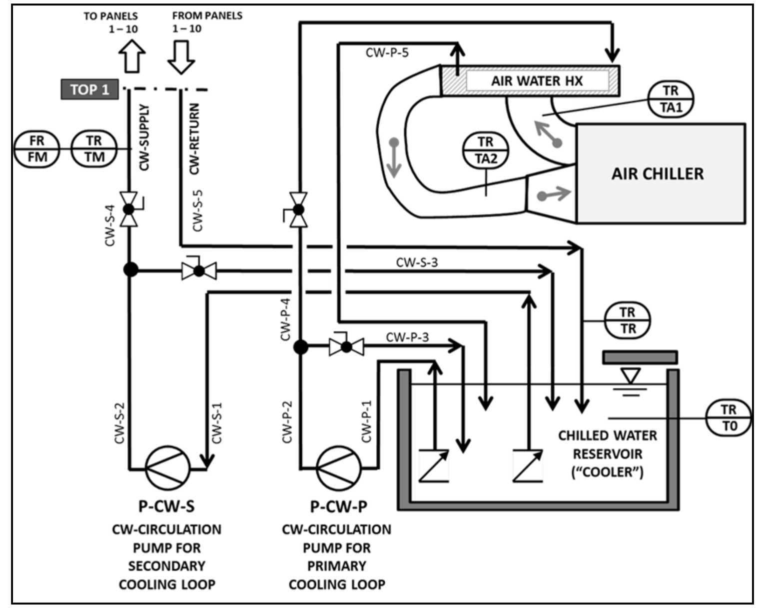
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

Figure E-5: Chilled water (CW) generation plant, piping of primary CW loop

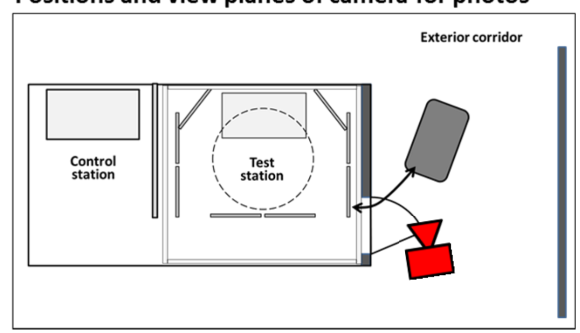


Piping of the CW plant – Secondary CW loop



P&I D sheet 2 of Appendix D:

Positions and view planes of camera for photos



TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

Figure E-5: Chilled water (CW) generation plant, piping of primary CW loop

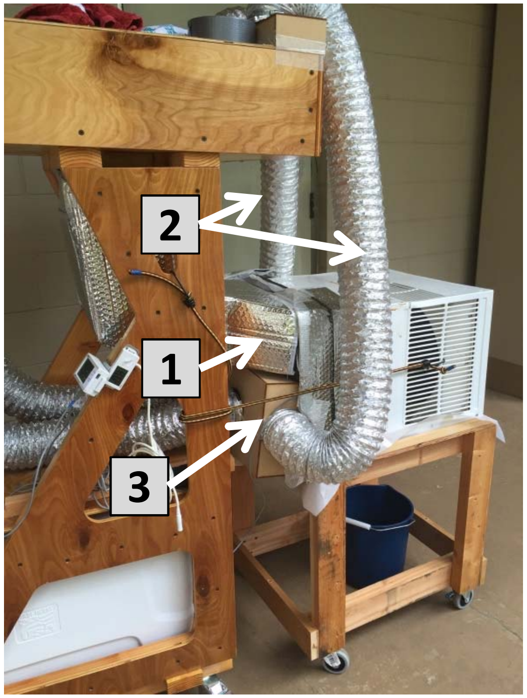


Photo A

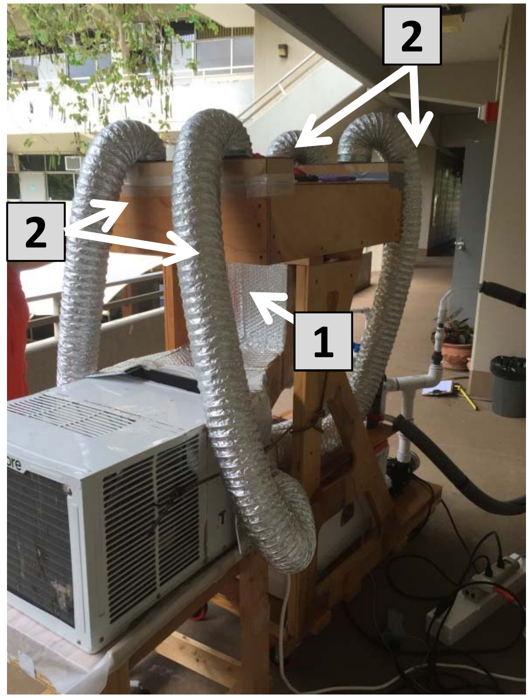


Photo B

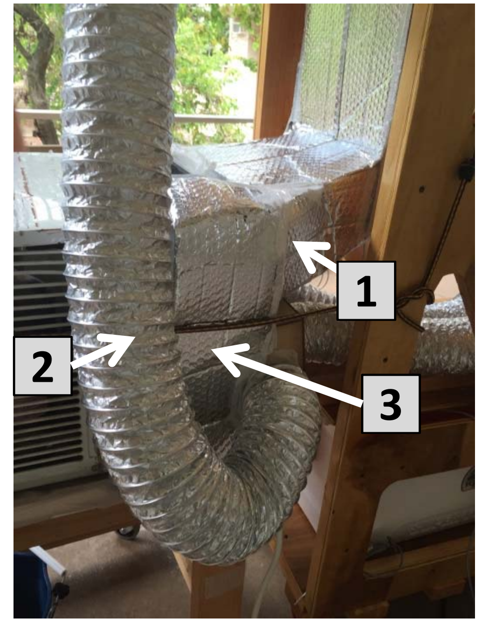
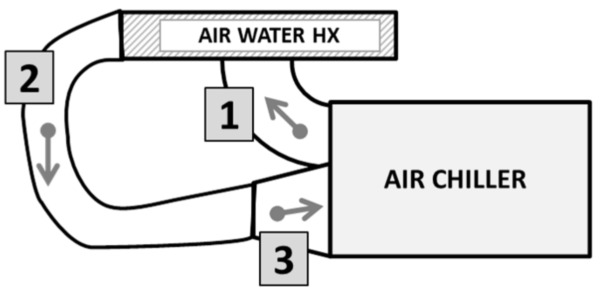


Photo B



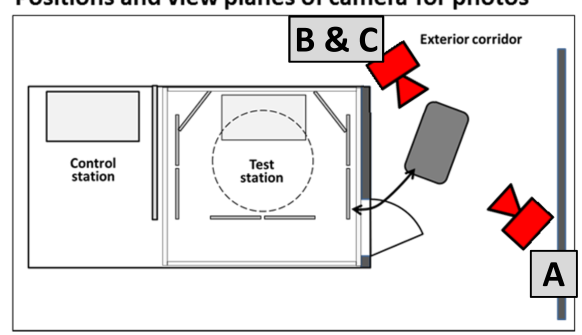
Chilled air handling

1 Chilled air from AC unit to HX

2 Return chilled air from HX to AC intake

3 Air intake of AC intake

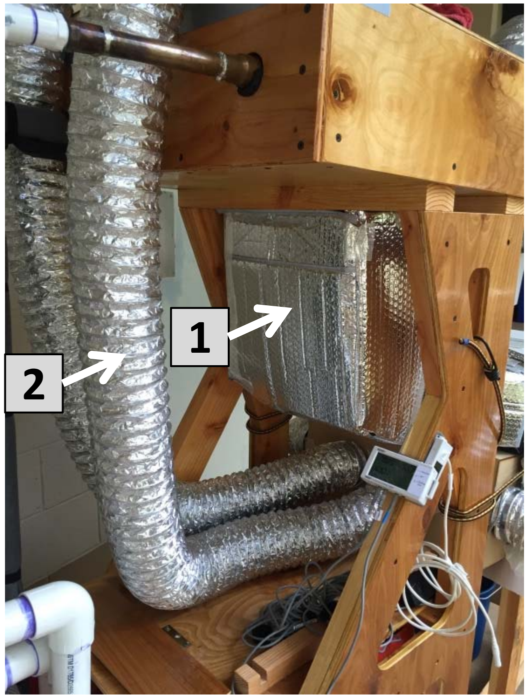
Positions and view planes of camera for photos



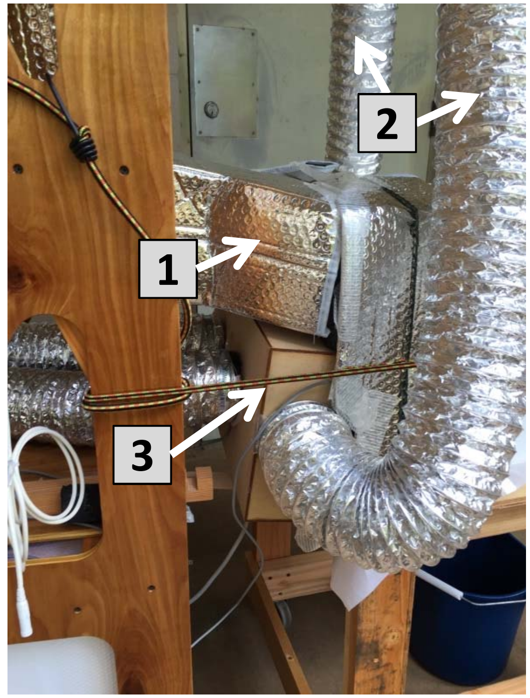
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

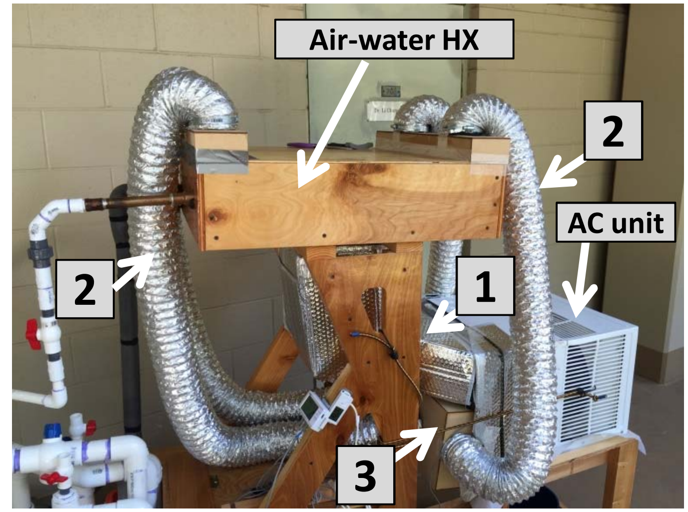
Figure E-6: Chilled water (CW) generation plant, Chilled air handling



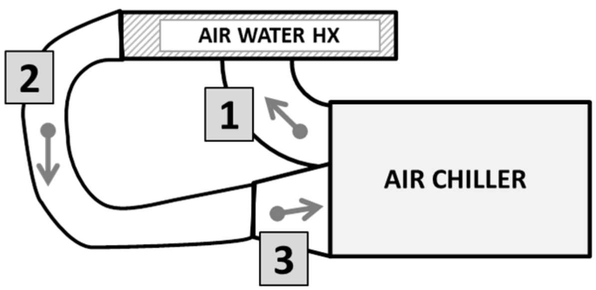
Picture A



Picture B



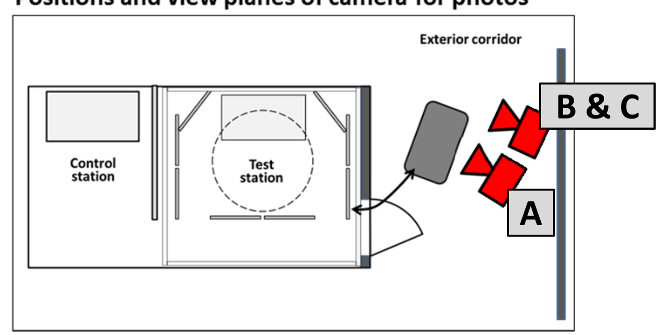
Picture C
(note: the air-to-water heat exchanger (HX) is contained in an insulated wooden box)



Chilled air handling

- **1** Chilled air from AC unit to HX
- **2** Return chilled air from HX to AC intake
- **3** Air intake of AC intake

Positions and view planes of camera for photos

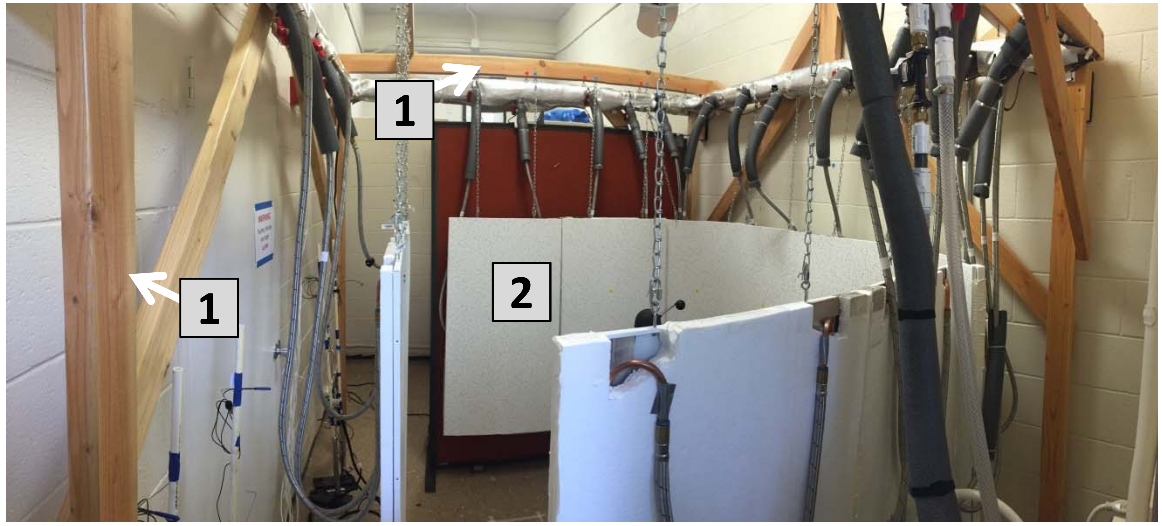


TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

Figure E-8: Chilled water (CW) generation plant, Chilled air handling

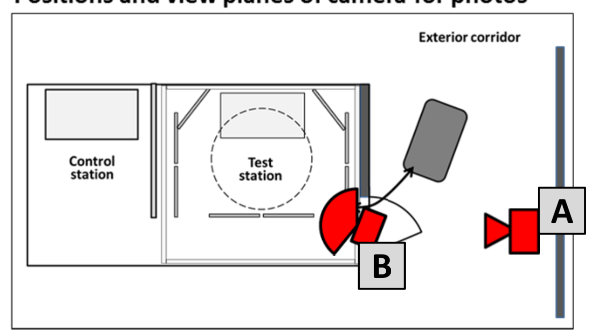
Picture A: View into the test station from the external corridor



Picture B: "Pano" image of test station

1	Wooden support structure
2	Radiant panels

Positions and view planes of camera for photos

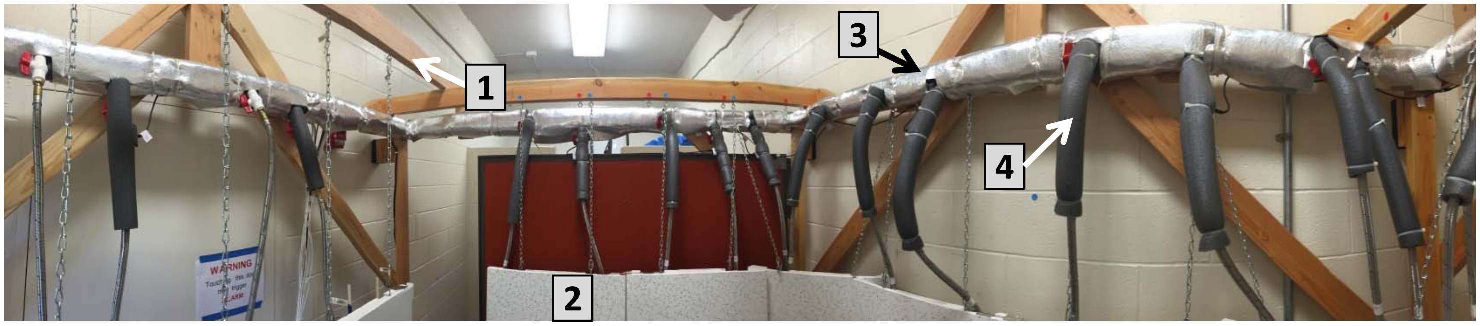


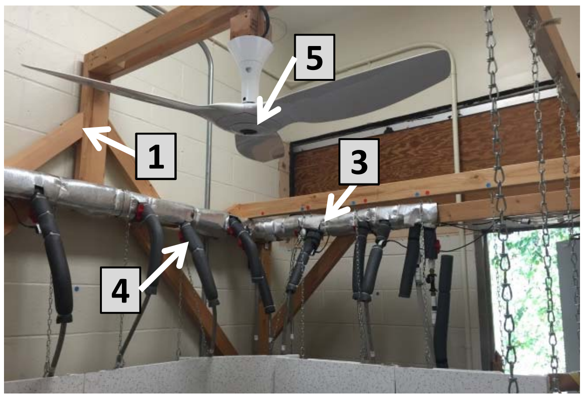
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

Figure E-9: Experimental set-up at the test station (indoor)

Picture A: “Pano” image of test station





Picture C

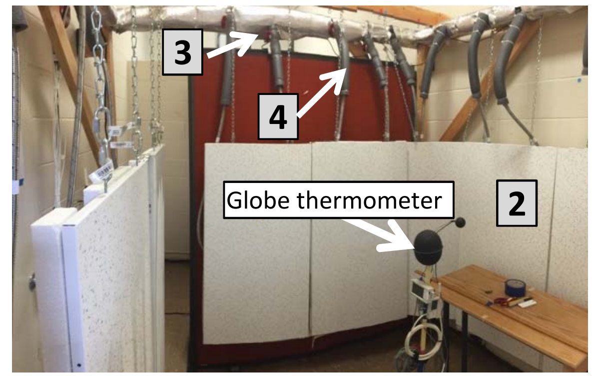
1 Wooden support structure

2 Radiant panels 1 through 10

3 Main CW supply and return pipe (insulated)

4 Individual CW supply and return of panels

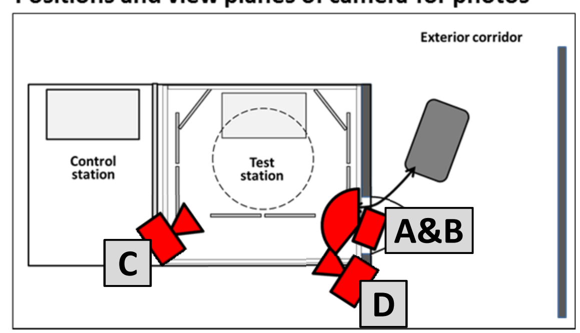
5 Ceiling fan



Picture D

Picture B: “Pano” image of test station

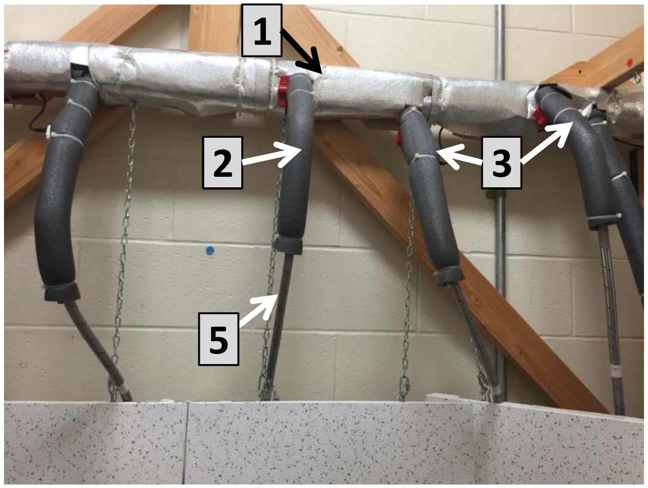
Positions and view planes of camera for photos



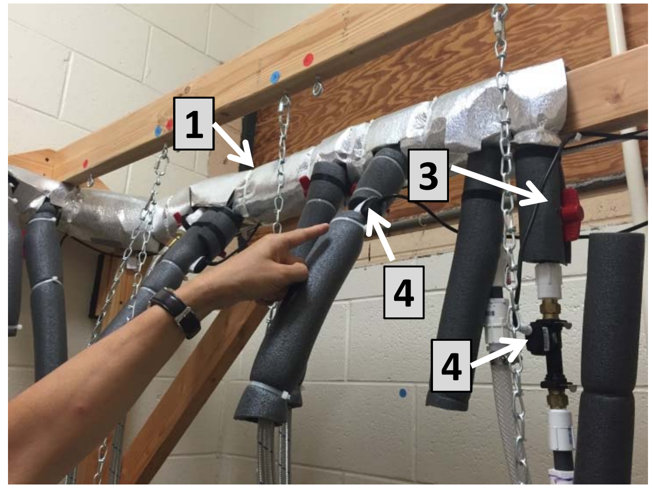
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

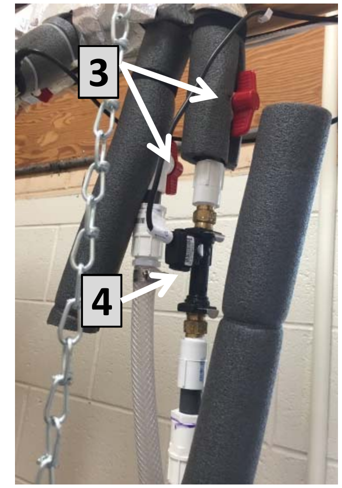
Figure E-10: Experimental set-up at the test station (indoor)



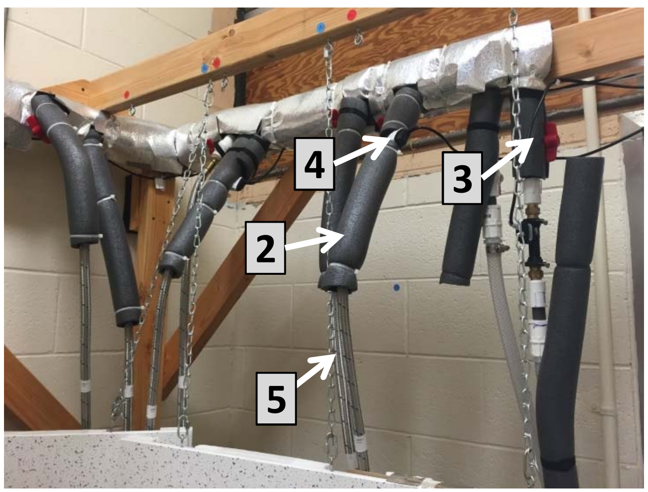
Picture A:



Picture B:



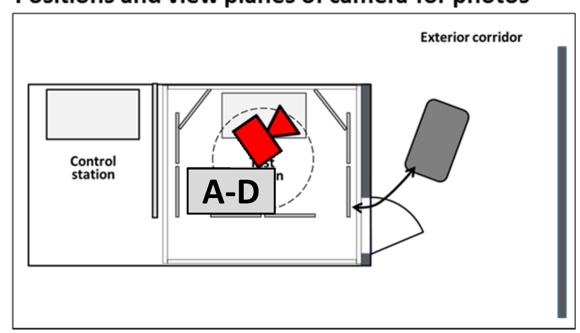
Picture C:
Note: insulation was removed to allow better view of flow meter and control valve



Picture D:

1	Main CW supply and return pipe (insulated)
2	Individual CW supply and return of panels
3	Flow shut-off and control valve
4	Flow meter
5	Flexible (armored) hoses

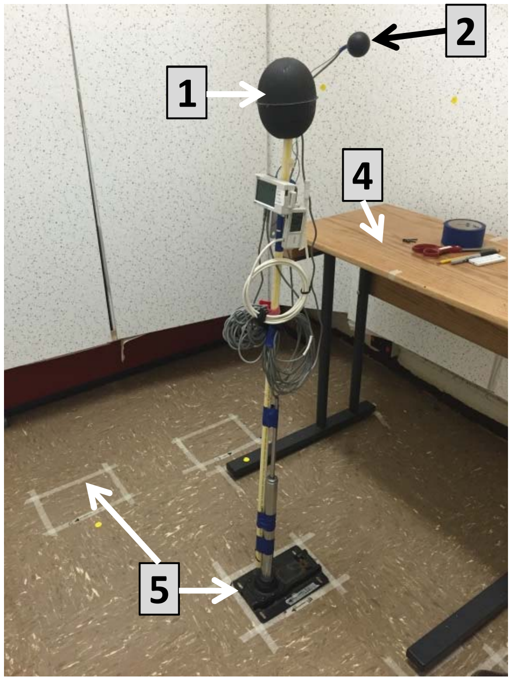
Positions and view planes of camera for photos



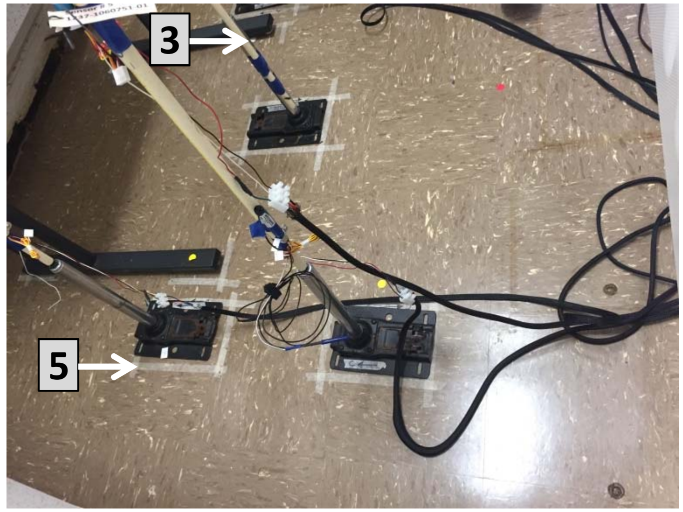
TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

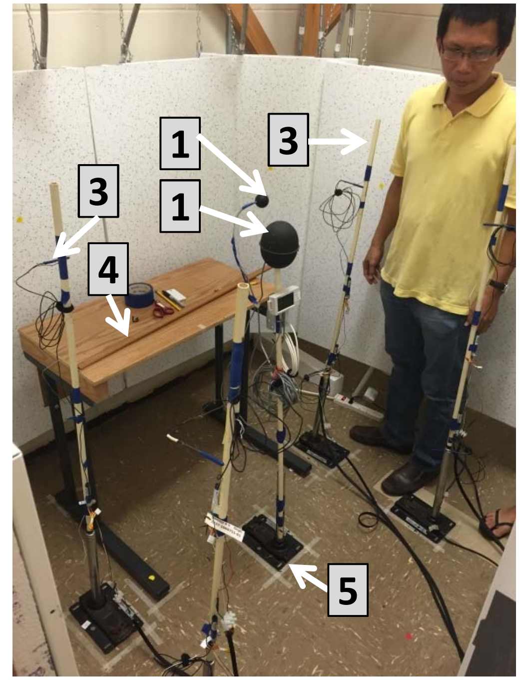
Figure E-10: Experimental set-up at the test station (indoor)



Picture A



Picture B



Picture C:

1 Globe thermometer (large)

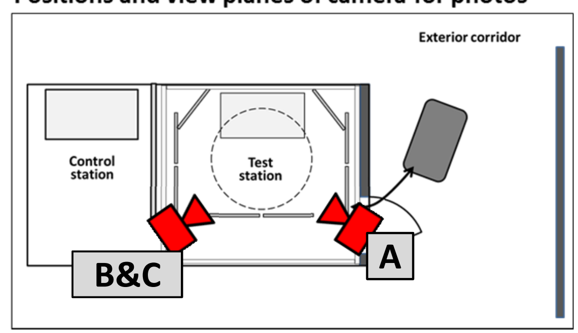
2 Globe thermometer (small)

3 Anemometer

4 Desk at which test person will sit

5 Marked instrument placements for globe thermometer and anemometers

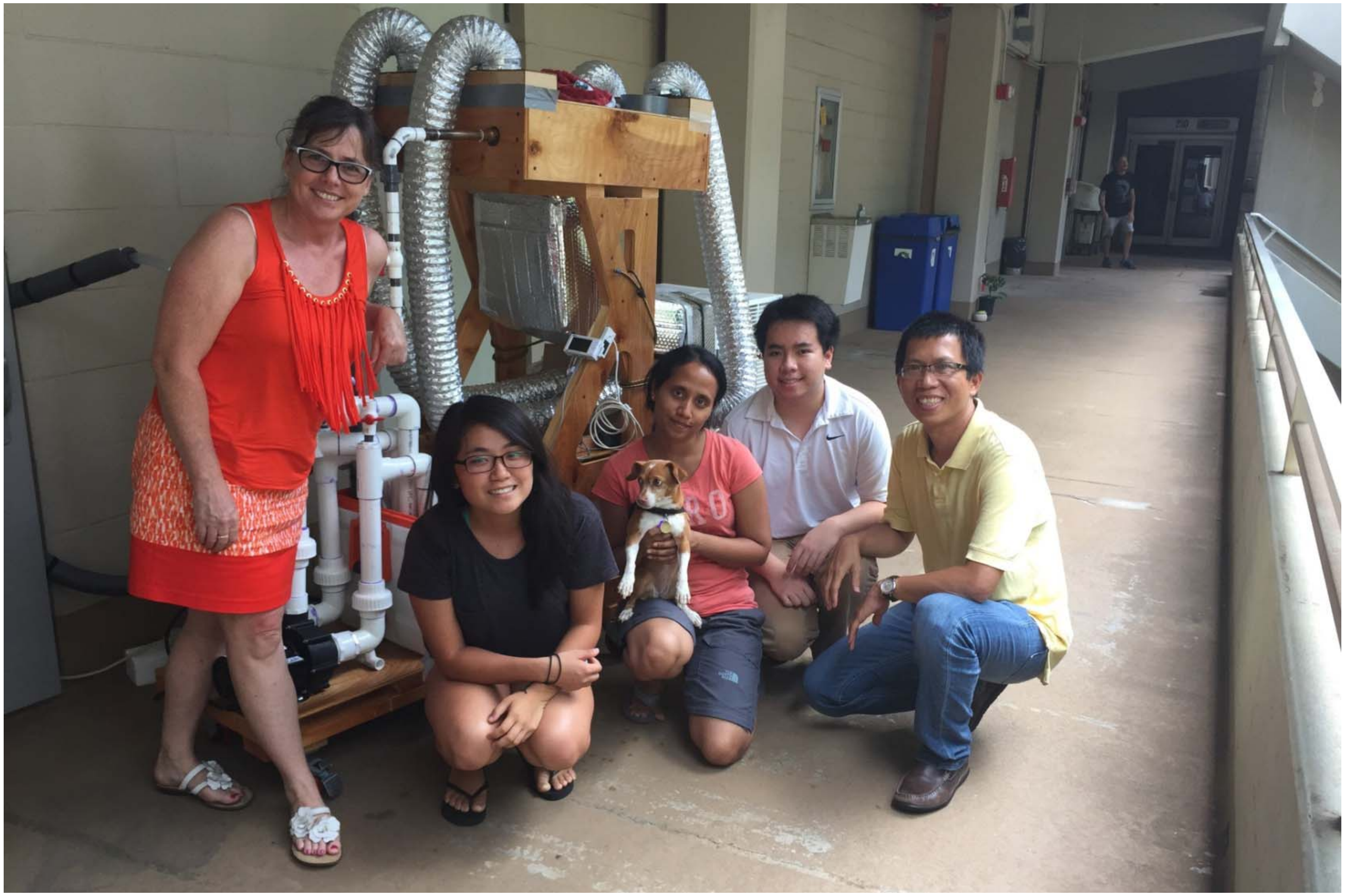
Positions and view planes of camera for photos



TEST SET-UP & PROTOTYPING OF NATURAL VENTIALTION ENHANCEMENT TECHNOLOGIES

Appendix E: Photo documentation of the Test Set-up

Figure E-11: Chilled water (CW) generation plant, experimental set-up at the test station (indoor)



The team who built the test set-up (from left: Eileen Peppard, Team leader; Allie Kim, EE student; Aarthi Padmanabhan, Post-Doc; Ethan Vo, Research intern; Tuan Tran, Post-Doc (other team members are not shown)

Figure E-12: Experimental set-up at the test station (indoor)

APPENDIX F:

COMFORT SURVEY FORM (Preliminary)

APPENDIX: HIG 204 Survey

1. **Please provide your study ID number.**

2. **What is the time right now?**

3. What is your age?
   - 21 or under
   - 22-29
   - 30 or under
   - 31-50
   - Over 50

4. What is your gender?
   - Female
   - Male

5. Do you practice recycling and energy efficient practices in your personal and work life?
   - Yes
   - No

   Comments:

6. What is the maximum length of time you have resided in a warm/humid region?
   - 1 month or less
   - 2-6 months
   - <1 year
   - 1-5 years
   - Over 5 years

7. Please list all activities you performed or carried out within the past hour:

- [ ] Walking
- [ ] Running/biking/jogging/dancing
- [ ] Other physical exercise (gym workout, play basketball/football/tennis/swimming, etc.)
- [ ] Exposure to outside elements (too hot and sunny)
- [ ] Exposure to outside elements (too cold or windy/rainy)
- [ ] None of the above
- [ ] Other: ____________

8. How often do you use the air conditioner in your home or vehicle?

- ○ Frequently (More than a few hours total per day)
- ○ Occasionally (Less than 15-30 minutes total per day)
- ○ Rarely (1-2 times per week)
- ○ Never
- ○ Comments: ____________

9. How often do you use a ceiling fan or personal fan in your home or vehicle?

- ○ Frequently (More than a few hours total per day)
- ○ Occasionally (Less than 15-30 minutes total per day)
- ○ Rarely (1-2 times per week)
- ○ Never
- ○ Comments: ____________

TEMPERATURE

10. Right now, how acceptable is the temperature at this workstation?

VERY ACCEPTABLE ○ ○ ○ ○ ○ ○ ○ NOT AT ALL ACCEPTABLE

11. Right now, you feel.....?

○	○	○	○	○	○	○
Hot	Warm	Slightly Warm	Neutral	Slightly Cool	Cool	Cold

12. You would prefer to be.....?

○	○	○
Cooler	No Change	Warmer

AIR MOVEMENT

13. Please choose the speed at which the ceiling fan is running at the moment:

○	○	○	○
OFF	Low	Medium	High

14. Right now, how acceptable is the air movement at this workstation?

VERY ACCEPTABLE ○ ○ ○ ○ ○ ○ ○ NOT AT ALL ACCEPTABLE

15. Right now, you feel that it is.....?

○	○	○	○	○	○	○
Too still	Moderately Still	Slightly Still	Comfortable	Slightly Breezy	Moderately Breezy	Too Breezy

16. You would prefer to have.....?

○	○	○
More Air Movement	No Change	Less Air Movement

HUMIDITY

17. Right now, how acceptable is the humidity level at this workstation?

VERY ACCEPTABLE ○ ○ ○ ○ ○ ○ ○ NOT AT ALL ACCEPTABLE

18. Right now, you feel that it is.....?

○	○	○	○	○	○	○
Too Dry	Moderately Dry	Slightly Dry	Comfortable	Slightly Humid	Moderately Humid	Too Humid

LOCAL THERMAL DISCOMFORT

19. Please mark, in the list below, all the points or zones near your skin where you experience thermal discomfort (feels too uncomfortable because of the surrounding air temperature being **WARM/HOT**):

- ☐ Head
- ☐ Face
- ☐ Breathing zone
- ☐ Chest
- ☐ Back
- ☐ Pelvis
- ☐ Arm
- ☐ Hand
- ☐ Leg
- ☐ Foot
- ☐ None of the above
- ☐ Other: ____________

20. Please mark, in the list below, all the points or zones near your skin where you experience thermal discomfort (feels too uncomfortable because of the surrounding air temperature being **COOL/COLD**):

- ☐ Head
- ☐ Face
- ☐ Breathing zone
- ☐ Chest
- ☐ Back
- ☐ Pelvis
- ☐ Arm
- ☐ Hand
- ☐ Leg
- ☐ Foot
- ☐ None of the above
- ☐ Other: ____________

CLOTHING

21. Please mark, in the list below, all the garments you are wearing now.

☐ Short-sleeved shirt or blouse 

☐ Sweater or jacket  

☐ Long-sleeved shirt or blouse 

☐ Tie 

☐ Shorts 

☐ Trousers, pants 

☐ Skirt or dress  

☐ Sandals or open-toed shoes 

☐ Shoes, sneakers, or boots 

22. Did you change the fan speeds during your time spent at this workstation? If yes, please choose the speed at which you are comfortable with the temperature around your skin:

○ OFF ○ Low ○ Medium ○ High

THANK YOU for participating in this survey! ☺

IV. Description of Project

1. Briefly describe the purpose and objectives of your research in non-technical language.
This project is intended to investigate some possible methods to improve thermal comfort among office occupants using airflow cooling and radiant cooling design techniques, on the UH Manoa campus. An office cubicle or a designated workstation at a convenient and approved location will serve as the test site for conducting these surveys.

Comfort is a subjective experience of the occupants. Therefore, in order to determine baseline and enhanced levels of individual comfort, occupants will be surveyed using a short online questionnaire, completed one or two times per day, to evaluate their responses to comfort enhancing measures implemented within the office space or designated workstation.

2. Briefly describe your research design and methods.
The survey is composed of several questions that will be distributed among the occupants, to create a baseline of initial thermal comfort/discomfort parameters within the office space. Respondents (random sample of undergraduate and graduate students from UH Manoa campus) will be briefed about the overall purpose of the study, and then asked to get comfortably seated within the office cubicle or designated workstation, which will be pre-chosen for the purpose of this study.
Questions will involve occupant responses regarding temperature, humidity, airflow conditions, and activities such as exercise, and clothing worn at the time within the office space. Similar post-implementation surveys will be taken at the end of the test period. Evaluation of spatial conditions will involve temperature, humidity, and airflow speed measurements. Occupant surveys will involve satisfaction level determinants and preferred thermal states for various spatial conditions (layout, workstation, thermal comfort, air quality, noise levels, etc.).
The entire study for which the respondent will be present for the data collection (through surveys) will last 45 minutes to one hour, approximately.

3. For research being conducted as "<u>educational curriculum</u>", describe how the activity being studied is part of "normal" educational practice.
This survey methodology is a key aspect of determining occupant satisfaction and thermal comfort within the designated workstation or study space. The project will serve the educational and research training needs of the students and postdoctoral fellows that are participating on the research team. The results will also serve to educate and inform the larger design community with empirical, research-based findings in the application of comfort standards in a workspace or study area setting, for a campus such as in a tropical setting like UH Manoa.

4. If you are using existing data, describe the source(s), the extent to which individuals are identified, and how you have access to the data.
There is no existing data that has been collected on the human subjects, and no identifiable or personal information will be collected. The study will have workstation identifiers assigned to each respondent, and survey results will be coded and anonymous to protect the privacy and identity of the individuals.

5. If your research will be observational, describe how the observations will be recorded (e.g., audio, video, field notes). If you are planning to audio the participants, please see Section V.

Data collected will be recorded using online questionnaire/survey forms, and supplemented with field notes and observational analysis of the spatial conditions. Short questionnaires will be completed two/three times during the day, to obtain occupant responses at different times over a typical day. Data from surveys collected will then be assimilated and analyzed, and compared against field notes of spatial conditions (temperature, humidity, and airflow measurements), to determine best practices and strategies for implementation and improvement of thermal comfort.
No audio/video of the respondents will be part of the documentation.

6. Describe your participant population (e.g., age, as special needs, etc…) How will you identify, contact, and recruit participants? How many participants do you intend to involve in your research? How will you explain your research to participants?
The study subjects or respondents will be randomly sampled from the set of undergraduate and graduate students, within the University of Hawaii at Manoa, who are 18 years of age or older. Survey respondents will be made familiar with the project and with some members of the research team, until they are aware of the scope of the project.
There will be a maximum of 100 participants, who will experience the pre-comfort as well as the post-comfort conditions within the designated workstation or study space selected.

Each of the respondents will be informed that the study is voluntary, asked to sign the consent form. One or more of the researchers conducting the study will be present during the entire duration of administering the questionnaire, and the respondents will be made well aware that that they can ask to stop at any time, should they change their mind about participation or if feeling any discomfort. Students will be solicited or recruited for this study, by first contacting department or unit heads, who will recommend the best ways of communication with potential subjects (students from their classes who would be interested in participating in the study).

IRB application protocol

(Testing experiments involving human respondents/subjects)

Step ONE: Determine whether or not the Project is "Not Human Subjects Research."

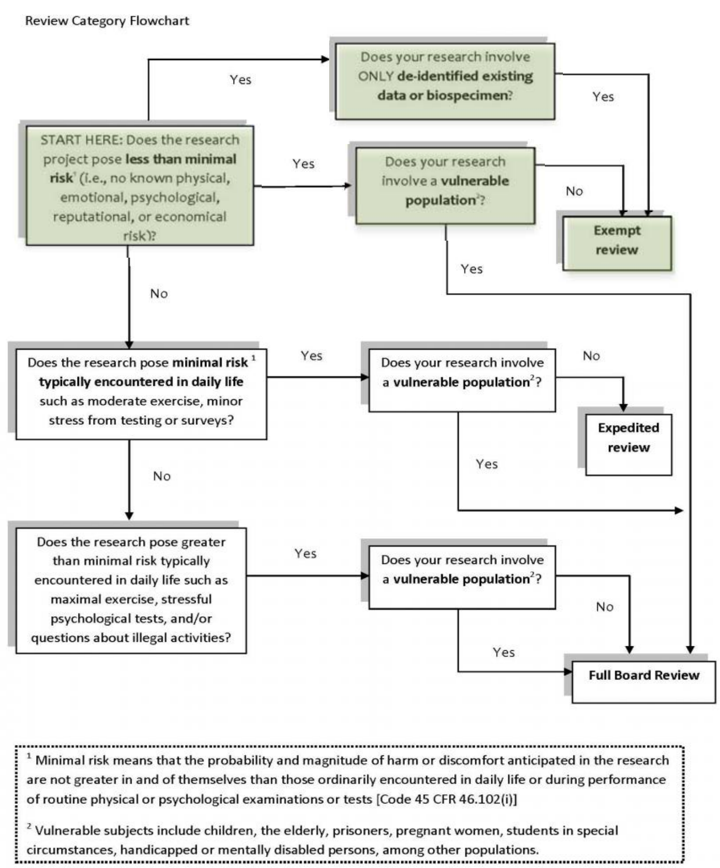
To help you determine whether your project is considered "human subjects research," you may use the guidance at the following link:

https://manoa.hawaii.edu/researchcompliance/sites/manoa.hawaii.edu.researchcompliance/files/resource/WKSH%20301_Is%20my%20project%20human%20subjects%20research_01.07.15_0.pdf.

This guidance page also located under the “Policies & Guidance” Quicklink page under the subheading “Reviewer Worksheets”.

Step TWO: Choose the type of Application Form.

To help determine whether the research qualifies for EXEMPT, EXPEDITED, or FULL-BOARD review, a decision tree is included within the “Review Category Flowchart” image included below (also located under “Policies & Guidance” on the UH IRB website).



Links to Application forms:

1) Application for Exempt Status (Word document; rev. 04/08/15) at link: (completed application included in the following pages within this appendix). https://manoa.hawaii.edu/researchcompliance/forms/exempt-application-04-08-15

1) Application for New Approval (Word document; rev. 06/30/15) - this form should be used for research that may qualify for either EXPEDITED or FULL-BOARD at link: https://manoa.hawaii.edu/researchcompliance/forms/non-exempt-biomed-and-sbs-application-06-30-15

2) Application for New Approval -- Cooperative IRB (Word document, rev. 10/29/14) at link: https://manoa.hawaii.edu/researchcompliance/forms/cooperative-irb-application-10-29-14

Step THREE: Application Form to be completed according to the instructions provided within the form.

Make sure to complete your required Human Subjects Research Training. Note: CITI training modules can be completed (applicant researcher and P.I., mandatory for the latter, must register) at the CITI training website: https://www.citiprogram.org/

Typically, for an Exempt application such as this one, the basic courses will be required to be completed and provided a curriculum completion report to the UH IRB:

1) CITI HEALTH INFORMATION PRIVACY AND SECURITY (HIPS)

2) STUDENTS CONDUCTING NO MORE THAN MINIMAL RISK RESEARCH

All applicable study documents (i.e., consent form documentation, recruitment material, surveys and instruments, etc.) to be included with the application.

Step FOUR: ATTACHMENTS TO BE SUBMITTED AS PART OF THE IRB APPLICATION:

2) Copy of consent form to be given to research participants. Examples of consent forms are available on the Human Studies Program website at: https://manoa.hawaii.edu/researchcompliance/templates, under "Templates".
    a) If audio recordings will be used as a part of the research records, there must be a clear description in the consent form of:

i) How the recordings will be used including any uses beyond this research project,

ii) How the recordings will be stored, and,

iii) What will be done with the recordings when the project is complete. A separate consent form, or yes/no checkbox on the main consent form must be provided so that participants can agree or refuse to be recorded.

b) If applicable, consent form should include language that describes how the data or recordings are likely to be used for future research purposes.

3) For research involving minors (ages 17 and younger), the following must be provided:

a) A parent/guardian consent form for their child to participate in research that includes space for a signature and date.

b) A way of obtaining assent or refusal to participate from the child(ren) that is understandable to them. If the participants are 5 to 11 years old, an oral assent script to be provided with an explanation of how to explain the project to them and obtain their assent or refusal to participate. If the participants are 12 to 17 years old, a written assent form to be provided that includes space for a signature and date.

c) Examples of consent forms (adults and minors) can be located on the UH IRB website at: https://manoa.hawaii.edu/researchcompliance/templates, under "Model Informed Consents for Social & Behavioral Science Research" (included in the following pages within this appendix).

4) If draft instruments (survey instruments and interview guides) are submitted, final drafts must be submitted for final Human Studies Program approval before use (included in the following pages within this appendix).

5) If recruitment flyers or advertisements are used, copies of these to be provided as well. Examples of recruitment flyers can be found on the Human Studies Program website at: https://manoa.hawaii.edu/researchcompliance/templates under "Model Recruitment Flyer".

6) Endorsement Letter: This is for studies that involve a certain department or institution, and can therefore help in strengthening the application if endorsed by the specific department (eg. Dean, Chair, Principal, etc.) Examples of endorsement letters can be found on the UH IRB website at: https://manoa.hawaii.edu/researchcompliance/templates under "Endorsement Letter Template".

7) Researchers' CITI (Collaborative Institutional Training Initiative) training completion report to be attached with the application. Instructions on how to complete the training can be located at the website under "Training". The application will not be reviewed until training requirement has been met (included in the following pages within this appendix).

Step FIVE: Completed application to be submitted to the Human Studies Program according to the instructions shown below:

Table: Quick reference on form and deadline per review category

Review Category	Which application to use	Deadline	How to Submit
Exempt	**Application for Exempt Status**	first-come first-serve	email only
Expedited	**Application for New Approval** or **Application for New Approval (Cooperative IRB)**	first-come first-serve	email and 2 hard copies
Full-Board	**Application for New Approval** **or** **Application for New Approval (Cooperative IRB)**	check IRB calendar	email and 2 hard copies

More links to the application forms, can be found at the links below:

1) **Biomedical IRB**

   Clinical research protocols and related research projects, including clinical trials that evaluate investigational drugs and devices or medical procedures:

   https://uhirb.biomed.hawaii.edu/biomed/Account/Login.aspx?ReturnUrl=%2fbiomed%2f

2) **Social & Behavioral Sciences IRB**

   Research protocols in the fields of psychological, education, sociology, etc. or that involve behavioral intervention:

   http://manoa.hawaii.edu/researchcompliance/institutional-review-board-irb-0

3) **Cooperative IRB**

   Federally-funded research that is performed by two or more members of a cooperative of local institutions:

   https://uhirb.biomed.hawaii.edu/socsci/Account/Login.aspx?ReturnUrl=%2fsocsci%2f

4) **Exempt Research**

   https://manoa.hawaii.edu/researchcompliance/sites/manoa.hawaii.edu.researchcompliance/files/resource/WKSH%20302_Requirements%20for%20Exempt%20Approval.pdf

5) Further guidance on completing application forms:

   https://manoa.hawaii.edu/researchcompliance/policies-guidance

University of Hawai'i

Consent to Participate in Research

Keller Hall SURVEYS: Thermal Comfort and Design Parameters

Aloha, we are a research team from the Environmental Research and Design Laboratory at the School of Architecture, and led by Eileen Peppard, the Principal Investigator (P.I.). This research project is being conducted within the University of Hawai`i to analyze existing cooling strategies and to propose new ways to keep occupants on campus (students/staff/faculty) cooled when high temperatures are prevalent seasonally. The primary objective of this project is to assess how occupants seated within a cubicle/workstation or study space experience thermal comfort/discomfort, and to assess thermal comfort through implementation of cooling strategies within a location on the UH Manoa campus. I am asking you to participate in this project because you are at least 18 years old and you are one of such users within the University campus.

Project Description – Activities and Time Commitment: If you decide to take part in this project, you will be asked to fill out a survey. The survey questions are mainly multiple-choice. However, there will be a few questions where you may add an open-ended response. The survey is accessed on a website to which I will provide you with a link. Completing the initial (one-time) survey will take approximately 10 minutes, and it will be sent to you twice/thrice per day. We expect that a total of 100 people will take part in this project.

Benefits and Risks: The findings from this project may help create a better environment and overall increase in thermal comfort in your study or office space and at your personal workstation. There is little to no risk to you in participating in this project.

Confidentiality and Privacy: I will not ask you for any personal information, such as your name or address. Please do not include any personal information in your survey responses.

Voluntary Participation: You can freely choose to take part or to not take part in this survey. There will be no penalty or loss of benefits for either decision. If you do agree to participate, you can stop at any time.

Questions: If you have any questions about this study, please call or email one of the researchers at (808) 956-2861 or Aarthi@hawaii.edu. You may also contact the Principal Investigator (P.I.) of the study, Eileen Peppard, at (808) 956-2861 or Peppard@hawaii.edu. If you have questions about your rights as a research participant, you may contact the UH Human Studies Program at (808) 956-5007 or uhirb@hawaii.edu.

To Access the Survey: Please use the link provided to you. You should find a webpage to the survey and instructions for completing it. Completing the survey will be considered as your consent to participate in this study.

Please print a copy of this page for your reference. Thank you for your cooperation!

CHS# ______

Application for Exempt Status for Human Subjects Research
University of Hawaii - Human Studies Program

Please type the information below. Thank you.

Researcher name: **Aarthi Padmanabhan**

Researcher email: Aarthi@hawaii.edu   Researcher phone: (808) 222-5254

Department: School of Architecture   Campus: UH Manoa

Status: ☐ Faculty

☐ Student
☐ Masters ☐ Ph.D. ☒ Other: Postdoctoral Research Fellow

Name of student's Faculty Advisor: Eileen Peppard

Advisor email: epeppard@hawaii.edu   Advisor phone: (808) 956-2861

Title of Research Project: RADIANT COOLING FOR THE TROPICS: Thermal Comfort and Design Parameters

Signatures

I certify that the Information in this application is accurate and complete.

Researcher: [signature]   Date: 1-7-2015

I have reviewed and approved this application:
[*Advisor: Please check student's application for the following required documents in this application*]

☒ 'Description of Project' questions answered
☒ Informed consent(s)/ assent(s)/ informational flyer(s), if applicable
☒ Surveys/ questionnaires, if applicable
☒ Online Training Requirement

Advisor: [signature] (for student research)   Date: 1-7-2015

This box for Human Studies Program Use Only:

Exempt Request: ☐ *Approved* ☐ *Not Approved* *Exempt Category* _______

Training: ☐ PI ☐ Advisor, if applicable Is this study involving? ☐DOH ☐ DOE

Reviewer comments / recommendations:

Approved by: ____ **Date:** _______________________

Application for Exempt Status for Human Subjects Research
University of Hawaii - Human Studies Program

1960 East-West Road, Biomedical Building B-104, Honolulu, HI 96822, (808) 956-5007, uhirb@hawaii.edu

Aloha! Most research involving human subjects at the University of Hawaii must be approved by the UH Human Studies Program. Some research may be exempt from certain Federal requirements. Please read and follow all instructions carefully when filling out this application. For more information, please go to the Human Studies Program website at www.hawaii.edu/irb or contact our office with any questions. Underlined words are defined in the Glossary on page 5.

I. Is Your Project "Research"?

To determine if your project qualifies as research, please answer the question below.

If you answer "Yes" to the following question, your project meets the federal definition of research. Please answer Section II to determine of your project is human subjects research. If you answer "No", your project does not meet the federal definition of research. No application is required.	
1. Is your project a systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge? (Underlined words are defined in the Glossary on page 5.)	☒ Yes ☐ No

II. Is Your Project "Human Subjects" Research?

To determine if your project qualifies as human subjects research, please answer the questions below.

If you answer "Yes" to either of the following 2 questions, your project does not require Human Studies Program review and approval and you do not need to complete or submit this application.	
1. Does your project involve **only** the analysis of publicly available data? Examples include census data, large public survey data sets with no individual identifiers, and public information available on the internet.	☐ Yes ☒ No
2. Is this a UH class project (whether individual or group) from which the data will only be submitted to your instructor for a class grade and will not be published, presented at an academic conference, given to an agency as a formal report, and will not be used in future research or to qualify for a graduate degree (e.g. Master's or Doctoral dissertation)?	☐ Yes ☒ No
If your answer to the following questions is "Yes" for both 1 and 2, or both 1 and 3, please complete Section III of this form. If you answer "No" for 1, 2, and 3 below, your project does not require Human Studies Program review and approval and you do not need to complete or submit this application.	
1. Does your research involve obtaining information about living individuals?	☒ Yes ☐ No
2. Will the information be obtained through intervention or interaction with these individuals?	☒ Yes ☐ No
3. Will your research involve access to private information from which individuals can be identified directly or indirectly through a link or code? This includes access to existing data that identifies individuals but these individuals will not be contacted in your research project.	☐ Yes ☒ No

III. Categories of Exemption

Complete all the categories below that apply to your research. If a category does not apply to your study, check "Not Applicable" (N/A). If your research does not meet the requirements for any of the six categories below, please complete and submit the standard Application for a New Study available on the Human Studies Program website at www.hawaii.edu/irb under "Forms".

Research on Educational Practices (Federal Category 1)	☒ N/A
Your research will take place in an established or commonly accepted K-12 educational setting, involving normal educational curriculum (appearing as normal classroom activities).	☐ Yes
If Yes, complete **Section IV** and **Section V** of this application.	

Research Involving Surveys or Interviews (Federal Category 2)	☐ N/A
1. Your research will involve the use of educational tests, surveys or interviews for participants ages 18 and older. (educational tests may include cognitive, diagnostic, aptitude, and achievement tests)	☒ Yes
2. Your survey/interview research will involve only adult participants (18 and older) who would **not** be considered part of a vulnerable population. (for definitions, see glossary on page 5)	☒ Yes
3. The research data that you collect (including field notes) will be recorded in such a manner that if participants can be identified, they would not be at risk of damage to their reputation, financial standing, employability, or criminal and civil liability **or** this data will be recorded anonymously (so that participants cannot be identified, either directly or through identifiers linked to them).	☒ Yes
If you answered "Yes" to 1, 2 and 3, complete **Section IV** and **Section V** of this application.	

Research Involving Public Observation (Federal Category 2)	☒ N/A
Your research will involve observation of human subjects in a public setting where there is no expectation of privacy.	☐ Yes
If Yes, complete **Section IV** of this application.	

Research Involving Public Officials (Federal Category 3)	☒ N/A
Your research will involve surveying or interviewing elected or appointed public officials (or candidates for public office).	☐ Yes
If Yes, complete **Section IV** and **Section V** of this application.	

Research Involving the Use of Existing Data (Federal Category 4)	☒ N/A
1. Your research will involve the study of existing data, documents, records, pathological specimens, or diagnostic specimens.	☐ Yes
2. You will record the information in such a manner that participants cannot be identified either directly or through identifiers linked to the participants, **or** the sources of these data are publicly available.	☐ Yes
If you answered Yes to 1 and 2, complete **Section IV** of this application.	

Research Involving Public Benefit or Service Program Evaluation (Federal Category 5)	☒ N/A
Your research will evaluate, study or otherwise examine a public benefit or service program at the request of a department or agency head. (IRB approval is required to perform research under this category.)	☐ Yes
If Yes, complete **Section IV** and **Section V** of this application.	

Research Involving Taste and Food Quality (Federal Category 6)	☒ N/A
Your research will involve an evaluation of taste and food quality, or a consumer acceptance assessment.	☐ Yes
If Yes, Complete S**ection IV** and **Section V** of this application.	

IV. Description of Project

Please attach 1-2 typed pages answering questions 1 through 6. Provide your answers as separate responses to each question.
(Do **not** attach a master's proposal or contract/grant.)

1. Briefly describe the purpose and objectives of your research in non-technical language.

2. Briefly describe your research design and methods.

3. For research being conducted as "educational curriculum," describe how the activity being studied is part of "normal" educational practice.

4. If you are using existing data, describe the source(s), the extent to which individuals are identified, and how you have access to the data.

5. If your research will be observational, describe how the observations will be recorded (e.g., audio, video, field notes). If you are planning to audio the participants, please see Section IV.

    a. If your project involves videotaping, please fill out an application for non-exempt review.

6. Describe your participant population (e.g., age, as special needs, etc…). How will you identify, contact and recruit participants? How many participants do you intend to involve in your research? How will you explain your research to participants?

V. Attachments

1. Please provide a consent form to be given to research participants. Examples can be found on the Human Studies Program website under "Forms".
    a. If audio recordings will be a part of the research records, there must be a clear description in the consent form of:
        i. how the recordings will be used including any uses beyond this research project,
        ii. how the recordings will be stored,
        iii. and what will be done with the recordings when the project is complete. A separate consent form, or yes/no checkbox on the main consent form must be provided so that participants can agree or refuse to be recorded.
    b. If applicable, include language in the consent form that describes how the data or recordings are likely to be used for future research purposes.

2. For research involving minors (ages 17 and younger), you must provide the following:
    a. A parent/guardian consent form for their child to participate in research that includes space for a signature and date.
    b. A way of obtaining assent or refusal to participate from the child(ren) that is understandable to them. If the participants are 5 to 11 years old, please provide an oral assent script with an explanation of how you will explain the project to them and obtain their assent or refusal to participate. If the participants are 12 to 17 years old, please provide a written assent form that includes space for a signature and date.

3. Attach a copy of all survey instruments and interview guides. If draft instruments are submitted, final drafts must be submitted for final Human Studies Program approval before use.

4. If you are using recruitment flyers, or advertisements, please provide copies of these as well. Examples can be found on the Human Studies Program website.

5. Attach a copy of your CITI training completion report. See Human Studies Program website under "Training" for instructions on how to complete the training. Your application will not be reviewed until training requirement has been met.

Approval of this Exempt Application is valid for the entire life of the research project and does not need to be renewed annually. However, any changes in the procedures or instruments must be prospectively approved by the Human Studies Program, a process which can occur via email to uhirb@hawaii.edu for Exempt projects. Once the study is complete, please notify the Human Studies Program also by email to uhirb@hawaii.edu.

If you have questions, or you are unsure whether your research project is Exempt, please call the Human Studies Program office at (808) 956-5007, or send an inquiry by email to uhirb@hawaii.edu.

VI. How to Submit Your Application:

Please provide Human Studies Program with this application (typed and signed on page 1), a description of the project, and all relevant documents listed in Section V.

- **Email to**: uhirb@hawaii.edu. Subject line: "Exempt Application". A signed application is required. To convert your signed application to an e-file, please scan.

VII. Glossary

Assent A child's affirmative agreement to participate in research. Mere failure to object should not, absent affirmative agreement, be construed as assent.

Application Form (these forms are found on the Human Studies Program website under "Forms at www.hawaii.edu/irb).

- **Application for Exempt Status for Human Subjects Research** Use this application to determine if and to apply for Human Studies Program approval as an exempt study.
- **Application for New Approval of a Study Involving Human Subjects** Use this application for research that is not exempt.

Consent Form A document which explains a research study (including a description of any procedures, the potential benefits and risks of participation, etc.) to potential research participants. Most consent forms require a signature and date of the participant. By signing the consent form, a participant asserts his or her voluntary agreement to participate in a study. Examples of consent forms are available on the Human Studies Program website at www.hawaii.edu/irb.

Educational Curriculum Includes teaching, curriculum development and other activities consistent with the process of formal education. To K-12 classroom participants, this research will look like normal classroom practice.

Educational Setting A school, classroom, and other locations where formal education is typically conducted.

Exempt Research Under federal regulations, specific categories of research can be designated as exempt from certain regulatory requirements as well as initial and continuing review by the IRB. Research at UH must be approved as exempt by the UH Human Studies Program.

Existing Data Data that has been previously compiled for research or non-research purposes, such as school records or census information. Existing data may include data sets, interview notes or audio or video tapes. (Note: to qualify for exempt status, the data must exist at the time of the application)

Generalizable Knowledge When study results are intended to answer a research question, to draw conclusions about a specific premise (or hypothesis), or to apply study results beyond the specific focus of the research (the research data or study participants), they are considered to be generalizable. Study results that will be published (in a scholarly journal, book, or on-line), placed in a library (such as a masters or doctoral dissertation), or presented at an academic meeting are considered to be generalizable.

Human Subject A human subject is a living individual about whom a researcher, whether professional or student, obtains data through intervention or interaction, or obtains identifiable private information about them.

Informed Consent The process by which a person voluntarily agrees to participate in research based on adequate knowledge and understanding of the research project.

Identifiable Data Data that can be used to identify individual research participants. Identifiers include but are not limited to names, addresses, phone numbers, social security numbers, geocodes, and images (but not voices). Identifiers may also include codes that can be used to link an individual's identity with information about them.

Private Information Information that an individual would reasonably expect to not be shared without the individual's permission. Private information may also refer to observed behavior about a person in a setting in which the person would not expect to be observed for research purposes without permission.

Public Benefit or Service Program A government agency or program established to provide services to eligible members of the public (e.g. WIC, Veterans Affairs, etc.) Research must be supervised by the agency in charge of the public benefit or service program. Please contact the Human Studies Program office if you believe your project may qualify under this category.

Vulnerable populations Children, prisoners, pregnant women, physically or mentally disabled persons, or economically or educationally disadvantaged persons.

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI)

CITI HEALTH INFORMATION PRIVACY AND SECURITY (HIPS) CURRICULUM COMPLETION REPORT

Printed on 04/04/2014

LEARNER	Eileen Peppard (ID: 4101002) 2525 Correa Road HIG 238 Honolulu HI 96822 United States
DEPARTMENT	Sea Grant
PHONE	8089562861
EMAIL	epeppard@hawaii.edu
INSTITUTION	University of Hawaii
EXPIRATION DATE	

CITI HEALTH INFORMATION PRIVACY AND SECURITY (HIPS) FOR STUDENTS AND INSTRUCTORS : This course for **Students and Instructors** will satisfy the mandate for basic training in the HIPAA. In addition other modules on keeping your computers, passwords and electronic media safe and secure are included.

COURSE/STAGE:	Basic Course/1
PASSED ON:	04/02/2014
REFERENCE ID:	12718544

REQUIRED MODULES	DATE COMPLETED	SCORE
About the Course	04/02/14	1/1 (100%)
Basics of Health Privacy	04/02/14	12/16 (75%)
Health Privacy Issues for Students and Instructors	04/02/14	4/4 (100%)
Basics of Information Security, Part 1	04/02/14	No Quiz
Basics of Information Security, Part 2	04/02/14	4/5 (80%)
Security Rules: Introduction to Federal and State Requirements*	04/02/14	6/6 (100%)
Completing the Privacy and Security Course	04/02/14	No Quiz

For this Completion Report to be valid, the learner listed above must be affiliated with a CITI Program participating institution or be a paid Independent Learner. Falsified information and unauthorized use of the CITI Progam course site is unethical, and may be considered research misconduct by your institution.

Paul Braunschweiger Ph.D.
Professor, University of Miami
Director Office of Research Education
CITI Program Course Coordinator

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI)

STUDENTS CONDUCTING NO MORE THAN MINIMAL RISK RESEARCH CURRICULUM COMPLETION REPORT

Printed on 04/04/2014

LEARNER	Eileen Peppard (ID: 4101002) 2525 Correa Road HIG 238 Honolulu HI 96822 United States
DEPARTMENT	Sea Grant
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INSTITUTION	University of Hawaii
EXPIRATION DATE	04/02/2017

STUDENTS - CLASS PROJECTS : This course is appropriate for students doing class projects that qualify as "No More Than Minimal Risk" human subjects research.

COURSE/STAGE:	Basic Course/1
PASSED ON:	04/03/2014
REFERENCE ID:	12718543

REQUIRED MODULES	DATE COMPLETED	SCORE
Belmont Report and CITI Course Introduction	04/02/14	3/3 (100%)
Students in Research	04/02/14	7/10 (70%)
History and Ethics of Human Subjects Research	04/03/14	5/7 (71%)
Basic Institutional Review Board (IRB) Regulations and Review Process	04/03/14	4/5 (80%)
Records-Based Research	04/03/14	2/2 (100%)
Genetic Research in Human Populations	04/03/14	2/2 (100%)
Research With Protected Populations - Vulnerable Subjects: An Overview	04/03/14	4/4 (100%)
Research and HIPAA Privacy Protections	04/03/14	4/5 (80%)
Conflicts of Interest in Research Involving Human Subjects	04/03/14	4/5 (80%)

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