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# A study on static pressure reset and instability in variable air volume HVAC systems

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# A study on static pressure reset and instability in variable air volume HVAC systems

By

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# ABSTRACT

This project began with testing five different versions of supply duct static pressure reset strategies that fall into two general categories: Proportional plus Integral control loops, and Trim and Respond control strategies. The testing took place from July 2009 through January 2011 at the Energy Resource Station in Ankeny. During this time, these five experimental control strategies were modified and altered in order to achieve substantial energy savings without unwanted instability. In the end, only one strategy, tiered Trim and Respond, was able to perform as desired by saving energy without displaying unstable behavior or significantly impacting maintenance costs.

The final stage of this project saw the tiered Trim and Respond strategy implemented in the Hixson-Lied building on the Iowa State University campus. This field test resulted in no apparent unstable behavior and savings of 37% per week in fan energy savings alone.

# CHAPTER1: INTRODUCTION

## Background

For decades, people have been trying to reduce the operating costs of commercial buildings. One way to reduce operating costs is by reducing energy consumption. In commercial buildings, energy is used to heat and cool the building, run office equipment such as computer systems and printers, provide area lighting and hot water among others. Within the United States, commercial energy consumption accounts for approximately 19% of total U.S. energy consumption (U.S. DOE/EIA 2009) each year. Of the amount delivered to commercial buildings, over half (51%) is used to operate the HVAC system alone (U.S. DOE/EIA 2003). Reducing energy consumption within the HVAC system holds potential for significant reductions in operating costs in commercial buildings. One way of reducing energy consumption in HVAC systems is to improve the air distribution system control strategy to increase efficiency.

One common way to distribute air in an HVAC system is by use of a Variable Air Volume (VAV) fan. In a VAV system, the fan responds to zone load requirements by varying air volumetric flow rate. The volumetric flow rate is controlled by using a complex system of pressure sensors and damper positions. Typically, the fans in HVAC systems are chosen to cool a building under design conditions, such as the hottest day of the typical year. Under these conditions, the VAV system maintains a constant static pressure within the air supply duct that will keep the zone dampers near 90% open. When loads are less than the design maximum, the zone dampers close as less air volume is required to cool the zone. When this happens, the VAV fan reduces its speed in order to reduce the volumetric flow rate of air while still maintaining the fixed supply static pressure. This process reduces energy consumption in low demand conditions, but is still inefficient.

One way to save even more energy in VAV systems is to employ a strategy referred to as static pressure reset or air fan pressure reset. Under this process, as the zone load decreases and the zone dampers begin to close, the duct static pressure set point is reduced in order to maintain damper positions mostly open. Ideally, this strategy keeps maximum damper positions around 98-99% open at all times. This would ensure that the minimum fan pressure rise is used and every zone's demand is met by providing the required amount of airflow to cool the zone.

Unfortunately, employing energy saving strategies on commercial HVAC systems can be very difficult. There are many problems that can discourage the implementation of strategies such as static pressure reset. Some problems are the presence of unstable behaviors such as oscillation, the complexity of implementing some strategies, the abundance of transient effects present in complex HVAC systems, and the time consuming analysis required to select reliable performance parameters. With such difficulties present, energy saving control strategies are often overlooked in existing buildings. To combat this problem, the goal of this project is to investigate static pressure reset strategies and then to find operating parameters that both save energy and eliminate or minimize instability.

## Literature Review

### Fan Energy Savings

Fan energy can make up a significant portion of the energy used in commercial HVAC systems. The amount of power consumed by a fan is proportional to the product of flow rate and pressure rise, both of which vary with fan speed. Fan power is proportional to the cube of fan speed. By reducing fan speed, energy can be saved in several ways. Not only does the slower fan speed reduce fan energy consumption, but it also leads to additional savings in other ways. Examples of these fringe benefits are reduced duct leakage due to lowered static pressure, reduced thermal load from cooling a smaller quantity of air, and a lesser heating effect from the fan's operation (Liu et. al, 2010). Of course these benefits are maximized when duct static pressure is reset when the system needs less cooling. Studies indicate that resetting static pressure can result in 30% to 50% fan energy savings (Taylor 2005).

Methods for saving fan energy can be as simple or as complicated as the operator desires. Simply scheduling fans to a reduced fixed static pressure during unoccupied times can save fan energy. Others choose to use advanced genetic algorithms to make HVAC systems operate more smoothly (Wang 2008). Others still incorporate many strategies together in an attempt to optimize performance while reducing energy consumption to the greatest extent possible (Murphy 2008).

## Control Strategies

There are many different strategies to minimize HVAC energy consumption. These strategies can be as simple as scheduling events such as a decrease in duct static pressure or adjusting the heating and cooling temperature set points during unoccupied hours. Complex strategies can also be used that employ tools such as genetic algorithms to solve for ideal operating parameters and set points. The challenge inherent in implementing energy saving strategies is coming up with a strategy that is relatively simple to employ and requires minimal setup to operate effectively. Promising strategies for reducing duct static pressure are the Proportional plus Integral (PI) control strategy and the Trim and Respond (TR) strategy. Among the literature, these two types of strategies emerged as the more prominent cost effective and relatively simple strategies.

PI control is a type of control that takes an error value and uses it to compute an output signal that can be used to increase or decrease the controlled variable. These control methods are a simpler set of a more complex control method known as PID or Proportional – Integral – Derivative. These control methods and their subsets have been used to control a wide range of equipment. As they pertain to HVAC, PID and PI controls are in place on many subsystems of a complex HVAC system. Fan speed, damper position, and flow rate demand are all often controlled by PI or PID controllers. In the past few decades, with the advent of Direct Digital Control (DDC) equipment, these control methods have begun to be implemented in pressure reset strategies.

Englander and Norford (1992) simulated the impact of modified PI and heuristic algorithms. The modified PI algorithm was written in such a way that it always increased the static pressure set point. To complement this, they included a positive decay term in the algorithm that gradually decreased static pressure. On its own, the PI algorithm used responds to increase duct pressure until the VAV boxes are at the desired damper position, but then is unable to decrease static pressure as it is written. With the addition of the decay term, the modified PI algorithm can then slowly reduce the static pressure until there is an unsatisfied zone, at which point the PI portion of the strategy again becomes dominant and begins the process again. One distinct advantage of this system is that it is continually trying to find the lowest possible static pressure. Also, this approach allows for different increase and decrease rates which might help to improve stability. However, this method may lead to some small “hunting” effect which is characterized by repeatedly increasing and decreasing the static pressure instead of finding an optimal set point.

The heuristic algorithm takes a look at the error and the change in error for all of the independent inputs (in this case the primary flow error from each VAV box) and then makes a decision to increase or decrease duct pressure slightly or to hold it as it is. This method is essentially a type of TR strategy. Like the other strategy employed, this one also possesses the ability to allow different rates when increasing or decreasing the duct static pressure. In the case of either control strategy, Englander and Norford stress that the use of a dead band may improve stability.

After implementing both of these strategies in simulation, Englander and Norford found that both strategies were acceptable for use. They both achieved relatively small steady-state flow rate error while allowing the damper positions to come to full-open (indicating minimum static pressure) within an hour. These factors mean that both strategies are able to save fan energy while satisfying occupant comfort requirements.

Despite the success of these two strategies, both exhibited some negative behaviors. The heuristic algorithm was not able to decrease duct pressure as rapidly as the modified PI algorithm. The heuristic algorithm also displayed a great deal of “hunting” behavior. The authors speculate that this could be dealt with by finding better control parameters. However, the authors note that finding the ideal control parameters is likely to be a time consuming task and simulation will probably be an extremely useful tool for finding them, particularly in the case of the modified PI algorithm, which is much more difficult to tune.

Wang and Burnett (1998) found that they were able to achieve relatively stable control in simulation by incorporating a dead band along with independent, separate PI controls for either increasing or decreasing the static pressure while using the VAV box damper positions as the error input. They also note that it was relatively easy to tune the PI loops with a few iterations, but acknowledge that these iterations were accomplished with simulation.

One major difference in the implementation of this version of PI control (other than the use of separate PI loops) is the use of damper position error instead of flow rate error in order to drive the reset process. This technique was combined with allowing a certain number of VAV box dampers to reach full-open before forcing the reset process into action. This strategy has the potential to save even more energy, but may result in starving the zones with the ignored VAV box dampers.

The use of separate PI loops for controlling the increase or decrease of the supply static pressure is certainly able to provide different rates for increasing and decreasing the static pressure, which will ultimately make the strategy more flexible. This method may also be able to better deal with any transient effects that behave differently when increasing static pressure than when decreasing it.

Tung and Deng (1997) found a way to combine both the PI strategy and the trim and respond method. By using a dead band, they were able to apply a PI controller to the fan control in order to reduce static pressure based upon flow rate error. One unique thing they did was to create two sums, one for the requested air flow over all VAV boxes and one for the actual air flow through all VAV boxes, and then took the difference of these two sums and used it for the error signal. If this error signal was within the dead band for too long, the static pressure was trimmed in order to find a lower static pressure. Once the flow rate exceeds the error dead band again, the PI controller adjusts the static pressure accordingly, which starts the process over again.

Although PI reset has been thoroughly researched, it’s not without limitation. For example, finding the error for the input requires knowledge of some indicator of airflow requirement for each zone. If the system does not report damper positions or flow rates to the central console, this type of control is impossible to implement. One way to implement static pressure reset in these cases is to employ a trim and respond control strategy instead. In fact, this is the true advantage of trim and respond: it can be implemented in almost any VAV system. It can be implemented even if the only zone level knowledge of flow demand is the presence of binary low flow alarms or damper full-open end switches (Taylor, 2007). The versatility of trim and respond methods make them an ideal option for systems with limited information available.

The goal of employing any static pressure reset strategy is to reduce energy consumption. When reset strategies are implemented, energy is saved by reducing fan speed but also by reducing wasted energy through system air leakage and thermal energy used to cool air flow that is not needed (Liu et. al, 2010). Unfortunately, attempting to utilize these methods can often come at the expense of unstable behavior, which can increase maintenance costs by causing unnecessary wear to equipment. Though this instability is mentioned in the literature (Englander and Norford, 1992; Taylor, 2007), little is mentioned about what actually causes it or how to effectively deal with it.

## Research Objectives

There are two distinct phases of this research project. The first is the testing phase, which took place in a laboratory-like setting where building control could be studied in great detail. During this phase, the objective was to identify energy saving control strategies and to attempt to map out stable operating parameters. The root causes of any observed instability were identified, if possible. The results of this phase are presented in Chapter 3 of this Thesis.

For phase two, the results from phase one of this project were then used to implement the best control strategy in a VAV equipped building on the Iowa State University campus. The best strategy was adapted to run in this building and then was observed to determine energy savings and to identify any additional instability in a new environment. The results of this phase are presented in Chapter 4 of this Thesis.

The contents of this thesis are arranged into 5 chapters and several appendices. Chapter 1 contains the introduction, which consists of the background information and literature review. Chapter 2 includes a description of the ERS testing facility as well as details of the tests themselves. Chapter 3 then discusses the results of the ERS testing and sets up a successful strategy for field testing. Chapter 4 contains information about the field test site and modifications required to implement a control strategy there. The results of the field test are also discussed in Chapter 4. Chapter 5 includes a summary of work as well as limitations and a discussion on future work.

# CHAPTER 2: TEST PROCEDURE

Testing was accomplished in a series of five tests. In each new test series, something was altered in order to observe its effect on system performance. These alterations included different artificial loading profiles, the introduction of new control algorithms, and the changing of various parameters within these control algorithms. Throughout the testing process, these alterations were made in order to discover which parameters had the greatest effect on system performance and stability as well as to identify regions in which these parameters resulted in stable operation. Before discussing these tests in detail, a description of the test facility will be given.

## Test Facility

Testing was performed at the Energy Resource Station (ERS) located at the Des Moines Area Community College (DMACC) campus in Ankeny, Iowa. This facility was built in 1995 by the Iowa Energy Center (IEC) for the purposes of demonstrating energy efficient technologies, training, testing, and the dissemination of information about energy efficient design and operation of buildings. This building is unique in that it offers two identical HVAC systems that can be tested side-by-side for comparison of energy efficient equipment and control strategies. A detailed description of the ERS can be obtained from documents published by the ERS (2010) or by Price and Smith (2000). The next few sections contain an overview of the pertinent information in these documents.

## Building Construction

The ERS is located at 41.71 degrees North latitude and 93.61 degrees West longitude with elevation of 937.0 feet above sea level. The facility is oriented to true astronomical (not magnetic) North and has a building height of 15 feet with a total surface area of 9,208 $ft^2$. The structure consists of slab-on-grade flooring and primarily precast concrete and steel frame construction.

The ERS facility can be divided into three distinct areas: general service area, test rooms A, and test rooms B. The general service area consists of a mechanical room including storage and service rooms, east and west classrooms, east and west vestibules, offices, a break area, a reception area, computer center, a display room, a media center, and restrooms. The two test room sets are virtually identical with the same construction specifications and consist of an interior room and three exterior rooms each. The exterior rooms are located in pairs along the East, South, and West walls. As such, these rooms are called East A/B, West A/B, South A/B, and Interior A/B throughout this report. See Figure 2.1 (below) for the building layout.

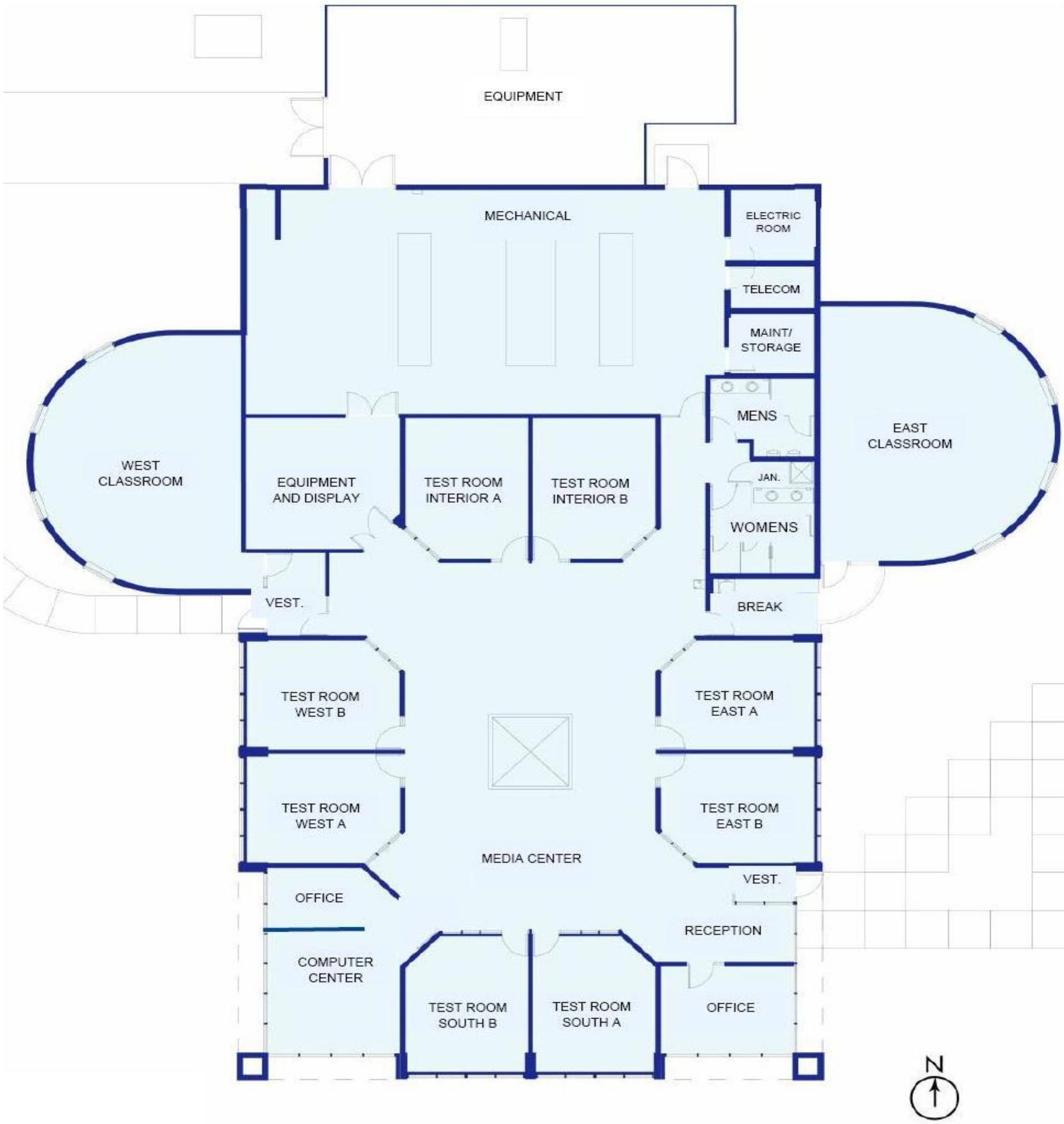


**Figure 0.1: ERS floor plan, taken from ERS (2010)**

The general service area is served by a single independent air handling unit (AHU-1) while the two sets of test rooms are served by two additional air handling units. These air handling units are named AHUA and AHUB and serve the A test rooms and B test rooms respectively. The HVAC systems will be discussed more extensively later in this report.

### Floor Construction

The floor consists of slab-on-grade construction. It is made up of a 4 inch thick layer of concrete on top of a 4 inch thick layer of sand. The entire interior space is carpeted with the exception of the mechanical room, which remains bare concrete.

### Test Room Wall Construction

The exterior test rooms have exterior walls that can be divided into three distinct sections:  upper wall, lower wall, and window. The lower wall is 3 feet tall and consists of three sections that are the two sides and a center section. The center section consists of 5/8 inch gypsum board, 1 1/2 inch rigid insulation, and a 4 inch precast concrete panel. A fan coil unit is installed in the center section of the B test rooms while this space is left open for future fan coil unit installation in the A test rooms. See Figure 2.2 for a detailed construction drawing of the center section of the exterior wall in a typical test room. The side sections are made up of 5/8 inch gypsum board, 6 inches of air space, 3 5/8 inch metal studs 16 inches on center with batt insulation, 1 inch rigid insulation, and a 4 inch precast concrete panel. The upper wall is identical in all exterior test rooms and consists of 5/8 inch gypsum board, 3 5/8 inch metal studs with batt insulation, 3/4 inch air space, 1 inch rigid insulation, and a 6 inch thick precast concrete panel.

The exterior windows measure roughly 5 feet high and 14.8 feet wide. They have 2 inch wide aluminum frames with 2 inch wide mullions and no exterior shading devices are used. The windows consist of double glazed 1/4 inch clear insulating glass with 1/2 inch air space between. These windows can be interchanged for windows with lower emissivity if needed. Thermal properties for the fenestration are shown in Table 2.1 below.

**Table 0.1: Fenestration thermal properties, recreated from ERS (2010)**

| Description | Type | Color | Overall U-Value Summer Btu/h*ft$^2$*$^o$F | Overall U-Value Winter Btu/h*ft$^2$*$^o$F | Visible Transmittance | Shading Coefficient |
|---|---|---|---|---|---|---|
| Base Clear Windows | Annealed Insulated | Clear | 0.55 | 0.48 | 81% | 0.85 |
| Alternate Standard Performance (Light Tint) Windows | Annealed Insulated | Light Tint | 0.35 | 0.33 | 73% | 0.76 |
| Alternate Standard Performance (Dark Tint) Windows | Annealed Insulated | Dark Tint | 0.33 | 0.31 | 23% | 0.26 |

The test rooms have interior walls that extend to the roof of the building to ensure that the test rooms are isolated from one another. The interior walls consist of 3 5/8 inch metal studs sandwiched between 5/8 inch gypsum board for all interior walls except the following: The East walls of test rooms interior B and South A, and the West walls of test rooms interior A and South B. These excepted walls consist of 6 inch metal studs sandwiched between 5/8 inch gypsum board. The walls separating the test rooms from the media center contain a window that measures 7 feet high and 6 feet wide. The window consists of single glazed 1/4 inch clear insulating glass and has an aluminum frame with thermal breaks. In addition, each test room has a standard hollow-core metal door.

## Roof Construction

The ERS has a flat roof that is constructed of an 8 inch thick pre-cast and pre-stressed cored-concrete slab, vapor barrier, 4 inch polyisocyanurate insulation, roof insulation tapering from nine inches thick at the center of the building to 4 inches thick near the perimeter, single-ply membrane, and river rock ballast. There is also a 100 square foot skylight that is centered above the media center.

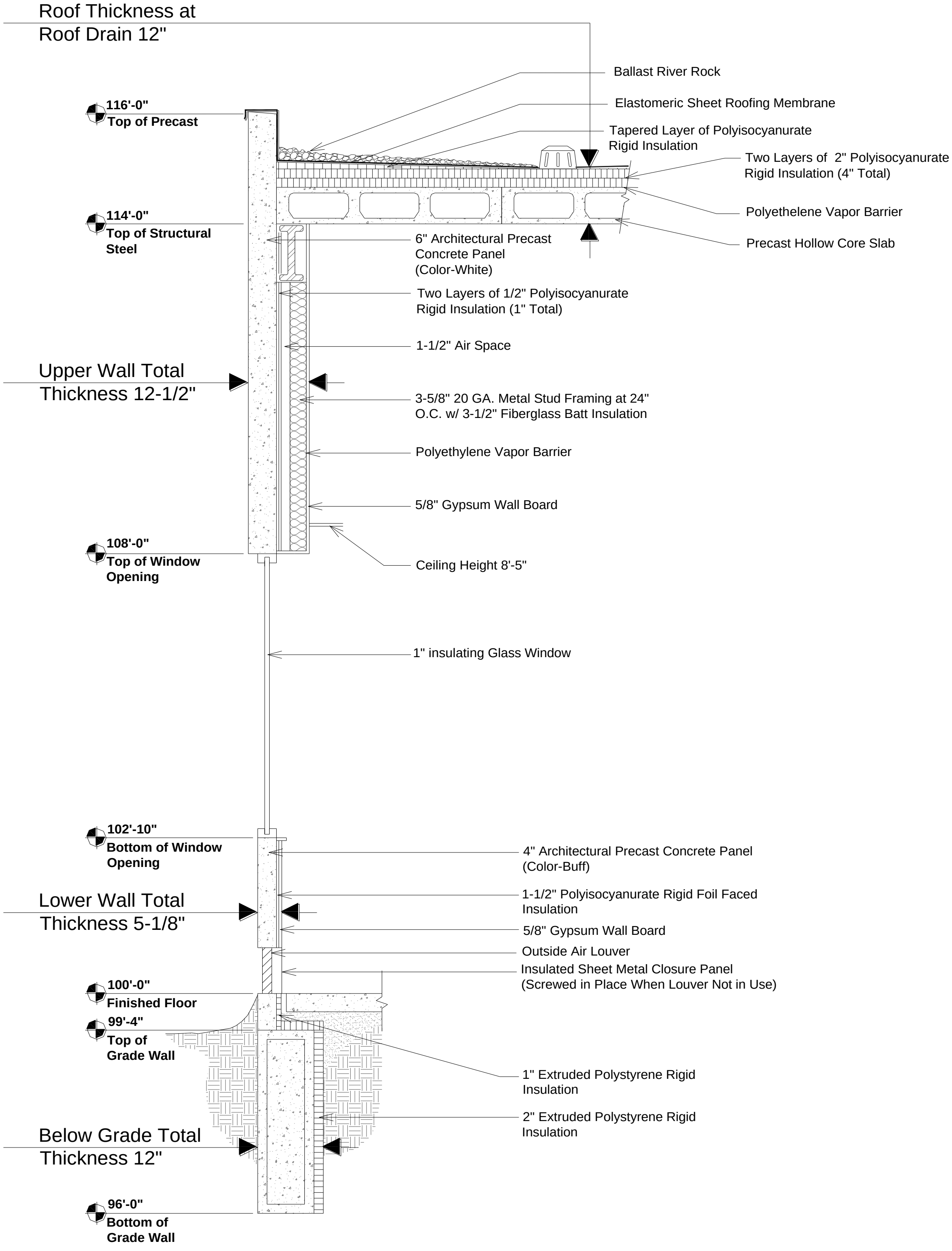


**Figure 0.2 Exterior wall center section cross-section, image taken from ERS (2010)**

### Internal Loading and Weather Station

The ERS has the ability to apply a variety of artificial thermal loads to each test room that include baseboard heating, a fan coil unit, ceiling lighting, and occupant loads. These artificial thermal loads can be scheduled to come on and off as needed for testing. The baseboard heaters can be operated in any of three modes providing up to 1800 watts of sensible load. The fan coil units can be operated in heating, cooling, or ventilation mode. It is also possible to control the fan speed in a variety of ways as the situation requires. The specific amount of heating or cooling load applied to the room from the FCU will vary with heating and cooling water and air flow rates. The lighting at the ERS can be used as a load source to simulate a variety of loading patterns. There are six light fixtures in each test room which can be operated in one of four different modes and provide up to 90 watts of load per fixture. Lastly, the ERS can simulate a variety of occupant loads including people and equipment. People can be simulated by using androids. These are sheet metal cylinders that have the capability of creating a thermal load or producing $CO2$ for one or two people at an office work activity level. A computer can also be activated to simulate office equipment loads.

The false loading capabilities enable testing of a wide variety of loads and loading schedules. All false loads are computer controlled and can be switched on or off according to their capabilities in nearly any order or on nearly any schedule. Tables 2.2 and 2.3 Below show information about the false loads utilized in the experiments. For a comprehensive list of available false loads see ERS, 2010.

**Table 0.2: Light and baseboard heater mode and power output, recreated from ERS (2010)**

| Lighting | | | | Baseboard Heater | | | |
|---|---|---|---|---|---|---|---|
| Mode | Stage | | Total Power (W) | Mode | Stage | | Total Power (W) |
| | 1 (180 W) | 2 (360 W) | | | 1 (900 W) | 2 (900 W) | |
| 1 | Off | Off | 0 | 1 | Off | Off | 0 |
| 2 | On | Off | 180 | 2 | On | Off | 900 |
| 3 | Off | On | 360 | 3 | On | On | 1800 |
| 4 | On | On | 520 | | | | |

**Table 0.3: Occupancy simulator mode and power level, recreated from ERS (2010)**

| Simulator | Mode | Capacity | Total |
|---|---|---|---|
| People | On | 250 BTU/hr Sensible<br>200 BTU/hr Latent | 450BTU<br>~132 W |
| | Off | 0 BTU/hr | 0 W |
| Equipment | On | 42 Watts Computer<br>46 Watts Monitor | 88 W |
| | Off | 4 Watts Computer<br><1 Watt Monitor | <5 W |

The ERS is also equipped with a weather station that is capable of acquiring a large amount of data regarding the natural environmental loads present. The ambient conditions and weather data that can be recorded include:

- Outdoor air dry-bulb temperature
- Relative humidity
- Wind speed
- Wind direction
- Barometric pressure
- Total normal incident solar flux
- Long wave radiation

The addition of the weather station along with the recorded false loads allows the formation of a complete picture of the natural and artificial loads present in each of the test rooms.

## HVAC Systems

In general, the HVAC system at the ERS consists of a central heating plant, a central cooling plant and three different air handling units (AHU's). The central heating plant provides heated water for the entire HVAC system while the central cooling plant has the ability to use either locally produced chilled water from one of the three air cooled chiller units or to accept chilled water supplied by the DMACC campus' chilled water service. The primary air handling unit, AHU-1, is used to supply the general service areas of the ERS and is also the largest due to the larger thermal load requirements. The two additional AHU's are called AHUA and AHUB and are used to service test rooms A and B respectively. A schematic of the HVAC layout for AHUA and AHUB is shown in Figure 2.3 (below).

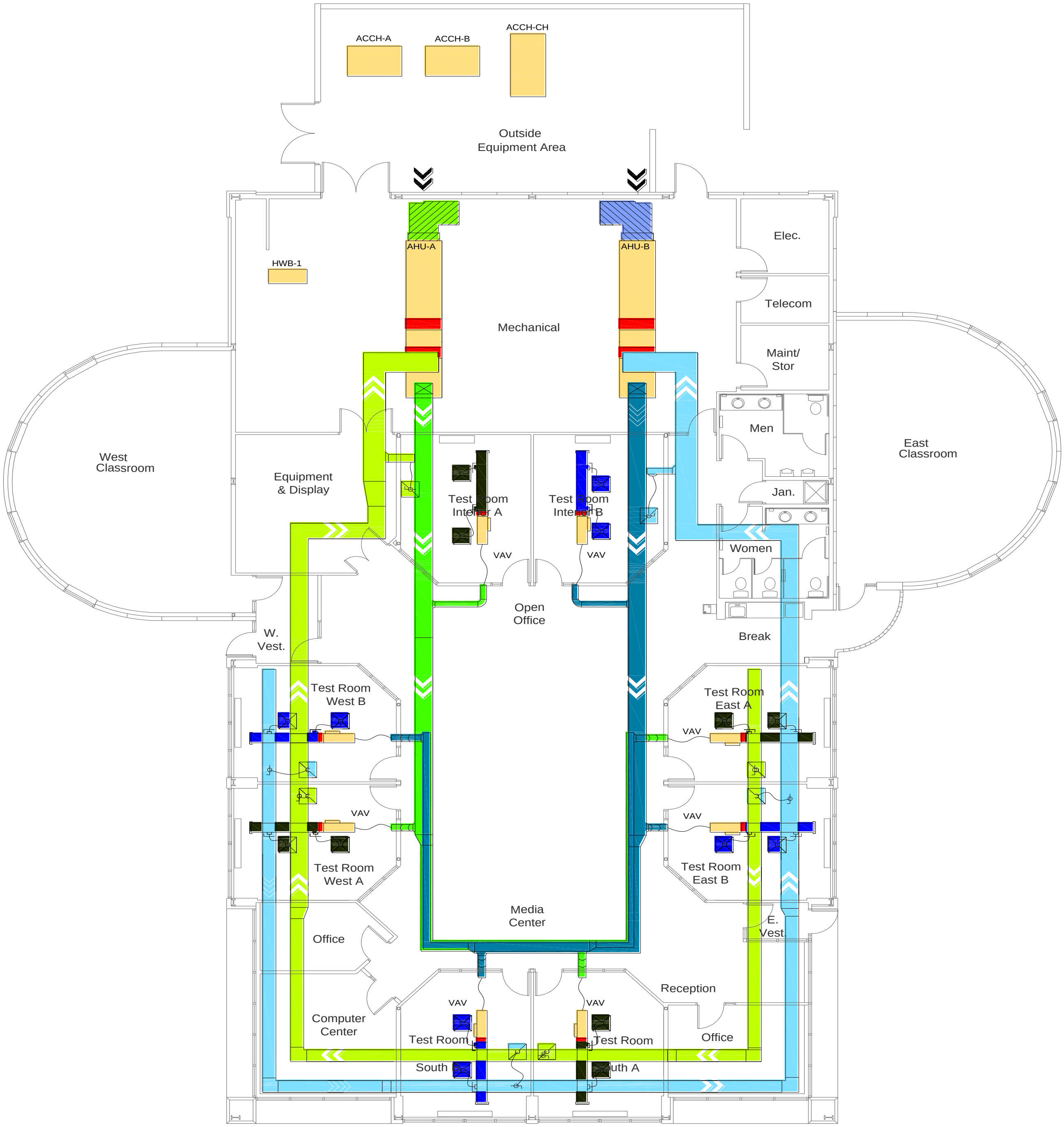


Figure 0.3: HVAC mechanical plan for AHUA and AHUB, image taken from ERS (2010)

### Test Room Air Handling Units

The test room AHU's are identical in model and scale and nearly identical in layout. Each AHU supplies four pressure independent VAV boxes, one in each of the serviced test rooms. See Figure 2.4 for mechanical equipment location. Each VAV box supplies two air diffusers in a given test room. Each test room also contains a return air grill. The VAV boxes for each test room are identical in model number but differ in that the interior test room VAV boxes are smaller in size. The VAV boxes are also unique in that they contain both hot water coils and electric reheat coils for a dual reheat capability. See Table 2.4 and 2.5 for the AHU and VAV design specifications.

**Table 0.4: Test room AHU design specifications, recreated from ERS (2010)**

| Design Item | AHUA and AHUB |
|---|---|
| Configuration | Horizontal Draw Through |
| Total Design Supply Air Flow | 3200 CFM |
| Preheat Coil - Outside Air | Heating Water 69 MBH<br>1 Row - 4.5 sq. ft. Face Area |
| Cooling Coil | Chilled Water 135 MBH<br>6 Row - 6.0 sq. ft. Face Area |
| Heating Coil | Heating Water 208 MBH<br>2 Row - 6.0 sq. ft. Face Area |
| Supply Air Fan | Centrifugal, Vertical Up Discharge<br>3.20 in. WG - Total Static Pressure |
| Return Air Fan | Centrifugal, Horizontal Discharge<br>1.25 in. WG - Total Static Pressure |

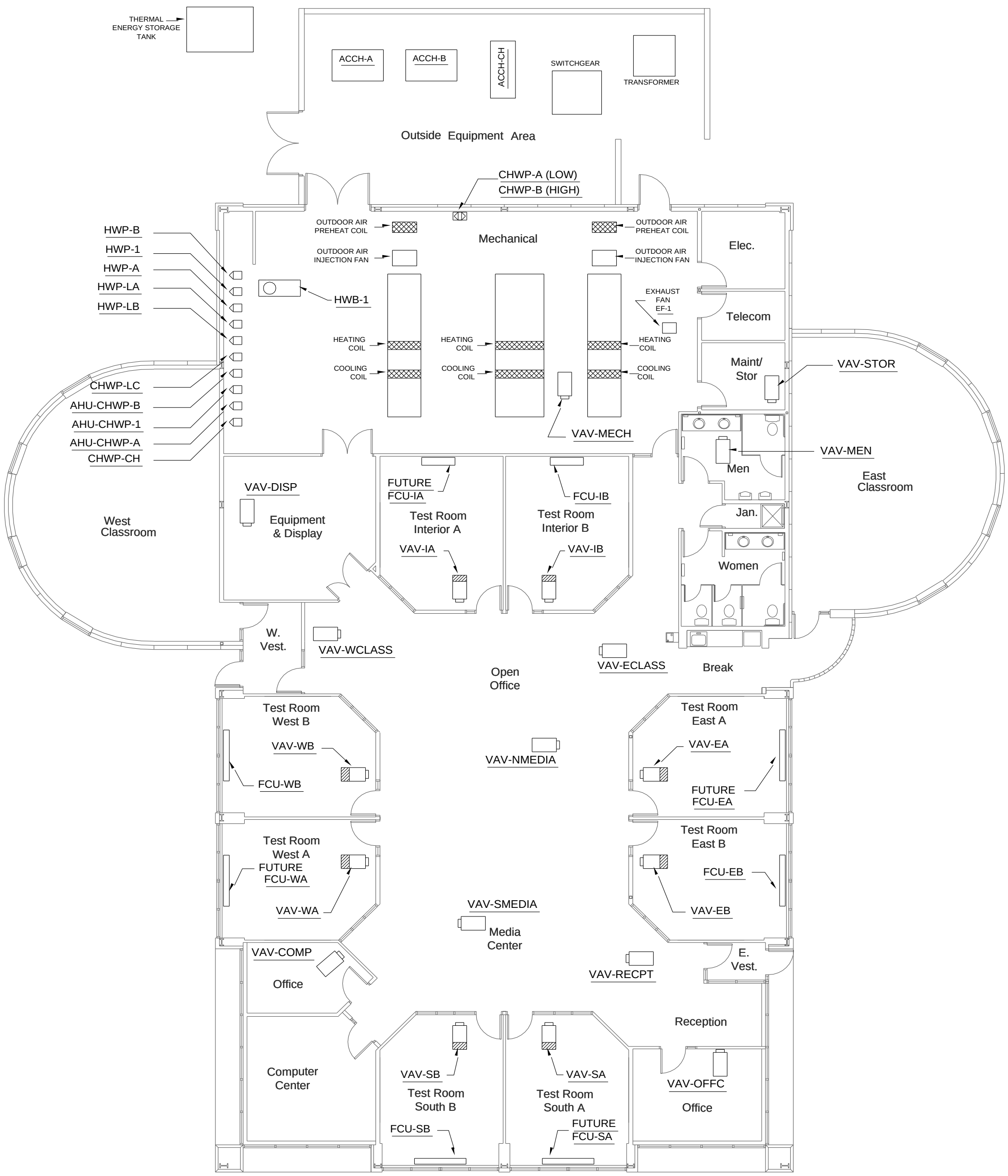


**Figure 0.4: Mechanical equipment location, image taken from ERS (2010)**

**Table 0.5: VAV box design specifications, recreated from ERS (2010)**

| Design Item | Exterior Test Rooms | Interior Test Rooms |
|---|---|---|
| Type | Single Duct, Pressure Independent | Single Duct, Pressure Independent |
| Size | 9 Inches | 7 Inches |
| Min/Max Airflow | 200 CFM / 1000 CFM | 80 CFM / 400 CFM |
| Hydronic Coil Flow Rate | 3.0 GPM | 2.0 GPM |
| Electric Coil Capacity | 2.0 kW | 5.0 kW |
| Electric Coil # of Stages / kW per Stage | 2 Stages / 1.0 kW per Stage | 3 Stages / 1.67 kW per Stage |

## Test Conditions

Each control strategy was tested under a variety of conditions. Tests were completed during various times of the year and under varying load conditions. Since the ERS provides the capability for testing different strategies side-by-side, one test strategy was often compared to another or to a fixed pressure strategy at the same time. During many of the tests, the strategies being compared were allowed to run for a period of time on one AHU and then were swapped so the effects of any system bias could be determined. For example, strategy 1 would be allowed to run on AHUA for three days during which time strategy 2 would run on AHUB. After the three days were completed, the strategies would switch so that strategy 1 was now on AHUB and strategy 2 was on AHUA.

Throughout testing, several different loading patterns were used. For the first two test series, the same load schedule was used for all test rooms. The initial test included two different loading schedules. The first loading schedule contained three distinct phases of loading. These phases were low load with low variability, high load with low variability, and a moderate load with high variability. The second loading schedule included only one phase which was a high load with high variability. See figures 2.5 and 2.6 (below) for a chart of the planned loading schedule for the initial tests.

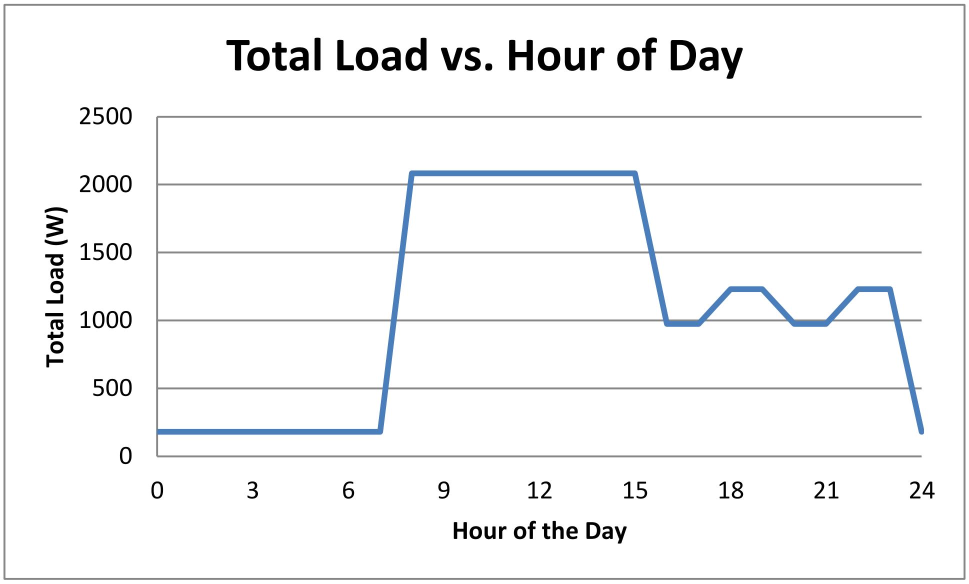


**Figure 0.5: Initial loading schedule consisting of three phases**

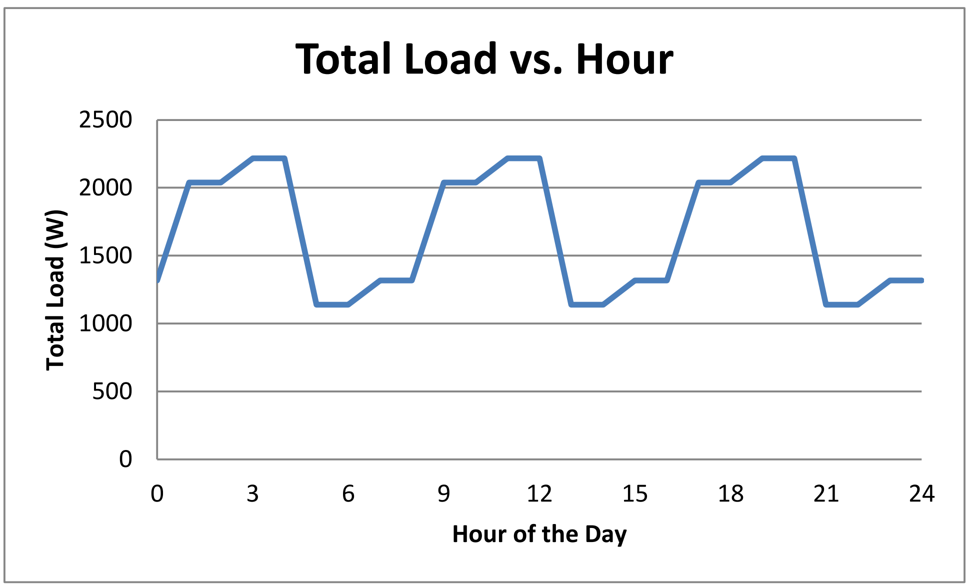


**Figure 0.6: Initial loading schedule with high load and high variability**

The second test series included a single load schedule that had the same three phases as the initial test, but in a different order (See Figure 2.7). By shifting the load schedule, it is more likely that the design conditions of the test rooms will not be exceeded by the combination of the artificial loads and the natural solar load. This load schedule was continually used for the exterior rooms for both the third and fourth test series. However, beginning in the third test series, the interior room load schedule was modified in order to avoid exceeding the design conditions of these rooms. See Figure 2.8 for the modified interior load schedule.

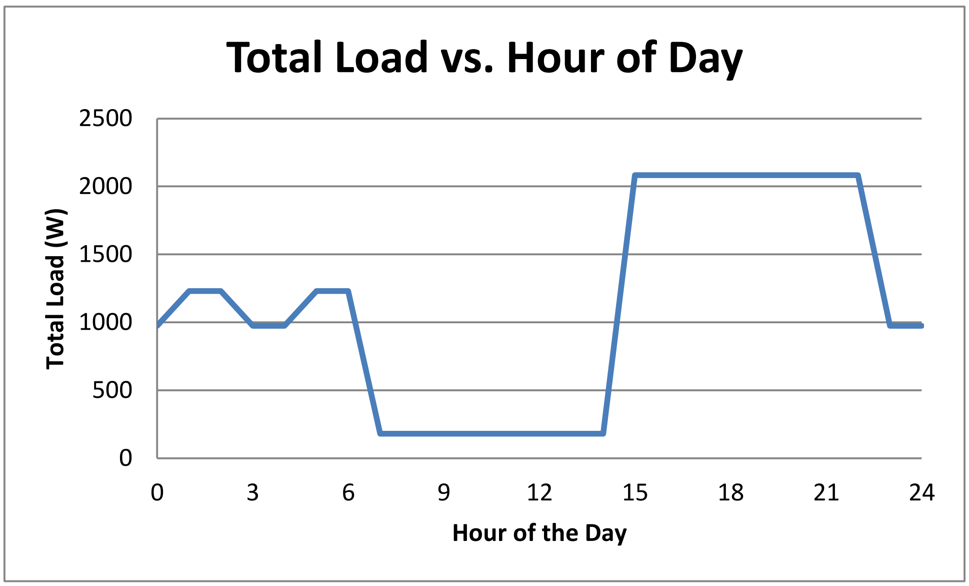


**Figure 0.7: Modified three phase loading schedule**

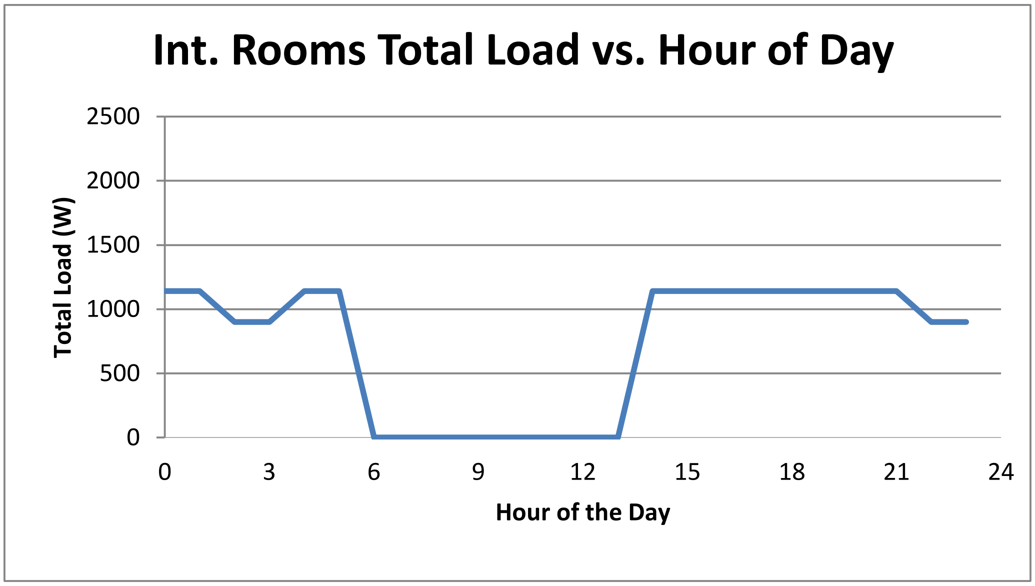


**Figure 0.8: Modified internal room loading schedule**

The fifth and final test included two different load schedules. The first load schedule was identical to those used in the third and fourth test (See Figures 2.7 and 2.8), while the second phase was changed to add additional variability. In the second phase, the large artificial load may cause the total room load to exceed design conditions and become an out of control zone. This was done in order to stress the control strategy to see how it would handle such a load. See Figure 2.9 and Figure 2.10 (below) for a chart of the planned external room and internal room loading schedule.

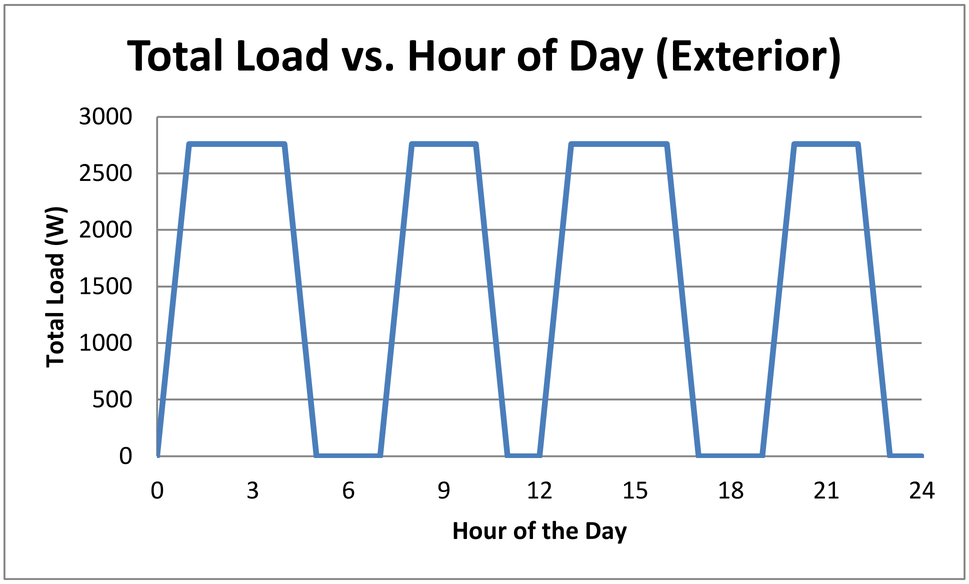


**Figure 0.9: Exterior room loading schedule for the second stage of Test 5**

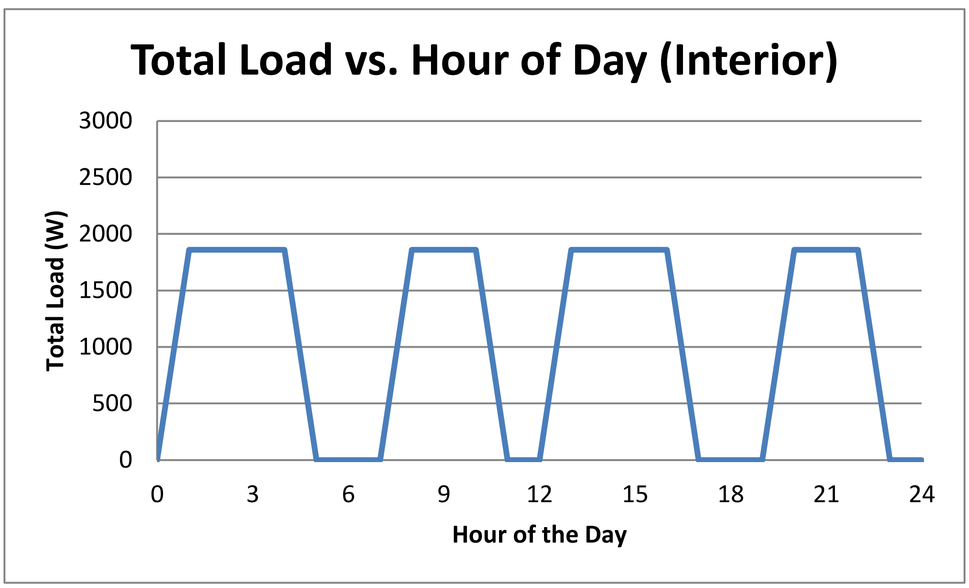


**Figure 0.10: Interior room loading schedule for the second stage of Test 5**

### Control Strategies to be Tested

Throughout the testing process, several variations of control strategies were implemented and observed. Arguably the most basic of these is the Proportional plus Integral (PI) controller. The PI controller consists of two terms, the proportional term and the integral term. For illustration purposes, a generic PI algorithm is shown below in Equation 2.1.

$$PI(t) = K_{prop}e(t) + K_{int}\int_0^t e(\tau)d\tau \qquad \text{(Eq. 2.1)}$$

In this equation, the first term is the proportional term and the second term is the integral term. The proportional term is found by calculating the present error, e, by taking the difference between the present set point and the present recorded value of a given control input and then multiplying this difference by a proportional gain factor, $K_{prop}$. In the case of static pressure reset based on damper position, this difference could be the difference between the recorded maximum damper position and the desired maximum damper position. The integral term requires keeping a running sum of all historical errors and then multiplying this sum by an integral gain factor, $K_{int}$. One potential problem of controlling with this method is that the integral term can become quite large before being multiplied by the gain factor. If this integral term becomes too large, it can cause additional overshoot and may lead to oscillating behavior. The chances of this overshoot and oscillation occurring are reduced if $K_{prop}$ and $K_{int}$ are properly set. Oscillation may also be minimized by using very small values for the gain constants, but this might also result in a very slow response.

PI control was used in two different reset strategies. The first was reset static pressure based upon maximum damper position and the second was reset fan speed based upon maximum damper position. These two methods calculated error from the desired maximum damper position and the recorded maximum damper position. The difference between the two is that one resets the supply fan speed set point while the other resets the supply duct static pressure set point. It was thought at the time that since static pressure varies proportionally with fan speed, it may be easier to control fan speed than to control duct static pressure directly.

In addition to PI control, a Trim and Respond (TR) control strategy was also tested. In its simplest form, this control method looks at a value for damper position and decides if it is too high or too low. If the observed value is too high, the controller may reduce or trim the controlled static pressure set point. Likewise if the observed value is too low, the controller may increase the static pressure set point, which is called a response. This type of control is extremely flexible and can be implemented in a variety of ways. It also allows the user to set different trim and respond rates which may be advantageous in some cases.

This basic strategy was implemented in three distinct ways. The first was the most simplistic; in this case if the maximum damper position exceeded a certain value, the duct static pressure set point would increase slightly. Similarly, if the maximum damper position was below a certain value, the duct static pressure set point would decrease slightly. This type of implementation can be advantageous because it is extremely simple to program and set up. The second implementation used a system of requests to increase or decrease the pressure set point. This system worked by creating an increase pressure request for each damper that exceeded the desired set point. It is also capable of creating multiple requests for recorded values that differ greatly from the desired set point. These requests then act like a multiplying factor, effectively increasing the response rate for greater numbers of requests. The controller then trims the static pressure set point by a small amount if there are no requests. In this way, the controller is always seeking to minimize static pressure while still supplying the necessary air flow to each zone.

The final implementation of the TR control strategy used a stepped response technique. In this technique, if the maximum damper position was within a specified range, the controller made no changes. If the damper position deviated from this range by a small amount, the controller created a small response in duct static pressure set point. If the deviation was large, the controller created a larger response in pressure set point. The steps were set up at small, moderate, and large deviations from the damper desired set point and created small, moderate, and large responses in duct pressure set point. This tiered response technique was used for both increasing and decreasing the pressure set point.

Throughout testing, the research team tested a variety of methods to attempt to stabilize system operation while saving fan energy. For each different type of strategy, different parameters were tested. For the PI control method, the test parameters were the desired maximum damper position, and the PI sum term. For the TR control method, the test parameters used were maximum damper position or maximum damper position range and trim rates. Although it is likely that additional parameters could have been tested and found to have an impact on stability and performance, this study is not an exhaustive one.

### Rogue Zone Strategies

A rogue zone can occur for a number of different reasons and can have a varied definition. For the purposes of this report, a rogue zone will be defined as a VAV box with a damper position that is driving the reset strategy a disproportionately large amount of the time. In addition, this damper position must be significantly greater than the majority of the other damper positions. For example, a zone may be controlling the reset strategy most of the time with a damper position of around 95% open, but this may not be considered a rogue zone if many other zone VAV damper positions are greater than 85% open. However, if this damper is at 95% open a majority of the time while most of the other damper positions are around 40% open, this zone may be considered a rogue zone.

There are many possible ways of dealing with rogue zones. While it is possible to deal with rogue zones in an automated way, this may not be desirable. It is far more useful to simply view data over a period of time to identify the rogue zone and then make a decision about what course of action to take. Since there are many different reasons why rogue zones occur, such as thermostat settings or equipment malfunction, it will be of the most benefit to investigate any rogue zone as it occurs.

Within the context of the testing phase at the ERS, rogue zones can be identified by the research team and then investigated to determine the cause and any effects on system or strategy performance. In addition to this, it is possible to introduce such a large artificial load into some of the rooms that it creates a rogue zone. This is a useful tool for determining the system's reaction to a known rogue zone or to a load that exceeds design conditions. If any undesired rogue zones occur while testing, the research team can eliminate them from the strategy altogether by eliminating their damper positions from the input to the control algorithm or by fixing the damper position.

## Performance Criteria

Performance can be measured in a variety of ways; in this case the performance was measured with a mix of primary and secondary performance criteria. Primary performance criteria included fan energy used, presence of oscillation, and temperature control. Secondary performance criteria included damper travel per hour, static pressure travel per hour, static pressure control, and flow rate control.

The primary criteria serve as the primary means of evaluating one control strategy against another. Since the control strategies are often run simultaneously, it is possible to compare them with a percentage difference. This is true in the case of fan energy used. The fan energy used is the summation of the fan energy in kWh used throughout the test cycle for both the supply fan and the return fan of the AHU's on which the test is conducted. This sum can then be compared between control strategies. Temperature is a primary consideration for occupant comfort as well as an indication of a control strategy's effectiveness. This parameter can be evaluated by finding the difference between the room temperature set point and the temperature as recorded in the room. The presence of oscillation is not something that can be easily confirmed mathematically, but must be qualitatively observed and documented. Oscillation in this case primarily refers to oscillation in the static pressure level or in damper positions. Since these two parameters are closely related, an oscillation in one should be represented by an oscillation in the other. Oscillation can be interpreted in a number of ways, see Figure 2.11 (below) for an example of what is considered oscillatory behavior in this experiment.

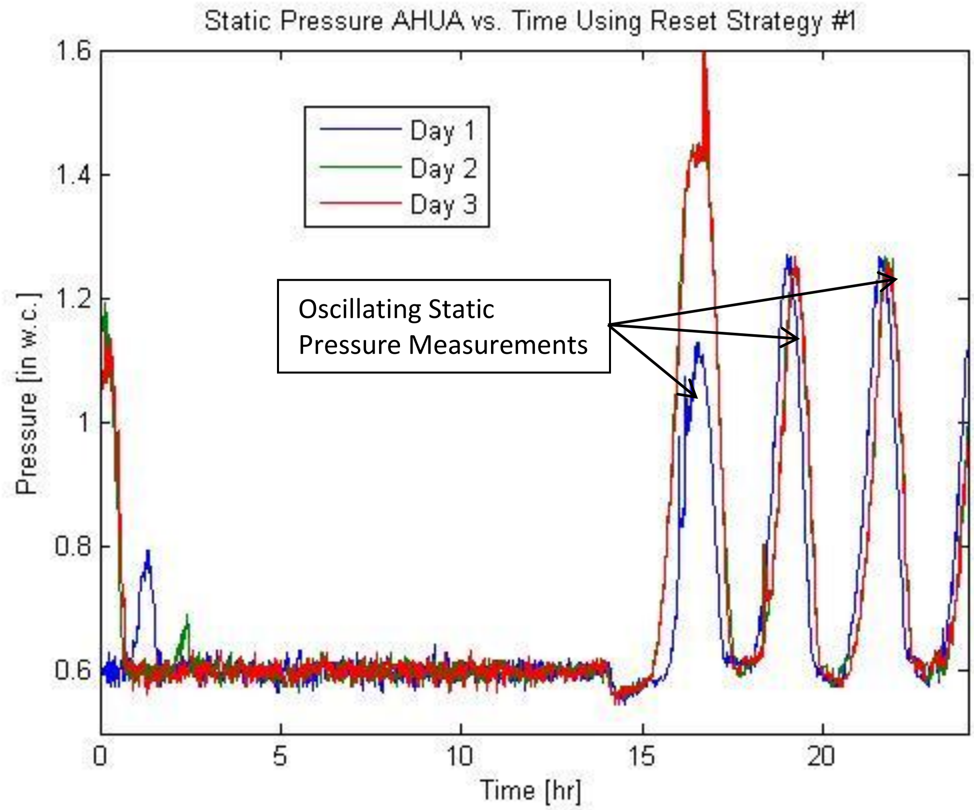


**Figure 0.11: An example of oscillation observed in this experiment**

The secondary criteria allow additional comparisons to be made between control strategies, but may not impact occupant comfort or energy usage. Damper travel per hour is a measure of the summation of the absolute value in damper position between each data point for each test divided by the number of test hours. This measurement is meant to give an idea of the level of wear-and-tear on the actuating mechanism on a damper. In this way it may be possible to make some inferences about additional maintenance costs. Static pressure travel per hour is measured and calculated in a similar way, but is meant to give an indication of potential oscillation or rapid changes in duct pressure. Static pressure control is a summation of the difference between the measured duct static pressure and the duct static pressure set point. This measurement is intended to provide a means of evaluating the ability of a control strategy to adhere to the assigned set point. Flow rate control is similar to static pressure control in that it is the summation of the differences between flow rate set point and measured flow rate for each damper at each data point. This measurement is intended to show a control strategy's ability to provide adequate air flow to each test room.

### Calculations

Calculating the performance parameters is a straightforward task. As a reminder, these performance metrics are fan energy consumed, temperature control, presence of oscillation, static pressure control, static pressure travel per hour, damper travel per hour, and flow rate control. Details on how these parameters are calculated can be found in the next few passages.

Fan energy consumed is calculated from the fan power data available in the Metasys data. The data is collected on a one minute interval in the unit of Watts. This measurement is totaled over the course of a particular test and then converted from Watt-minutes to kWhr using standard conversions. The total kWh used by each AHU is then compared using a simple percentage difference with the experimental control value as the reference. The accuracy of the power measurements is +/- 0.2% of the reading plus an additional +/- 1.6 Watts for both the supply and return fan.

Temperature control is calculated based on the temperature data recorded from each room and a cooling set point of 72 $^{o}$F. During each test, an arithmetic mean and variance is calculated for each test room as well as an aggregate mean and variance for all test rooms served by each air handler. The two sets of aggregate values are compared by a simple difference. The accuracy of the temperature measurements is +/- 0.18 $^{o}$F.

Presence of oscillation is not a calculated data comparison. Instead, the duct static pressure data is plotted against the time of the test. Upon viewing the plot, a judgment is made on the presence of oscillation and then this oscillation is discussed if present.

Static pressure control is based upon the duct static pressure, as measured by the AHU, and the static pressure set point. The difference between these two values is then calculated before finding the arithmetic mean and variance for each AHU. These means should ideally be close to zero, and their difference is used to compare AHU performance. The accuracy of the pressure measurements is +/- 0.5% of full span output.

Static pressure travel per hour and damper travel per hour are calculated in exactly the same way. In either case, the difference is taken between successive values on a single AHU. The absolute value of this difference is then totaled over the entire test and then divided by the number of test hours. This aggregate static pressure or damper travel per hour is then compared for each AHU with a simple difference. The AHU with the least travel per hour will be considered to perform better. The accuracy of the damper positions measurements is unknown, and the accuracy of the static pressure measurements can be found in the previous paragraph.

Flow rate control is found in much the same way that static pressure control is found. That is, the difference is taken between the VAV flow rate and the flow rate set point for each VAV box. The arithmetic mean and variance are then found for each room in the test as well as the aggregate value for each AHU. The aggregate values are then compared with a simple difference. The AHU with the smaller aggregate value will be considered as performing better. The accuracy for the VAV box flow rates is not available from the ERS.

## Summary

Testing at the ERS, with the abundance of data collection capabilities and calibrated equipment, provides the ability to study HVAC systems in a laboratory like setting. The two test HVAC units will have a variety of strategies tested on them under several different loading conditions. These test results can then be compared with the calculation of some simple performance parameters that reflect research goals.

# CHAPTER 3: ERS RESULTS

From July 2009 through January 2011, five series of tests were run at the ERS testing facility. During these tests, several different experimental control strategies were employed as outlined in Chapter 2. These strategies are:

Strategy 0: Fixed pressure strategy that may or may not be changed on a schedule.

Strategy 1: PI pressure reset based on maximum damper position.

Strategy 2: Trim and respond based on maximum damper position.

Strategy 3: PI fan speed reset based on maximum damper position.

Strategy 4: Trim and respond based on the number of pressure requests.

Strategy 5: Tiered trim and respond based on maximum damper position.

In analyzing the test data, a numbering convention was created. The numbering convention will take the form of “Test 2.3a.” This numerical test identifier uses the first numeral to the left of the decimal point to identify the test series. The first numeral to the right of the decimal place is used to identify the test strategy. Finally, the alphanumeric value at the end is used to indicate the particular test run within that series. In the example of “Test 2.3a,” this would mean that this is the first in a series of tests run during Test 2 that tested the performance of control strategy three.

Before proceeding with the analysis of the test data, it is important to clarify a few assumptions made in data interpretation. These assumptions are:

1. Some equipment operation was not able to be measured directly. However, there are on/off signals available for most of these equipment data points. For the purposes of

analysis, it was assumed that if a device was turned on, that it was operating as expected unless otherwise proven.

2. The equipment operation, including power levels, outlined in Price and Smith (2000) and ERS (2010) is accurate and up to date.
3. All of the power applied to any piece of equipment in the test room is transferred into the test room as a thermal load with the exception of data collection and control equipment which will be considered to have a negligible load impact.

## Similarity Tests

Throughout the course of testing, it was necessary to prove that the two AHU's operated similarly to one another before testing any experimental control strategies. Indeed, this was the main focus for Test 1. In addition to Test 1, a similarity test was applied at some point during each test series to verify continued similar operation. The word "similar" as used above, is simply meant to imply that the two systems operate closely enough to one another that any systemic effects from either AHU can be ignored. This definition is applied a bit differently for each performance criterion. The performance criteria are fan energy consumed, temperature control, presence of pressure oscillation, static pressure travel per hour, static pressure control, damper travel per hour, and flow rate control. These criteria appear in Table 3.1 below along with their respective similarity thresholds.

**Table 0.1: Similarity thresholds used for data analysis**

| Similarity Rules | |
|---|---|
| Criterion | Similarity Threshold |
| fan energy | ± 5% |
| temperature control | ± 0.3 $^{o}$F |
| static pressure travel per hour | ± 0.2" w.c. |
| static pressure control | ± 0.2" w.c. |
| damper travel per hour | ± 5% |
| flow rate control | ± 50 cfm |

The similarity rules shown above were chosen based upon the expected range scale of the performance criteria used. In the cases of temperature control, static pressure travel per hour, and static pressure control, the value was set at 5% of the maximum theoretical difference range. For the criteria of fan energy, damper travel per hour, and flow rate control the value was set at 2.5% of the maximum theoretical difference range (not to be confused with the +/- 5% shown in the table for fan energy and damper travel per hour which stand for % difference and % open, respectively). The reason for the tighter thresholds on these variables is that they play a more important role in the study. The fan energy used will be one of the primary deciding factors when it comes to choosing a reset strategy to implement in a real building. As for the damper travel and flow rate criteria, they are directly related to independent variables in the control strategy. As such, it is prudent to hold them to a more stringent standard.

Applying these thresholds to the values calculated for each performance parameter yields the information shown in Table 3.2 (below). In most cases, the AHU's appear very similar in operation to one another. The most common difference occurred in static pressure travel per hour. This may be due to the inherent difficulty in controlling static pressure exactly during the course of operation. When viewing the static pressure plots, there is a great deal of what appears to be “noise” in the measurements. This “noise” was not filtered out when calculating that static pressure travel criterion. Furthermore, there is a small difference in the amplitude of this phenomenon between AHU’s. See Figure 3.1 (below) for a plot of one of the tests that exhibits this behavior. It is likely that this frequent small difference between successive static pressure measurements contributes greatly to this difference in static pressure travel. However, the similarity tests by and large suggest that the AHU’s operate similarly enough to be considered the same for purposes of analysis. This can be stated because there are more cases of similarity than difference, even in the individual performance criterion categories.

**Table 0.2: Results from the initial similarity test**

| Similarity Test Results Summary | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | Test Run | | | | | | |
| | 1.0 | 2.0a | 2.0b | 3.0a | 3.0b | 4.0 | 5.0 |
| Fan Energy | 2.52% | 0.35% | -0.15% | -2.11% | -3.78% | -4.71% | 0.08% |
| Temperature | 0.17 | 0.11 | 0.12 | 0.00 | 0.00 | 0.01 | 0.14 |
| Static Pressure | | | | | | | |
| Oscillation | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Travel | 0.01 | 0.22 | 0.28 | 0.24 | 0.19 | 0.02 | 0.09 |
| Control | 0.01 | 0.01 | 0.01 | 0.00 | 0.03 | 0.00 | 0.01 |
| Damper Travel | -3.58% | -2.77% | -2.70% | -7.46% | 0.33% | -3.20% | 1.45% |
| Flow Rate Control | -7.32 | -2.02 | -2.40 | -0.70 | -1.71 | -23.01 | 0.88 |
| - Values shown are differences between AHU means.<br>- Shaded values indicate disimilar behavior. | | | | | | | |

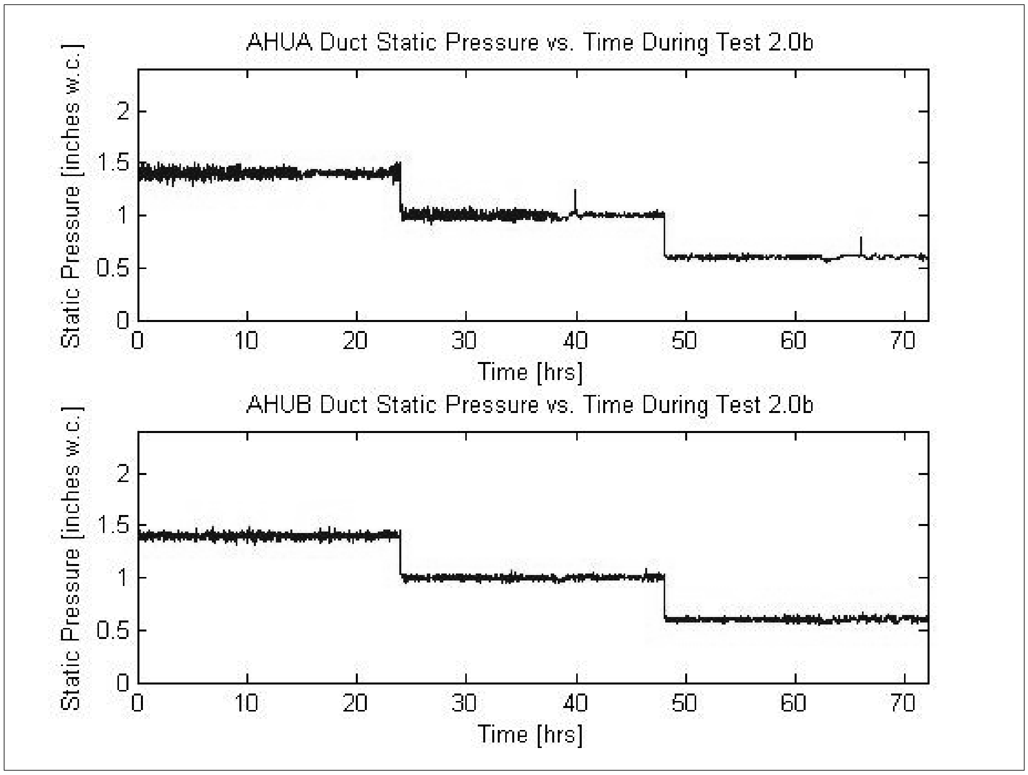


**Figure 0.1 Duct static pressure over time in AHUA and AHUB using a scheduled fixed pressure strategy, note the difference in noise amplitude between the two plots**

With similar operation verified to be a reasonable assumption, there is one additional condition which must be addressed before proceeding with the strategy analysis. The applied artificial load must be verified in order to conclude that the systems operate as expected and that similar loading is applied to each test strategy in a test series.

One problem in particular presented itself early on in the artificial load analysis. Due to the nature of the system, some loads may come on or turn off at different times in different rooms. The difference in time may only be a few minutes, but this can strongly impact the mean difference in calculated artificial load because of the size of some of the loads imposed. This resulted in several room pairs with a large mean difference in calculated artificial load even though there was little effective difference between the two.

For example, it will make little difference in the grand scheme of the test if one stage of baseboard heat comes on five minutes later than its counterpart. For this reason a qualitative approach was taken instead. The loads were plotted over the course of the test for each room pair. These plots were then compared for any apparent major differences.

At this point, another major problem also presented itself. Some of the data was corrupted and resulted in false calculation data. This occurred during the second test series in the South A room as well as throughout most of the tests in the West A room. In specific, the South A room has the second stage baseboard heat signal recorded as -999.99 (an error value) for several minutes at a time during the second test series. This value is also present in the Android 2 signal from the West A room. In both cases, this value should either be a 0 or a 1 to indicate an on or off signal. Since the error value was recorded, it must be assumed that the true artificial load is unknown in these rooms.

Further analysis of this data corruption yields another way to assume that the artificial loads applied are similar to one another for each room pair. In the case of the similarity test runs, it can be observed that with similar control strategies there is no significant difference between the other performance criteria measured for each room. For example, even though the artificial loads are unknown, temperature control, flow rate control, and fan energy consumed are very similar in all of the tests where the data was corrupted. This lends credence to the notion that the artificial loads can be assumed to be the same even though the corrupted data doesn't allow this conclusion explicitly. In addition, the corrupted data may not matter that much. In the case of the South A room, the error values are only present for a few minutes at a time while the Android 2 signal in the West A room is not a major contributor to the uncertain load at only 163 Watts. These facts, along with the AHU performance data, provide sufficient support for the artificial load similarity assumption. Table 3.3 (below) gives the results of the qualitative analysis of the artificial loads. The “unknown” conclusion will remain in place for posterity even though from this point forward, the artificial loads applied in those instances will be assumed to be similar.

**Table 0.3: Results from the artificial load similarity test**

| False Load Similarity Summary | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Room Pairs | Test Run | | | | | | | | | |
| | 1.0 | | | | | | | | | |
| East | similar | | | | | | | | | |
| Internal | similar | | | | | | | | | |
| South | similar | | | | | | | | | |
| West | similar | | | | | | | | | |
| | 2.0a | 2.0b | 2.1a | 2.1b | 2.2a | 2.2b | 2.3a | 2.3b | | |
| East | similar | similar | similar | similar | similar | similar | similar | similar | | |
| Internal | similar | similar | similar | similar | similar | similar | similar | similar | | |
| South | unknown | unknown | similar | similar | unknown | unknown | unknown | unknown | | |
| West | similar | similar | similar | similar | similar | unknown | unknown | unknown | | |
| | 3.0a | 3.0b | 3.1 | 3.2 | 3.3 | 3.4 | | | | |
| East | similar | similar | similar | similar | similar | similar | | | | |
| Internal | similar | similar | similar | similar | similar | similar | | | | |
| South | similar | similar | similar | similar | similar | similar | | | | |
| West | unknown | unknown | unknown | unknown | unknown | unknown | | | | |
| | 4.0 | 4.1a | 4.1b | 4.1c | 4.2a | 4.2b | 4.3a | 4.3b | 4.5a | 4.5b |
| East | similar | similar | similar | similar | similar | similar | similar | similar | similar | similar |
| Internal | similar | similar | similar | similar | similar | similar | similar | similar | similar | similar |
| South | similar | similar | similar | similar | similar | similar | similar | similar | similar | similar |
| West | unknown | unknown | unknown | unknown | unknown | unknown | unknown | unknown | unknown | unknown |
| | 5.0 | 5.5a | 5.5b | 5.5c | 5.5d | 5.5e | 5.5f | 5.5g | | |
| East | similar | similar | similar | similar | similar | similar | similar | similar | | |
| Internal | similar | similar | similar | similar | similar | similar | similar | similar | | |
| South | similar | similar | similar | similar | similar | similar | similar | similar | | |
| West | unknown | unknown | unknown | unknown | unknown | unknown | unknown | unknown | | |

## Test Series 2

With similarity established with a reasonable certainty, the experimental control strategies can now be analyzed. A summary for Test 2 is shown in Table 3.4 below. More specific values and tables can be found in the appendix. For the sake of analysis, specific number values will be discussed in conjunction with the results shown in Table 3.4 below. One important point in the analysis is that the similarity thresholds for the performance criteria were used here to establish whether or not a particular control strategy was clearly better in regard to a particular performance criterion. This was done for reasons of consistency. After using a series of thresholds to determine if the systems operate similarly, it would be contradictory to define a different set of thresholds to determine if the systems operate differently.

For the series 2 tests, the following strategies were evaluated:

- Test 2.1 – Strategy 1: PI static pressure reset based on maximum damper position.
- Test 2.2 – Strategy 2: Trim and respond static pressure based on maximum damper position.
- Test 2.3 – Strategy 3: PI fan speed reset based on maximum damper position.

**Table 0.4: Comparison of control strategy results for Test Series 2**

| Test 2 Results Summary | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Test Run | | | | | | | | | | | |
| | 2.1a | | 2.1b | | 2.2a | | 2.2b | | 2.3a | | 2.3b | |
| comparisons | rank | value | rank | value | rank | value | rank | value | rank | value | rank | value |
| Fan Energy | B | 14.65% | B | 16.01% | B | 15.71% | B | 8.53% | - | | - | |
| Temperature | - | | - | | - | | - | | - | | - | |
| Static Pressure | | | | | | | | | | | | |
| Oscillation | y | | y | | y | | y | | y | | y | |
| Travel | B | 0.36 | B | 0.31 | B | 0.20 | W | 0.31 | W | 0.78 | - | |
| Control | - | | - | | - | | - | | W | 0.45 | W | 0.21 |
| Damper Travel | - | | - | | - | | W | 10.98% | W | 24.74% | W | 16.99% |
| Flow Rate Control | - | | - | | - | | - | | - | | - | |

- a "B" is used to indicate when the test strategy performed better than the fixed pressure strategy, "W" is used to indicate when the test strategy performed worse, and a "-" is used to indicate when the two are similar. Values will not be given for the case of similarity.

- "yes" or "no" will be used to indicate presence of oscillation. These ratings are shown as "y" or "n."

- Shaded rankings indicate an improvement in performance.

Table 3.4 represents the results of the first round of control strategy testing. A few items of note on the table are that the shaded cells represent when an experimental strategy outperformed a fixed pressure strategy in a particular performance criterion. Unshaded cells indicate when an experimental strategy performed similar to or worse than a fixed pressure strategy.

From the table above, it is possible to determine which control strategies outperformed the fixed pressure strategy. The results indicate that Strategy 1, the PI reset of static pressure strategy, outperformed the fixed pressure strategy more consistently than did the other two test strategies. Strategy 1 was able to reduce static pressure travel per hour in both tests while also consistently saving energy. Strategy 2 was able to save energy, but performed worse in one test on static pressure travel per hour and on damper travel per hour. Strategy 3 performed worse in the areas of static pressure travel per hour, static pressure control, and damper travel per hour. In all other unmentioned categories, the experimental strategies performed on a par with the fixed pressure strategy.

Oscillation of static pressure level is one of the potential instability problems mentioned in the research proposal used for this study. After the second test series, it can be concluded that this oscillation is present in all three experimental control strategies. However, the oscillation present in the experimental strategies takes on specific attributes for each strategy. Figures 3.2, 3.3, and 3.4 (below) contain examples of the types of oscillation present for Strategies 1, 2, and 3 respectively.

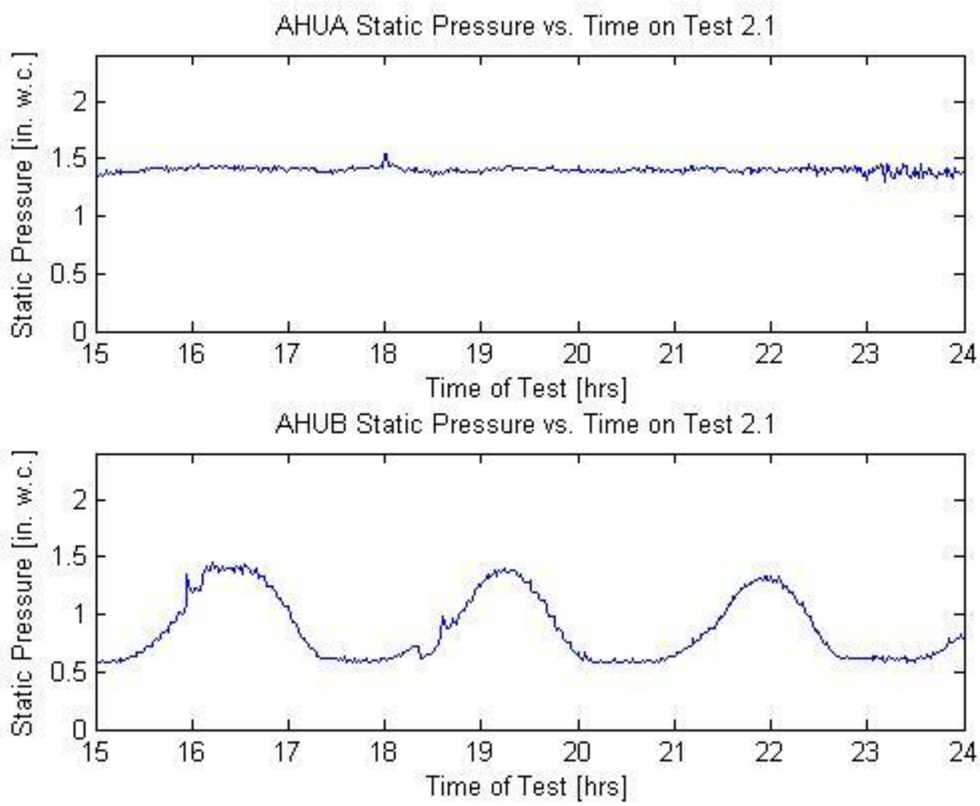


**Figure 0.2: Detail of oscillation present when employing Strategy 1, PI reset of static pressure set point based on maximum damper position**

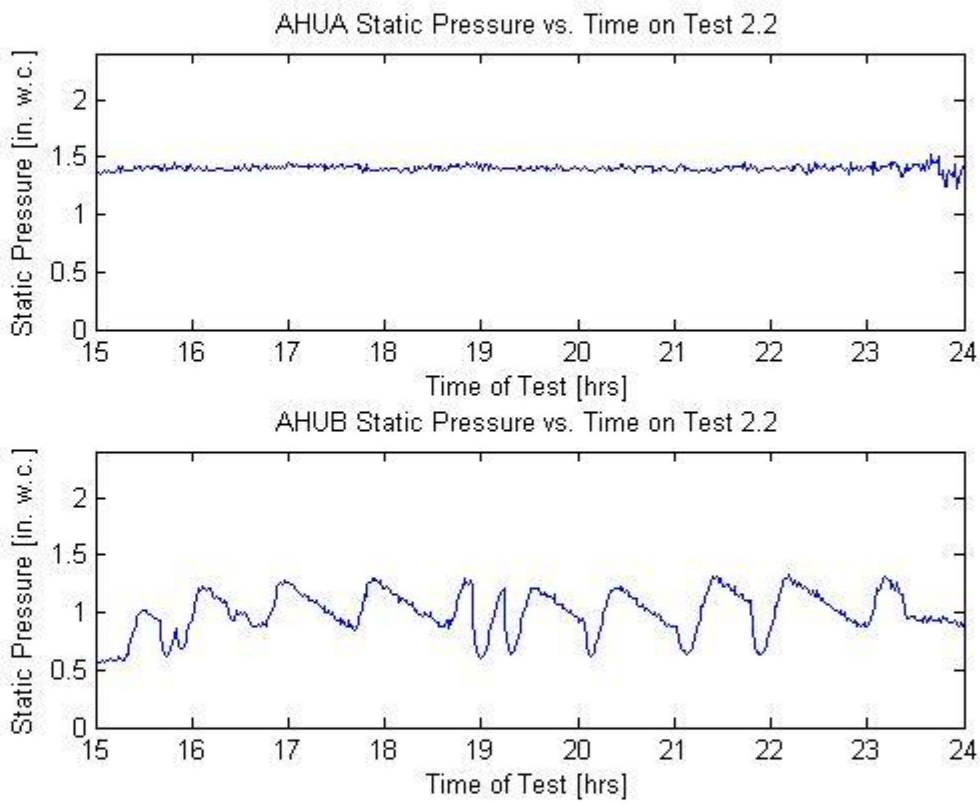


**Figure 0.3: Detail of oscillation present when employing Strategy 2, Trim and Respond static pressure set point based on maximum damper position**

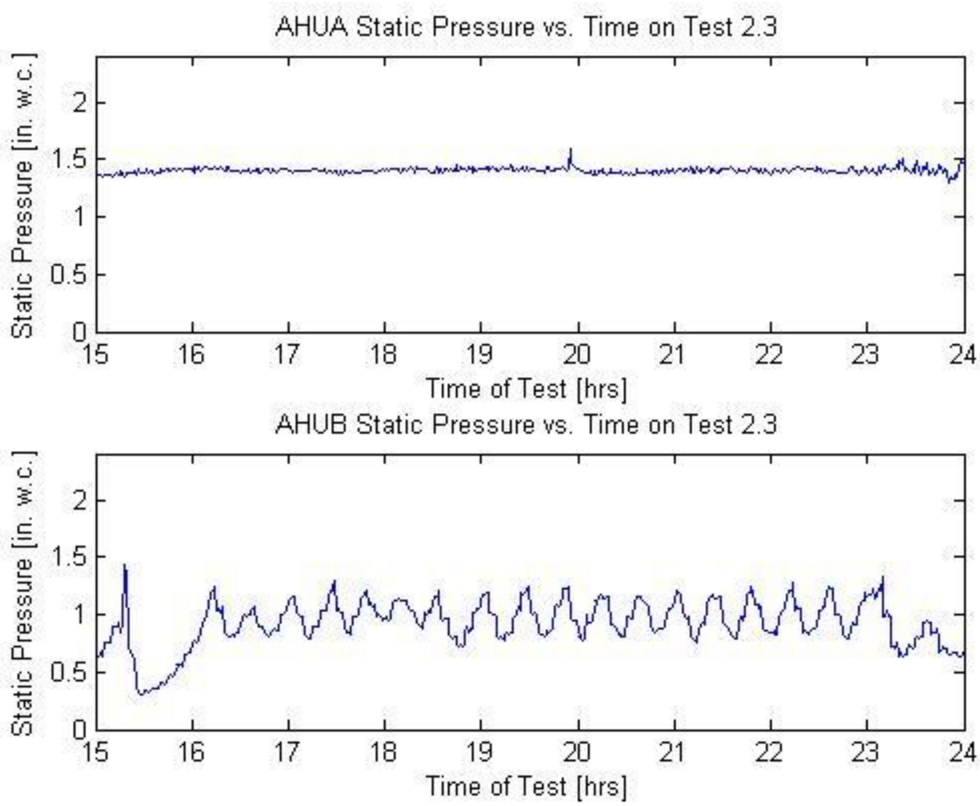


**Figure 0.4: Detail of oscillation present when employing Strategy 3, PI reset of fan speed based upon maximum damper position**

The types of oscillation shown above are very distinct from one another. The oscillation present for Strategy 1 is reminiscent of an undamped second order response, the oscillation during the use of Strategy 2 strongly resembles a saw-tooth waveform, and the oscillation observed during the use of Strategy 3 appears to resemble a triangular waveform but with much more jagged, irregular features. Although these three different types of oscillation seem to have little in common, their presence in all of the static pressure reset strategies may indicate that the oscillation itself may have a common underlying cause that is external to the reset control strategy.

To summarize the results of Test 2: All of the experimental control strategies displayed some sort of oscillatory behavior during the test. However, Strategy 1 and Strategy 2 were able to save fan energy over the course of the test. Overall, the majority of the performance criteria indicated performance similar to a fixed pressure strategy over the course of this test. The strategy that performed the worst was Strategy 3. This strategy performed similar to the fixed pressure strategy or worse for the duration of its employment. On the other hand, Strategy 1 performed the best in this test series as it performed better than or similar to the fixed pressure strategy for each performance category.

At this point, it would be premature to eliminate any strategy altogether. Some modifications to the control parameters may allow marked improvement in the next test series. Test 3 does exactly this; it seeks to observe any changes in the performance criteria by adjusting different parameters. Specifically, Test 3 was focused primarily on how the parameter changes affected the oscillatory behavior.

## Test Series 3

Test series 3 saw the introduction of the fourth pressure reset strategy, Trim and Respond based upon a number of pressure requests. This strategy creates a pressure increase request for each damper position greater than a specified level. There are also provisions for making several pressure increase requests for each damper above an even higher specified level. When no dampers exceed the increase thresholds, the static pressure is trimmed.

In addition to the introduction of a new control strategy, the internal room artificial load was altered. Under the previous tests, the internal room load exceeded the room design conditions. By reducing the internal room load, it was possible to determine to what extent the overloaded room contributed to unstable behavior. As in Test Series 2, the similarity thresholds will be used to compare strategies to a fixed pressure control strategy.

For the series 3 tests, the following strategies were evaluated:

- Test 3.1 – Strategy 1: PI static pressure reset based on maximum damper position.
- Test 3.2 – Strategy 2: Trim and respond static pressure based on maximum damper position.
- Test 3.3 – Strategy 3: PI fan speed reset based on maximum damper position.
- Test 3.4 – Strategy 4: Trim and respond static pressure reset based on pressure requests.

**Table 0.5: Comparison of control strategy results for test series 3**

| Test 3 Results Summary | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Test Run | | | | | | | |
| | 3.1 | | 3.2 | | 3.3 | | 3.4 | |
| comparisons | rank | value | rank | value | rank | value | rank | value |
| Fan Energy | B | 15.59% | B | 18.14% | B | 26.46% | B | 17.70% |
| Temperature | | | | | | | | |
| Static Pressure | | | | | | | | |
| Oscillation | Y | | N | | N | | N | |
| Travel | B | 0.55 | B | 0.33 | | | B | 0.47 |
| Control | | | | | W | 0.21 | | |
| Damper Travel | | | | | W | 52.07% | | |
| Flow Rate Control | | | | | | | | |

- a "B" is used to indicate when the test strategy performed better than the fixed pressure strategy, "W" is used to indicate when the test strategy performed worse,and a "-" is used to indicate when the two are similar. Values will not be given for the case of similarity.

- "yes" or "no" will be used to indicate presence of oscillation. These ratings are shown as "Y" or "N."

- Shaded rankings indicate an improvement in performance.

The results of test series 3 are shown in Table 3.5 (above). As with previous tables, the shaded cells indicate that the experimental control strategy showed an improvement in performance over the fixed static pressure strategy. Unlike previous testing, all of the experimental control strategies saved some fan energy over the fixed pressure strategy. Strategy 3 saved the most energy by percentage at 26.46%. However, this strategy also performed the worst in the categories of static pressure control and damper travel per hour. In the performance category of static pressure travel per hour, strategies 1,2, and 4 all showed some improvement over the fixed pressure strategy. As in test series 2, this appears to be due to the reduced noise amplitude present in the static pressure measurement. Finally, in the static pressure oscillation category, strategies 2, 3 and 4 showed little if any oscillatory behavior in static pressure. Strategy 1 still displayed wild swings in static pressure during two of the high load time periods. Figures 3.5, 3.6, 3.7 and 3.8 (all below) contain plots of the duct static pressure over time comparing the experimental strategies to their fixed pressure counterparts.

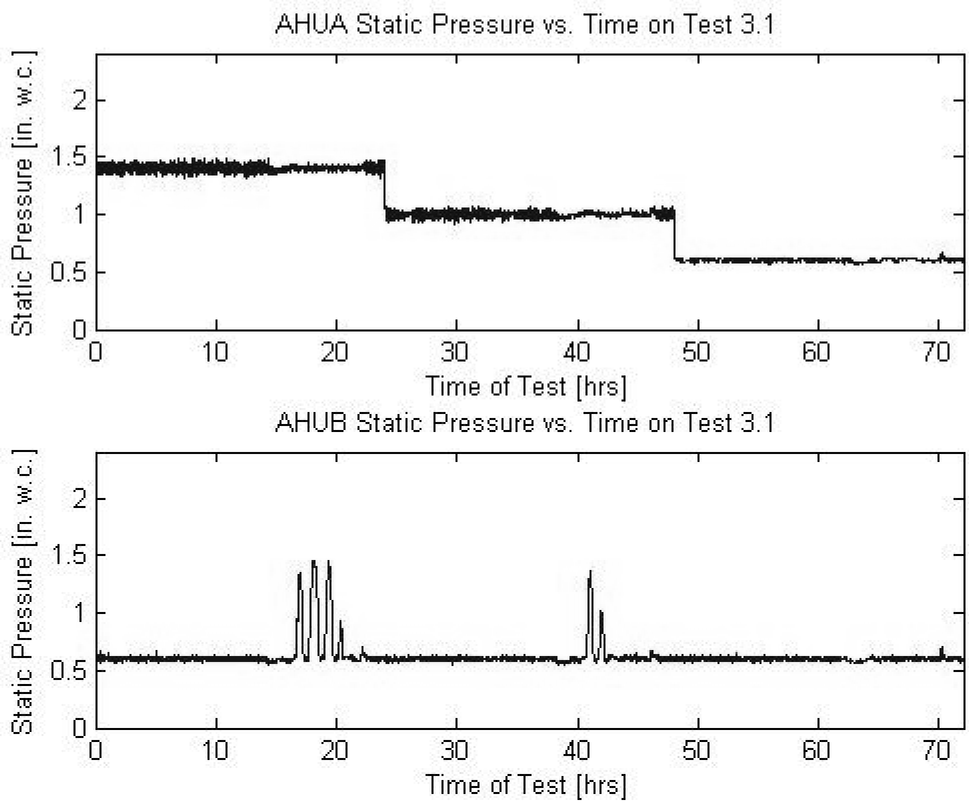


**Figure 0.5: Static pressure plots when employing a scheduled fixed pressure strategy on AHUA (top) and Strategy 1, PI reset of fan speed based on maximum damper position, on AHUB (bottom)**

The oscillations present in Figure 3.5 resemble that of previous tests for this strategy. During periods of high loading (even with the reduced internal loads), there were wild swings from the minimum to near the maximum static pressure set points of 0.6 in. w.c. and 1.4 in.

w.c., respectively. However, these oscillations only occurred in two out of three high loading periods. Further investigation is needed to determine any possible systemic causes of this oscillation as well as any environmental factors that may contribute to its presence or its apparently intermittent behavior.

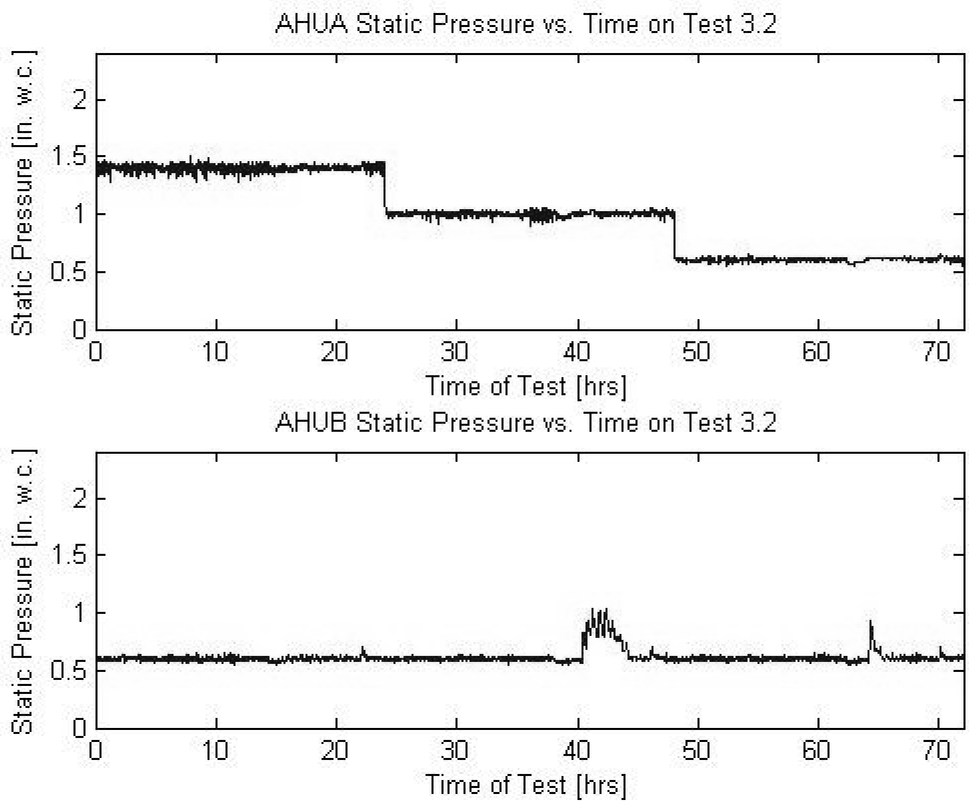


**Figure 0.6: Static pressure plots when employing a scheduled fixed pressure strategy on AHUA (top) and Strategy 2, Trim and Respond of static pressure set point based on maximum damper position, on AHUB (bottom)**

The static pressure plot depicted above in Figure 3.6 shows the static pressure response from Strategy 2 during test series 3 compared to the scheduled fixed static pressure strategy. At one of the peak loading times, shown on the plot beginning at 40 hrs into the test, there is an increase of static pressure that lasts for a few hours and appears to “hunt” for a constant static pressure at its peak. This is somewhat different from the oscillation observed previously using this control strategy. Because of the significant improvement in duration and amplitude compared to Test 2, and because the amplitude is about the same as some of the noise in AHUA, this hunting at the peak of the static pressure plot was not considered oscillation. Still, the fact that this occurred in only one of the three peak loading periods implies an environmental trigger rather than a systemic one.

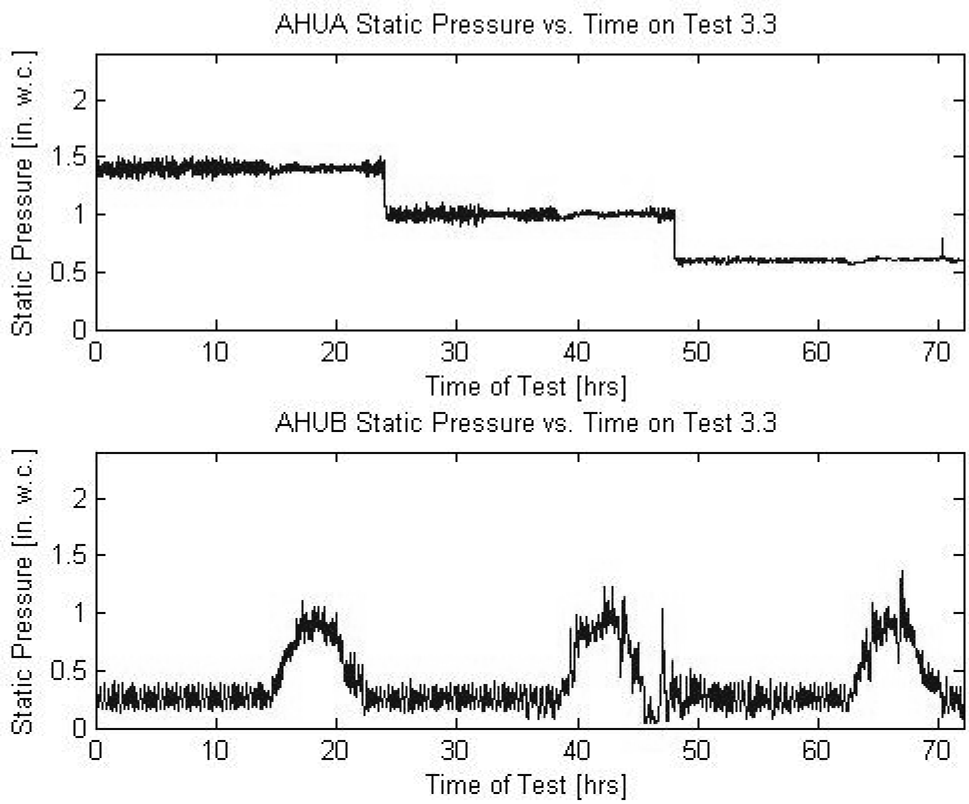


**Figure 0.7: Static pressure plots when employing a scheduled fixed pressure strategy on AHUA (top) and Strategy 3, PI reset of fan speed based on maximum damper position, on AHUB (bottom)**

The pressure plot of Strategy 3 compared to the fixed pressure strategy, shown above in Figure 3.7, is unlike the plots of the other strategies. The first thing to take notice of is the presence of increased noise amplitude in recorded static pressure level. This increased amplitude explains the poor performance of the static pressure control criterion. Even at the minimum static pressure set point, the strategy seems unable to adhere reliably to the set point. Also of note is that there was an increase in static pressure for each period of high loading, something not observed in Tests 3.1 and 3.2. In addition, there does not appear to be any oscillatory behavior (other than increased “noise”), although this could simply be obscured by the noise level.

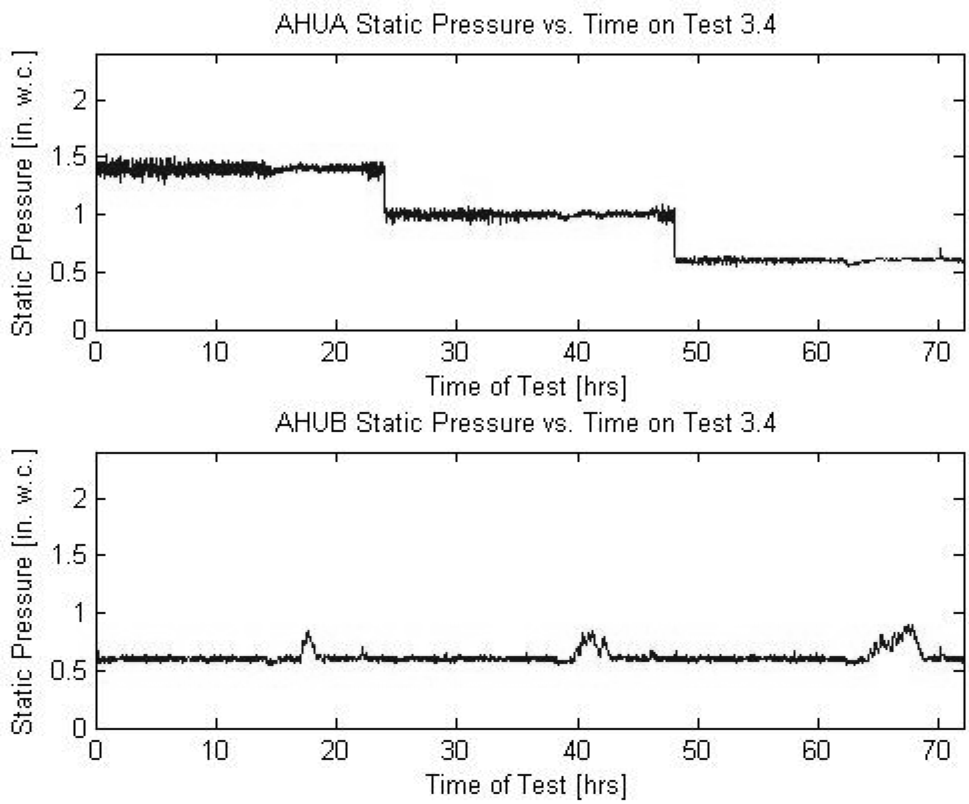


**Figure 0.8: Static pressure plots when employing a scheduled fixed pressure strategy on AHUA (top) and Strategy 4, Trim and Respond of static pressure based on pressure requests, on AHUB (bottom)**

Strategy 4 performed extremely well during Test 3. Figure 3.8 above depicts the static pressure when using the control strategy compared to the scheduled fixed static pressure. For each period of maximum loading, there appears to be a rise in static pressure in response. These rises appear to be very minimal and do not approach the maximum static pressure set point as in the first strategy. There is also no oscillation phenomenon present in the static pressure plot for the reset strategy.

One important trend to note in Figures 3.5, 3.6, 3.7, and 3.8 is that noise level on the scheduled fixed static pressure seems to decrease with static pressure set point, and also appears to decrease during times of peak loading. Further investigation is needed to identify the cause of this noise and to determine its impact, if any, on the static pressure reset strategies. A likely conclusion is that during high load and low pressure scenarios, damper positions would presumably be at or near 100% open. At this damper position level, there would be little effect on duct static pressure from minor damper position movements.

The results of Test 3 showed that overloading a zone likely contributes to the unstable behavior previously observed. In all cases, unstable oscillation was intermittent during Test 3 compared to universally present in Test 2. Also, with the exception of Strategy 1, the unstable oscillation was virtually eliminated from the static pressure reset strategies. The unstable behavior present may still be caused by overloading a zone. It is possible that the environmental load combined with the artificial load exceeded the cooling capacity of one or more of the exterior rooms. Additional analysis is required in order to confirm or refute this. In any case, overloaded rooms cannot cause instability by themselves. Instead, the control system responds to this environmental stimulus with the unstable behavior. To help identify whether or not the control strategies themselves contain parameters that can influence this instability, the increased load was returned to the interior rooms in the next test and various parameters were adjusted in order to view their effects on the unstable behavior. This was the purpose of Test Series 4.

## Test Series 4

Test series 4 was broken up into four distinct segments, one for each control strategy tested. The control strategies tested were:

- Test 4.1 – Strategy 1: PI static pressure reset based on maximum damper position.
- Test 4.2 – Strategy 2: Trim and respond static pressure based on maximum damper position.
- Test 4.3 – Strategy 3: PI fan speed reset based on maximum damper position.
- Test 4.4 – Strategy 4: Trim and respond static pressure reset based on pressure requests.

During these four testing phases, parameters were adjusted in an attempt to view their impact on the oscillation level present. For the PI based control algorithms, the factors adjusted were the maximum damper position (used as the control input) and the magnitude of the error sum term found in the integral portion of the PI algorithm. For the trim and respond control strategies, the parameters that were adjusted were the maximum damper position and the trim rate. In order to keep the discussion coherent, the results from Test 4 are broken out into multiple tables. Each table contains the results obtained from testing only one type of control strategy. Table 3.6 below is the first of these tables and depicts only results obtained from using Strategy 1, PI reset of static pressure set point based upon maximum damper position.

**Table 0.6: Results summary table for tests using Strategy 1, PI reset of static pressure set point based on maximum damper position**

| Test 4 Results Summary | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Test Run | | | | | | | | | | | |
| | 4.1a | | | 4.1b | | | 4.1c | | | 4.1d | | |
| comparisons | AHUA | Rank | AHUB | AHUA | Rank | AHUB | AHUA | Rank | AHUB | AHUA | Rank | AHUB |
| Fan Energy | | B | 5.55% | | B | 6.00% | | | | | B | 5.56% |
| Temperature | | | | | | | | | | | | |
| Static Pressure | | | | | | | | | | | | |
| Oscillation | Y | | Y | Y | | Y | Y | ----> | Y | Y | ----> | Y |
| Travel | | | | | | | | | | | | |
| Control | | | | | | | | | | | | |
| Damper Travel | | | | | | | | | | | | |
| Flow Rate Control | | | | | | | | | | | | |

- a "B" is used to indicate when one test strategy performed better than the other while a "-" is used to indicate when the two are similar. When a strategy performs better, a value will appear in the column of the AHU that performed better. Values will not be given for the case of similarity.

- "yes" or "no" will be used to indicate presence of oscillation. These ratings are shown as "y" or "n." If both AHU's show oscillation, an arrow may appear, pointing to the AHU showing an improvement in oscillation behavior.

- Shaded rankings indicate an improvement in performance.

Table 3.6 (above) depicts the results of four different tests employing Strategy 1. Each test employed a unique set of parameters to observe the effects on AHU performance and stability. The first test was considered a rerun of the PI strategy used in in Test 3.1. Test 4.1b set the minimum duct static pressure to 0.2 in. w.c. instead of 0.6 in. w.c. In Test 4.1c, the minimum duct static pressure was reset to 0.6 in. w.c. in both AHU's while the maximum damper position was reset from 90% in both AHU's to 80% in AHUA and 70% in AHUB. In Test 4.1d, the maximum damper position was returned to 90% in both AHU's while the error sum used in the integral portion of the PI algorithm was limited to a value of +/- 10% on AHUA and a value of 0% on AHUB. In previous tests, the error sum was limited to +/- 100%.

A small difference in fan power used appears during Test 4.1a and 4.1b. This is unusual because the same strategy was implemented on both AHUA and AHUB in both of these tests. Because all of the known parameters in this test were implemented in the same manner, this energy consumption difference remains unexplained. However, it is very near to the threshold for similarity so the difference will be noted but ignored for the time being.

Figures 3.9, 3.10, 3.11, and 3.12 (all below) compare the duct static pressure in AHUA and AHUB for each test in the Test 4.1 series. As expected, the oscillation of the static pressure returned in both AHU's. The oscillation occurs once again during the peak load times. In this series the duct static pressure limits were 1.4 inches w.c. for the upper limit and 0.6 inches w.c. for the lower limit. When the oscillation occurs, the static pressure bounces back and forth between the minimum and maximum set point. For the next test, the effect on oscillation of reducing the minimum static pressure set point was observed.

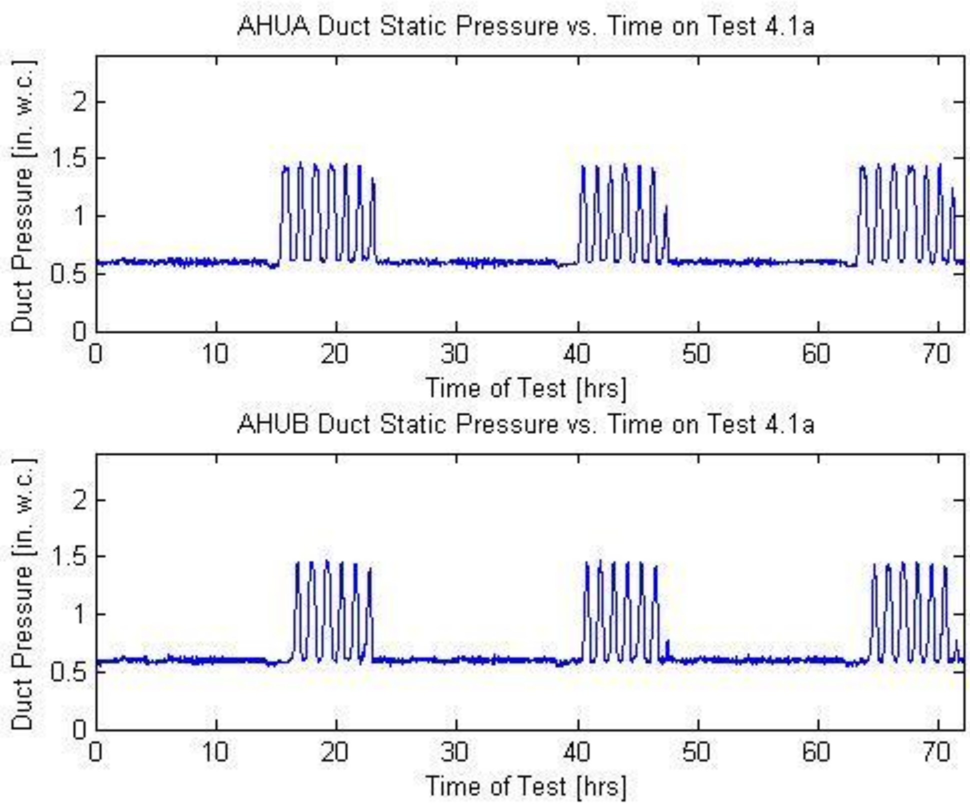


**Figure 0.9: Static pressure plots when employing Strategy 1, PI reset of static pressure set point based on maximum damper position, on both AHU's with similar operating parameters and a minimum static pressure of 0.6 inches w.c.**

Figure 3.10 (below) shows the effect of the reduced pressure set point in both AHU's. Oscillation similar to that previously observed still occurs during times of peak loading. However, additional oscillation occurs with reduced amplitude during times between these stronger oscillations. For the next test, the minimum static pressure will be returned to 0.6 inches w.c.

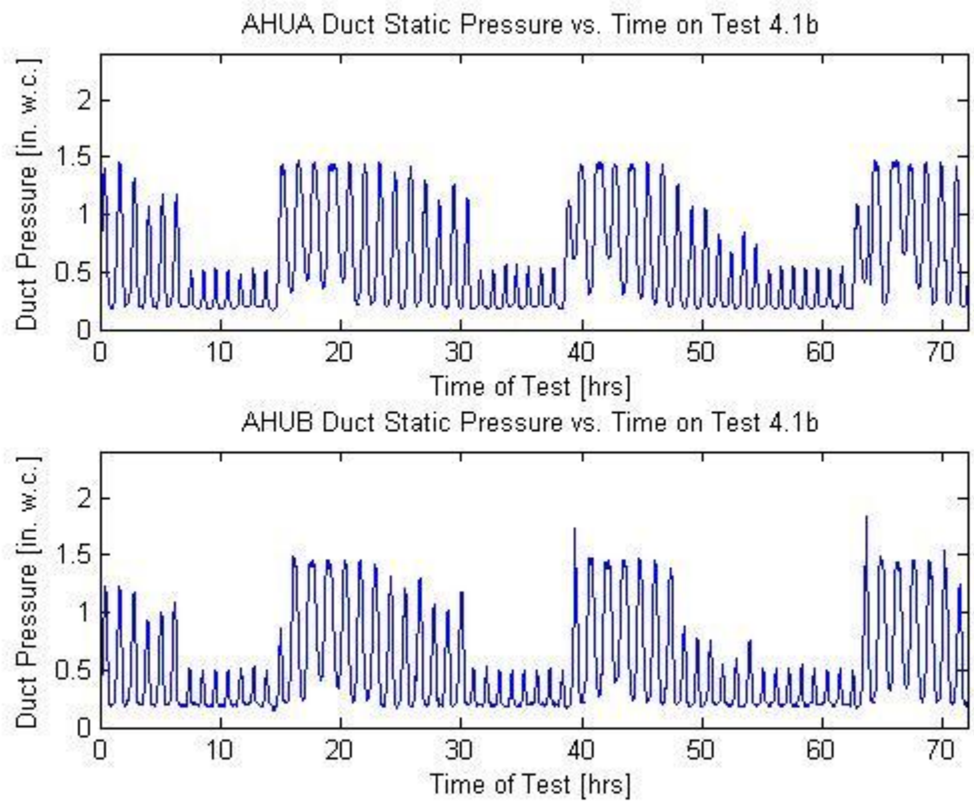


**Figure 0.10: Static pressure plots when employing Strategy 1, PI reset of static pressure set point based on maximum damper position, on both AHU's with similar operating parameters and a minimum static pressure of 0.2 inches w.c.**

Figure 3.11 (below) shows the effect of the parameter changes in Test 4.1c. This test saw the return of the static pressure minimum to 0.6 inches w.c. and the reduction in the maximum damper position used as the basis for calculating error in the PI equation. The maximum damper position was adjusted from 90% in both AHU's to 80% in AHUA and 70% in AHUB. In this manner, two new set points were tested simultaneously so that their effects could be compared. It was hoped that by reducing the maximum damper position set point value, a greater degree of control would be possible with the damper. The effects visible in Figure 3.11 indicate that this reduction in parameter did little to affect the amplitude of the oscillation. However, it did result in a reduced number of oscillations, from eight peaks to only six. It would be possible to further reduce the maximum damper position set point, but this action would greatly reduce the energy savings potential for this control strategy. The lack of significant effect on the oscillation amplitude makes further reductions not worth the energy savings sacrifice.

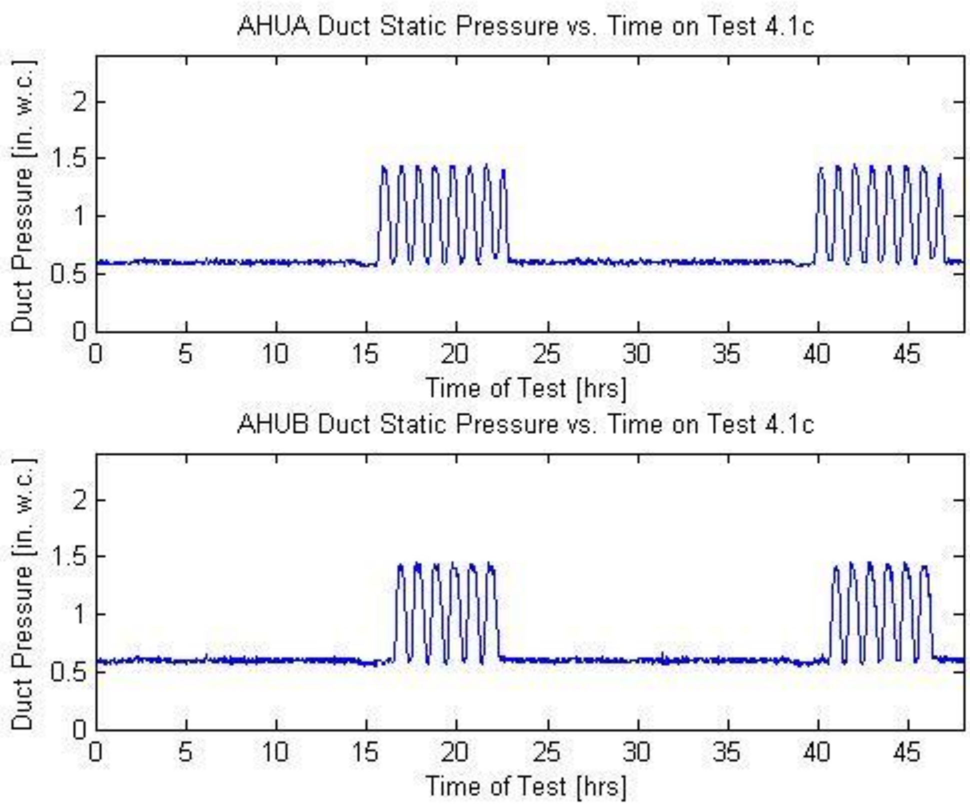


**Figure 0.11: Static pressure plots when employing Strategy 1, PI reset of static pressure based on maximum damper position, on both AHU's but with maximum damper position set to 80% on AHUA and 70% on AHUB**

Figure 3.12 (below) shows the effect on changing the value limit of the sum term used in the integral portion of the PI algorithm. In previous implementations, this value was limited to +/- 100. This was done to keep the PI algorithm from attempting to adjust the static pressure set point too quickly. During Test 4.1d, this sum was limited to +/- 10 in AHUA and 0 in AHUB. By making the sum term zero, the PI control algorithm effectively becomes a simple Proportional controller only. In the plots shown in Figure 3.12, the static pressure plot becomes more jagged when it transitions from increasing static pressure to decreasing static pressure. The oscillation still occurs in both AHU's, but it has slightly reduced amplitude. The reduction in oscillation without eliminating it altogether even without any integral term whatsoever suggests the oscillation is already present, but is made worse by the integral term. This seems to indicate that the instability may have its origins in the proportional error term or in some system external to the control algorithm.

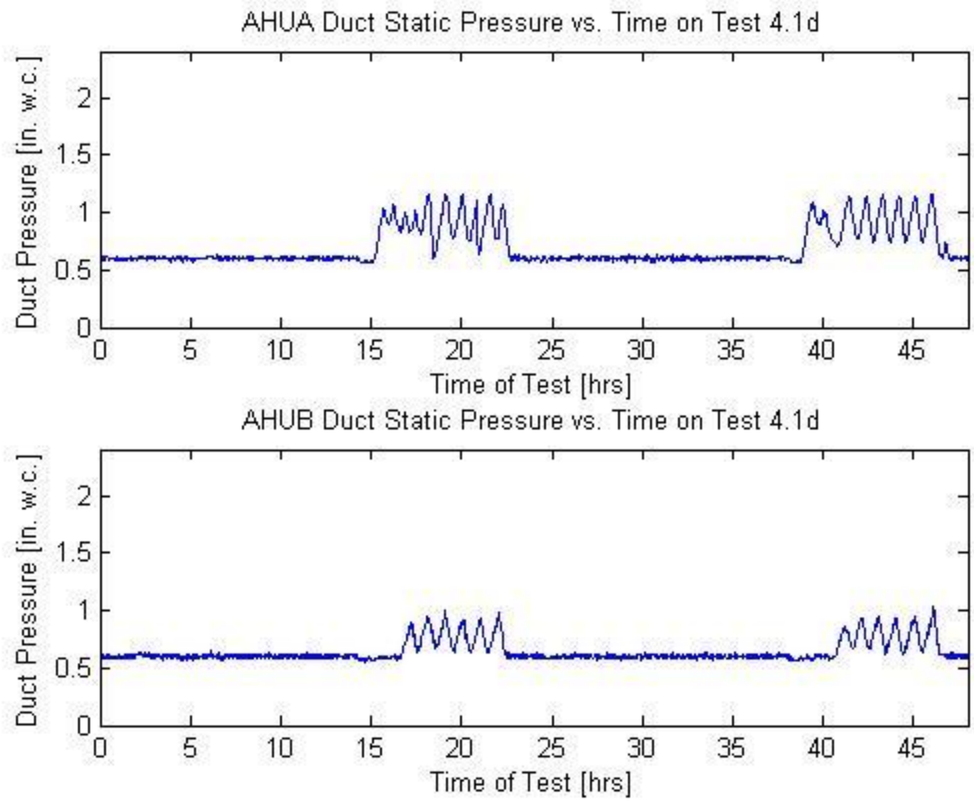


**Figure 0.12: Static pressure plots when employing Strategy 1, PI reset of static pressure based on maximum damper position, on both AHU's but with the integral sum term limited to +/- 10 on AHUA and 0 on AHUB**

Strategy 2 is the first of the two Trim and Respond strategies tested in this series. This particular version is the simpler of the two and adjusts static pressure based upon the maximum damper position only. The parameters tested during this test series were the maximum damper position and the trim rate. Table 3.7 (below) shows the results of changing these parameters. The details will be discussed in conjunction with the pressure plots to follow.

**Table 0.7: Results summary table for tests employing Strategy 2, Trim and Respond of static pressure based on maximum damper position**

| Test 4 Results Summary *cont'd* | | | | | | |
|---|---|---|---|---|---|---|
| Parameter | Test Run | | | | | |
| | 4.2a | | | 4.2b | | |
| comparisons | AHUA | Rank | AHUB | AHUA | Rank | AHUB |
| Fan Energy | | | | | B | 8.10% |
| Temperature | | | | | | |
| Static Pressure | | | | | | |
| Oscillation | Y | B | N | Y | ----> | Y |
| Travel | | | | | | |
| Control | | | | | | |
| Damper Travel | | | | | | |
| Flow Rate Control | | | | | | |

- a "B" is used to indicate when one test strategy performed better than the other while a "-" is used to indicate when the two are similar. When a strategy performs better, a value will appear in the column of the AHU that performed better. Values will not be given for the case of similarity.

- "yes" or "no" will be used to indicate presence of oscillation. These ratings are shown as "y" or "n." If both AHU's show oscillation, an arrow may appear, pointing to the AHU showing an improvement in oscillation behavior.

- Shaded rankings indicate an improvement in performance.

During the first test of this series (4.2a), the maximum and minimum damper positions were adjusted from 90% and 80% to 80% and 70%, respectively. Note that the 10% dead-band is maintained in this adjustment. The resulting performance was largely similar between the two AHU's. The key items to note are that the unstable behavior was virtually eliminated with the reduction in maximum damper position while energy consumption was not significantly different.

The second test of this series had the opposite results as the first test. By reducing the trim rate from .02 in both AHU's in the previous tests to .005 in AHUA and .01 in AHUB, the intent was to smooth out the plot and eliminate some of the frequent oscillation. Resulting analysis yielded a reduction in fan energy by using a higher trim rate and little or no effect on oscillation amplitude with a change in trim rate. The only difference in the unstable behavior was that increasing the trim rate decreases the period of oscillation. Figures 3.13 and 3.14 (below) show the pressure plots of these two tests.

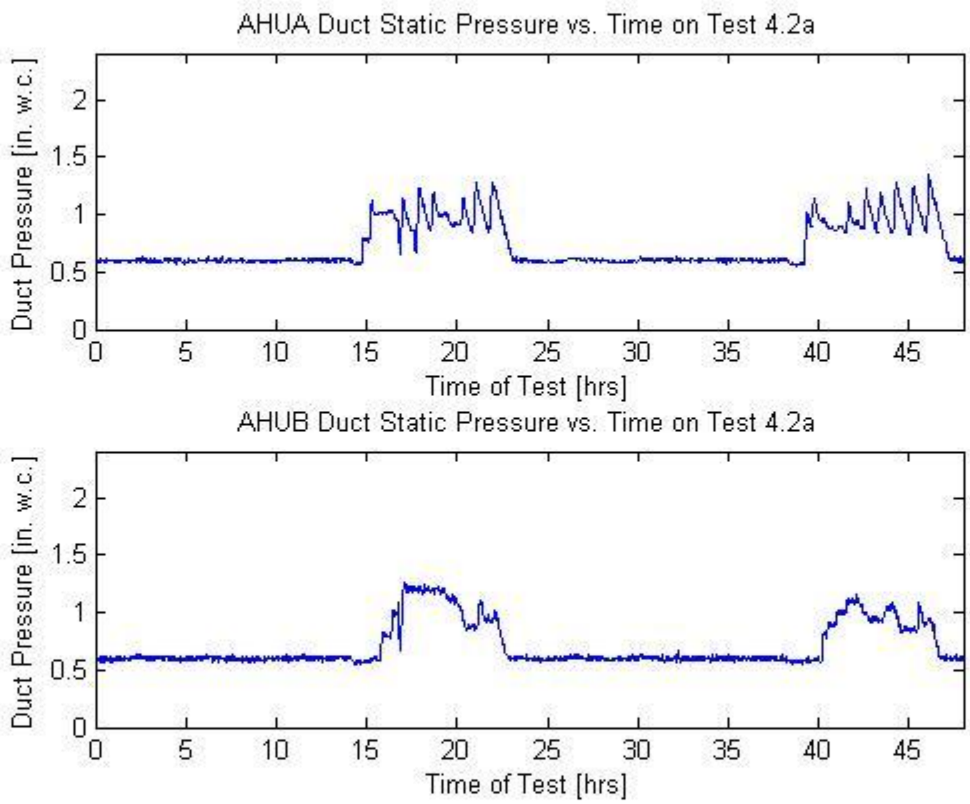


**Figure 0.13: Static pressure plots when employing Strategy 2, Trim and Respond of static pressure set point based on maximum damper position, on both AHU's but with a 10% reduction in maximum and minimum desired damper positions on AHUB**

The static pressure profile from Test 4.2a shows a distinct difference in oscillation between the two AHU’s (see Figure 3.13 above). Reducing the maximum and minimum damper positions seems to have nearly eliminated any unstable behavior.

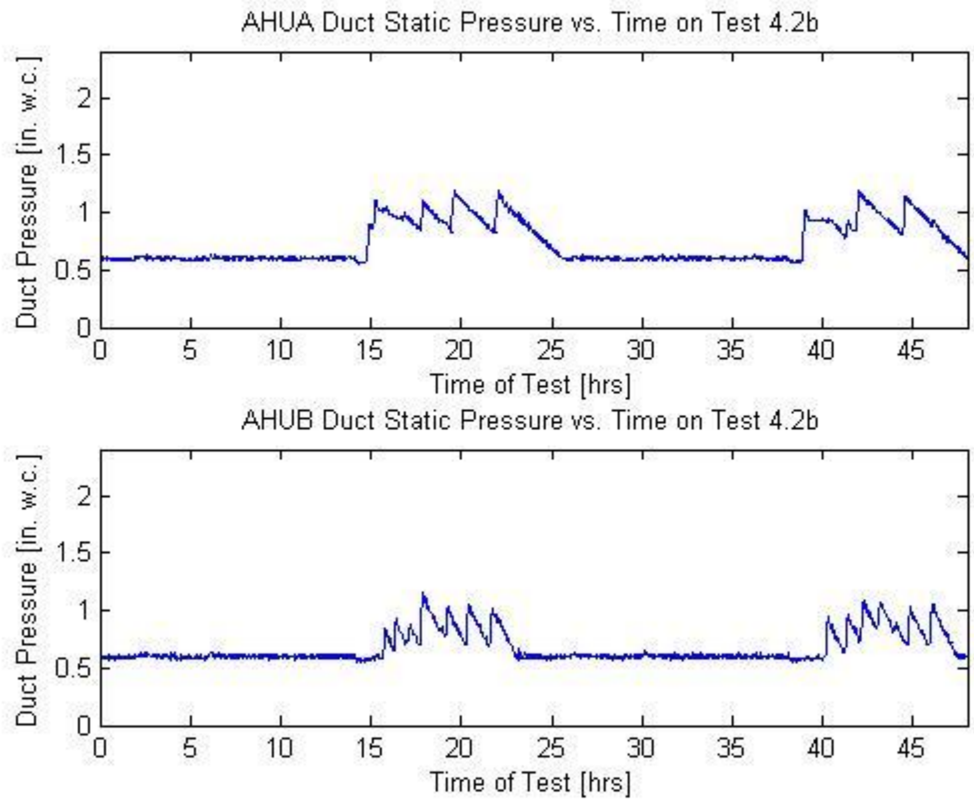


**Figure 0.14: Static pressure plots when employing Strategy 2, Trim and Respond of static pressure set point based on maximum damper position, on both AHU's but with a trim rate of .005 on AHUA and .01 on AHUB**

Reduction of the trim rate in Strategy 2 seems to have little effect on oscillation amplitude (see Figure 3.14). Though the pressure profile has fewer peaks with a lower trim rate, the amplitude of the peaks actually increased slightly. Reducing the trim rate also had the unwanted side effect of reducing the energy savings achieved by the strategy.

**Table 0.8: Results summary table for tests using Strategy 3, PI reset of fan speed based on maximum damper position**

| Test 4 Results Summary *cont'd* | | | | | | |
|---|---|---|---|---|---|---|
| Parameter | Test Run | | | | | |
| | 4.3a | | | 4.3b | | |
| comparisons | AHUA | Rank | AHUB | AHUA | Rank | AHUB |
| Fan Energy | | B | 6.72% | | B | 9.21% |
| Temperature | | | | | | |
| Static Pressure | | | | | | |
| Oscillation | Y | ----> | Y | Y | | Y |
| Travel | | B | 0.42 | | | |
| Control | | | | | | |
| Damper Travel | | B | 35.22% | | B | 5.96% |
| Flow Rate Control | | | | | | |

- a "B" is used to indicate when one test strategy performed better than the other while a "-" is used to indicate when the two are similar. When a strategy performs better, a value will appear in the column of the AHU that performed better. Values will not be given for the case of similarity.

- "yes" or "no" will be used to indicate presence of oscillation. These ratings are shown as "y" or "n." If both AHU's show oscillation, an arrow may appear, pointing to the AHU showing an improvement in oscillation behavior.

- Shaded rankings indicate an improvement in performance.

Strategy 3 is the second strategy to employ a PI control method. In this strategy, maximum damper position resets fan speed rather than duct static pressure. Test 4.3 was executed in order to observe the effects on stability and performance of adjusting the maximum damper position and the PI sum term. This is very similar to what was done to Strategy 1 during Tests 4.1c and d. During the first test (4.3a), the maximum damper position was changed from 90% in previous tests to 80% in AHUA and 70% in AHUB. The results of these actions were a greatly improved damper travel per hour parameter in AHUB. There were also notable improvements in fan energy savings and static pressure travel per hour on AHUB. Table 3.8 (above) contains the outcome from Test series 4.3. The effects on oscillation will be discussed with the accompanying graph shown in Figure 3.15.

The second test (4.3b) of this series was used to observe the effect of limiting the integral sum term in the PI algorithm. The maximum value of the sum for this test was reduced from +/- 100 in previous tests to +/- 10 in AHUA and 0 in AHUB. Limiting the sum term to zero effectively makes it a proportional only control algorithm. Major improvements from this adjustment were a decrease in energy consumption and a reduction in damper travel per hour in AHUB.

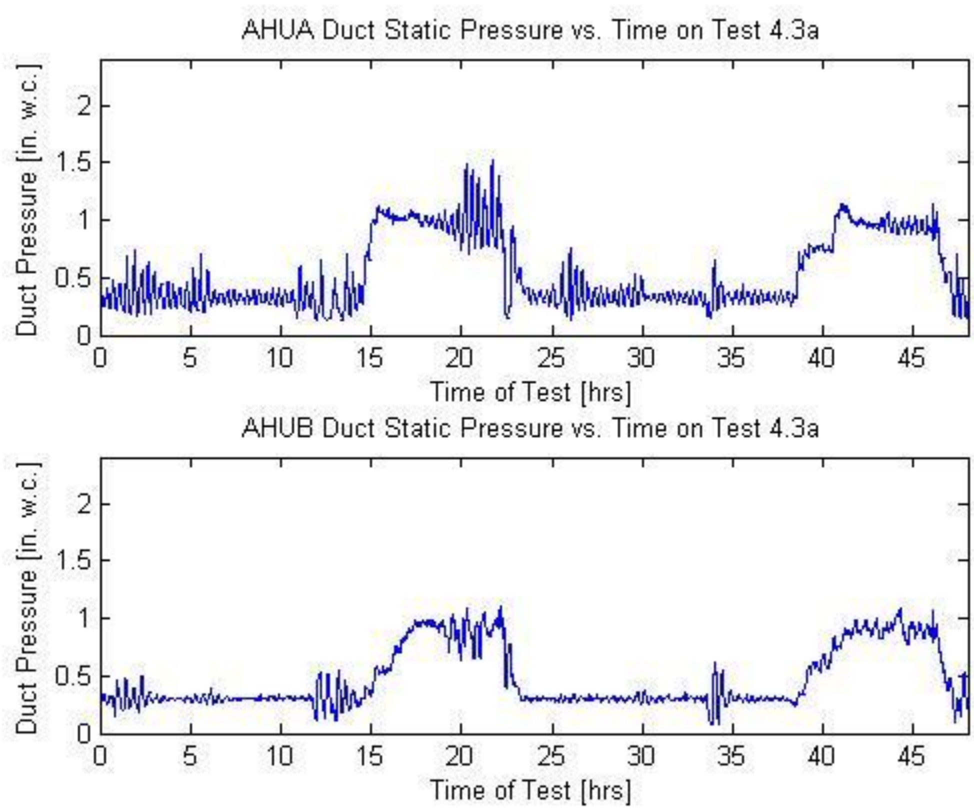


**Figure 0.15: Static pressure plots when employing Strategy 3, PI reset of fan speed based on maximum damper position, on both AHU's but with the maximum desired damper position set to 80% on AHUA and 70% on AHUB**

Test 4.3a showed remarkable improvement in the appearance of the static pressure plot (see Figure 3.15 above). There is far less hunting that occurs when the damper position is adjusted from 90% previously to 70% in AHUB. This reduced hunting effect is likely responsible for the improvements in both static pressure travel per hour and damper travel per hour.

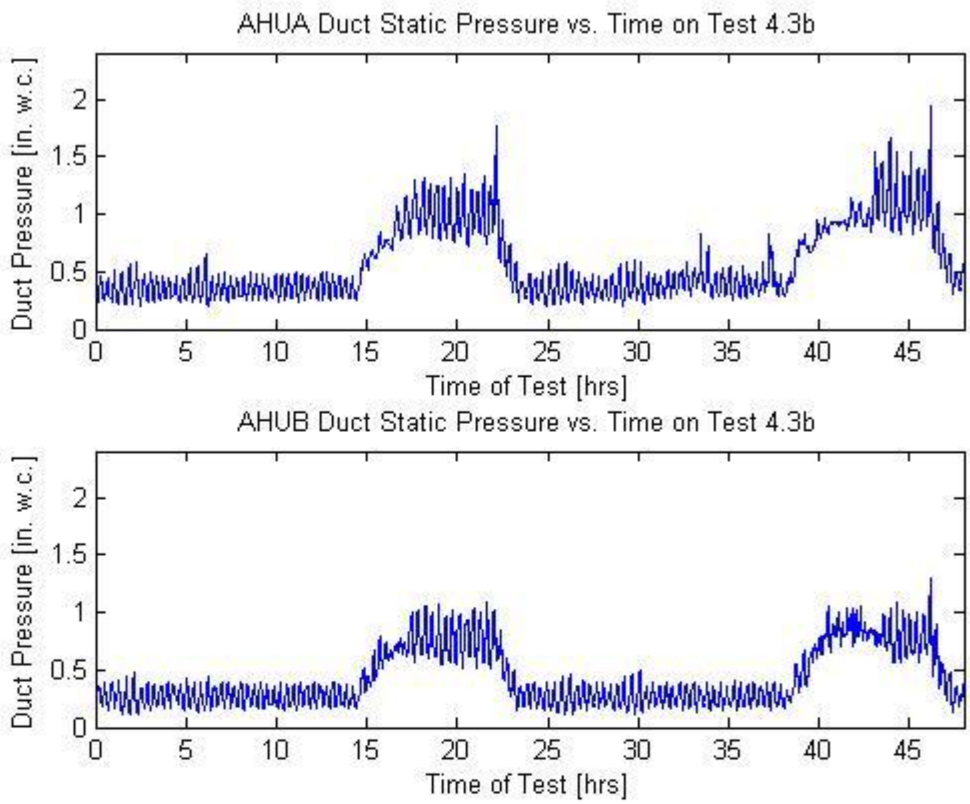


**Figure 0.16: Pressure plots when employing Strategy 3, PI reset of fan speed based on maximum damper position, in both AHU's but with the integral sum term limited to +/- 10 in AHUA and 0 in AHUB**

Limiting the integral sum term unfortunately did not yield any significant improvement in unstable behavior (see Figure 3.16 above). Hunting is present in both AHU's and seems relatively consistent between the two. The oscillation in AHUA is slightly more erratic during peak loading times, but there is not enough evidence to attribute this to the change in sum term limits.

The next strategy tested was the trim and respond by static pressure request method. As with the previous Trim and Respond method, the parameters adjusted were maximum and minimum damper positions and the pressure trim rate. The results from testing Strategy 4 are displayed in Table 3.9 (below).

**Table 0.9: Results summary table for tests using Strategy 4, Trim and Respond of static pressure set point based on the number of pressure requests**

| Test 4 Results Summary *cont'd* | | | | | | |
|---|---|---|---|---|---|---|
| Parameter | Test Run | | | | | |
| | 4.4a | | | 4.4b | | |
| comparisons | AHUA | Rank | AHUB | AHUA | Rank | AHUB |
| Fan Energy | | | | | | |
| Temperature | | | | | | |
| Static Pressure | | | | | | |
| Oscillation | N | B | Y | Y | | Y |
| Travel | | | | | | |
| Control | | | | | | |
| Damper Travel | | | | | | |
| Flow Rate Control | | | | | | |

- a "B" is used to indicate when one test strategy performed better than the other while a "-" is used to indicate when the two are similar. When a strategy performs better, a value will appear in the column of the AHU that performed better. Values will not be given for the case of similarity.

- "yes" or "no" will be used to indicate presence of oscillation. These ratings are shown as "y" or "n." If both AHU's show oscillation, an arrow may appear, pointing to the AHU showing an improvement in oscillation behavior.

- Shaded rankings indicate an improvement in performance.

The results of Test 4.4a and 4.4b are shown in Table 3.9 (above). None of the performance parameters showed any significant improvement except for oscillation, which only showed improvement in Test 4.4a. The stability and oscillation results are discussed below in conjunction with the static pressure plots.

Some important features of Strategy 4 to remember are that there are two maximum damper positions and error in maximum damper position creates a number of requests which affects the magnitude of the static pressure set point adjustment. This strategy uses the lower of the two maximum damper positions to generate a single increase static pressure request, while the higher of the two generates multiple static pressure increase requests. The minimum damper position set point is used to trim the static pressure. These set points, in ascending order, were 70%, 80%, and 95% in previous tests. For this test, they were set to 60%, 70%, and 80% in AHUA and 70%, 80%, and 90% in AHUB. For Test 4.4b, these set points were returned to 70%, 80% and 95% in both AHU's while the pressure trim rate was set to 0.005 for AHUA and 0.007 for AHUB. The impact on static pressure oscillation for these two tests is shown below in Figure 3.17 and Figure 3.18.

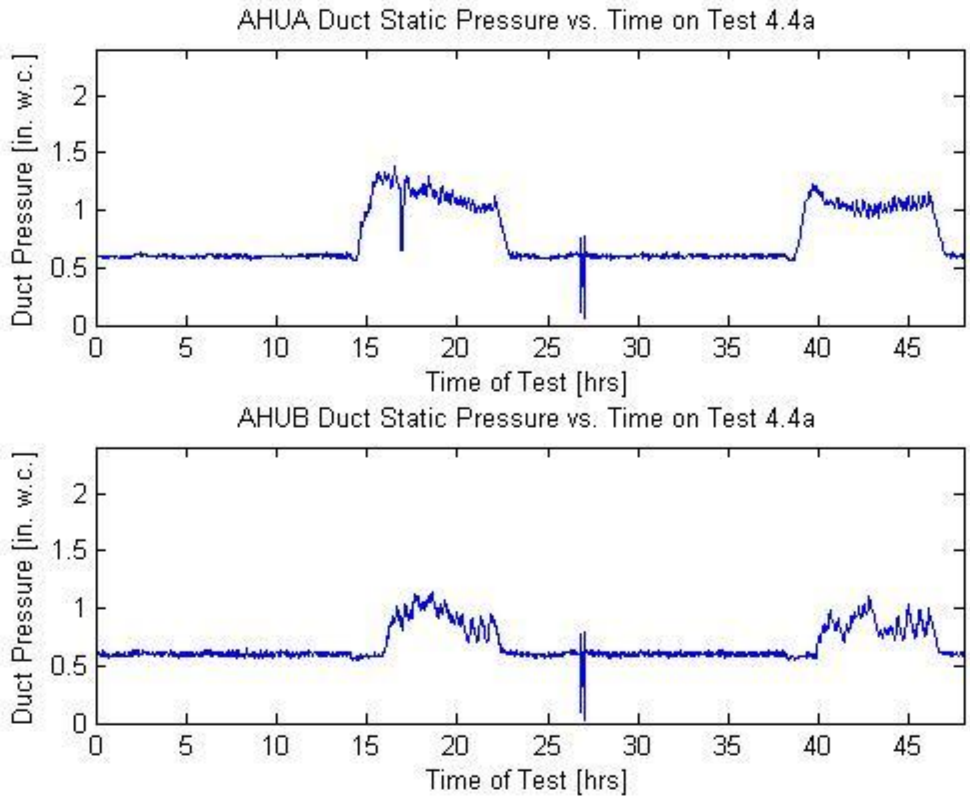


**Figure 0.17: Static pressure plots when employing Strategy 4, Trim and Respond of static pressure set point based on static pressure requests, on both AHU's but with a reduction in desired damper positions of 20% in AHUA and 10% in AHUB**

Test 4.4a resulted in a reduced level of hunting behavior in AHUA. Reducing the maximum and minimum damper positions in AHUA has resulted in a smoother curve that lacks almost any oscillation. Some of this hunting behavior is still present in AHUB with the slightly higher damper position set points.

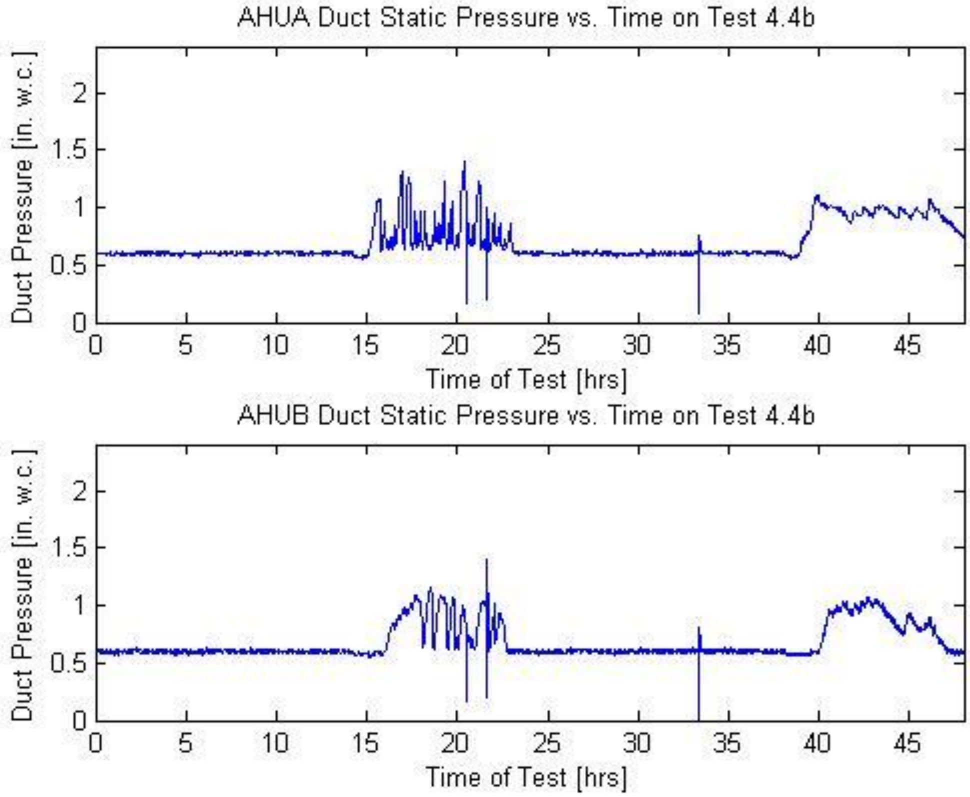


**Figure 0.18: Static pressure plots when employing Strategy 4, Trim and Respond of static pressure set point based on static pressure requests, on both AHU's but with trim rates of .005 in AHUA and .007 in AHUB**

Test 4.4b (results shown above in Figure 3.18) resulted in little comparable difference between the two AHU's. There may be marginally less oscillation present in AHUB, particularly during the first period of high loading, but this is insufficient to declare any significant difference between the two AHU's.

At this point in testing, a winning strategy had to be picked in order to proceed to final field testing in a campus building. Upon review of the previous tests, the strategy chosen was the Trim and Respond Strategy in general. Both versions of the Trim and Respond strategy were able to nearly eliminate any unstable behavior with minor parameter adjustments. As a result, this family of strategies was chosen to be the basis of another evolution of this strategy:  Strategy 5. This strategy will be discussed at length in the appropriate section of this chapter, but comment is first necessary on the strategies dropped from this point forward in testing.

### Dropped Strategy Final Comments

This study has not been an exhaustive one. Time and equipment scheduling factors left many possibilities unexplored. In choosing to halt additional testing on the PI based control strategies, it should be noted that additional testing may prove these strategies viable and reliable. Some of these unexplored possibilities include adjusting the proportional and integral gain constants, or perhaps changing the time between successive calculations. Though it is often dismissed out of hand, it may be worth investigating the addition of the derivative term to create a full PID strategy. Or, in the case of Strategy 3, it may be possible to eliminate many of the nested PI/D loops and control fan speed through room temperature or VAV flow rate.

## Test Series 5

Test 5 will be analyzed somewhat differently than the previous tests. The primary focus of the first part of this test was observing the impact on performance of implementing various delay times between successive actions by the control strategy. This is in anticipation of field testing a version of the control strategy in a situation in which the control may only get to act every few minutes. As such, this test employs a strategy that is allowed to act every 1, 3, 5, or 15 minutes. After observing these time effects, the strategy was tested for energy performance using the 15 minute interval. This interval was expected to be the interval used in the field controller. Although this turned out later to be a false expectation, it was necessary to study the energy performance in this scenario before implementation.

The test strategy used in this test series was modified from the two previous versions of Trim and Respond. This version uses a dead band, like the two previous versions, but also included the ability for the system to respond or trim faster for large deviations from dead band limits. Conceptually, it is a hybrid of the two previous versions, but it was modified to use maximum damper position instead of pressure requests and to be able to both trim and respond quickly in case of a large load change.

As previously stated, the first part of this test only sought to observe unstable behavior as a result of adjusting the delay interval. The results of this first round of tests are shown in Table 3.10 (below).

**Table 0.10: Oscillation results summary for interval testing**

| Test 5.5 Interval Testing | | |
|---|---|---|
| Test | Interval (min) | Oscillation |
| 5.5a | 1 | N |
| 5.5b | 1 | N |
| 5.5c | 3 | Y |
| 5.5d | 5 | Y |
| 5.5e | 15 | Y |

The results indicate that instability is present for interval times greater than 1 minute. These results suggest that the reaction speed of a control strategy could be a potential cause of unstable behavior.

There were two tests run with 1 minute intervals, Test 5.5a and Test 5.5b. These tests used two different sets of damper position set points. The first test used a relatively low dead band group that included 90%, 75%, and 60% for the upper damper position limits, and 50%, 40%, and 30% for the lower damper position limits. This left a dead band of 50% to 60% in which no action would be taken. In the second test, the upper damper position limits were set to 90%, 85%, and 80% while the lower damper position limits were set to 70%, 65%, and 60%. This set a dead band of 70% to 80% which should allow for additional fan energy savings.

Plots of the static pressure over time during the interval test portion of Test 5 are displayed below in Figure 3.19 through Figure 3.23 with additional discussion.

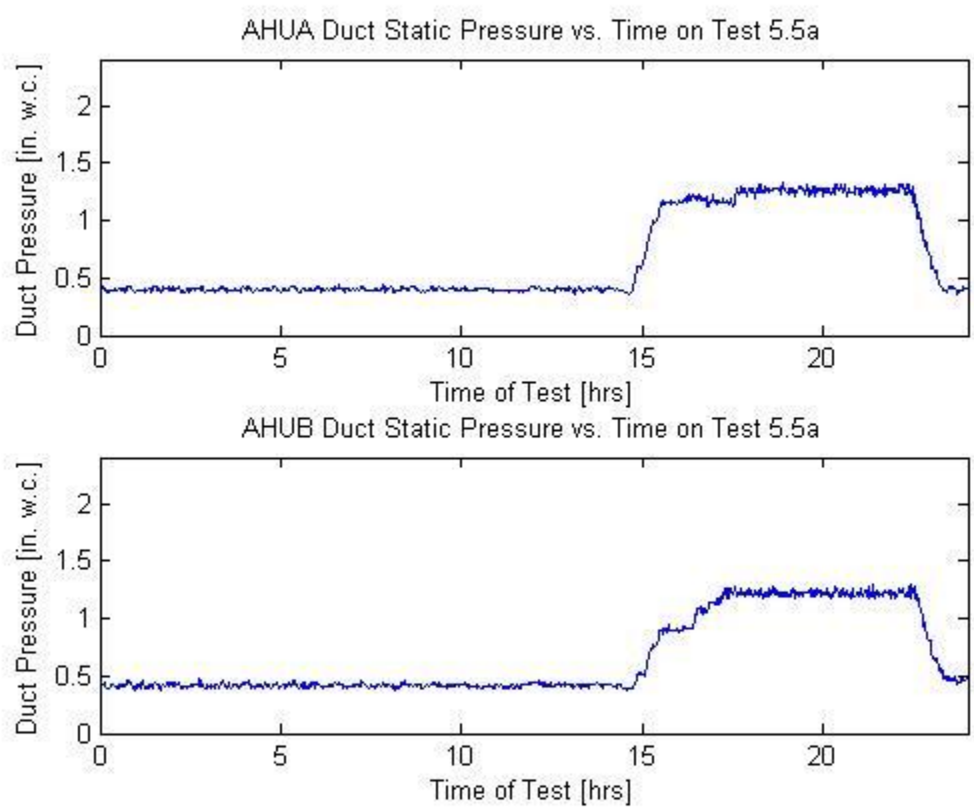


**Figure 0.19: Static pressure plots when using Strategy 5, tiered Trim and Respond of static pressure set point based on maximum damper position, on both AHU's with the relatively low dead band**

Test 5.5a (Figure 3.19 above) implemented the lower valued damper position dead band (50%-60%). This resulted in a relatively high static pressure of about 1.3 inches w.c. during peak load times. No unstable behavior was observed at this damper level and at this time interval.

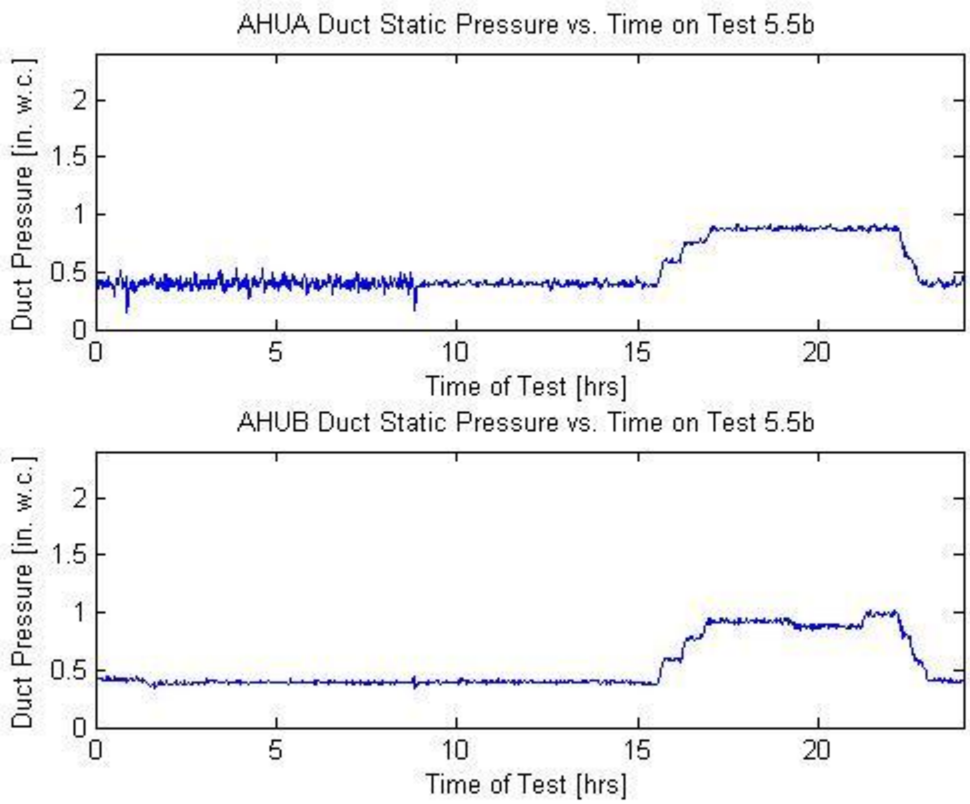


**Figure 0.20: Static pressure plots when using Strategy 5, tiered Trim and Respond of static pressure set point based on maximum damper position, on both AHU's with the relatively high dead band**

Test 5.5b (Figure 3.20 above) also used the 1 minute interval time, but relied on a higher dead band value (70% to 80%) to operate. The results were again no observed unstable behavior, but a significant reduction of duct static pressure from 1.3 inches w.c. to

0.9 inches w.c. during peak load times. This should translate into additional fan energy savings during this time period.

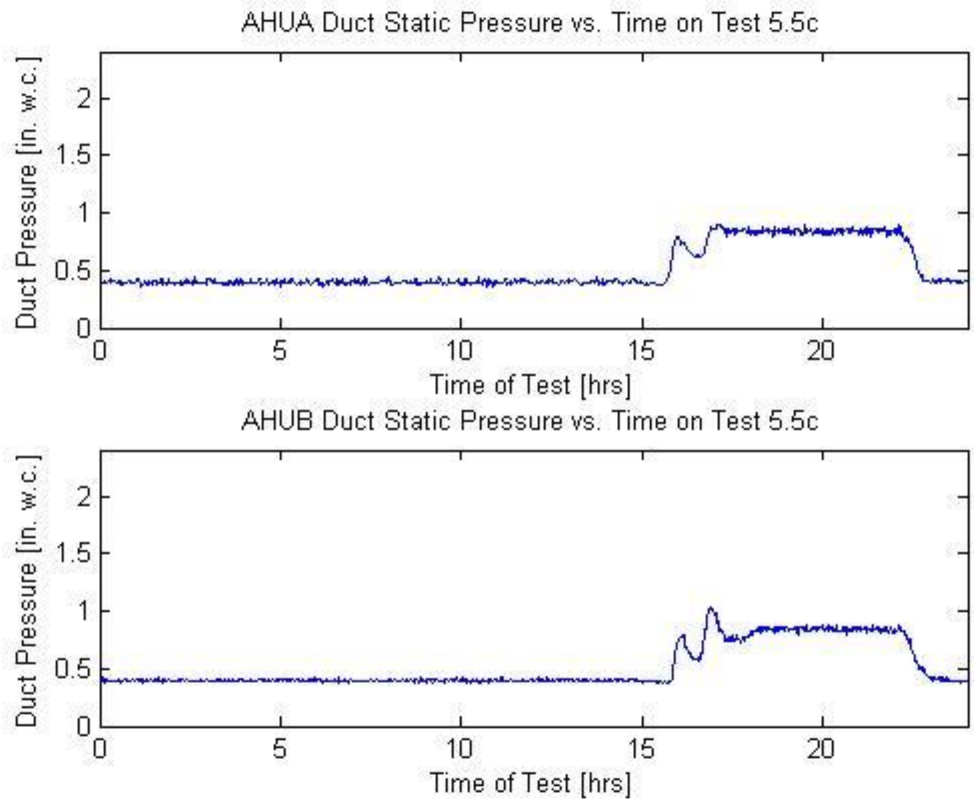


**Figure 0.21: Static pressure plots when employing Strategy 4, tiered Trim and Respond of static pressure set point based on maximum damper position, on both AHU's with a calculation interval of 3 minutes**

Test 5.5c (Figure 3.21 above) resulted in the first observation of unstable behavior. The graph indicates that for a period of about two hours, from 3:40pm to 5:30pm, oscillations took place in the duct pressure level. These oscillations then disappeared and a relatively constant pressure level followed for the remaining peak load segment. Though the strategy appeared to have gained control, the presence of this oscillation is the first indicator that response speed may contribute directly to unstable behavior.

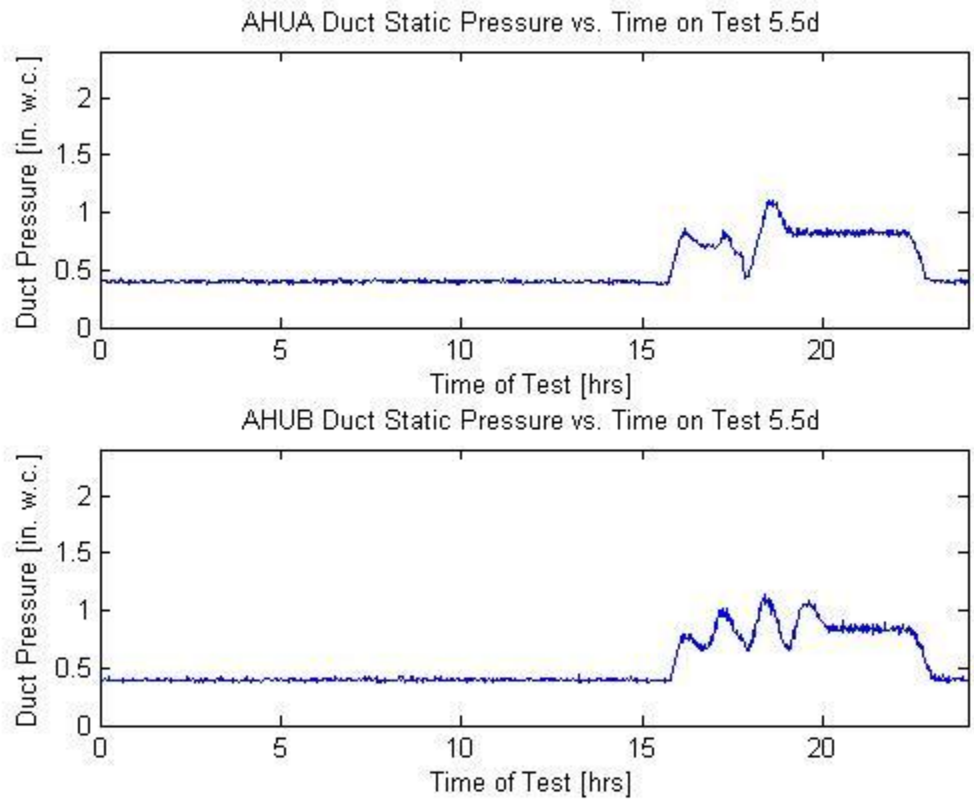


**Figure 0.22: Static pressure plots when employing Strategy 4, tiered Trim and Respond of static pressure set point based on maximum damper position, on both AHU's with a calculation interval of 5 minutes**

Test 5.5d (Figure 3.22 above) resulted in the worst display of unstable behavior for all of Test 5. The same type of oscillation as that found in Test 5.5c occurs, but for a much longer period of time; a little more than four hours from 3:50pm to 8:10pm. After this oscillation, the system appeared to have regained control and held a nearly constant set point for the duration of the high load period.

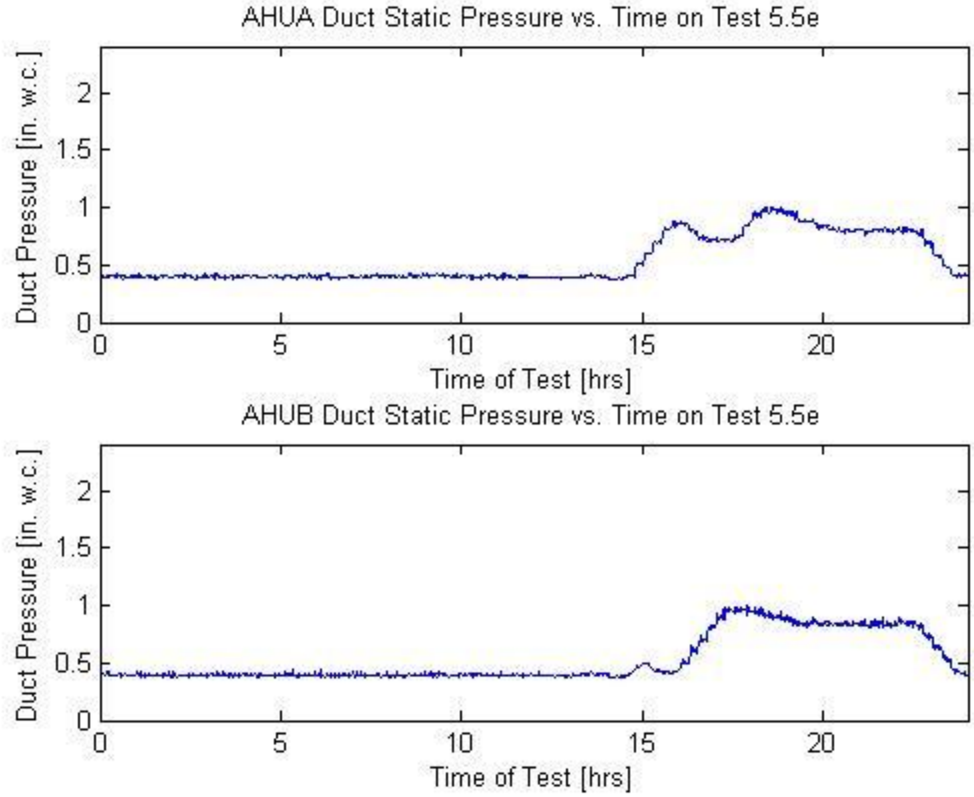


**Figure 0.23: Static pressure plots when employing Strategy 4, tiered Trim and Respond of static pressure set point based on maximum damper position, on both AHU's with a calculation interval of 15 minutes**

Test 5.5e (Figure 3.23 above) resulted in reduced oscillation for the 15 minute interval as compared to the two previous tests at intervals of 3 and 5 minutes. The oscillations present have a much longer period as observe on AHUA, but are virtually nonexistent on AHUB. This change in behavior suggests that there is a speed of action for the control algorithms that maximizes unstable behavior. The implications of this find are that control strategies would have to act either relatively quickly or very slowly in order to maintain stable control. This presents a few problems with algorithm programming. If a strategy acts too quickly, it can over drive a fan motor which could possible cause damage to the fan motor. If a strategy acts too slowly, it would be very difficult to save significant amounts of energy simply because the strategy would be less capable of responding to a reduced load quickly enough to capitalize on energy savings. These constraints combined with the interval effect could result in only a few narrow bands of acceptable action speeds that cool the space adequately, save fan energy, and protect the system from unnecessary damage.

With this in mind, the next test compared the tiered Trim and Respond algorithm against a fixed static pressure. For this test, the 15 minute interval was used in performing static pressure set point calculations. For the reset strategy, maximum and minimum damper positions were set to 90%, 85%, and 80% for the upper limits and 70%, 65%, and 60% for the lower limits. The supply pressure had a maximum of 2.0 inches w.g. and a minimum of 0.4 inches w.g. For the fixed pressure strategy, the duct static pressure used a fixed set point of 1.4 inches w.g. This set of parameters was used in two tests for this phase. The first test saw the Trim and Respond algorithm implemented on AHUA, while it was employed on AHUB during the second test. During these two tests, the fixed pressure strategy was employed on the opposite AHU. The results of these two tests can be found in Table 3.11 (below).

**Table 0.11: Results summary for energy comparisons between Strategy 4, tiered Trim and Respond, and a fixed pressure set point strategy**

| Test 5.5 Results Summary | | | | | | |
|---|---|---|---|---|---|---|
| Parameter | Test Run | | | | | |
| | 5.5f | | | 5.5g | | |
| comparisons | AHUA | Rank | AHUB | AHUA | Rank | AHUB |
| Fan Energy | 55.90% | B | | | B | 35.70% |
| Temperature | | | | | | |
| Static Pressure | | | | | | |
| Oscillation | N | | N | N | | N |
| Travel | 0.82 | B | | | B | 1.02 |
| Control | | | | | | |
| Damper Travel | | | | | | |
| Flow Rate Control | | | | | | |

- a "B" is used to indicate when one test strategy performed better than the other while a "-" is used to indicate when the two are similar. When a strategy performs better, a value will appear in the column of the AHU that performed better. Values will not be given for the case of similarity.

- "yes" or "no" will be used to indicate presence of oscillation. These ratings are shown as "y" or "n." If both AHU's show oscillation, an arrow may appear, pointing to the AHU showing an improvement in oscillation behavior.

- Shaded rankings indicate an improvement in performance.

As Table 3.11 indicates, the TR strategy resulted in substantial fan energy savings; 55.9% when employed on AHUA and 35.7% when used on AHUB. Also, there were no unstable behavior observations. Plots of the static pressure vs. time can be found below in Figure 3.24 and Figure 3.25 for tests 5.5f and 5.5g respectively.

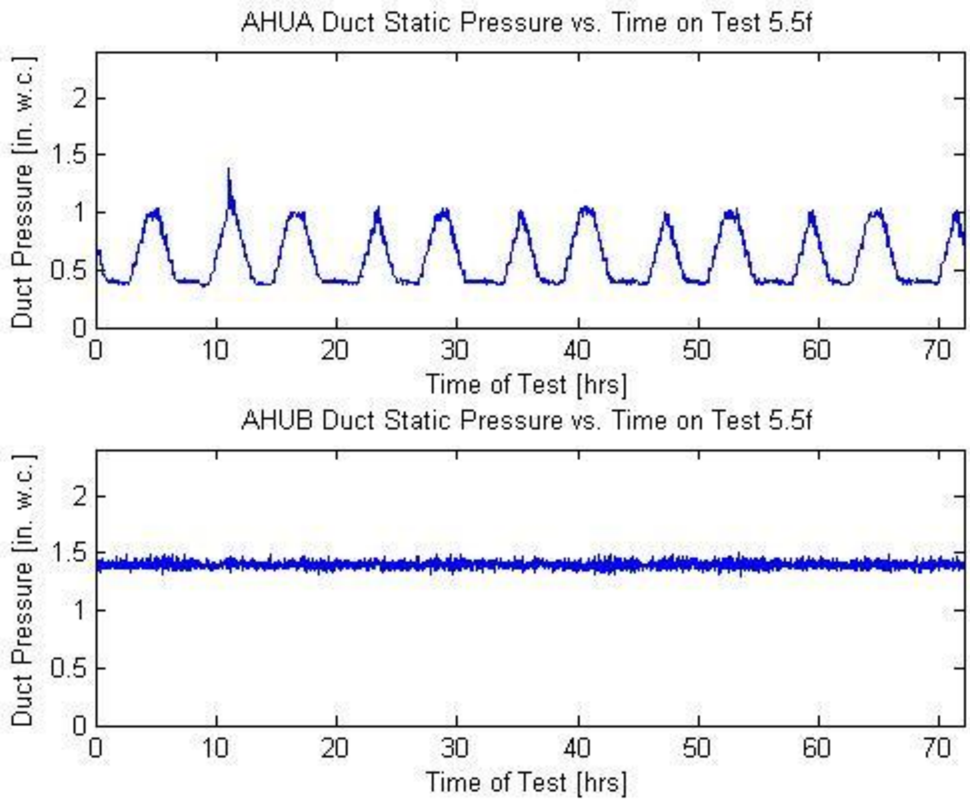


**Figure 0.24: Static pressure plots when employing Strategy 4, tiered Trim and Respond, on AHUA and a fixed pressure strategy on AHUB**

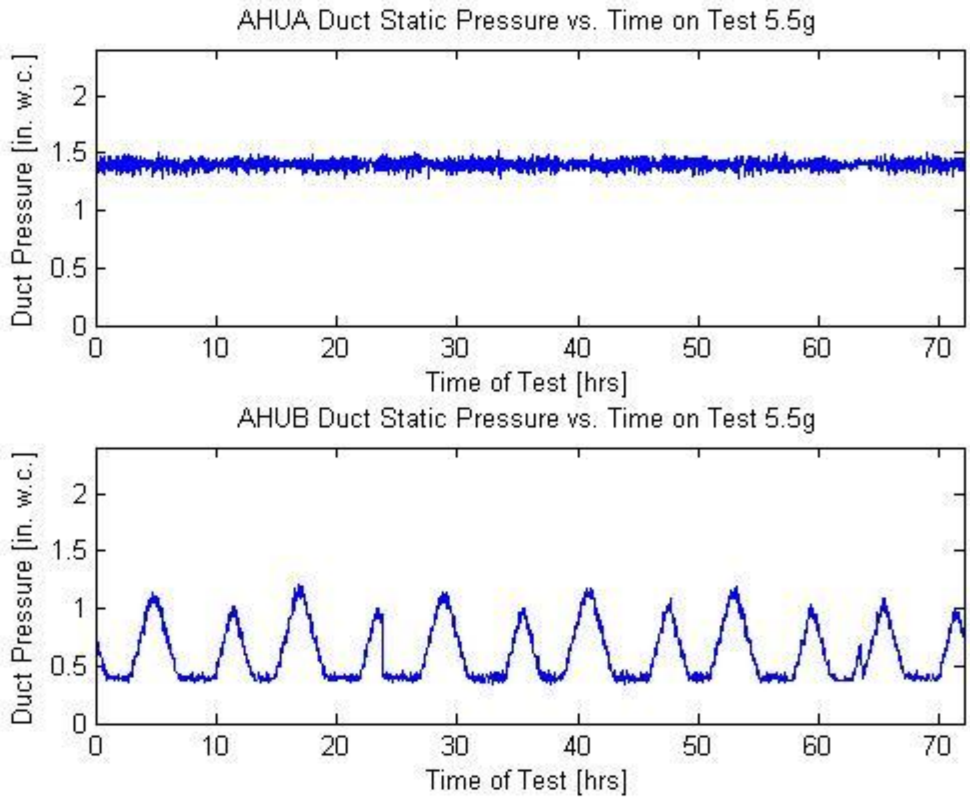


**Figure 0.25: Static pressure plots when employing Strategy 4, tiered Trim and Respond, on AHUB and a fixed pressure strategy on AHUA**

With the testing phase complete, progressing to a field test in an ISU campus building is the next stage of the research project. Implementing into an existing building presents several challenges. Up to this point, strategy programming has been external to the primary building control system. The primary challenge will be creating a version of the program in Metasys, the software package used in the Hixson-Lied Academic Success Center's building automation system.

# CHAPTER 4: FIELD TESTING SETUP AND RESULTS

## Field Test Setup

After testing a variety of control strategies, a best strategy was picked and then work began on implementing this strategy in a building. During this phase of the implementation, the research team met several times with representatives of the Facilities Planning and Management department of Iowa State University. The result of these meetings was choosing to implement the best control strategy at the Hixson-Lied Academic Success Center. This building is located on the Eastern side of the ISU campus on Beach Avenue. Figure 4.1 (below) shows a photograph (obtained from the Facilities Planning and Management website) of the building's Northeast façade.


**Figure 0.1: Photograph of the Hixson-Lied Academic Success Center obtained from the ISU Facilities Planning and Management website**

The primary relevant features of this building are that it was constructed in 2007 and is equipped with a full VAV system. The building is 35,000 square feet and contains rooms with functions expected at academic institutions including: a 52 station computer lab, quiet reading areas, two 60-seat classrooms, group learning rooms, conference rooms, and office space. In addition to these general characteristics, the building contains one air handling unit located in the third floor mechanical space.

The air handler, AHU-1, is a mixed air unit that contains a 50 HP supply fan and a 15 HP return fan. AHU-1 is designed to deliver 34,000 CFM of air at a maximum total static pressure of 3.00 inches w.g., though it is more frequently operated in the range of 1.5 – 2.2 inches w.g. The air handler delivers conditioned air to the non-mechanical parts of the building via pressure independent VAV boxes and fan powered VAV boxes. In all, there are 51 VAV damper positions to monitor for this test which includes 23 dampers associated with fan powered boxes, and four fan coil units. There is an additional pressure independent VAV box that supplies cooling to the mechanical room, but this damper was not tracked during the course of this test. In addition to the two larger fans, there are two exhaust fans in the building. The exhaust fans include a 1.00 HP unit which serves the bathroom exhaust, and a smaller 0.50 HP unit which serves two storage areas.

This building, with its DDC control system, is considered to be representative of many commercial and institutional buildings. As such, selecting this building for testing provided a platform for evaluating potential performance in real-world settings. This real-world setting included several obstacles to implementing a trim and respond control strategy.

## Implementation

One problem confronted early on was the difference in monitoring capabilities. At the ERS, there was an extensive data collection system which provided data on virtually every control point in the HVAC system. In most buildings, this data collection system is not present or is scaled back significantly. In the Hixson building, there were many points that were not monitored, such as fan power and damper position feedback.

In addition to the physical hurdles, there was another significant challenge: implementing the control strategy completely in Metasys. In the ERS testing phase, the control strategies were all written in Matlab and then interfaced with Metasys. Creating the program in Johnson Controls' GPL required the assistance of a facilities engineer who was familiar with the program.

## Hardware

In the ERS implementation, fan power was used as a metric to evaluate control strategy performance. In the Hixson building, this monitoring equipment had to be added to the existing control system. This included the installation of current transducers and their associated hardware. The transducers and hardware can be seen in Figure 4.2 (below). Transducers were added to both the supply fan and the return fan. The exhaust fans were ignored in this study.

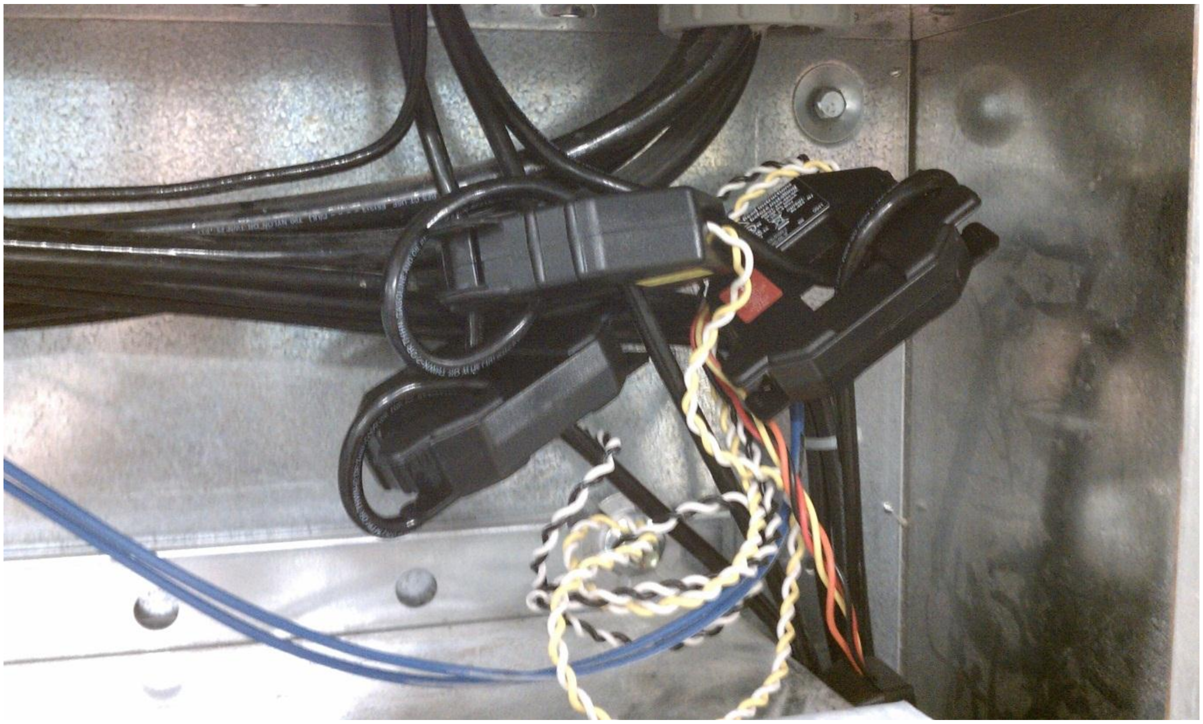

Figure 0.2: Current transducers installed on the return fan power

As figure 4.2 indicates, the power wire was wrapped twice around the transducer in the return fan. This was to help overcome the limitations of the sensor's lower range. The value recorded by the meter was then corrected in Metasys with a meter multiplier. The only sensors available in the time required were units that had unreported accuracy below 10% of their maximum range. The maximum range for these CT's was 100A for the return fan unit, and 400A for the supply fan unit. These units spent a good deal of the time on this test recording data in the range below 10% of maximum range. It is presumed that below this range, the accuracy of the data collected will be good enough for comparison purposes.

Damper position feedback was not available in the Hixson building. Instead, damper position command was used as the input to the control strategy. This requires the assumption that the dampers are in working order and functional. If this is not the case, it could result in either a starved zone or a VAV box stuck open too far. The effect of this situation on the control strategy is unknown and presently untested.

## Software

The strategy was divided into three distinct sections for implementation into Metasys. The sections were the *maximum selection section, the response section*, and *the limit-check section*. Each section consisted of a number of fairly simple building blocks that worked together to achieve a specific function.

In the *maximum selection section*, damper positions were compared in order to select a single maximum damper position. This had to be done in increments; the comparator blocks could only compare eight values at a time, so seven blocks were used to compare all of the 51 dampers. Each block then output the maximum of the damper positions that were put into it. The seven resulting maximums were then put into another maximum comparison block to select the maximum of the maximums. This final maximum damper position was then passed to the next section of the program:  the response section.

The *response section* is the most complicated part of the strategy. It consists of six comparison blocks, each with a true or false output. These comparison blocks compared the maximum damper position present value to a fixed set point that was different for each block and a bias value. This True/False output was then passed to another block. If this signal was true, the block would output a response value to increase or decrease the static pressure. These response outputs were then totaled among all of the response values. This totaled response value was then passed to the limit-check section.

To provide a better picture of how the response section works, a few more details need to be provided and perhaps an example. The first stage of the response section consists of six comparison blocks, as stated before. Each of these blocks compares the maximum damper position from the maximum selection section to a unique set point with a bias. The bias was set to 1 unit, in this case 1%. The unique set points were 98%, 95%, and 92% for the increase static pressure portion and 87%, 84%, and 81% for the decrease static pressure portion. In the increase static pressure portion, the block created a true value if the damper position was greater than the set point minus 1%, in the decrease static pressure portion, the block sends a true value if the damper position was less than the set point plus 1%. In other words, the 92% comparison block would be true at any value greater than 91%. Similarly, the 84% comparison block would be true for any value less than 85%.

The next part of the response section is made up of the output blocks. If these blocks receive a true signal, they output a static pressure adjustment value. The adjustment value is different for each block. In the case of the increase pressure portion, the values are .01 inches w.g. for the 92% block, .02 inches w.g. for the 95% block, and .03 inches w.g. for the 98% block. Similarly, the values are -.01 inches w.g. for the 87% block, -.02 inches w.g. for the 84% block, and -.03 inches w.g. for the 81% block. The outputs from these blocks are then totaled before sending this total to the next section. Totaling the blocks has the effect of allowing the pressure set point to rapidly increase in the event of a dramatic and sudden load change. For illustration purposes, a maximum damper position of 95% will create two true signals: one at the 92% block and the other at the 95% block. These two true outputs then trigger the next blocks to output their adjustment values of .01 inches w.g. and .02 inches w.g. The total for these two blocks is then .03 inches w.g. and this value is sent to the limit check section. A functional description of this process is shown in Table 4.1 (below) and the parameter values chosen for the Hixson test are shown in Table 4.2 (below).

**Table 0.1: Execution details of TR test strategy**

| Hixson Test Execution Details | | |
|---|---|---|
| **parameter information** | | |
| symbol | | definition |
| MDP | | Maximum Damper Position |
| SPSet | | Static Pressure Setpoint |
| H1,2,3 | | High Damper Position cutoff values (see Table 4.2) |
| L1,2,3 | | Low Damper Position cutoff values (see Table 4.2) |
| Trim1,2,3 | | Trim Rates (see Table 4.2) |
| Respond 1,2,3 | | Respond rates (see Table 4.2) |
| **execution statements** | | |
| condition | | response |
| IF | MDP > H3 | SPSet = SPSet + Respond1 + Respond2 + Respond3 |
| IF | MDP > H2 | SPSet = SPSet + Respond1 + Respond2 |
| IF | MDP > H1 | SPSet = SPSet + Respond1 |
| IF | MDP < L1 | SPSet = SPSet + Trim1 |
| IF | MDP < L2 | SPSet = SPSet + Trim1 + Trim2 |
| IF | MDP < L3 | SPSet = SPSet + Trim1 + Trim2 + Trim3 |

**Table 0.2: TR Parameter values**

| TR Strategy Parameter Test Values | | | | |
|---|---|---|---|---|
| | H | L | Trim | Respond |
| 1 | 98 | 87 | -0.01 | 0.01 |
| 2 | 95 | 84 | -0.02 | 0.02 |
| 3 | 92 | 81 | -0.03 | 0.03 |

Selection of the adjustment values followed a simple rule of thumb: The strategy should be able to traverse the range of static pressure limits from one end to the other in 15 minutes at the lowest adjustment level. Metasys is capable of making calculations and adjustments every 5 seconds as configured at the Hixson building. In this case, the static pressure maximum and minimum were 2.2 and 0.4 inches w.g., respectively. Simple arithmetic then yields a value of .01 inches w.g. This value was then doubled for the second tier and tripled for the third tier. This means that if a damper position of 99% were maintained, the strategy would increase static pressure from its minimum to its maximum or vice versa in only 2.5 minutes.

The *limit check section* is designed to make sure that the increase or decrease in static pressure does not exceed preset limits. This is also the portion of the strategy that applies a new set point to the system. This section takes the proposed total increase or decrease in static pressure and then adds it to the current system static pressure. This proposed new static pressure is then compared to both the minimum and maximum static pressure limits, in this case 0.4 inches w.g. and 2.2 inches w.g., respectively. If the proposed new pressure set point is less than the minimum limit or greater than the maximum limit, the strategy chooses the minimum limit or the maximum limit, respectively, as the new static pressure set point. For example, if the proposed new pressure is 0.2 inches w.g., the strategy will choose 0.4 inches w.g. instead. If the proposed new pressure is 2.5 inches w.g., the strategy will choose 2.2 inches w.g. instead. If the proposed new set point is 1.8 inches w.g., this value will be allowed through unchanged and become the new static pressure set point.

Once the strategy was programmed, the next step was making a schedule. The proposed schedule was to alternate between the TR control strategy and a fixed static pressure override on a weekly basis. This would provide for a comparison between strategies that would minimize environmental effects from weather changes. In total, there would be 7 weeks of TR strategy control and 6 weeks of fixed pressure override. In this case, the Facilities Planning and Management staff chose 1.5 inches w.g. for the fixed pressure override.

## Results

After implementation, the data collected was downloaded and analyzed. For the purposes of consistency, the same similarity thresholds used for the ERS were also used in the Hixson building. The TR strategy and fixed pressure strategy were then compared for similarity. The results of this comparison can be found in Table 4.1 (below).

**Table 0.3: Results comparison for the Hixson-Lied field test**

| Field Test Results Summary | | | | | | |
|---|---|---|---|---|---|---|
| Parameter | Strategy | | | | | |
| | TR strategy | | | fixed strategy | | |
| comparisons | value | Rank | diff. | value | Rank | diff. |
| Fan Energy | 1395.01 | B | 37.03% | 2215.23 | | |
| Temperature | 0.19 | B | 0.47 | 0.66 | | |
| Static Pressure | | | | | | |
| Oscillation | | N | | | N | |
| Travel | 0.66 | - | | 0.48 | - | |
| Control | 0.00 | - | | 0.02 | - | |
| Damper Travel | 7.39% | | | 2.33% | B | 5.06% |
| Flow Rate Control | -5.25 | - | | -2.21 | - | |

- a "B" is used to indicate when one test strategy performed better than the other while a "-" is used to indicate when the two are similar. When a strategy performs better, a value will appear in the diff column of the AHU that performed better. Values will not be given for the case of similarity.

- "yes" or "no" will be used to indicate presence of oscillation. These ratings are shown as "Y" or "N."

- Shaded rankings indicate an improvement in performance.

In analyzing the data, there were a few modifications needed in order to make a better comparison. Since the TR strategy operated for 7 weeks and the fixed strategy operated for 6 weeks, a comparison of total fan energy used would be fruitless. Instead, the total fan energy used by each strategy was averaged on a weekly basis. This enables a comparison of the fan energy used per week. The other performance metrics were calculated in the same way as with the ERS data (see Chapter 2).

As Table 4.1 shows, the TR strategy and the fixed pressure strategy performed similarly to one another in the performance parameters of static pressure travel per hour, static pressure control, and flow rate control. The TR strategy performed worse than the fixed pressure strategy in the damper travel per hour column. This result is somewhat expected since the premise of this strategy is to alter duct static pressure, which will cause damper position movement. In this case, the difference is relatively small at 5.06% per hour, which is just outside of the similarity threshold.

The parameters that showed improvement were the fan energy per week and the temperature control. The temperature control difference is outside the similarity threshold of +/- 3 $^{o}$F at a value of 0.47 $^{o}$F. This means that on an aggregate level, the TR strategy did a better job of controlling room temperature to set point. This is somewhat surprising, since this result was never observed in the ERS testing. Fan energy used per week was calculated as a percentage difference. The TR strategy was able to use on average %37.03 less energy each week over the fixed pressure strategy. This means 820.2 kWh less per week, 42,651 kWh less per year, and at a rate of $0.09/kWh, a savings of $3,839/year on fan energy alone.

Oscillation of static pressure is the final performance parameter. During the field test, there was no oscillation observed. There was a small amount of hunting that was present during certain times while employing the TR strategy. Figure 4.3 through Figure 4.6 (below) show plots of static pressure over the course of the tests for each strategy.

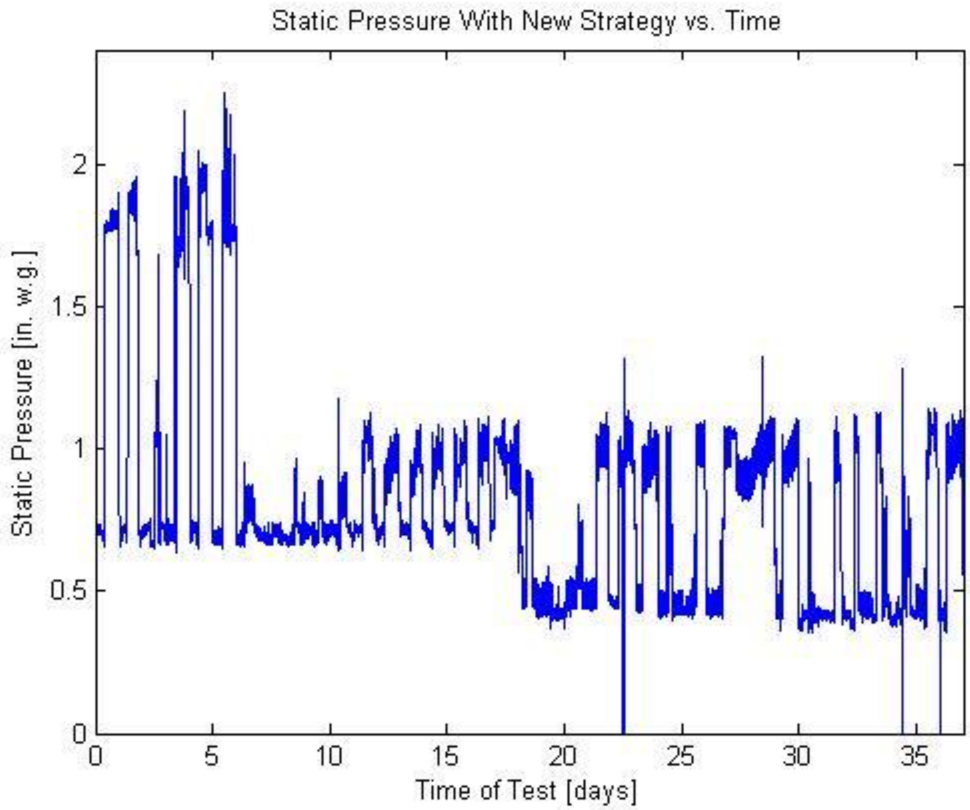


**Figure 0.3: Static pressure plot when tiered Trim and Respond is employed in Hixson-Lied**

Figure 4.3 shows a plot of static pressure over time when the TR strategy is employed on AHU-1 in the Hixson-Lied building. The plot is comprehensive and shows the weeks when the TR strategy was run concatenated together in one long graph. One striking feature of this graph is the dramatic increase and decrease in static pressure that coincides with the building's occupancy schedule. This is a major indication that the strategy is doing well at responding to changes in applied load. Also, there is no oscillation visible in the aggregate view.

There were some minor changes that were implemented during the testing phase. One was the elimination of two rogue zones (more on this later) after the first week. The effect of this can be observed on the graph when the maximum static pressure stops rising above 1.0 inches w.g. after about day 7. The other change was made at about day 18; at this point, the minimum static pressure was lowered to 0.4 inches w.g., which was the originally intended value.

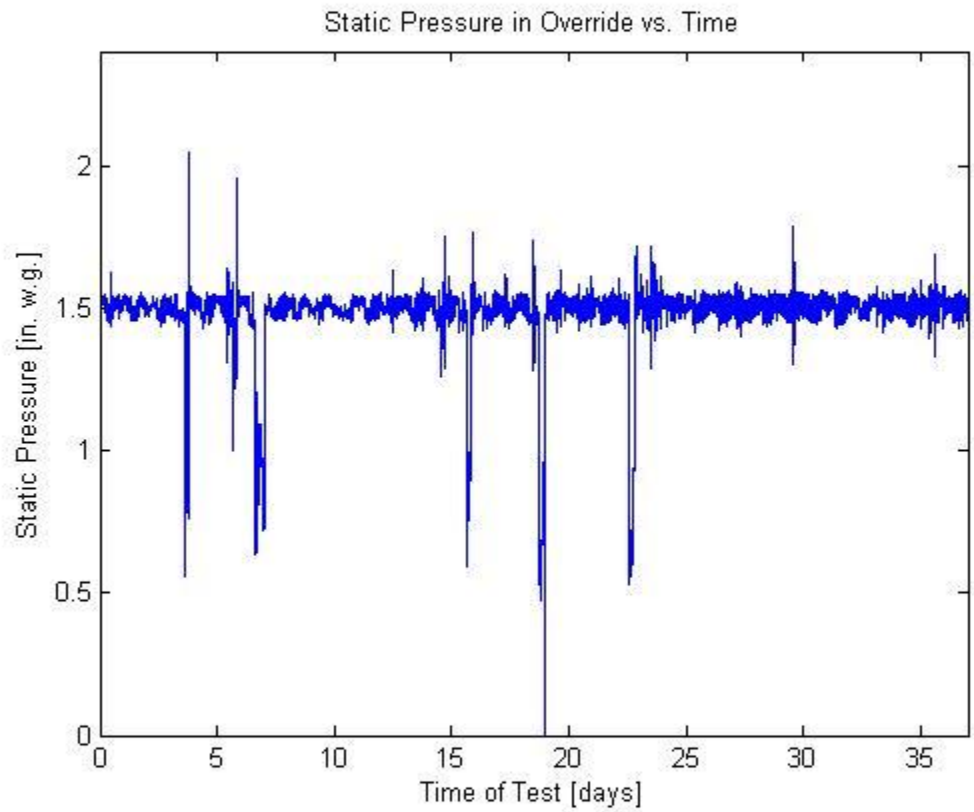


**Figure 0.4: Static pressure plot when fixed pressure strategy is employed in Hixson-Lied**

The plot of the constant static pressure strategy results vs. time can be found in Figure 4.4 (above). One feature of the plot is that, for the most part, the override strategy was able to maintain a relatively constant set point. However, there were large departures from set point that cannot be completely explained at present. It is possible that these large dips and spikes are due to equipment malfunction or measurement errors, but more investigation is needed.

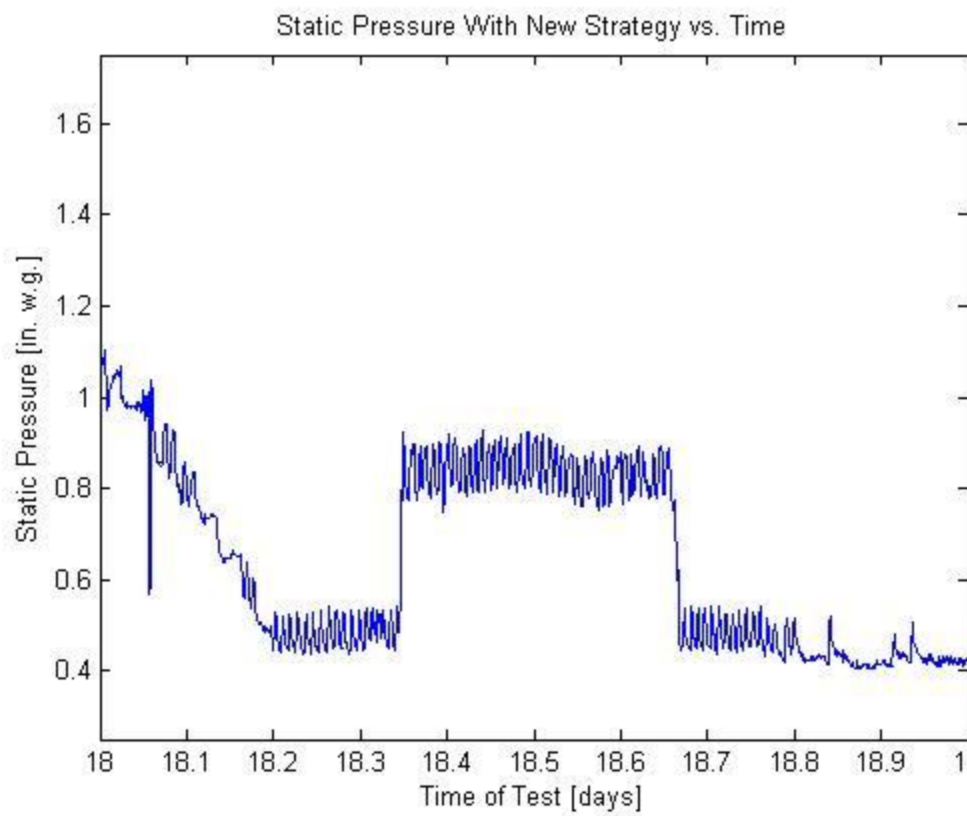


**Figure 0.5: Detail static pressure plot when tiered Trim and Respond is employed in Hixson-Lied**

Figure 4.5 is a detail view of Figure 4.3 that focuses on day 18. This is a good example of the hunting behavior previously mentioned. This behavior is somewhat undesirable, but the strategy is able to limit this phenomenon to amplitude of 0.15 inches w.g. Some possible reasons this behavior occurs could be that the dead band is too narrow, causing the strategy to slightly overshoot it each time. On the other side of that argument, the strategy may act slightly too quickly without giving the dampers sufficient time to respond to the increased pressure, which could result in the same overshoot.

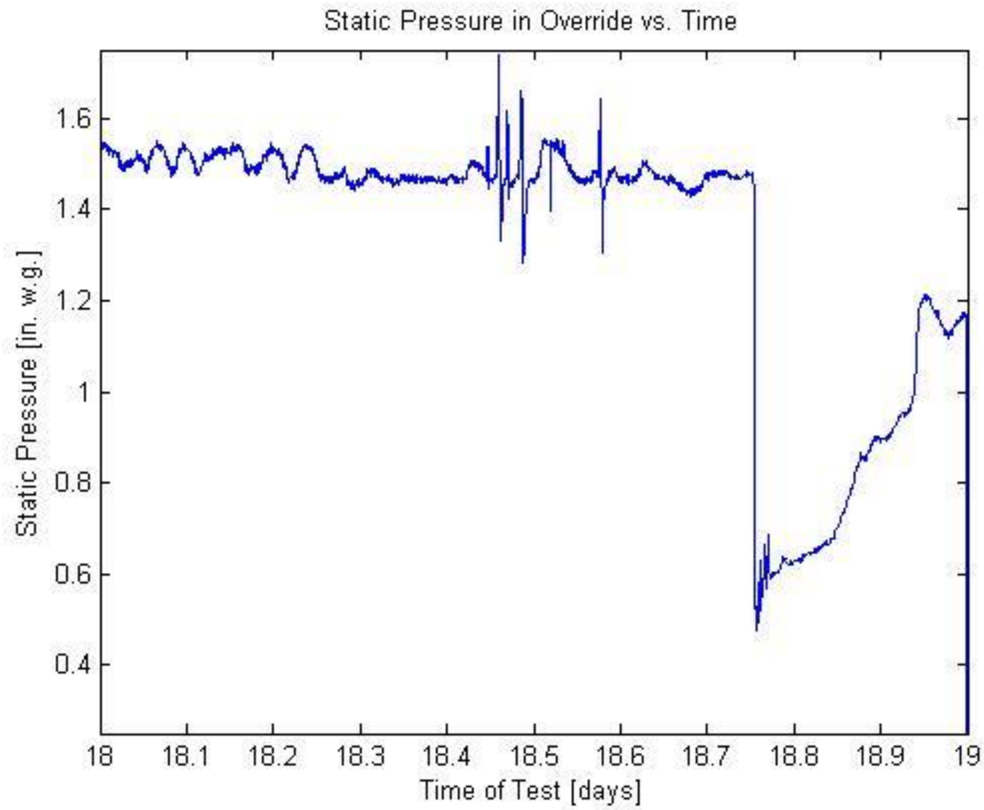


**Figure 0.6: Detail static pressure plot when fixed static pressure strategy is employed in Hixson-Lied**

Similar to Figure 4.5, Figure 4.6 (above) is a detail image of static pressure vs. time for the override static pressure strategy. The intent of this graph is to show the difference in variation of static pressure between the two strategies employed. This plot should depict a relatively constant static pressure, but at different times throughout testing, there were sharp changes in static pressure.

## Weather

Weather data specific to the Hixson-Lied building is unavailable. However, local weather data including hourly temperature readings and hourly solar radiation are available for the Ames area. This data allows for an inferred comparison of weather during the test weeks at the Hixson-Lied building. Table 4.4 (below) contains total average hourly air temperature and average daytime solar radiation during the test weeks. Table 4.4 also includes maximum and minimum weekly averages of these values for further comparison.

**Table 0.4: Local weather data averages, Temperature in $^{o}$F and solar radiation in kcal/(hr*m$^2$)**

| Hixson test weather comparison | | |
|---|---|---|
| **fixed pressure** | solar radiaion | temperature |
| average | 270.7 | 63.5 |
| max weekly avg | 364.6 | 81.1 |
| min weekly avg | 143.9 | 45.2 |
| **TR reset** | solar radiaion | temperature |
| average | 283.8 | 57.2 |
| max weekly avg | 368.4 | 81.1 |
| min weekly avg | 145.9 | 38.7 |

The weather comparisons contain some mixed results. The solar radiation per hour was slightly higher for the TR strategy tests weeks, but the average hourly air temperature was lower. From the raw data, the reason for the difference in temperature means is largely due to a single week with a very low average air temperature. The solar radiation, on the other hand, is different due to a consistently slightly higher weekly average. To put this into context: The TR strategy may have had a slightly reduced cooling load one week due to a lower than average outdoor air temperature, but had to contend with a consistently higher solar heat gain. These two conditions and their effects on the fan energy used may cancel to some extent, but it is highly unlikely that a single week of reduced cooling load due to outdoor air temperature would account for all of the 37% reduction in fan energy, which is also a weekly average.

## Rogue Zones

During the initial week of testing, two rogue zones were discovered. These two zones were originally flagged in analysis of the data when they were consistently in control of the static pressure reset strategy. These rooms were 1080D and 2242; both rooms were originally scheduled as study rooms. In both cases, these study rooms had later had computers installed in them. In the case of 2242, three large network printers were also installed. The additional equipment load was not accounted for in the original commissioning and balancing.

To combat this problem, a determination was first made regarding occupant comfort and equipment cooling. In this case, it was decided that since these spaces do not contain regular offices or classrooms, that their cooling requirements could be somewhat sidelined. This was accomplished by implementing an operator override on the damper position point in Metasys.

Overriding the damper position in Metasys has no actual effect on the damper position in this case. Since this point was brought out as an analog output, it cannot be commanded with any result. An override of damper position that resulted in a change in damper position can only happen if the damper position point is an analog input. However, since the control strategy uses damper position command, it will reference the overridden value instead of the value given to the damper by the system. These damper commands were overridden to values of 40% open for 1080D and 60% open for 2242. This most likely resulted in certain periods where the dampers were at or near 100% open (despite the command value) but were not meeting airflow requests, i.e. the VAV boxes were starved.

This method appears to have been effective, during the course of the test, the maximum static pressure never greatly exceeded 1.0 inches w.g. after this change was implemented, and there were no related customer complaints.

# CHAPTER 5: SUMMARY AND FUTURE WORK

## Summary of Work

Over the course of testing, two families of static pressure reset strategies were evaluated: Trim and Respond and Proportional plus Integral control. After five rounds of testing at the ERS, a version of Trim and Respond, called tiered Trim and Respond, was chosen to be modified for implementation in a campus building. This strategy was chosen because its operation was shown to be stable, without oscillation, and capable of saving fan energy. Once implemented in the building, the strategy demonstrated its ability to reduce operating costs by cutting fan energy. It could handle rogue zones effectively with some operator monitoring. The strategy was able to do this without significant adverse effects on the system. The only performance category where the tiered Trim and Respond underperformed was damper travel per hour. This increase was just outside the similarity threshold and may have a very minor impact on maintenance costs, which should be outweighed by the significant 37% energy savings.

## Limitations

The control strategies developed in this research, were done with one type of system in mind. Specifically, a mixed-air AHU which supplies air to pressure-independent VAV boxes with DDC controls. It is also worth noting that both test buildings had relatively new equipment and were less than or about 10 years old. The ERS was the oldest building at about 12 years old, but its equipment is continually being calibrated and repaired in order to be ready to perform research. The Hixson building was only about 4 years old when this research was completed, which would make the equipment relatively new.

It is also worth noting that many campus buildings have laboratories and research areas. These areas have their own unique ventilation requirements that depend upon a variety of factors. Some of these factors include equipment heat rejection, chemicals present, research schedule, and whether or not animals are present to name a few. Implementing a static pressure reset strategy that includes laboratory rooms will require an extra level of scrutiny to verify that ventilation requirements are met and comply with local health and safety requirements.

As with laboratory ventilation requirements, there remain a variety of untested aspects of static pressure reset strategies. The next section, Future Work, discusses many of these aspects in more detail.

## Future Work

This research focused on only a small aspect of static pressure reset. There is much additional work that can be done. There are questions raised by this research that should be further investigated. These sets of questions and comments can be divided into three sections:  Analysis, New Strategies, and Strategy Implementation.

### Analysis

The ERS was able to collect extensive data on the versions of static pressure reset strategies tested here. Some of this data was unused in this report, such as solar and meteorological data. Analyzing this data might help to direct additional research and perhaps answer a few questions along the way. Some important aspects to study would be the effect of solar load on oscillation. It is likely that with the addition of solar load, the total load on some of the exterior rooms may have exceeded design conditions for the room. In this situation, the room may call for more air than the damper maximum will allow. This could have an impact on stability.

Data errors were problematic in calculating applied artificial load. Studying these data errors to find out how the equipment behaved when they were present is important. The equipment could have operated normally, but there is no way to know for certain without redundant monitoring.

Plotting VAV flow rate vs. damper position for several pressure levels may help to determine an optimal set point for maximum damper position. Ideally, this set point would be as high as possible and in a region of fairly constant slope. In this type of region, small changes in damper position in one direction would not result in extremely large or small changes in VAV flow rate.

Finally, studying the data for clues as to why strategies oscillate. Ideally, when overloaded, these strategies would simply operate at their maximum pressure or damper position levels until the load subsided. In the observations here, the static pressure would sometimes oscillate wildly. Analysis could yield the reason these oscillations occurred.

### New Strategies

In addition to analyzing existing data, it would be beneficial to continue to test new strategies or revise and retest old ones. It is possible that a set of parameters can be found for each control strategy that would result in stable operation. This would provide building operators with a variety of choices for energy saving strategies.

The PI strategies tested earlier should be retested with a variety of parameters in order to find a root cause for unstable operation. It is just as important to know what causes the instability as it is to know how to avoid it. In the process, newer more robust strategies may be discovered that will operate without oscillation and with increased efficiency.

Commissioning is a key factor in deploying any HVAC system. A look into commissioning processes and how they could incorporate selecting and tuning a static pressure reset strategy would be beneficial. Although buildings change over time, it is likely easier to start out with a static pressure reset strategy employed than it would be to try and get one to work after commissioning.

### Strategy implementation

Once a control strategy has been found that operates in a stable manner, incorporating this strategy in to a broader energy saving concept is the next logical step. There are other pieces of equipment that contribute to energy consumption in an HVAC system such as pumps and electric heaters. These devices should be studied to find additional energy savings.

In addition to controlling other devices, fan energy may be further reduced by operating the supply and return fans on a schedule. For example, the fans could be turned off altogether at night throughout the year, provided that the logic to accomplish this includes a night-cycle that keeps pipes from freezing or prevents equipment from overheating. Another possible scheduling solution is to turn off air to classrooms when class is not scheduled. These types of strategies would necessarily need to incorporate some sort of warm-up or cool-down cycle in the beginning to ensure occupant comfort.

## Recommendations

The recommendation of this research is that static pressure reset strategies like the final Trim-and-Respond strategy be implemented in the buildings that can support them as part of a broader energy saving concept that includes a variety of equipment and controls. By incorporating additional energy saving strategies and concepts, energy savings on the order of 30%-50% would be a reasonable goal.

In the near future, this strategy could be implemented on any campus air handler that serves classrooms and student spaces. The proposed air handler would have to have pressure independent VAV boxes for air distribution and a variable speed fan. It would have to be able to collect information on damper position (command signal is sufficient) and duct pressure at a minimum.

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# APPENDIX A: SIMILARITY TEST TABLES AND GRAPHS

## TEST 1.0

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-6 |
| AHUA | 131.26 |
| AHUB | 127.95 |
| % difference | 2.52% |

| Fan Power Consumed [kW-hr] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | mean | variance |
| AHUA | 28.30142 | 27.89835 | 19.76791 | 21.05689 | 14.03746 | 20.19313 | 21.87586 | 29.38888 |
| AHUB | 26.21801 | 26.90093 | 18.73958 | 20.01003 | 14.97864 | 21.10436 | 21.32526 | 20.75423 |
| % difference | 7.36% | 3.58% | 5.20% | 4.97% | -6.70% | -4.51% | 2.52% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -0.21237 |
| | variance | 2.098164 |
| AHUB | mean [$^{o}$F] | -0.38188 |
| | variance | 1.548309 |
| difference | | 0.169509 |

| Temperature Control [$^{o}$F Average] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUA | East | -0.26321 | -0.03452 | -0.62421 | -0.53415 | -0.82421 | -0.90278 | -0.53051 |
| | Internal | 0.235583 | 0.411699 | 0.360144 | 0.434812 | 0.632887 | 0.291481 | 0.394434 |
| | South | -0.33792 | 0.003272 | -0.6298 | -0.58218 | -0.79655 | -0.88009 | -0.53721 |
| | West | -0.71091 | -0.61718 | -0.68914 | -0.72673 | -0.9953 | -1.1523 | -0.81526 |
| | mean | -0.26911 | -0.05918 | -0.39575 | -0.35206 | -0.49579 | -0.66092 | |
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUB | East | -0.79343 | -0.63276 | -0.67781 | -0.70851 | -0.95076 | -0.97382 | -0.78951 |
| | Internal | 0.006142 | 0.1694 | 0.094918 | 0.294037 | 0.486183 | -0.03286 | 0.169636 |
| | South | -0.69948 | -0.5531 | -0.57713 | -0.56949 | -0.77419 | -0.81688 | -0.66505 |
| | West | -0.95481 | -0.68331 | -0.66604 | -0.70253 | -0.92486 | -1.29216 | -0.87062 |
| | mean | -0.61039 | -0.42494 | -0.45652 | -0.42162 | -0.54091 | -0.77893 | |

| Temperature Control [$^{o}$F Variance] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUA | East | 2.783281 | 3.17789 | 1.044253 | 1.273904 | 0.929657 | 0.929325 | 1.689718 |
| | Internal | 3.547996 | 4.344698 | 4.023172 | 4.271809 | 5.214999 | 3.770618 | 4.195549 |
| | South | 2.275898 | 3.52047 | 0.977056 | 1.21501 | 0.942299 | 0.92554 | 1.642712 |
| | West | 1.358506 | 1.290356 | 1.052964 | 1.033565 | 0.908523 | 0.941407 | 1.097554 |
| | mean | 2.49142 | 3.083354 | 1.774361 | 1.948572 | 1.99887 | 1.641722 | |
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUB | East | 1.274093 | 1.281066 | 1.053516 | 1.058499 | 0.876697 | 0.923655 | 1.077921 |
| | Internal | 2.574858 | 3.382486 | 2.981253 | 3.487059 | 4.349049 | 2.43112 | 3.200971 |
| | South | 1.330275 | 1.319224 | 0.910255 | 1.090609 | 0.965971 | 0.966724 | 1.097177 |
| | West | 1.754663 | 1.342833 | 1.025764 | 1.023421 | 0.923185 | 1.039857 | 1.184954 |
| | mean | 1.733472 | 1.831402 | 1.492697 | 1.664897 | 1.778726 | 1.340339 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.059708 |
| | variance | 0.201163 |
| AHUB | mean | 1.046632 |
| | variance | 0.044764 |
| difference | | 0.013076 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | 4 | 5 | 6 | mean | variance |
| AHUA | 1.287292 | 1.001583 | 0.972125 | 0.678417 | 0.595917 | 1.822917 | 1.059708 | 0.201163 |
| AHUB | 1.137083 | 1.077417 | 0.921375 | 0.9095 | 0.825458 | 1.408958 | 1.046632 | 0.044764 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.00142 |
| | variance | 0.001346 |
| AHUB | mean | -0.00674 |
| | variance | 0.182378 |
| difference | | 0.005324 |

| Static Pressure Control [inches w.g.] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUA | mean | -0.00409 | -0.00316 | 0.000303 | -0.00146 | 0.000621 | -0.00286 | -0.00177 |
| | variance | 0.001836 | 0.001892 | 0.000998 | 0.001203 | 0.000392 | 0.001836 | |
| AHUB | mean | -0.00081 | -0.02701 | -0.00051 | -0.00175 | -0.02114 | -0.00099 | -0.0087 |
| | variance | 0.000529 | 0.899338 | 0.00037 | 0.000863 | 0.554686 | 0.000861 | |

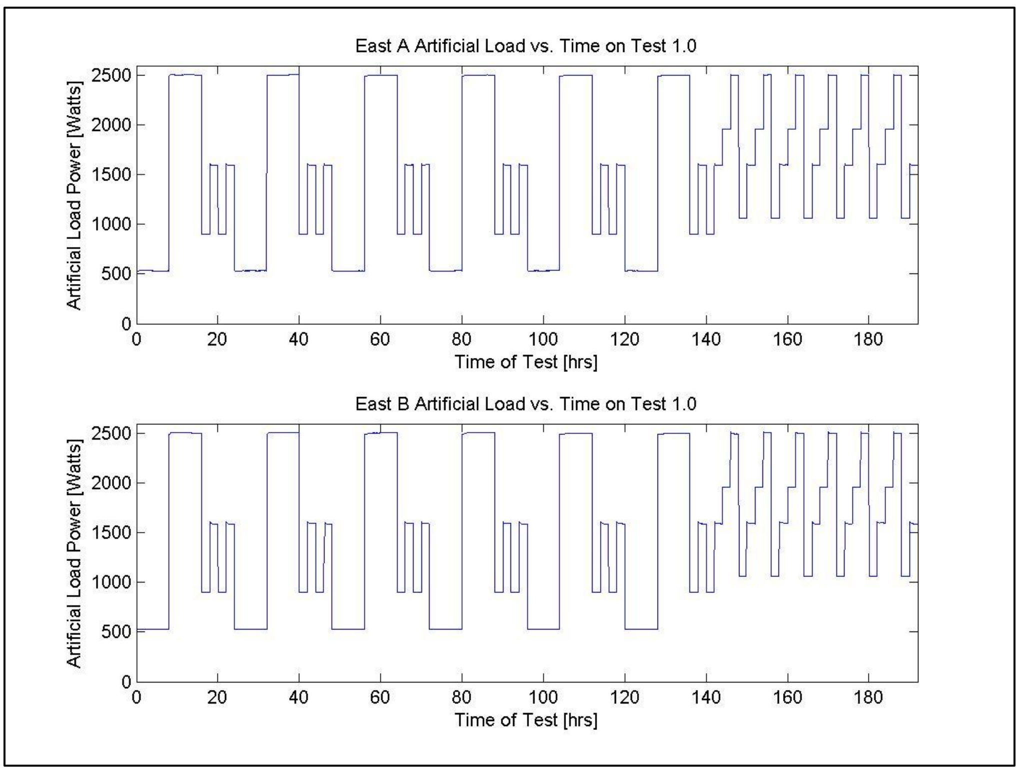
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 31.21877 |
| | variance | 100.6048 |
| AHUB | mean | 34.79807 |
| | variance | 61.78332 |
| difference | | -3.5793 |

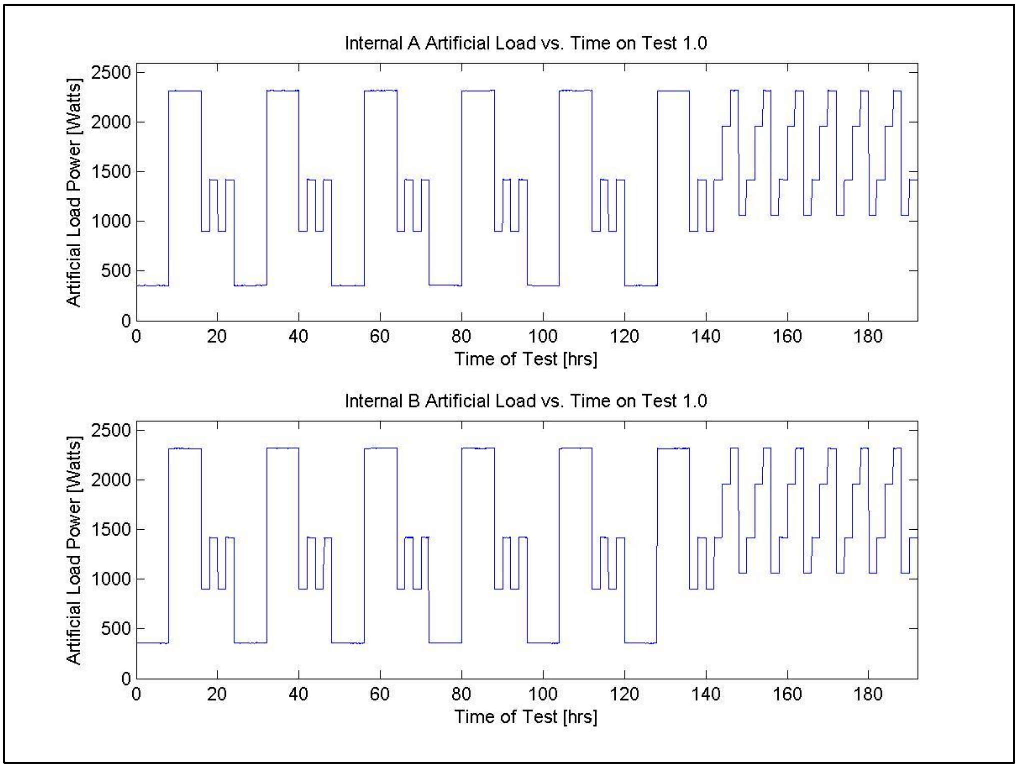
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean | variance |
| AHUA | East | 26.639 | 27.52242 | 38.18638 | 36.763 | 47.05496 | 32.35975 | 34.75425 | 58.20246 |
| | Internal | 19.50992 | 22.16638 | 16.79375 | 15.94783 | 14.47679 | 26.82596 | 19.28677 | 21.13616 |
| | South | 28.43242 | 31.84858 | 30.95496 | 44.95288 | 34.51458 | 31.02092 | 33.62072 | 34.62819 |
| | West | 40.694 | 41.90096 | 46.77583 | 41.53592 | 27.60896 | 24.11092 | 37.10443 | 81.61224 |
| | mean | 28.81883 | 30.85958 | 33.17773 | 34.79991 | 30.91382 | 28.57939 | | |
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean | variance |
| AHUB | East | 32.26117 | 37.80329 | 37.88379 | 36.81438 | 43.91254 | 42.70579 | 38.56349 | 17.91792 |
| | Internal | 23.25975 | 22.37408 | 26.50738 | 21.04667 | 14.30425 | 35.99475 | 23.91448 | 51.20768 |
| | South | 38.09725 | 31.51754 | 35.93463 | 46.71396 | 43.10196 | 27.16913 | 37.08908 | 52.11794 |
| | West | 44.89317 | 37.66683 | 35.39863 | 45.24133 | 42.70113 | 32.30733 | 39.7014 | 28.79384 |
| | mean | 34.62783 | 32.34044 | 33.9311 | 37.45408 | 36.00497 | 34.54425 | | |

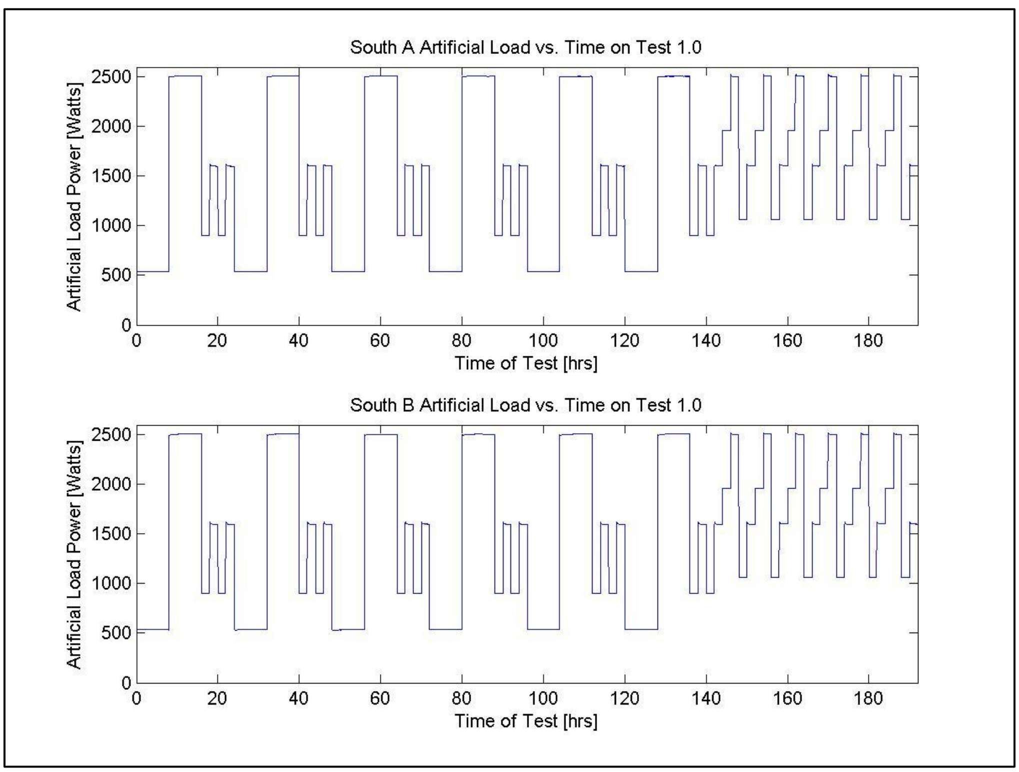
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -10.3901 |
| | variance | 1478.586 |
| AHUB | mean | -3.0664 |
| | variance | 327.1906 |
| difference | | -7.32368 |

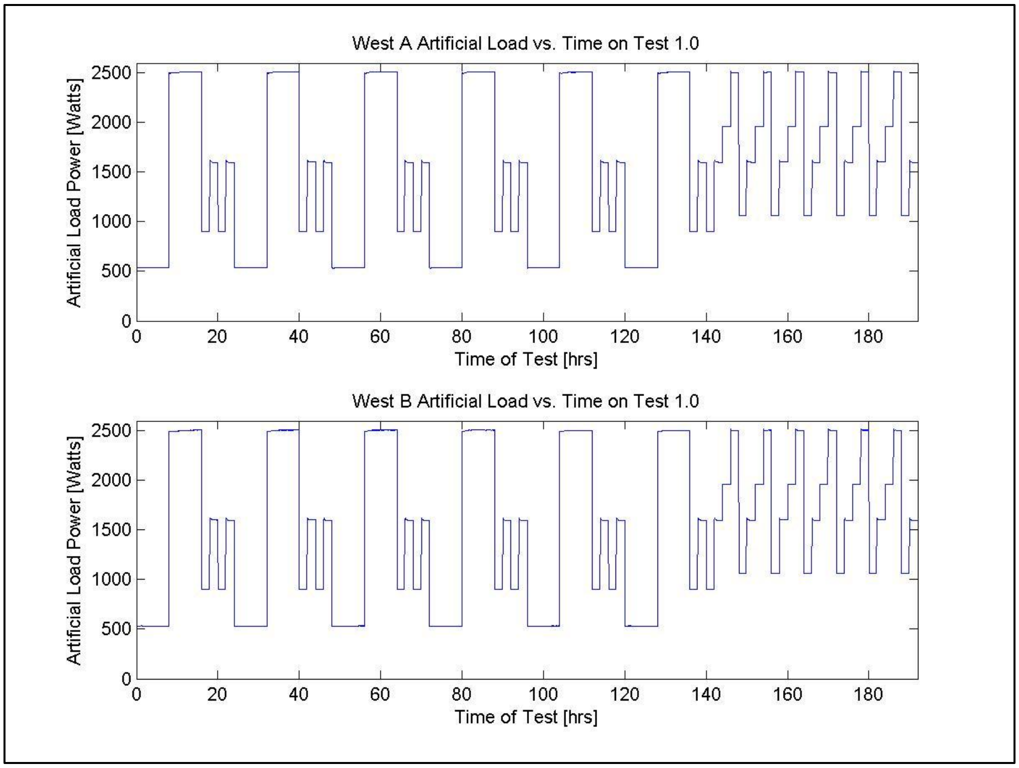
| Flow Rate Control [CFM Average] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUA | East | -21.7911 | -55.2019 | -0.0099 | -65.1197 | 0.16684 | 0.191146 | -23.6274 |
| | Internal | -0.01701 | -0.02422 | -3.15825 | -15.4692 | -32.1362 | 0.209549 | -8.43255 |
| | South | -18.2846 | -39.0198 | -0.05399 | -13.2888 | 0.028559 | -0.04905 | -11.778 |
| | West | 0.282813 | -2.78906 | -0.04141 | 0.029774 | -0.11406 | -0.05391 | -0.44764 |
| | mean | -9.95247 | -24.2587 | -0.81589 | -23.462 | -8.01372 | 0.074436 | |
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUB | East | -0.11059 | -5.31832 | -0.05625 | -0.01719 | -0.00373 | 0.063368 | -0.90712 |
| | Internal | -0.03915 | 0.023177 | -7.99036 | -20.6889 | -35.9219 | 0.418056 | -10.6998 |
| | South | -1.7099 | -25.5754 | -0.09861 | -1.48403 | 0.010503 | 0.028906 | -4.80476 |
| | West | -0.02691 | -0.62648 | 0.024219 | 0.082292 | 0.061111 | 0.050521 | -0.07254 |
| | mean | -0.47164 | -7.87426 | -2.03025 | -5.52695 | -8.9635 | 0.140213 | |

| Flow Rate Control [CFM Variance] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUA | East | 1848.916 | 7081.287 | 138.2364 | 11693.37 | 30.30304 | 23.29909 | 3469.236 |
| | Internal | 25.63266 | 32.79266 | 80.49085 | 424.9557 | 1142.724 | 18.23939 | 287.4726 |
| | South | 1561.077 | 4831.461 | 22.12273 | 2891.262 | 13.75011 | 18.30546 | 1556.33 |
| | West | 518.1728 | 1033.884 | 115.4134 | 124.7222 | 17.5145 | 20.5697 | 305.0462 |
| | mean | 988.4497 | 3244.856 | 89.06587 | 3783.578 | 301.073 | 20.10341 | |
| | Day | 1 | 2 | 3 | 4 | 5 | 6 | mean |
| AHUB | East | 24.72699 | 312.0145 | 19.60802 | 23.27472 | 17.28448 | 20.29654 | 69.53421 |
| | Internal | 37.63338 | 28.64945 | 167.354 | 599.8314 | 1322.211 | 46.51951 | 367.0331 |
| | South | 388.0512 | 3733.655 | 21.11014 | 323.1571 | 44.72627 | 33.76453 | 757.4106 |
| | West | 25.53185 | 501.6961 | 92.1011 | 103.4919 | 49.84399 | 13.42717 | 131.0153 |
| | mean | 118.9859 | 1144.004 | 75.04333 | 262.4388 | 358.5164 | 28.50194 | |




Internal A Artificial Load vs. Time on Test 1.0
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 1.0
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 1.0
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 1.0
Artificial Load Power [Watts]
Time of Test [hrs]




**TEST 2.0a**

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 49.66901062 |
| AHUB | 49.4969804 |
| % difference | 0.35% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 21.63803 | 15.28759 | 12.74339 | 16.55634 | 20.98595 |
| AHUB | 20.37843 | 15.89858 | 13.21997 | 16.49899 | 13.08126 |
| % difference | 5.82% | -4.00% | -3.74% | 0.35% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -0.80044 |
| | variance | 2.105061 |
| AHUB | mean [$^{o}$F] | -0.90557 |
| | variance | 1.811237 |
| difference | | 0.105128 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.06335 | -1.06914 | -1.00685 | -1.04645 |
| | Internal | 0.066476 | 0.171939 | 0.412917 | 0.217111 |
| | South | -0.95747 | -1.18243 | -1.19365 | -1.11119 |
| | West | -1.33337 | -1.27529 | -1.17503 | -1.26123 |
| | mean | -0.82193 | -0.83873 | -0.74065 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.31133 | -1.29111 | -1.25738 | -1.28661 |
| | Internal | -0.34579 | -0.19932 | 0.281121 | -0.088 |
| | South | -0.8518 | -1.08187 | -1.01682 | -0.9835 |
| | West | -1.67276 | -1.10925 | -1.01048 | -1.26416 |
| | mean | -1.04542 | -0.92039 | -0.75089 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 1.012195 | 0.992794 | 0.963381 | 0.989457 |
| | Internal | 2.823789 | 3.226353 | 4.534548 | 3.52823 |
| | South | 1.150681 | 0.9967 | 1.070326 | 1.072569 |
| | West | 1.684134 | 1.139313 | 1.351371 | 1.391606 |
| | mean | 1.6677 | 1.58879 | 1.979907 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.191062 | 1.075321 | 1.0691 | 1.111828 |
| | Internal | 1.652859 | 1.952933 | 3.607667 | 2.404486 |
| | South | 1.107567 | 0.994406 | 0.97548 | 1.025818 |
| | West | 2.618738 | 1.083256 | 1.073123 | 1.591706 |
| | mean | 1.642557 | 1.276479 | 1.681342 | |

| Static Pressure Travel Aggregate Values | | |
| --- | --- | --- |
| AHUA | mean | 1.317431 |
| | variance | 0.447374 |
| AHUB | mean | 1.101806 |
| | variance | 0.093223 |
| difference | | 0.215625 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
| --- | --- | --- | --- | --- | --- |
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.869333333 | 1.509375 | 0.573583 | 1.317431 | 0.447374 |
| AHUB | 1.378583333 | 1.152542 | 0.774292 | 1.101806 | 0.093223 |

| Static Pressure Control Aggregate Values | | |
| --- | --- | --- |
| AHUA | mean | 0.00057 |
| | variance | 0.00074 |
| AHUB | mean | -0.01276 |
| | variance | 0.742146 |
| difference | | 0.013329 |

| Static Pressure Control [inches w.g.] | | | | | |
| --- | --- | --- | --- | --- | --- |
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00052 | 0.000647 | 0.001582 | 0.00057 |
| | variance | 0.00106 | 0.000792 | 0.000366 | |
| AHUB | mean | -0.03827 | -0.00042 | 0.000415 | -0.01276 |
| | variance | 2.225635 | 0.000464 | 0.000392 | |

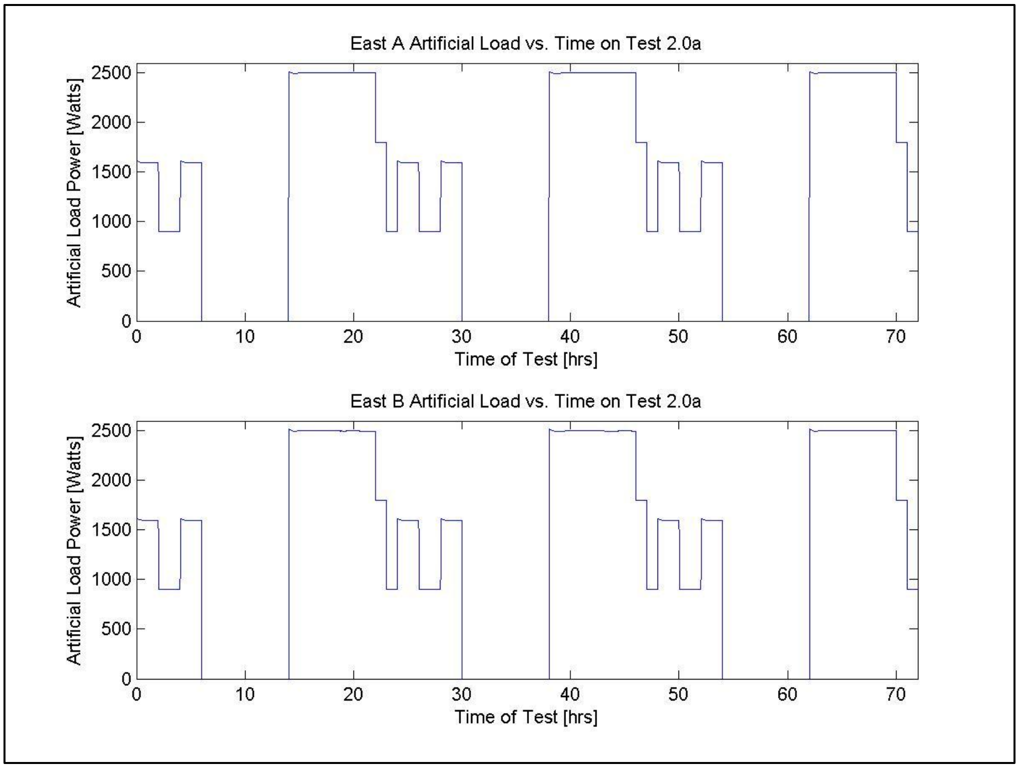
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 32.07178 |
| | variance | 86.46655 |
| AHUB | mean | 34.84617 |
| | variance | 100.3904 |
| difference | | -2.77438 |

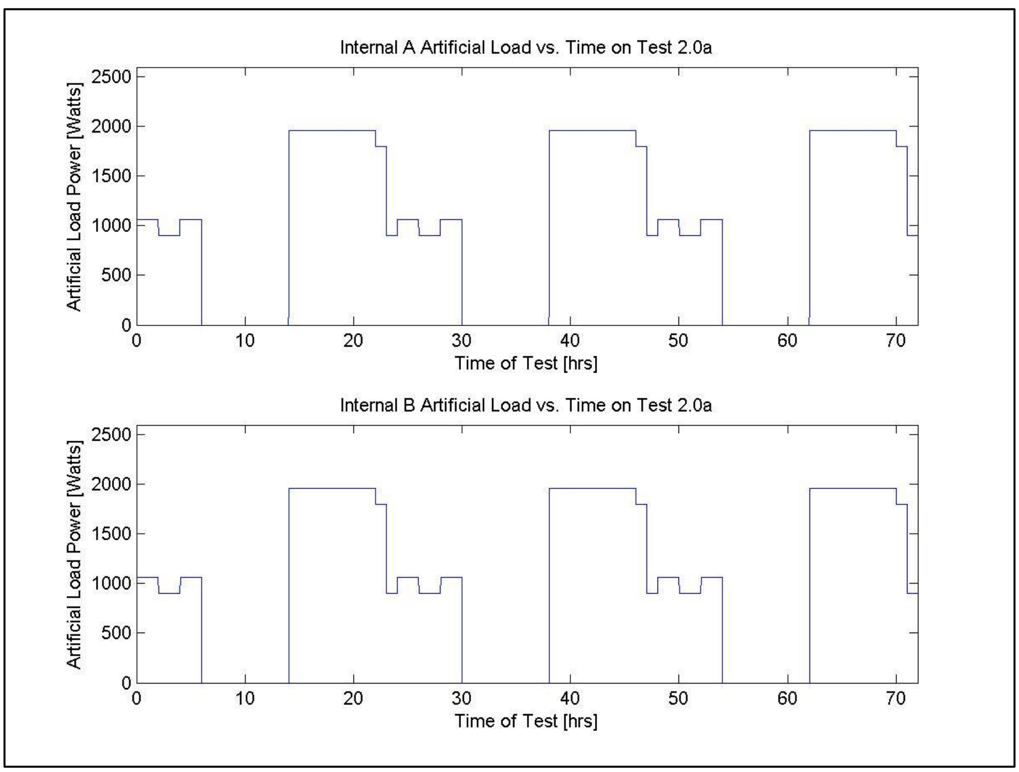
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 22.39221 | 26.953 | 36.90496 | 28.75006 | 55.07703 |
| | Internal | 34.52096 | 24.84621 | 11.9065 | 23.75789 | 128.7418 |
| | South | 36.73779 | 34.72058 | 31.52796 | 34.32878 | 6.900725 |
| | West | 42.30167 | 36.07587 | 45.97371 | 41.45042 | 25.03525 |
| | mean | 33.98816 | 30.64892 | 31.57828 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 35.41254 | 36.01638 | 23.82575 | 31.75156 | 47.20495 |
| | Internal | 34.37179 | 30.34733 | 11.16054 | 25.29322 | 153.8486 |
| | South | 42.57621 | 45.479 | 45.72475 | 44.59332 | 3.066651 |
| | West | 31.65354 | 44.50813 | 37.07804 | 37.74657 | 41.64528 |
| | mean | 36.00352 | 39.08771 | 29.44727 | | |

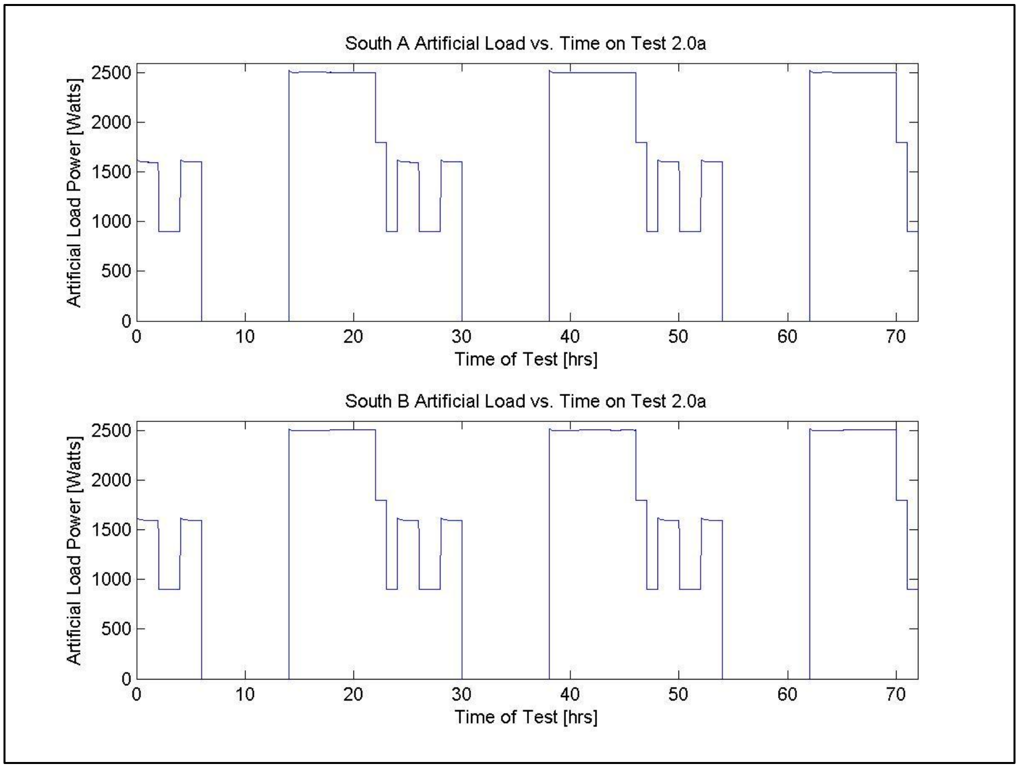
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -4.80294 |
| | variance | 809.8154 |
| AHUB | mean | -2.78655 |
| | variance | 266.4912 |
| difference | | -2.0164 |

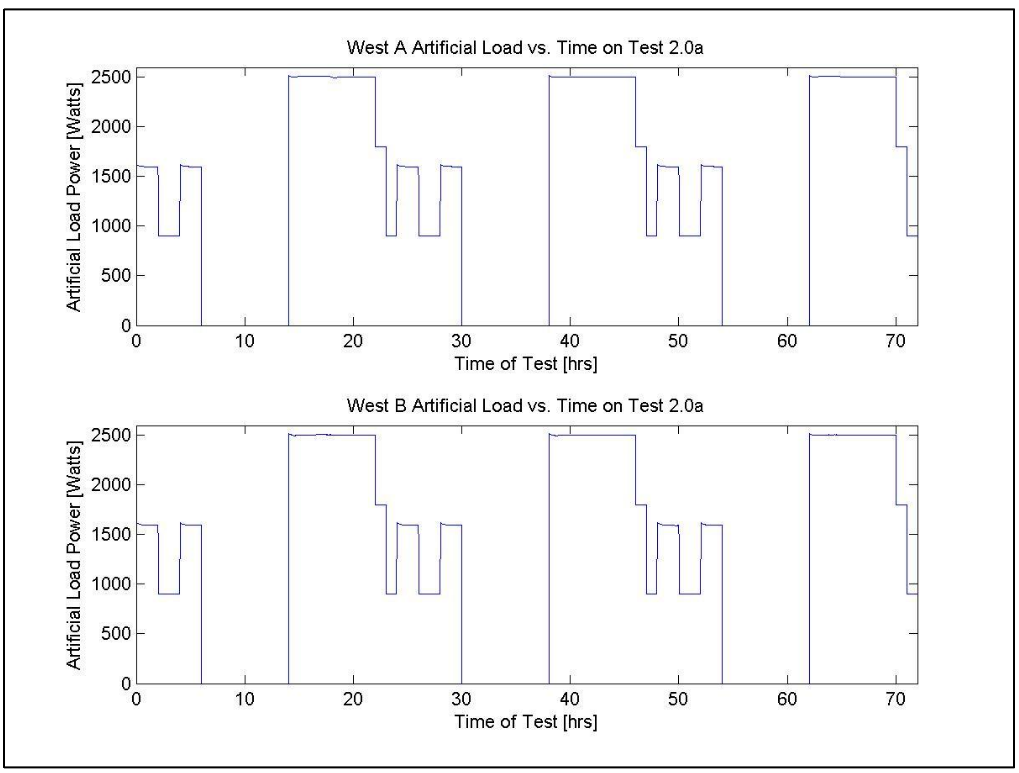
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.10825 | -0.03316 | -0.02595 | -0.05579 |
| | Internal | -0.03229 | -0.16797 | -35.6949 | -11.965 |
| | South | 0.086198 | 0.036806 | -0.04036 | 0.027546 |
| | West | 0.185764 | 0.034635 | -21.8759 | -7.21849 |
| | mean | 0.032856 | -0.03242 | -14.4093 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.018576 | -0.01398 | -0.05304 | -0.01615 |
| | Internal | 0.244358 | -0.11623 | -33.6262 | -11.166 |
| | South | 0.001997 | 0.054427 | -0.01615 | 0.013426 |
| | West | 0.021528 | 0.007378 | 0.038802 | 0.022569 |
| | mean | 0.071615 | -0.0171 | -8.41415 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 23.05 | 20.95586 | 20.81292 | 21.60626 |
| | Internal | 15.09225 | 17.817 | 1688.224 | 573.7111 |
| | South | 20.10259 | 13.93591 | 21.10844 | 18.38231 |
| | West | 101.8966 | 18.93058 | 6285.076 | 2135.301 |
| | mean | 40.03536 | 17.90984 | 2003.805 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 16.54281 | 14.4323 | 9.89515 | 13.62342 |
| | Internal | 22.39263 | 24.26868 | 1920.149 | 655.6034 |
| | South | 33.3473 | 20.91487 | 41.33747 | 31.86655 |
| | West | 14.52985 | 17.26694 | 26.50793 | 19.43491 |
| | mean | 21.70315 | 19.2207 | 499.4724 | |


East A Artificial Load vs. Time on Test 2.0a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
East B Artificial Load vs. Time on Test 2.0a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 2.0a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 2.0a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


South A Artificial Load vs. Time on Test 2.0a
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 2.0a
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 2.0a
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 2.0a
Artificial Load Power [Watts]
Time of Test [hrs]

**TEST 2.0b**

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 45.86817348 |
| AHUB | 45.935144 |
| % difference | -0.15% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 18.28158 | 15.63877 | 11.94782 | 15.28939 | 10.12069 |
| AHUB | 18.24103 | 15.6841 | 12.01002 | 15.31171 | 9.810367 |
| % difference | 0.22% | -0.29% | -0.52% | -0.15% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -0.9264 |
| | variance | 2.071369 |
| AHUB | mean [$^oF$] | -1.05119 |
| | variance | 2.159245 |
| difference | | 0.124782 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.11387 | -1.17235 | -1.21711 | -1.16778 |
| | Internal | -0.01091 | -0.20437 | 0.359858 | 0.048193 |
| | South | -1.20451 | -1.06291 | -1.33268 | -1.20003 |
| | West | -1.28507 | -1.46286 | -1.41007 | -1.386 |
| | mean | -0.90359 | -0.97562 | -0.9 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.31388 | -1.36155 | -1.36408 | -1.3465 |
| | Internal | -0.42879 | -0.29261 | 0.283336 | -0.14602 |
| | South | -1.10809 | -0.90393 | -1.20617 | -1.07273 |
| | West | -1.19769 | -1.90347 | -1.81731 | -1.63949 |
| | mean | -1.01211 | -1.11539 | -1.02605 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 1.029088 | 1.083579 | 1.103901 | 1.07219 |
| | Internal | 2.749655 | 1.96486 | 4.109707 | 2.941407 |
| | South | 1.05313 | 1.404089 | 1.258338 | 1.238519 |
| | West | 1.129471 | 1.87782 | 2.000286 | 1.669192 |
| | mean | 1.490336 | 1.582587 | 2.118058 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.097301 | 1.201017 | 1.222742 | 1.173687 |
| | Internal | 1.512419 | 1.698895 | 3.647228 | 2.28618 |
| | South | 1.017999 | 1.164826 | 1.188643 | 1.123823 |
| | West | 1.150609 | 4.013553 | 2.618424 | 2.594195 |
| | mean | 1.194582 | 2.019573 | 2.169259 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.383847 |
| | variance | 0.561492 |
| AHUB | mean | 1.101097 |
| | variance | 0.10874 |
| difference | | 0.28275 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 2.068958333 | 1.498958 | 0.583625 | 1.383847 | 0.561492 |
| AHUB | 1.469458333 | 1.000417 | 0.833417 | 1.101097 | 0.10874 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.00054 |
| | variance | 0.000995 |
| AHUB | mean | -0.00801 |
| | variance | 0.276909 |
| difference | | 0.008554 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00085 | 0.000616 | 0.001851 | 0.00054 |
| | variance | 0.001645 | 0.000961 | 0.000376 | |
| AHUB | mean | -0.00062 | -0.02376 | 0.000331 | -0.00801 |
| | variance | 0.001033 | 0.829061 | 0.000645 | |

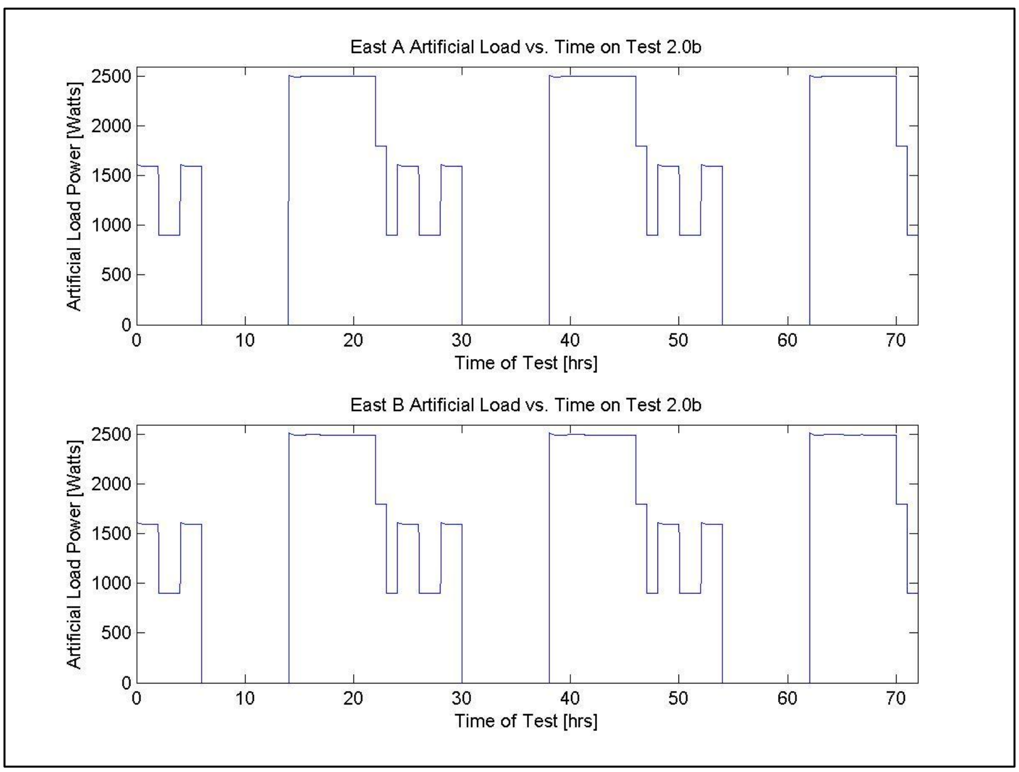
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 32.35145 |
| | variance | 78.80776 |
| AHUB | mean | 35.04698 |
| | variance | 59.99078 |
| difference | | -2.69552 |

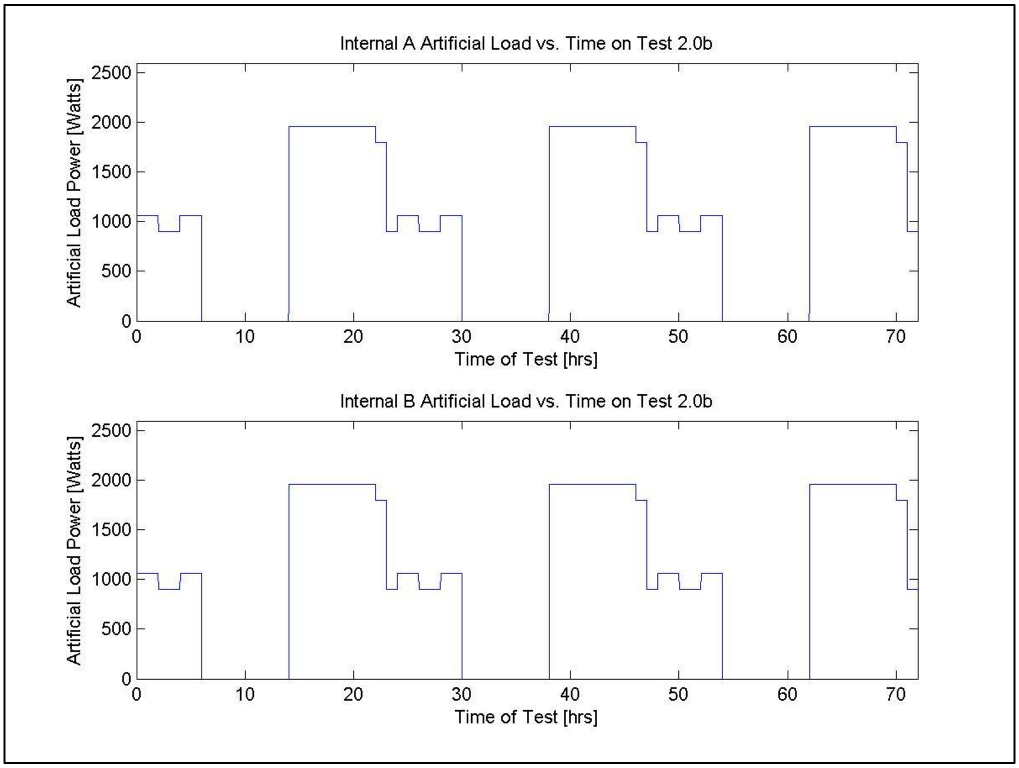
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 23.61517 | 35.52438 | 43.70013 | 34.27989 | 102.0129 |
| | Internal | 34.5395 | 27.11542 | 12.86458 | 24.83983 | 121.3342 |
| | South | 31.93342 | 35.20704 | 36.8395 | 34.65999 | 6.241866 |
| | West | 25.36475 | 37.50288 | 44.01071 | 35.62611 | 89.55962 |
| | mean | 28.86321 | 33.83743 | 34.35373 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 36.13413 | 42.44408 | 38.00679 | 38.86167 | 10.502 |
| | Internal | 36.19825 | 31.87679 | 12.96758 | 27.01421 | 152.6495 |
| | South | 32.42496 | 42.98838 | 33.93454 | 36.44929 | 32.63942 |
| | West | 37.17508 | 37.619 | 38.79417 | 37.86275 | 0.699918 |
| | mean | 35.4831 | 38.73206 | 30.92577 | | |

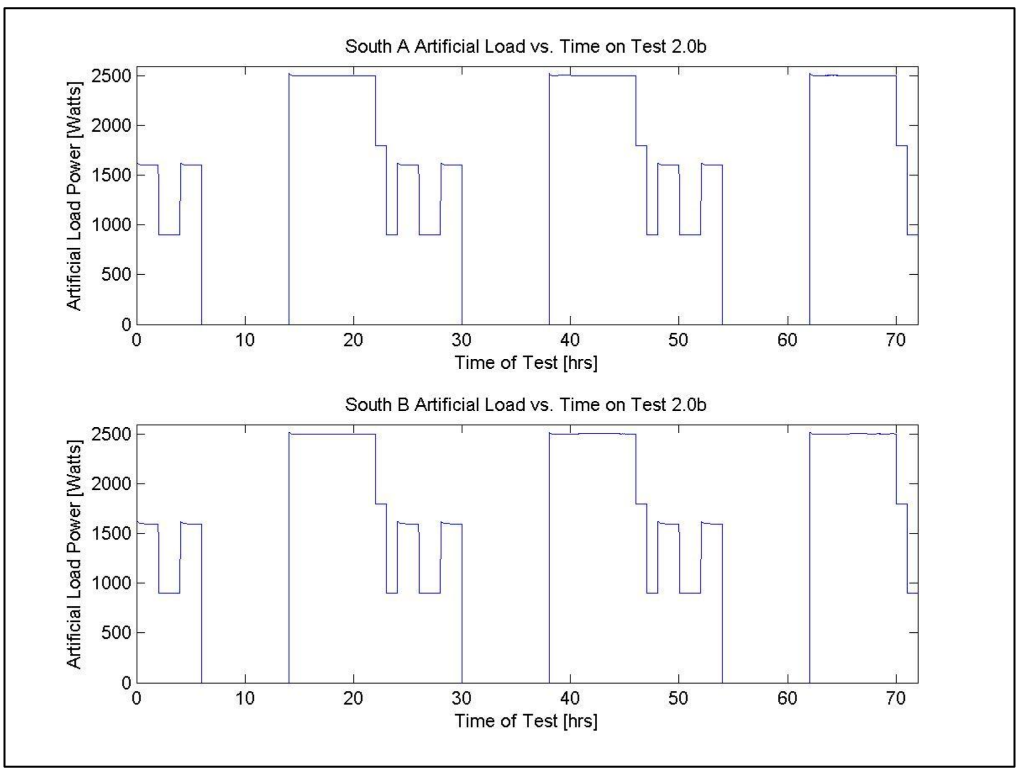
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -5.29271 |
| | variance | 1090.469 |
| AHUB | mean | -2.89706 |
| | variance | 291.008 |
| difference | | -2.39565 |

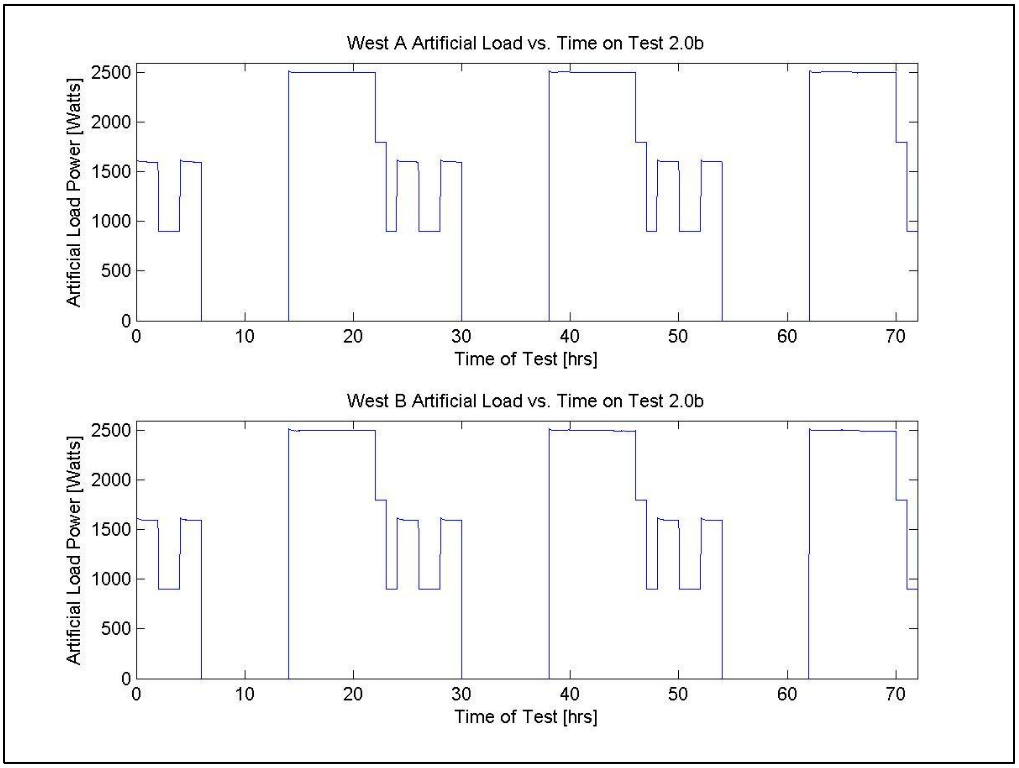
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.316493 | -0.01424 | 0.01684 | 0.106366 |
| | Internal | 0.301997 | -0.01337 | -32.4286 | -10.7133 |
| | South | 0.070139 | 0.104601 | -0.03958 | 0.045052 |
| | West | 0.116667 | 0.05 | -31.9935 | -10.6089 |
| | mean | 0.201324 | 0.031749 | -16.1112 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.06693 | 0.072569 | -0.02977 | -0.00804 |
| | Internal | 0.438194 | -0.00512 | -35.2061 | -11.591 |
| | South | -0.10747 | 0.082639 | -0.04557 | -0.02347 |
| | West | 0.061719 | 0.066406 | -0.02526 | 0.034288 |
| | mean | 0.08138 | 0.054123 | -8.82667 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 21.36363 | 15.03348 | 24.50934 | 20.30215 |
| | Internal | 36.44039 | 16.75714 | 1801.155 | 618.1175 |
| | South | 19.48526 | 32.21828 | 17.00466 | 22.90274 |
| | West | 21.54608 | 154.1431 | 9193.832 | 3123.174 |
| | mean | 24.70884 | 54.538 | 2759.125 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 19.6786 | 17.16242 | 13.30174 | 16.71426 |
| | Internal | 44.17243 | 32.89555 | 2102.815 | 726.6275 |
| | South | 15.00299 | 21.76026 | 23.38588 | 20.04971 |
| | West | 15.34147 | 17.3496 | 31.67873 | 21.4566 |
| | mean | 23.54887 | 22.29196 | 542.7952 | |




Internal A Artificial Load vs. Time on Test 2.0b
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 2.0b
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 2.0b
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 2.0b
Artificial Load Power [Watts]
Time of Test [hrs]




## TEST 3.0a

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 46.79221443 |
| AHUB | 47.77730408 |
| % difference | -2.11% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 18.4434 | 15.78429 | 12.56453 | 15.5974 | 8.666467 |
| AHUB | 18.84443 | 16.07262 | 12.86025 | 15.92577 | 8.968772 |
| % difference | -2.17% | -1.83% | -2.35% | -2.11% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.64063 |
| | variance | 2.784857 |
| AHUB | mean [$^{o}$F] | -1.6443 |
| | variance | 2.730581 |
| difference | | 0.003669 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.64689 | -0.74533 | -1.13607 | -1.1761 |
| | Internal | -1.61611 | -1.67822 | -1.65426 | -1.64953 |
| | South | -1.7666 | -1.82858 | -1.70473 | -1.76664 |
| | West | -1.94477 | -2.05517 | -1.91082 | -1.97025 |
| | mean | -1.74359 | -1.57683 | -1.60147 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.87592 | -1.157 | -1.58885 | -1.54059 |
| | Internal | -1.70736 | -1.80816 | -1.7766 | -1.76404 |
| | South | -1.66278 | -1.59883 | -1.47679 | -1.57946 |
| | West | -1.70045 | -1.77109 | -1.60776 | -1.6931 |
| | mean | -1.73663 | -1.58377 | -1.6125 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 3.008255 | 0.784279 | 1.541135 | 1.777889 |
| | Internal | 3.010223 | 2.951974 | 2.998689 | 2.986962 |
| | South | 2.964897 | 2.750412 | 2.919218 | 2.878175 |
| | West | 3.005989 | 3.02782 | 3.024653 | 3.019487 |
| | mean | 2.997341 | 2.378621 | 2.620924 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 2.896914 | 1.310511 | 2.109877 | 2.105767 |
| | Internal | 2.82E+00 | 2.70E+00 | 2.78E+00 | 2.765335 |
| | South | 3.012777 | 2.644861 | 2.756429 | 2.804689 |
| | West | 3.13E+00 | 3.066181 | 3.17E+00 | 3.122216 |
| | mean | 2.964234 | 2.429349 | 2.704923 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.339431 |
| | variance | 0.53733 |
| AHUB | mean | 1.095597 |
| | variance | 0.12812 |
| difference | | 0.243833 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.933042 | 1.565167 | 0.520083 | 1.339431 | 0.53733 |
| AHUB | 1.463542 | 1.074667 | 0.748583 | 1.095597 | 0.12812 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.001232 |
| | variance | 0.000732 |
| AHUB | mean | 0.000222 |
| | variance | 0.000413 |
| difference | | 0.001011 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.000135 | 1.05E-03 | 2.51E-03 | 0.001232 |
| | variance | 0.001029 | 0.000849 | 0.000317 | |
| AHUB | mean | 0.000459 | -0.00025 | 0.00046 | 0.000222 |
| | variance | 0.000483 | 0.000424 | 0.000331 | |

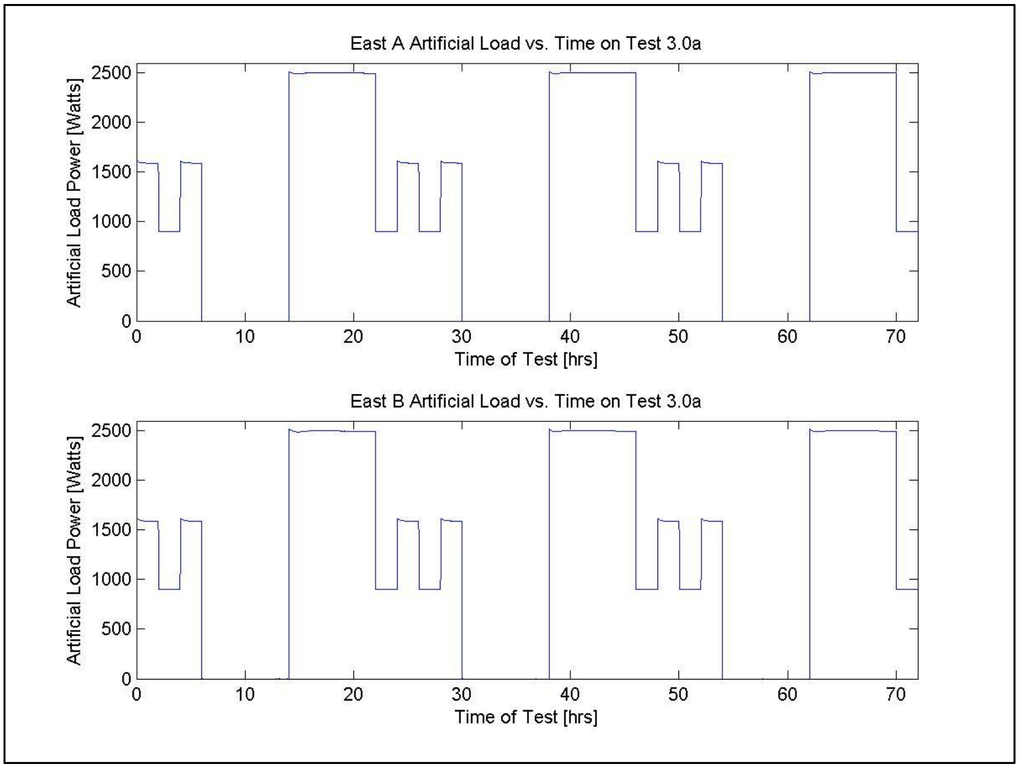
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 30.9101 |
| | variance | 59.67758 |
| AHUB | mean | 38.37425 |
| | variance | 84.41422 |
| difference | | -7.46415 |

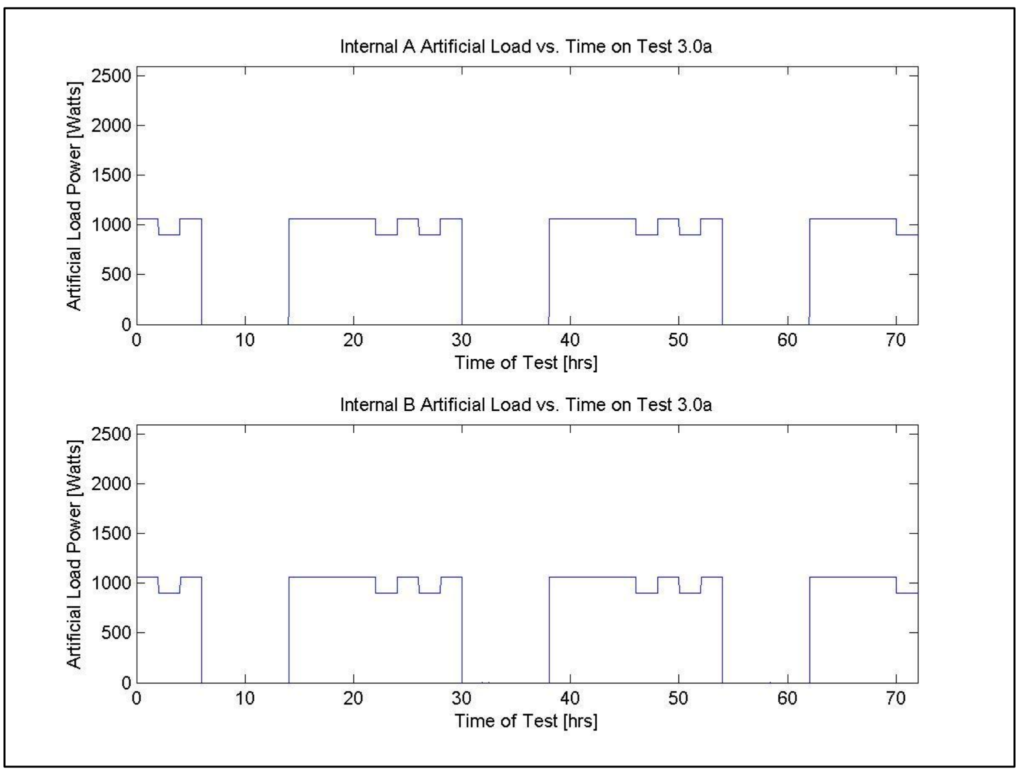
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 30.41508 | 28.51363 | 30.73379 | 29.8875 | 1.441043 |
| | Internal | 26.29258 | 23.41025 | 14.15992 | 21.28758 | 40.17969 |
| | South | 32.63667 | 36.16904 | 42.00033 | 36.93535 | 22.35998 |
| | West | 28.47667 | 38.98071 | 39.13258 | 35.52999 | 37.31775 |
| | mean | 29.45525 | 31.76841 | 31.50666 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 33.97538 | 38.63321 | 38.7675 | 37.12536 | 7.446318 |
| | Internal | 44.5865 | 48.03279 | 13.04213 | 35.22047 | 371.8785 |
| | South | 39.59658 | 44.32675 | 43.07771 | 42.33368 | 6.008802 |
| | West | 36.52388 | 45.78921 | 34.13938 | 38.81749 | 37.87514 |
| | mean | 38.67058 | 44.19549 | 32.25668 | | |

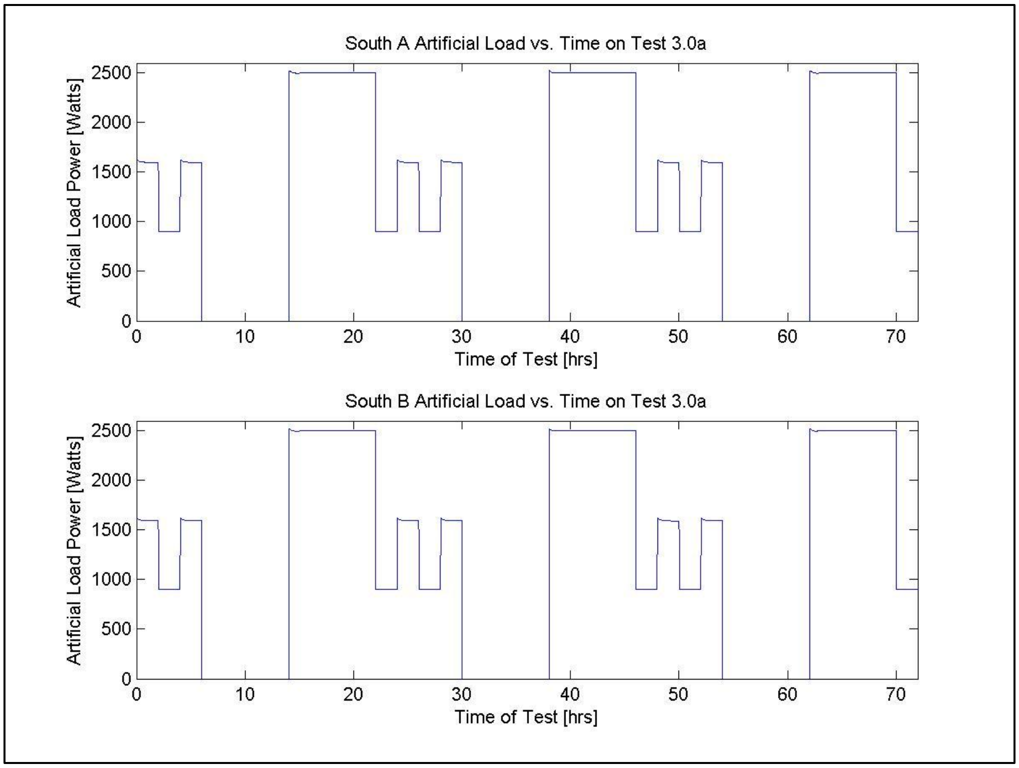
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -1.02012 |
| | variance | 101.1192 |
| AHUB | mean | -0.31553 |
| | variance | 44.25697 |
| difference | | -0.70459 |

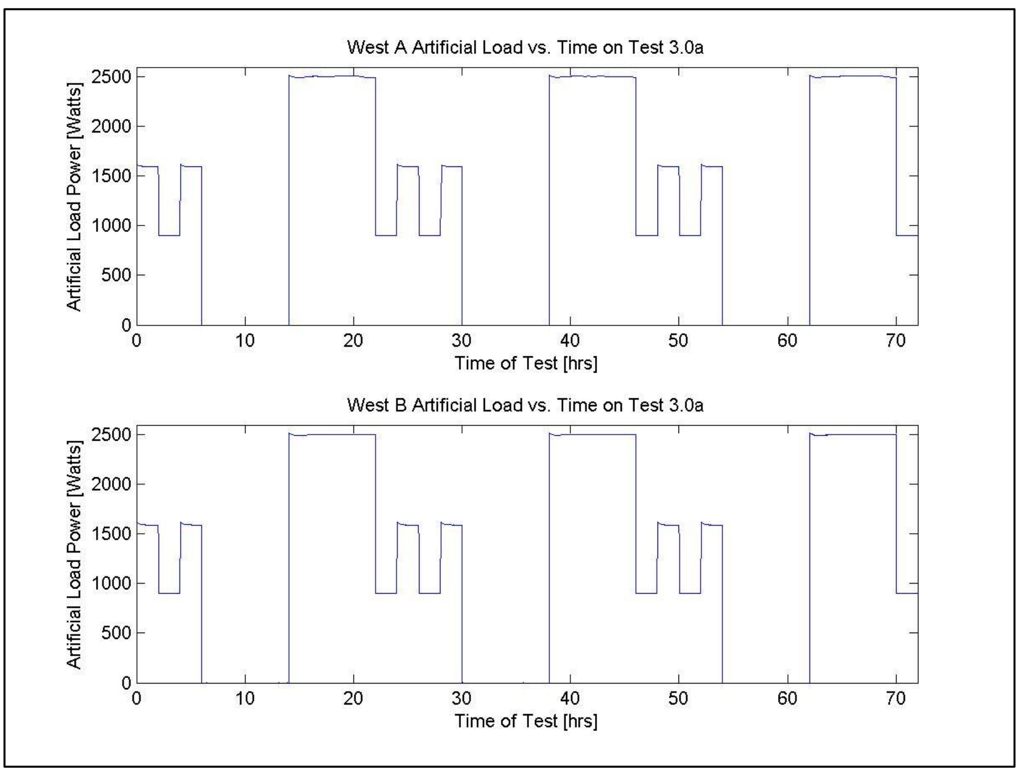
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.03429 | 0.085677 | -0.03012 | 0.007089 |
| | Internal | -0.0145 | -0.03993 | -0.0658 | -0.04008 |
| | South | 0.062153 | 0.023698 | 0.051302 | 0.045718 |
| | West | 0.186806 | 0.000694 | -12.4672 | -4.09323 |
| | mean | 0.050043 | 0.017535 | -3.12795 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.19314 | -0.03568 | -0.07057 | -0.0998 |
| | Internal | 0.019184 | -0.02283 | -0.07361 | -0.02575 |
| | South | -0.06398 | 0.042622 | -0.01675 | -0.0127 |
| | West | 0.044965 | 0.020399 | -3.43698 | -1.12387 |
| | mean | -0.04824 | 0.001128 | -0.89948 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 20.08939 | 17.62498 | 21.64795 | 19.78744 |
| | Internal | 7.072507 | 6.596389 | 4.747448 | 6.138782 |
| | South | 15.62748 | 21.88444 | 22.21841 | 19.91011 |
| | West | 24.15123 | 20.66945 | 888.7733 | 311.198 |
| | mean | 16.73515 | 16.69382 | 234.3468 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.99E+01 | 1.58E+01 | 1.53E+01 | 16.97557 |
| | Internal | 12.30652 | 12.26178 | 4.141663 | 9.569987 |
| | South | 1.79E+01 | 1.95E+01 | 2.30E+01 | 20.11362 |
| | West | 15.88145 | 20.83911 | 344.0398 | 126.9201 |
| | mean | 16.48012 | 17.08518 | 96.61918 | |


East A Artificial Load vs. Time on Test 3.0a
Artificial Load Power [Watts]
Time of Test [hrs]
East B Artificial Load vs. Time on Test 3.0a
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 3.0a
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 3.0a
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 3.0a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
South B Artificial Load vs. Time on Test 3.0a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


West A Artificial Load vs. Time on Test 3.0a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
West B Artificial Load vs. Time on Test 3.0a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]

## TEST 3.0b

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 49.07252482 |
| AHUB | 50.92571775 |
| % difference | -3.78% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 16.82003 | 13.57784 | 18.67465 | 16.35751 | 6.654809 |
| AHUB | 17.19008 | 14.1954 | 19.54024 | 16.97524 | 7.176451 |
| % difference | -2.20% | -4.55% | -4.64% | -3.78% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^o$F] | -1.36194 |
| | variance | 3.018425 |
| AHUB | mean [$^o$F] | -1.36627 |
| | variance | 2.851027 |
| diff | | 0.004333 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.06642 | -0.22027 | -1.34424 | -0.87698 |
| | Internal | -1.59112 | -1.61409 | -1.64345 | -1.61622 |
| | South | -1.34518 | -1.4914 | -1.47809 | -1.43822 |
| | West | -1.48886 | -1.52021 | -1.53992 | -1.51633 |
| | mean | -1.37289 | -1.21149 | -1.50142 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.30516 | -0.54734 | -1.50909 | -1.12053 |
| | Internal | -1.73357 | -1.79259 | -1.83138 | -1.78585 |
| | South | -1.06489 | -1.28016 | -1.33029 | -1.22511 |
| | West | -1.33277 | -1.28097 | -1.38703 | -1.33359 |
| | mean | -1.3591 | -1.22527 | -1.51445 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 2.199331 | 0.228374 | 3.248844 | 1.892183 |
| | Internal | 3.092278 | 3.070986 | 2.971889 | 3.045051 |
| | South | 3.010116 | 2.829537 | 3.200506 | 3.013387 |
| | West | 3.297612 | 4.170131 | 3.233626 | 3.567123 |
| | mean | 2.899834 | 2.574757 | 3.163716 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 2.686125 | 0.462668 | 3.175795 | 2.108196 |
| | Internal | 2.78E+00 | 2.68E+00 | 2.57E+00 | 2.679155 |
| | South | 2.231689 | 2.675623 | 3.119229 | 2.675514 |
| | West | 3.22E+00 | 3.95185 | 3.34E+00 | 3.50282 |
| | mean | 2.729841 | 2.442789 | 3.051633 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.264278 |
| | variance | 0.547284 |
| AHUB | mean | 1.069667 |
| | variance | 0.142528 |
| diff | | 0.194611 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.213917 | 0.550958 | 2.027958 | 1.264278 | 0.547284 |
| AHUB | 1.0485 | 0.703167 | 1.457333 | 1.069667 | 0.142528 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.00145 |
| | variance | 0.000915 |
| AHUB | mean | -0.02582 |
| | variance | 1.069387 |
| diff | | 0.027273 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.002556 | 2.84E-03 | -1.05E-03 | 0.00145 |
| | variance | 0.000684 | 0.000393 | 0.001661 | |
| AHUB | mean | -0.03202 | -0.01479 | -0.03066 | -0.02582 |
| | variance | 1.481065 | 0.361503 | 1.366895 | |

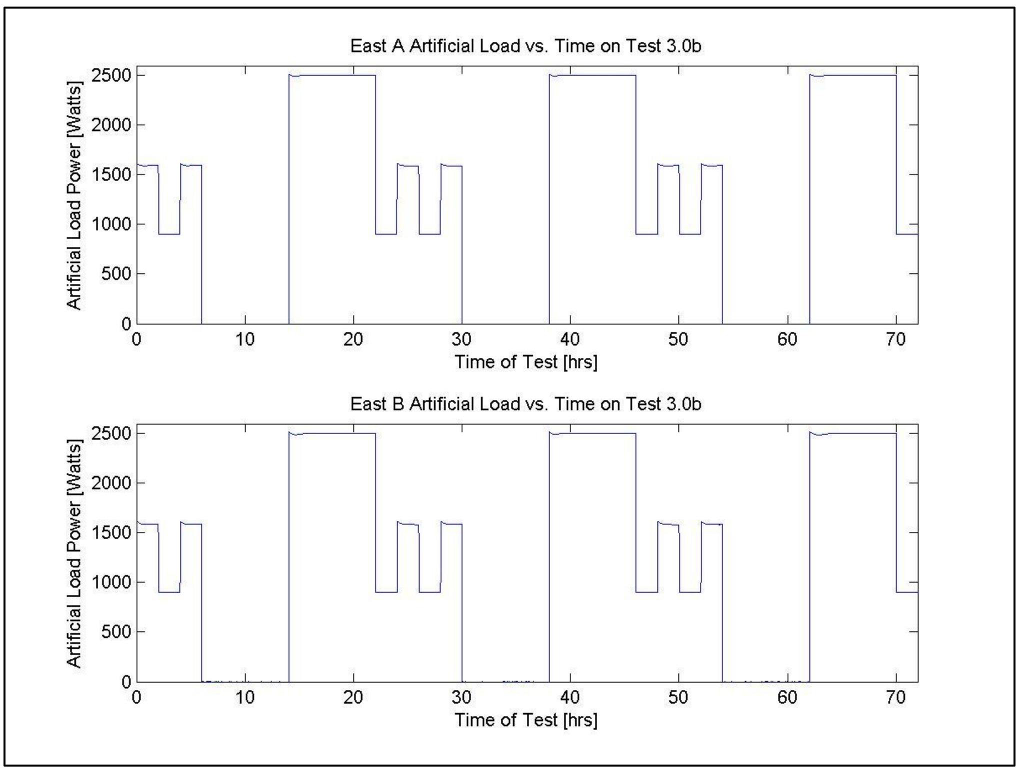
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 33.72179 |
| | variance | 41.59257 |
| AHUB | mean | 33.39177 |
| | variance | 109.8767 |
| difference | | 0.330021 |

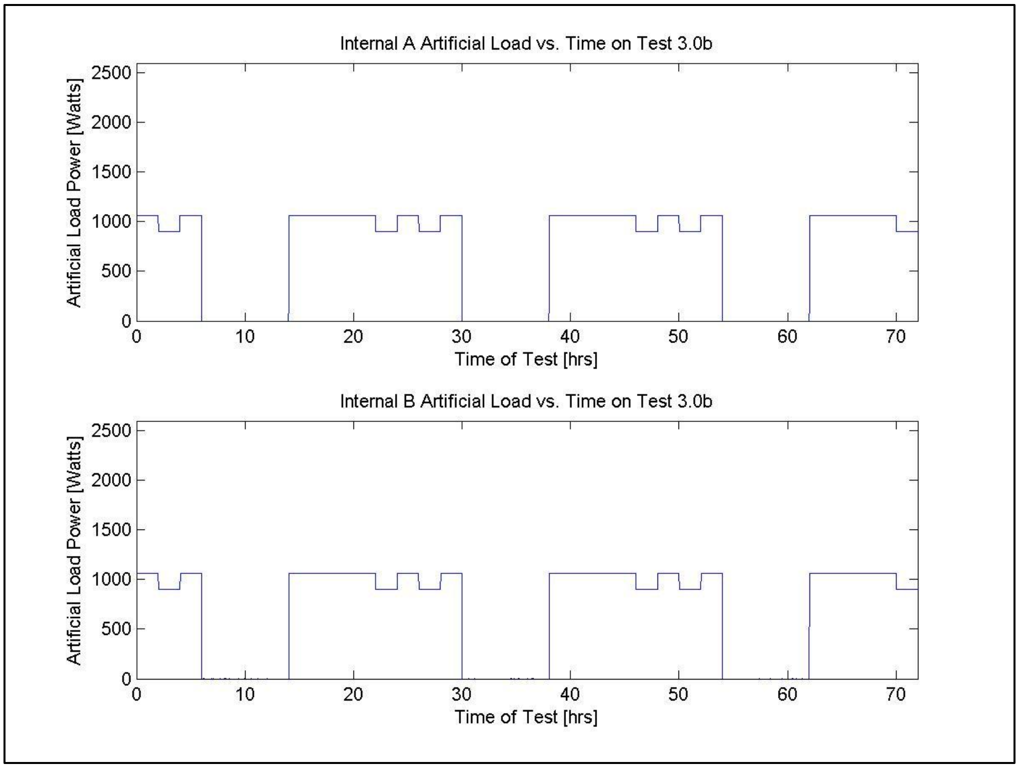
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 38.32033 | 36.07283 | 28.68992 | 34.36103 | 25.38394 |
| | Internal | 31.55067 | 15.89879 | 33.25375 | 26.90107 | 91.51271 |
| | South | 38.41146 | 35.45433 | 33.36633 | 35.74404 | 6.42627 |
| | West | 38.61221 | 39.11417 | 35.91667 | 37.88101 | 2.956986 |
| | mean | 36.72367 | 31.63503 | 32.80667 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 41.42846 | 36.40283 | 25.79779 | 34.54303 | 63.67359 |
| | Internal | 27.64863 | 10.45029 | 49.91675 | 29.33856 | 391.5422 |
| | South | 43.19746 | 30.26229 | 24.72575 | 32.7285 | 89.86264 |
| | West | 41.08292 | 34.54929 | 35.23875 | 36.95699 | 12.88632 |
| | mean | 38.33936 | 27.91618 | 33.91976 | | |

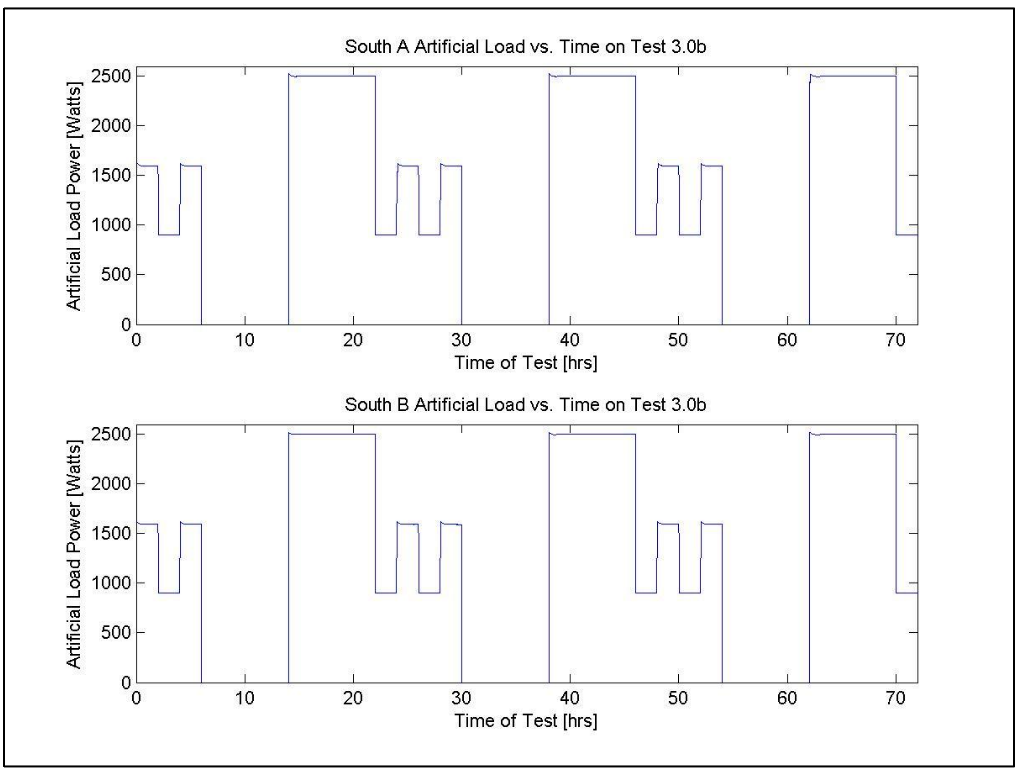
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -6.9866 |
| | variance | 2289.032 |
| AHUB | mean | -5.27548 |
| | variance | 1753.373 |
| difference | | -1.71111 |

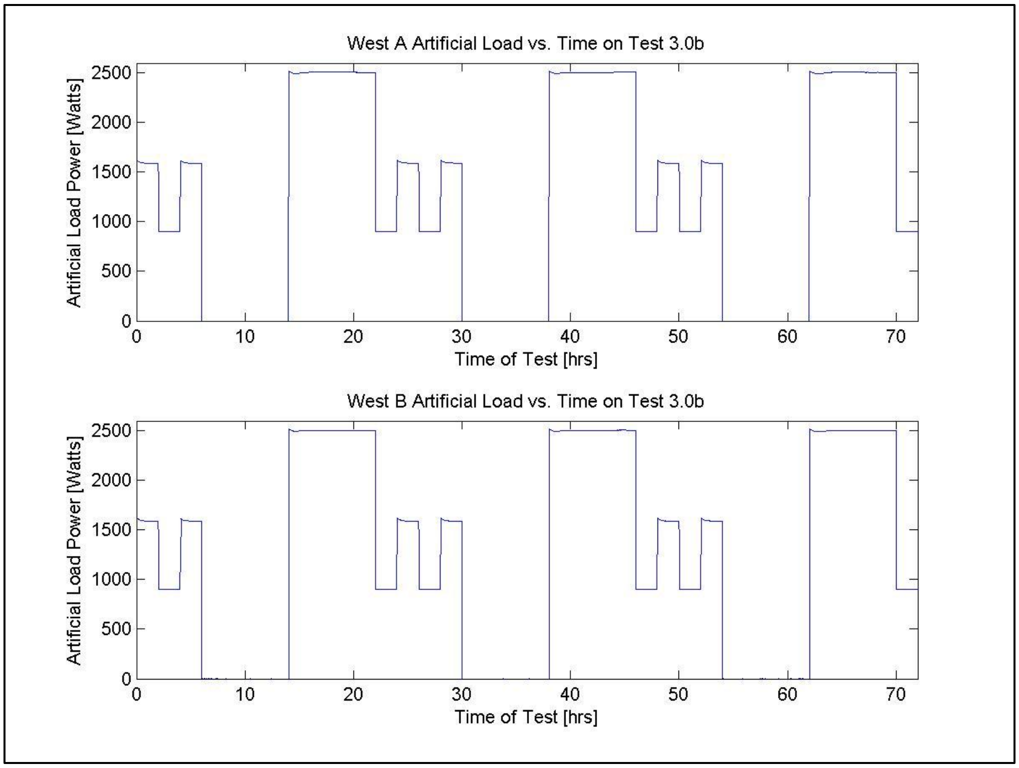
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.25686 | -4.20208 | 0.136111 | -1.44094 |
| | Internal | -0.00243 | -0.08238 | 0.099045 | 0.004745 |
| | South | -0.03811 | -0.01215 | 0.040191 | -0.00336 |
| | West | 0.050174 | -79.4359 | -0.13472 | -26.5068 |
| | mean | -0.06181 | -20.9331 | 0.035156 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.06328 | -0.06085 | 0.129427 | 0.001765 |
| | Internal | -0.02622 | -0.06667 | 0.136111 | 0.01441 |
| | South | 0.005816 | 0.004253 | 0.122309 | 0.044126 |
| | West | 0.032118 | -63.5487 | 0.029861 | -21.1622 |
| | mean | -0.01289 | -15.918 | 0.104427 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 29.6768 | 301.9923 | 20.25348 | 117.3075 |
| | Internal | 8.705345 | 5.791192 | 11.2345 | 8.577014 |
| | South | 17.45145 | 18.81928 | 19.0891 | 18.45328 |
| | West | 27.71955 | 21253.77 | 25.27918 | 7102.258 |
| | mean | 20.88829 | 5395.094 | 18.96407 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.67E+01 | 1.63E+01 | 1.53E+01 | 16.11602 |
| | Internal | 7.85429 | 3.358587 | 14.97269 | 8.728521 |
| | South | 2.22E+01 | 2.35E+01 | 2.27E+01 | 22.80081 |
| | West | 18.47306 | 17167.91 | 17.44299 | 5734.61 |
| | mean | 16.3201 | 4302.787 | 17.58456 | |




Internal A Artificial Load vs. Time on Test 3.0b
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 3.0b
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 3.0b
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 3.0b
Artificial Load Power [Watts]
Time of Test [hrs]




## TEST 4.0

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 53.37155798 |
| AHUB | 55.88558348 |
| % difference | -4.71% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 19.82698 | 19.55705 | 13.98753 | 17.79052 | 10.86528 |
| AHUB | 20.85409 | 19.3724 | 15.6591 | 18.62853 | 7.162003 |
| % difference | -5.18% | 0.94% | -11.95% | -4.71% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.05133 |
| | variance | 3.281008 |
| AHUB | mean [$^{o}$F] | -1.05867 |
| | variance | 2.685982 |
| difference | | 0.007349 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.21496 | -0.4532 | 0.155824 | -0.50411 |
| | Internal | -1.44543 | -1.44239 | -0.9024 | -1.2634 |
| | South | -1.31164 | -1.10263 | -1.05376 | -1.15601 |
| | West | -1.44707 | -1.45653 | -0.94173 | -1.28178 |
| | mean | -1.35477 | -1.11369 | -0.68552 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.27552 | -0.49124 | -0.22469 | -0.66382 |
| | Internal | -1.48152 | -1.50562 | -1.34187 | -1.443 |
| | South | -1.10536 | -0.84014 | -0.79907 | -0.91486 |
| | West | -1.26283 | -1.28307 | -1.09317 | -1.21303 |
| | mean | -1.28131 | -1.03002 | -0.8647 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 2.860652 | 0.77634 | 0.766054 | 1.467682 |
| | Internal | 3.418257 | 3.446085 | 5.590105 | 4.151482 |
| | South | 3.080841 | 2.303313 | 2.447144 | 2.610433 |
| | West | 3.320915 | 3.316647 | 5.493647 | 4.043736 |
| | mean | 3.170167 | 2.460596 | 3.574237 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 2.992514 | 0.744315 | 0.29621 | 1.344346 |
| | Internal | 3.33E+00 | 3.30E+00 | 3.91E+00 | 3.513621 |
| | South | 2.476269 | 1.555455 | 1.635515 | 1.88908 |
| | West | 3.22E+00 | 3.232263 | 3.82E+00 | 3.425379 |
| | mean | 3.004274 | 2.208855 | 2.41619 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.970722 |
| | variance | 0.54962 |
| AHUB | mean | 0.947625 |
| | variance | 0.099147 |
| difference | | 0.023097 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.794833 | 0.759292 | 0.358042 | 0.970722 | 0.54962 |
| AHUB | 1.234458 | 0.997708 | 0.610708 | 0.947625 | 0.099147 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.00098 |
| | variance | 0.000554 |
| AHUB | mean | 3.29E-05 |
| | variance | 0.000413 |
| difference | | 0.000947 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.001847 | 1.99E-03 | -8.94E-04 | 0.00098 |
| | variance | 0.000902 | 0.000425 | 0.000332 | |
| AHUB | mean | -0.00012 | 0.000158 | 5.97E-05 | 3.29E-05 |
| | variance | 0.000452 | 0.000436 | 0.000352 | |

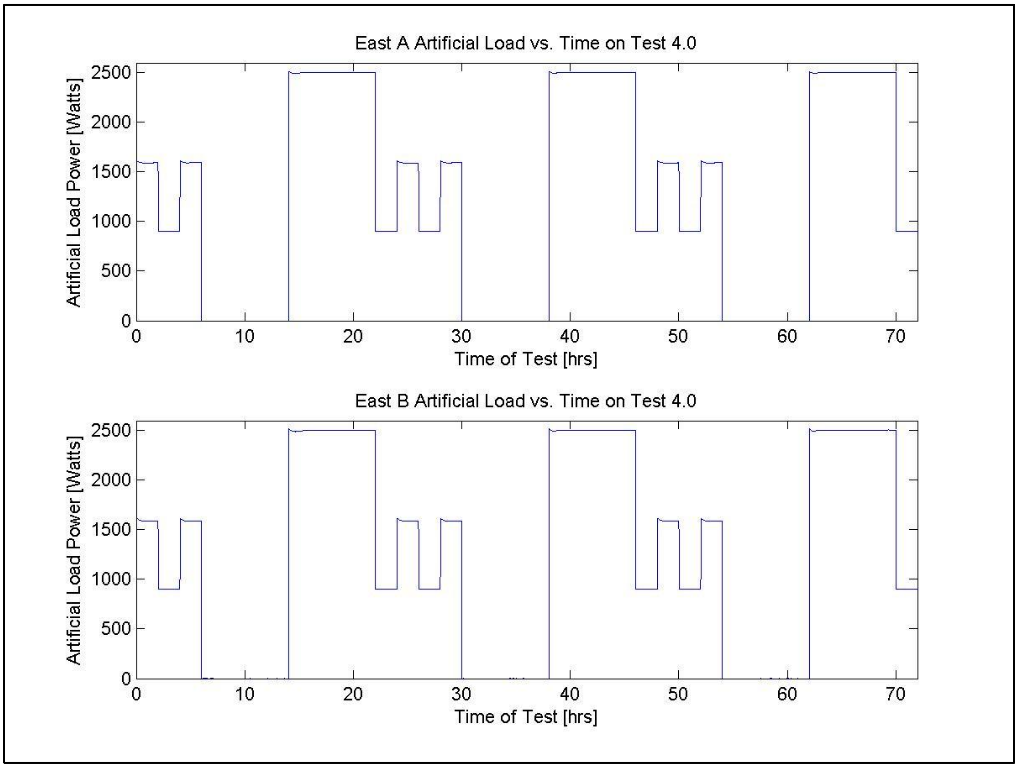
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 27.80039 |
| | variance | 50.82359 |
| AHUB | mean | 31.0037 |
| | variance | 66.14053 |
| difference | | -3.20332 |

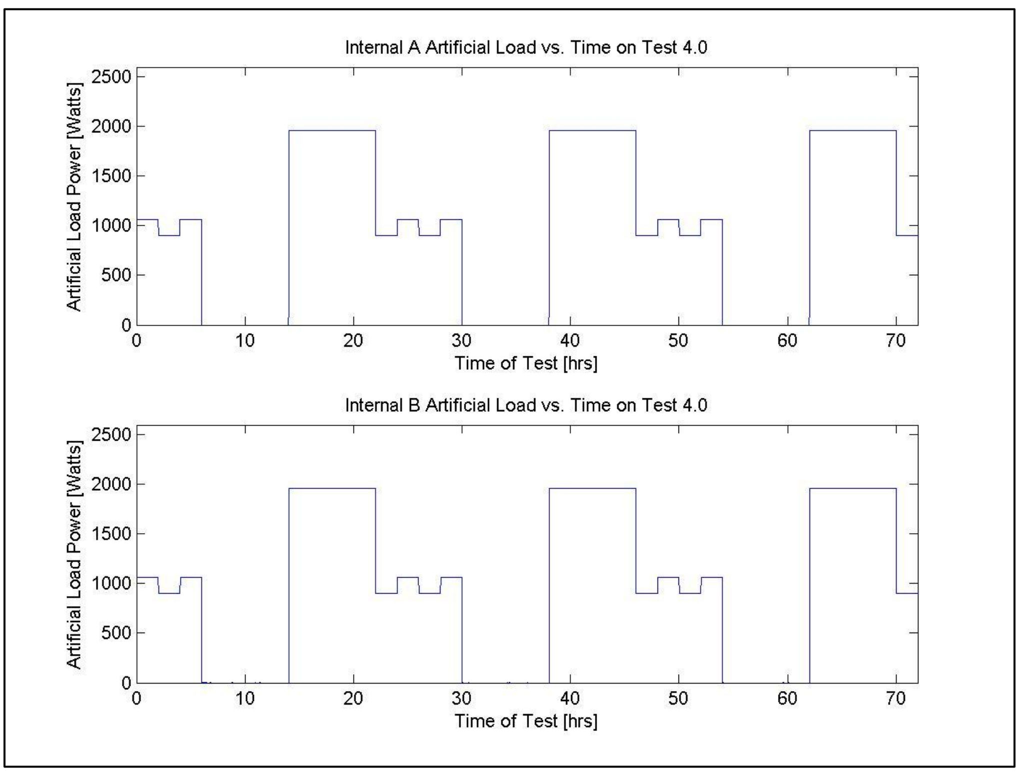
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 31.34946 | 38.64725 | 30.52879 | 33.5085 | 19.97344 |
| | Internal | 26.19846 | 23.61008 | 9.767958 | 19.85883 | 78.04424 |
| | South | 26.21317 | 30.80904 | 23.58579 | 26.86933 | 13.36675 |
| | West | 34.18592 | 28.60179 | 30.10696 | 30.96489 | 8.347647 |
| | mean | 29.48675 | 30.41704 | 23.49738 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 32.66371 | 38.37858 | 38.21996 | 36.42075 | 10.59281 |
| | Internal | 26.83063 | 22.781 | 14.02204 | 21.21122 | 42.8631 |
| | South | 27.33046 | 29.51288 | 39.49992 | 32.11442 | 42.09994 |
| | West | 40.63796 | 36.74892 | 25.41842 | 34.26843 | 62.52322 |
| | mean | 31.86569 | 31.85534 | 29.29008 | | |

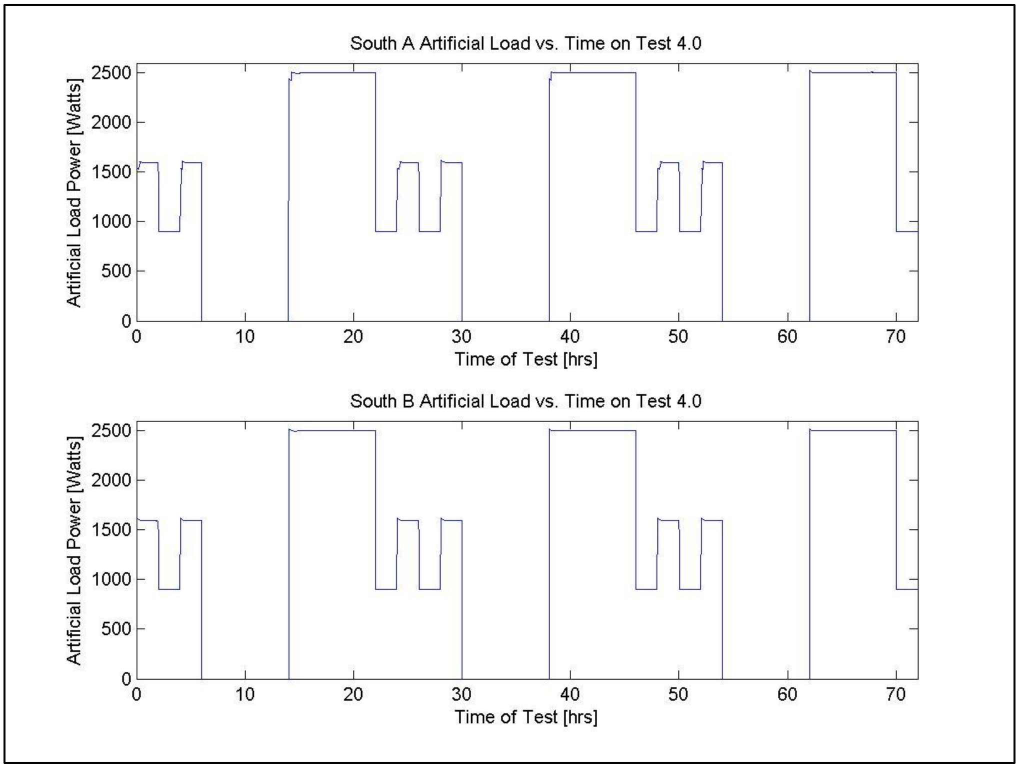
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -30.2389 |
| | variance | 9994.091 |
| AHUB | mean | -7.23001 |
| | variance | 1950.015 |
| difference | | -23.0089 |

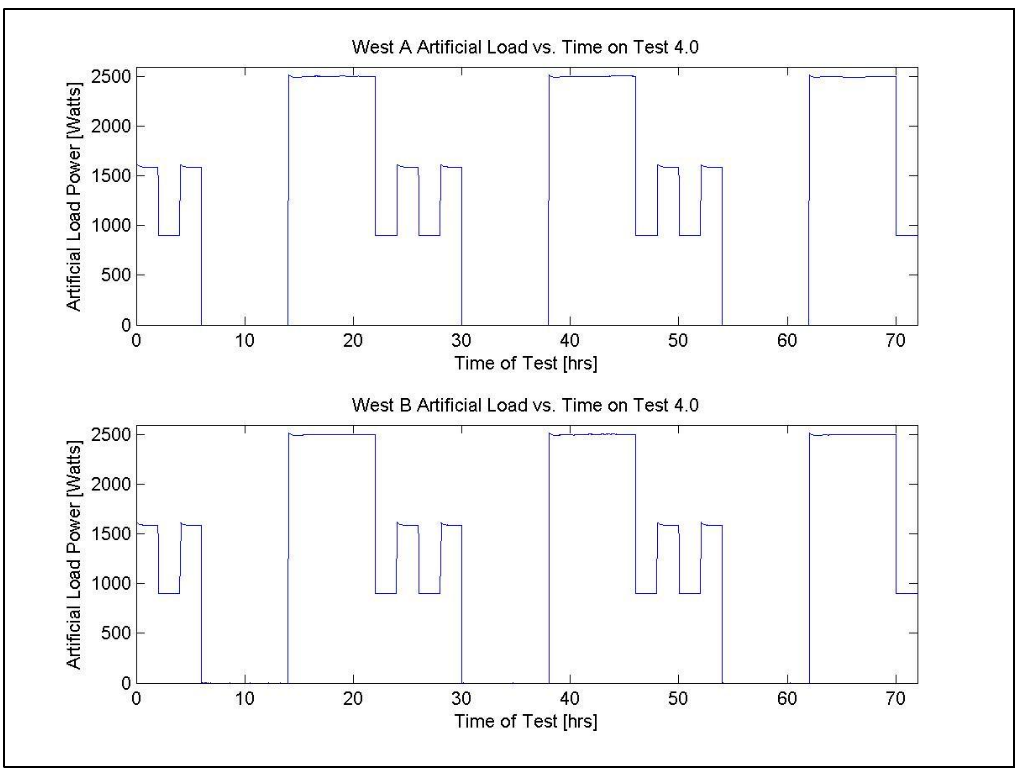
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.04878 | -9.79453 | -134.172 | -48.0051 |
| | Internal | 0.042361 | -0.02161 | -36.9366 | -12.3053 |
| | South | -0.13741 | -0.14644 | -56.5076 | -18.9305 |
| | West | -0.08186 | -11.667 | -113.395 | -41.7148 |
| | mean | -0.05642 | -5.4074 | -85.2529 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.01701 | -0.19635 | -0.02153 | -0.0783 |
| | Internal | 0.055903 | -0.0059 | -19.64 | -6.53001 |
| | South | 0.024826 | 0.047396 | -0.06493 | 0.002431 |
| | West | -0.11753 | -0.0105 | -66.8145 | -22.3142 |
| | mean | -0.01345 | -0.04134 | -21.6352 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 23.16512 | 1182.16 | 39265.34 | 13490.22 |
| | Internal | 8.017336 | 9.761791 | 2765.983 | 927.9207 |
| | South | 20.04064 | 19.57339 | 16675.89 | 5571.836 |
| | West | 21.97802 | 1659.161 | 33659.78 | 11780.31 |
| | mean | 18.30028 | 717.6641 | 23091.75 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 2.02E+01 | 2.06E+01 | 1.82E+01 | 19.65085 |
| | Internal | 8.26075 | 7.784147 | 1194.238 | 403.4275 |
| | South | 1.31E+01 | 2.14E+01 | 2.85E+01 | 20.98556 |
| | West | 18.80719 | 21.77107 | 17816.68 | 5952.42 |
| | mean | 15.08074 | 17.87345 | 4764.409 | |


East A Artificial Load vs. Time on Test 4.0
Artificial Load Power [Watts]
Time of Test [hrs]
East B Artificial Load vs. Time on Test 4.0
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 4.0
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.0
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.0
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.0
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


West A Artificial Load vs. Time on Test 4.0
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
West B Artificial Load vs. Time on Test 4.0
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]

# TEST 5.0

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 43.28097713 |
| AHUB | 43.24513023 |
| % difference | 0.08% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 18.12841 | 14.65745 | 10.49511 | 14.42699 | 14.60666 |
| AHUB | 18.01957 | 14.58656 | 10.63901 | 14.41504 | 13.64024 |
| % difference | 0.60% | 0.48% | -1.37% | 0.08% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -2.17796 |
| | variance | 3.609104 |
| AHUB | mean [$^oF$] | -2.31446 |
| | variance | 3.904535 |
| difference | | 0.136504 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -2.16361 | -2.25722 | -2.3779 | -2.26624 |
| | Internal | -1.3842 | -1.41072 | -1.26926 | -1.35472 |
| | South | -2.33889 | -2.42643 | -2.50991 | -2.42508 |
| | West | -2.61494 | -2.63972 | -2.74271 | -2.66579 |
| | mean | -2.12541 | -2.18352 | -2.22494 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -2.58332 | -2.63529 | -2.70303 | -2.64055 |
| | Internal | -1.43649 | -1.47016 | -1.26374 | -1.39013 |
| | South | -2.39025 | -2.50796 | -2.53295 | -2.47705 |
| | West | -2.46311 | -2.58161 | -3.20566 | -2.75013 |
| | mean | -2.21829 | -2.29876 | -2.42634 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 2.9493 | 3.058216 | 3.193155 | 3.06689 |
| | Internal | 3.419593 | 3.440203 | 3.987556 | 3.615784 |
| | South | 3.059184 | 3.191689 | 3.289893 | 3.180256 |
| | West | 3.474499 | 3.529973 | 3.729612 | 3.578028 |
| | mean | 3.225644 | 3.30502 | 3.550054 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 3.257454 | 3.414338 | 3.500734 | 3.390842 |
| | Internal | 3.30E+00 | 3.27E+00 | 4.13E+00 | 3.567775 |
| | South | 3.145042 | 3.283721 | 3.320296 | 3.249687 |
| | West | 3.37E+00 | 3.557472 | 5.44E+00 | 4.121376 |
| | mean | 3.268649 | 3.381751 | 4.096859 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.459792 |
| | variance | 0.418659 |
| AHUB | mean | 1.367458 |
| | variance | 0.249974 |
| difference | | 0.092333 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.921583 | 1.737542 | 0.72025 | 1.459792 | 0.418659 |
| AHUB | 1.857375 | 1.387 | 0.858 | 1.367458 | 0.249974 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.000604 |
| | variance | 0.000772 |
| AHUB | mean | -5.96E-03 |
| | variance | 0.156746 |
| difference | | 0.006564 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.001278 | -7.99E-05 | 6.14E-04 | 0.000604 |
| | variance | 0.001026 | 0.000928 | 0.000362 | |
| AHUB | mean | -0.00023 | 0.000353 | -1.80E-02 | -0.00596 |
| | variance | 0.001077 | 0.000794 | 0.468366 | |

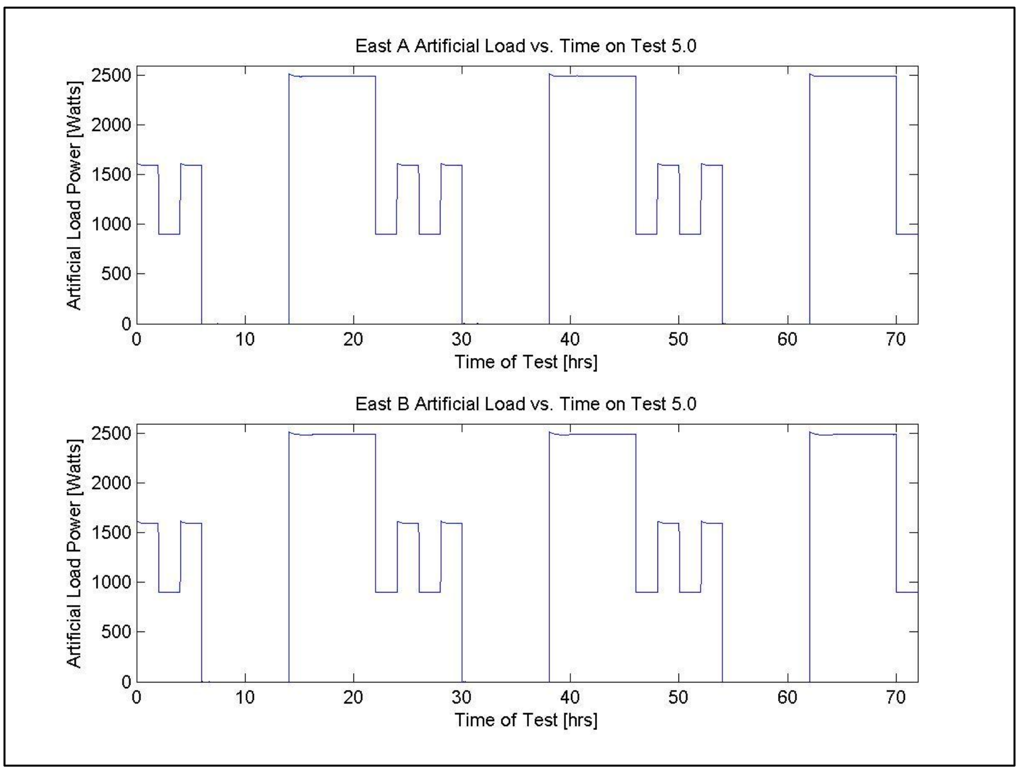
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 28.12132 |
| | variance | 67.39729 |
| AHUB | mean | 26.67405 |
| | variance | 42.76123 |
| difference | | 1.447271 |

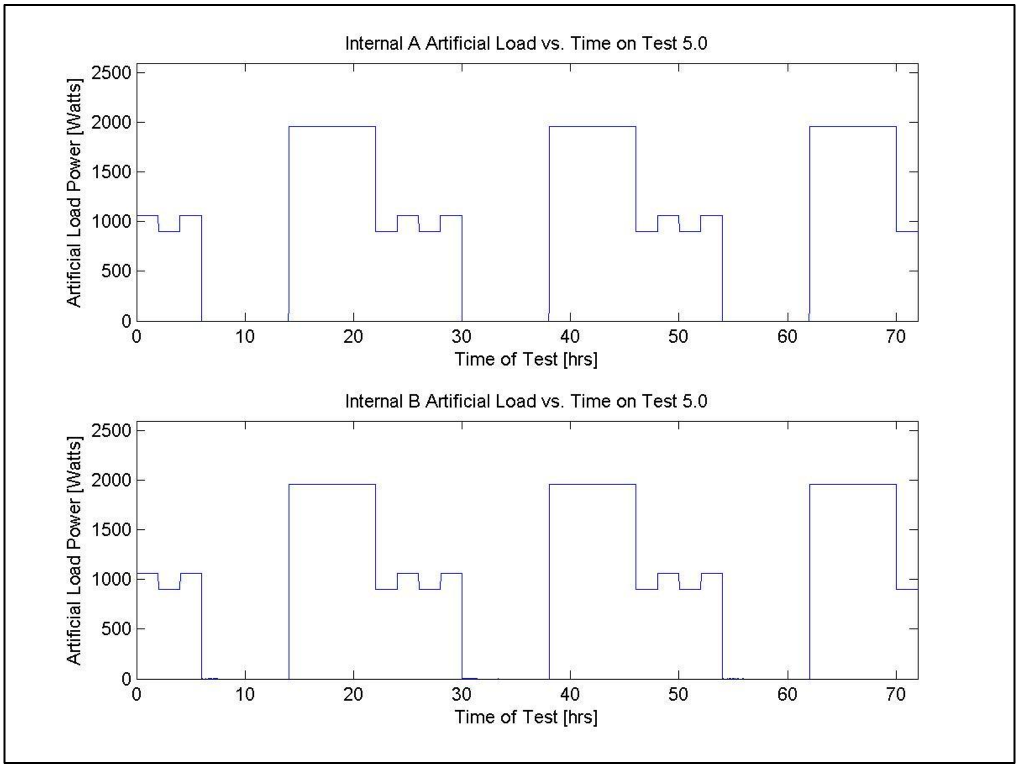
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 28.27233 | 24.54704 | 38.13008 | 30.31649 | 49.25868 |
| | Internal | 27.01433 | 26.03058 | 14.75188 | 22.59893 | 46.42415 |
| | South | 18.05492 | 21.54921 | 32.50033 | 24.03482 | 56.80121 |
| | West | 27.32183 | 36.96938 | 42.31392 | 35.53504 | 57.73362 |
| | mean | 25.16585 | 27.27405 | 31.92405 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 19.57721 | 37.57221 | 24.99621 | 27.38188 | 85.22356 |
| | Internal | 28.01879 | 28.0635 | 14.17508 | 23.41913 | 64.08973 |
| | South | 21.31254 | 30.43571 | 33.08725 | 28.2785 | 38.1511 |
| | West | 26.84175 | 33.04742 | 22.96092 | 27.61669 | 25.88477 |
| | mean | 23.93757 | 32.27971 | 23.80486 | | |

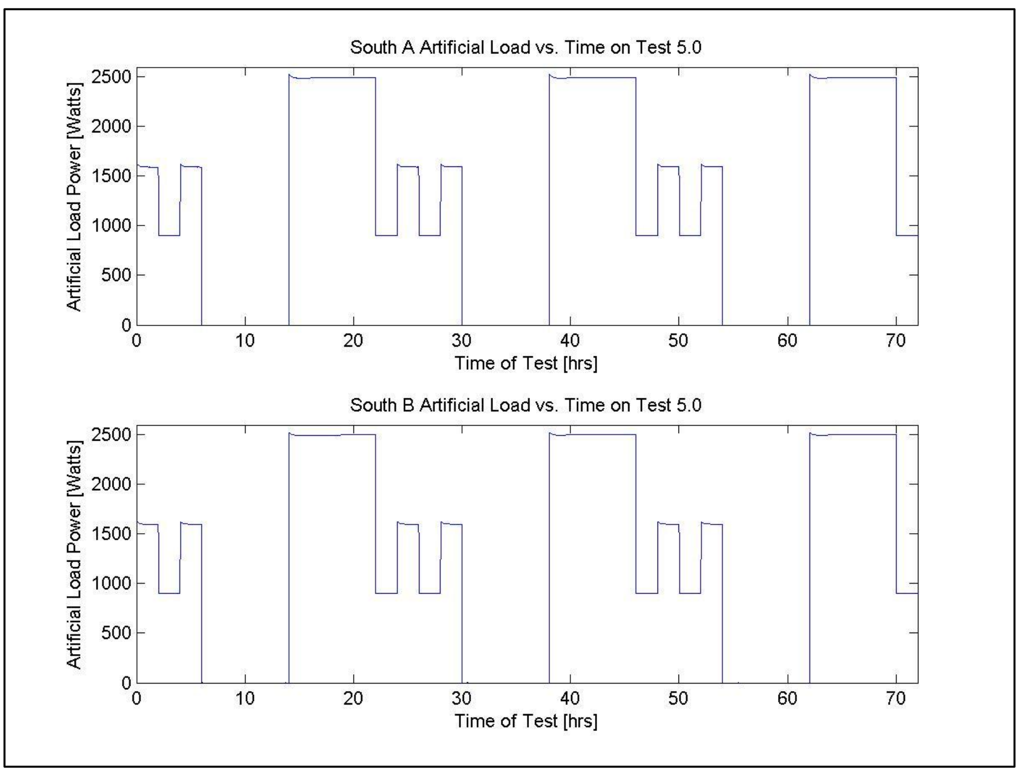
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -1.28963 |
| | variance | 97.21548 |
| AHUB | mean | -2.16926 |
| | variance | 210.6492 |
| difference | | 0.87963 |

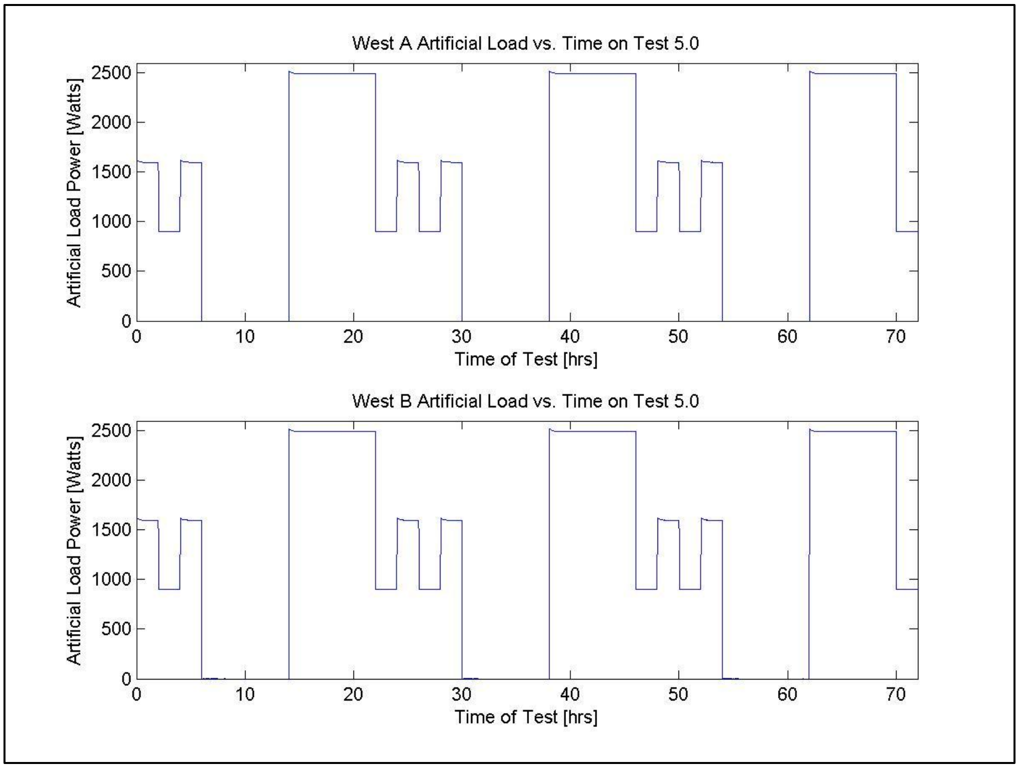
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.23776 | 0.171528 | -0.05729 | 0.117332 |
| | Internal | 0.016753 | -0.05816 | -15.7108 | -5.25072 |
| | South | -0.00304 | 0.065017 | -0.0349 | 0.009028 |
| | West | -0.09688 | 0.059635 | -0.06519 | -0.03414 |
| | mean | 0.03865 | 0.059505 | -3.96704 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.30564 | 0.043663 | 0.007813 | -0.08472 |
| | Internal | -0.00095 | -0.05686 | -25.3491 | -8.46898 |
| | South | -0.18811 | -0.1434 | 0.019444 | -0.10402 |
| | West | 0.007552 | -0.05712 | -0.00833 | -0.0193 |
| | mean | -0.12179 | -0.05343 | -6.33255 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 23.26734 | 20.04752 | 15.71149 | 19.67545 |
| | Internal | 8.837226 | 9.230545 | 768.0165 | 262.0281 |
| | South | 20.09371 | 8.563427 | 12.06964 | 13.57559 |
| | West | 20.06859 | 19.12319 | 15.15596 | 18.11591 |
| | mean | 18.06672 | 14.24117 | 202.7384 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 2.15E+01 | 1.67E+01 | 1.04E+01 | 16.18336 |
| | Internal | 7.859222 | 7.420746 | 1796.009 | 603.763 |
| | South | 1.95E+01 | 1.82E+01 | 1.35E+01 | 17.07895 |
| | West | 10.84551 | 11.74204 | 9.061019 | 10.54952 |
| | mean | 14.9343 | 13.51356 | 457.2332 | |




Internal A Artificial Load vs. Time on Test 5.0
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 5.0
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


South A Artificial Load vs. Time on Test 5.0
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
South B Artificial Load vs. Time on Test 5.0
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


West A Artificial Load vs. Time on Test 5.0
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]
West B Artificial Load vs. Time on Test 5.0
Artificial Load Power [Watts]
Time of Test [hrs]

# APPENDIX B: TEST SERIES 2 RESULTS TABLES AND GRAPHS

## TEST 2.1a

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-6 |
| AHUA | 44.01866428 |
| AHUB | 50.46723947 |
| % difference | -14.65% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 13.33962 | 15.34585 | 15.3332 | 14.67289 | 1.333245 |
| AHUB | 19.85371 | 17.19587 | 13.41767 | 16.82241 | 10.46025 |
| % difference | -48.83% | -12.06% | 12.49% | -14.65% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -0.78737 |
| | variance | 2.213394 |
| AHUB | mean [$^oF$] | -0.90967 |
| | variance | 1.763165 |
| difference | | 0.122293 |

| Temperature Control [$^oF$ Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.21297 | -0.97694 | -1.06136 | -1.08375 |
| | Internal | 0.171806 | 0.079044 | 0.049718 | 0.100189 |
| | South | -1.21462 | -0.80056 | -0.79597 | -0.93705 |
| | West | -1.24519 | -1.30782 | -1.13366 | -1.22889 |
| | mean | -0.87524 | -0.75157 | -0.73532 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.29145 | -1.20734 | -1.23919 | -1.24599 |
| | Internal | -0.288 | -0.34071 | 0.124499 | -0.16807 |
| | South | -1.19439 | -0.86496 | -0.74541 | -0.93492 |
| | West | -1.2358 | -1.49469 | -1.13858 | -1.28969 |
| | mean | -1.00241 | -0.97692 | -0.74967 | |

| Temperature Control [$^oF$ Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 1.094229 | 0.989366 | 0.958447 | 1.014014 |
| | Internal | 3.467752 | 3.11909 | 3.04813 | 3.211657 |
| | South | 1.274745 | 1.659039 | 1.636738 | 1.523507 |
| | West | 1.731497 | 2.041306 | 2.108203 | 1.960335 |
| | mean | 1.892056 | 1.9522 | 1.937879 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.174714 | 1.127618 | 1.052861 | 1.118398 |
| | Internal | 1.676464 | 1.625787 | 3.066846 | 2.123032 |
| | South | 1.109195 | 1.111631 | 1.272387 | 1.164404 |
| | West | 1.242872 | 1.926075 | 2.049403 | 1.73945 |
| | mean | 1.300811 | 1.447778 | 1.860374 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.741417 |
| | variance | 0.002724 |
| AHUB | mean | 1.100708 |
| | variance | 0.116112 |
| difference | | -0.35929 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 0.6915 | 0.737125 | 0.795625 | 0.741417 | 0.002724 |
| AHUB | 1.442166667 | 1.099292 | 0.760667 | 1.100708 | 0.116112 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.00063 |
| | variance | 0.000472 |
| AHUB | mean | -0.01079 |
| | variance | 0.467765 |
| difference | | 0.01016 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00119 | -0.00016 | -0.00055 | -0.00063 |
| | variance | 0.000422 | 0.000474 | 0.00052 | |
| AHUB | mean | 0.000474 | -0.03185 | -0.001 | -0.01079 |
| | variance | 0.000491 | 1.402335 | 0.000453 | |

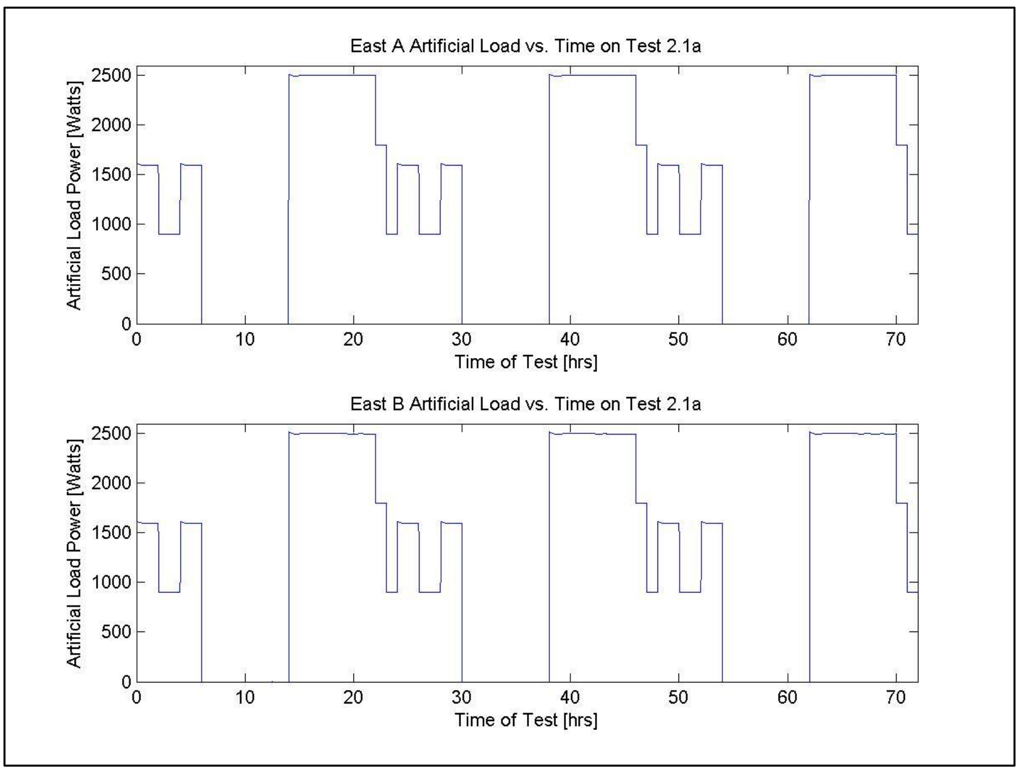
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 37.58582 |
| | variance | 77.16903 |
| AHUB | mean | 34.75559 |
| | variance | 68.23776 |
| difference | | 2.830226 |

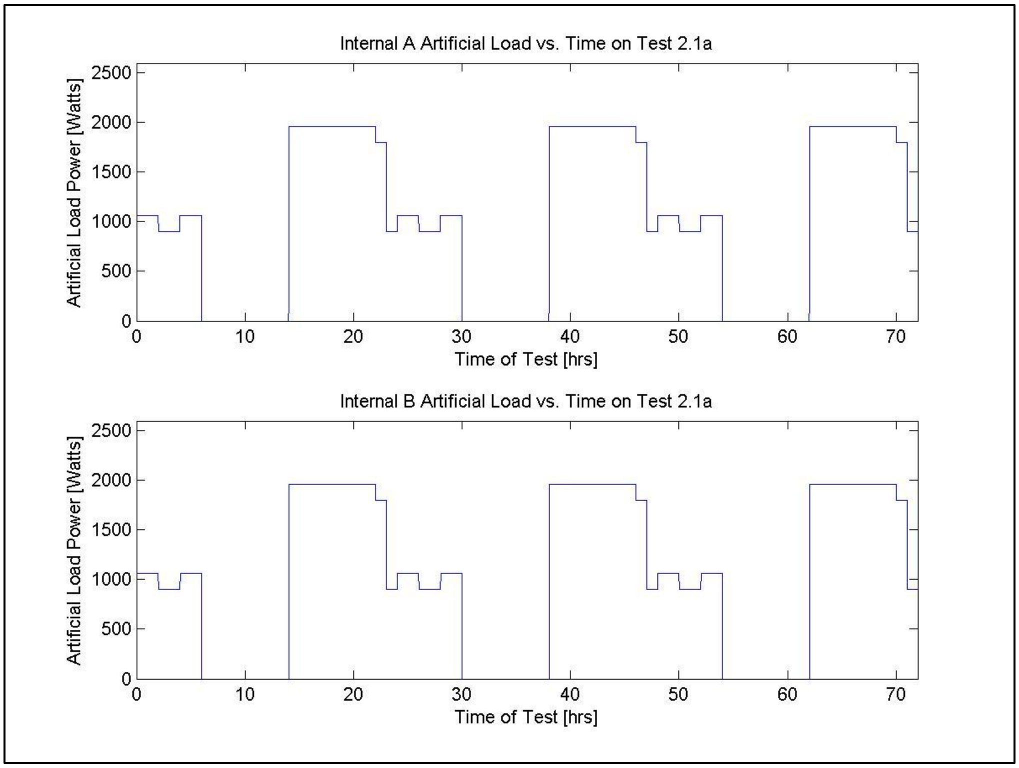
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 41.56392 | 40.11458 | 38.87992 | 40.18614 | 1.804804 |
| | Internal | 24.06963 | 23.0995 | 26.65613 | 24.60842 | 3.380118 |
| | South | 36.94754 | 39.91075 | 43.56954 | 40.14261 | 11.00304 |
| | West | 46.291 | 38.3795 | 51.54783 | 45.40611 | 43.93852 |
| | mean | 37.21802 | 35.37608 | 40.16335 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 37.55625 | 37.79946 | 41.08037 | 38.81203 | 3.873837 |
| | Internal | 32.12908 | 33.55125 | 11.43654 | 25.70563 | 153.2107 |
| | South | 32.4065 | 42.28958 | 40.74713 | 38.48107 | 28.27009 |
| | West | 32.40063 | 40.89175 | 34.77858 | 36.02365 | 19.18745 |
| | mean | 33.62311 | 38.63301 | 32.01066 | | |

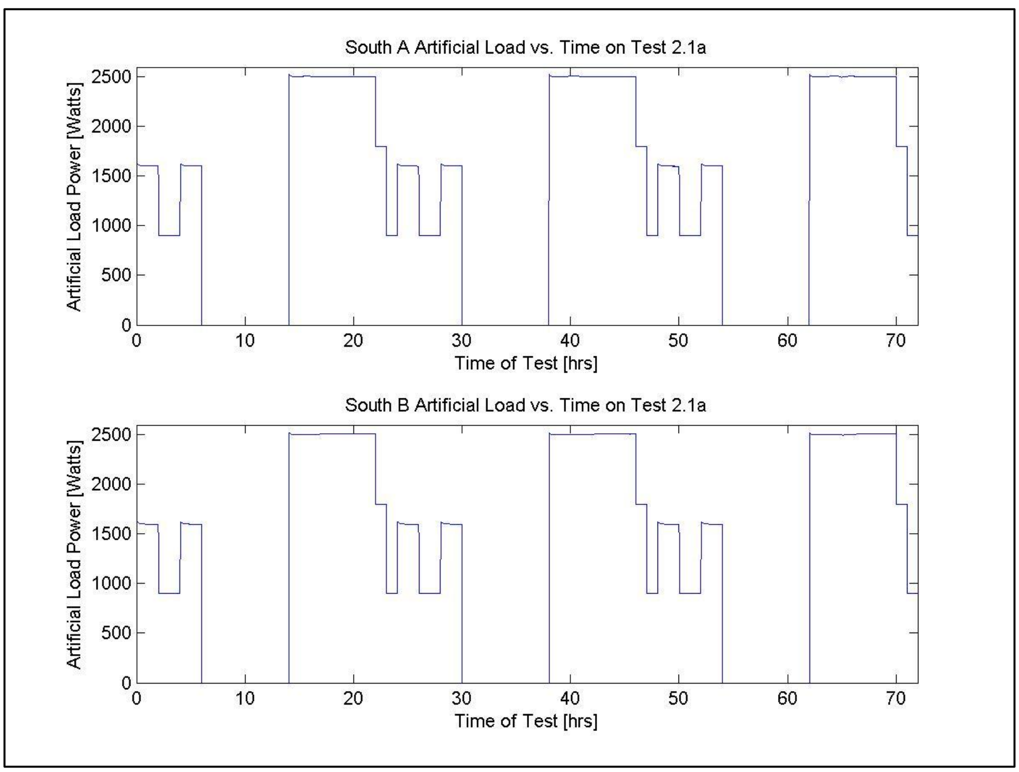
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -13.021 |
| | variance | 2925.467 |
| AHUB | mean | -8.90533 |
| | variance | 2199.918 |
| difference | | -4.11564 |

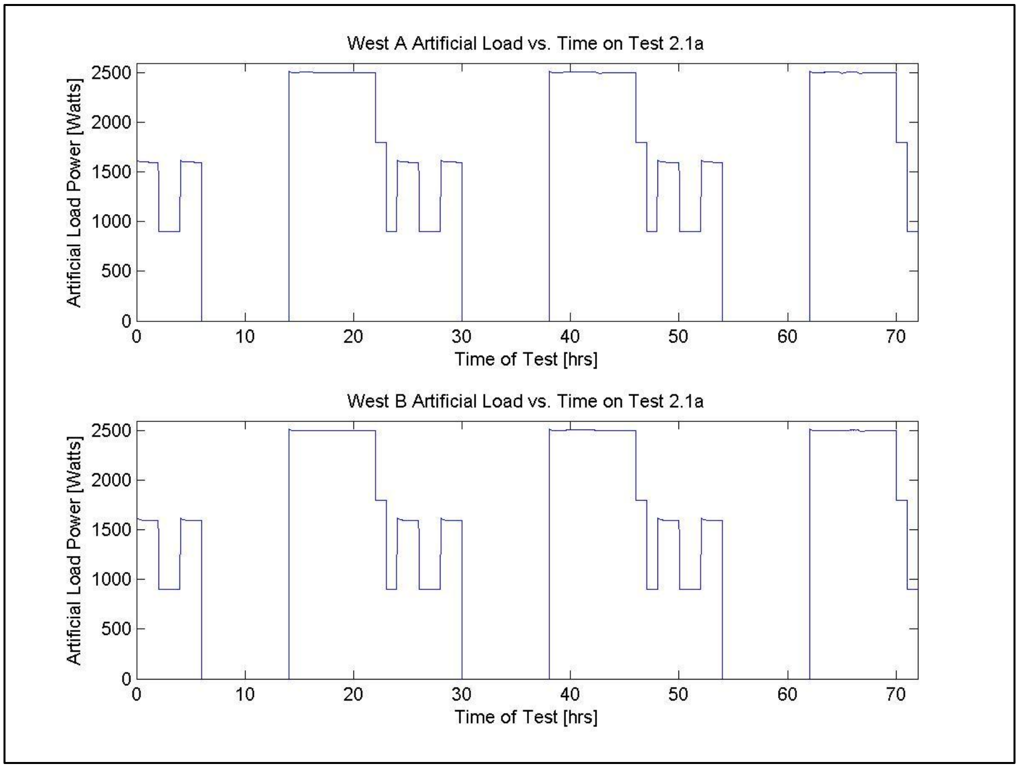
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.087326 | -0.002 | -0.0441 | 0.013744 |
| | Internal | -18.8758 | -16.4161 | -15.5728 | -16.9549 |
| | South | -5.5072 | -20.1921 | -20.2773 | -15.3255 |
| | West | -15.1302 | -22.4753 | -21.8462 | -19.8172 |
| | mean | -9.85647 | -14.7714 | -14.4351 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.12005 | -0.08455 | -0.02075 | -0.07512 |
| | Internal | -0.04835 | -0.02813 | -32.9685 | -11.015 |
| | South | -0.10634 | 0.040712 | -30.9846 | -10.3501 |
| | West | 0.040712 | -0.02396 | -42.5602 | -14.1811 |
| | mean | -0.05851 | -0.02398 | -26.6335 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 21.77353 | 19.03243 | 20.43794 | 20.41463 |
| | Internal | 1235.08 | 1097.696 | 1087.206 | 1139.994 |
| | South | 944.3781 | 6153.792 | 6228.128 | 4442.099 |
| | West | 4935.867 | 6261.336 | 6228.326 | 5808.51 |
| | mean | 1784.275 | 3382.964 | 3391.025 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 15.97123 | 14.55322 | 15.0568 | 15.19375 |
| | Internal | 14.34763 | 24.0798 | 1897.418 | 645.2819 |
| | South | 21.25535 | 21.50411 | 9119.684 | 3054.148 |
| | West | 13.61375 | 23.98672 | 12325.62 | 4121.074 |
| | mean | 16.29699 | 21.03096 | 5839.445 | |




Internal A Artificial Load vs. Time on Test 2.1a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0 10 20 30 40 50 60 70
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 2.1a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0 10 20 30 40 50 60 70
Time of Test [hrs]


South A Artificial Load vs. Time on Test 2.1a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0 10 20 30 40 50 60 70
Time of Test [hrs]
South B Artificial Load vs. Time on Test 2.1a
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0 10 20 30 40 50 60 70
Time of Test [hrs]




# TEST 2.1b

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-6 |
| AHUA | 55.90979232 |
| AHUB | 46.9588971 |
| % difference | 16.01% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 22.82817 | 19.05931 | 14.02231 | 18.6366 | 19.5198 |
| AHUB | 15.599 | 15.72115 | 15.63874 | 15.65297 | 0.003882 |
| % difference | 31.67% | 17.51% | -11.53% | 16.01% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -0.7109 |
| | variance | 2.130692 |
| AHUB | mean [$^oF$] | -0.79495 |
| | variance | 1.69751 |
| difference | | 0.084048 |

| Temperature Control [$^oF$ Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.03926 | -1.10037 | -1.0358 | -1.05848 |
| | Internal | -0.01655 | 0.047558 | 0.426457 | 0.152487 |
| | South | -0.89702 | -0.81545 | -0.77804 | -0.83017 |
| | West | -1.23679 | -1.18643 | -0.8991 | -1.10744 |
| | mean | -0.79741 | -0.76367 | -0.57162 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.24458 | -1.28142 | -1.25564 | -1.26055 |
| | Internal | -0.12213 | -0.08404 | -0.084 | -0.09672 |
| | South | -0.69094 | -0.65752 | -0.71104 | -0.6865 |
| | West | -1.1293 | -1.19546 | -1.08329 | -1.13602 |
| | mean | -0.79674 | -0.80461 | -0.78349 | |

| Temperature Control [$^oF$ Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.958152 | 0.983948 | 0.951984 | 0.964695 |
| | Internal | 2.593941 | 2.821429 | 4.271428 | 3.228933 |
| | South | 1.137294 | 1.293955 | 1.551426 | 1.327558 |
| | West | 1.376613 | 1.501773 | 2.836148 | 1.904845 |
| | mean | 1.5165 | 1.650276 | 2.402746 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.086522 | 1.06828 | 1.108611 | 1.087804 |
| | Internal | 2.330237 | 2.360142 | 2.333098 | 2.341159 |
| | South | 1.242605 | 1.183768 | 1.154417 | 1.193597 |
| | West | 1.291286 | 1.517403 | 1.198298 | 1.335662 |
| | mean | 1.487662 | 1.532399 | 1.448606 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.252764 |
| | variance | 0.40576 |
| AHUB | mean | 0.94425 |
| | variance | 0.002692 |
| difference | | 0.308514 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.795291667 | 1.411625 | 0.551375 | 1.252764 | 0.40576 |
| AHUB | 0.927916667 | 1.002333 | 0.9025 | 0.94425 | 0.002692 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.0006 |
| | variance | 0.000791 |
| AHUB | mean | -0.0013 |
| | variance | 0.000743 |
| difference | | 0.000701 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00121 | -0.00049 | -8.82E-05 | -0.0006 |
| | variance | 0.001036 | 0.000934 | 0.000403 | |
| AHUB | mean | -0.00224 | -0.00123 | -0.00043 | -0.0013 |
| | variance | 0.000828 | 0.00071 | 0.000692 | |

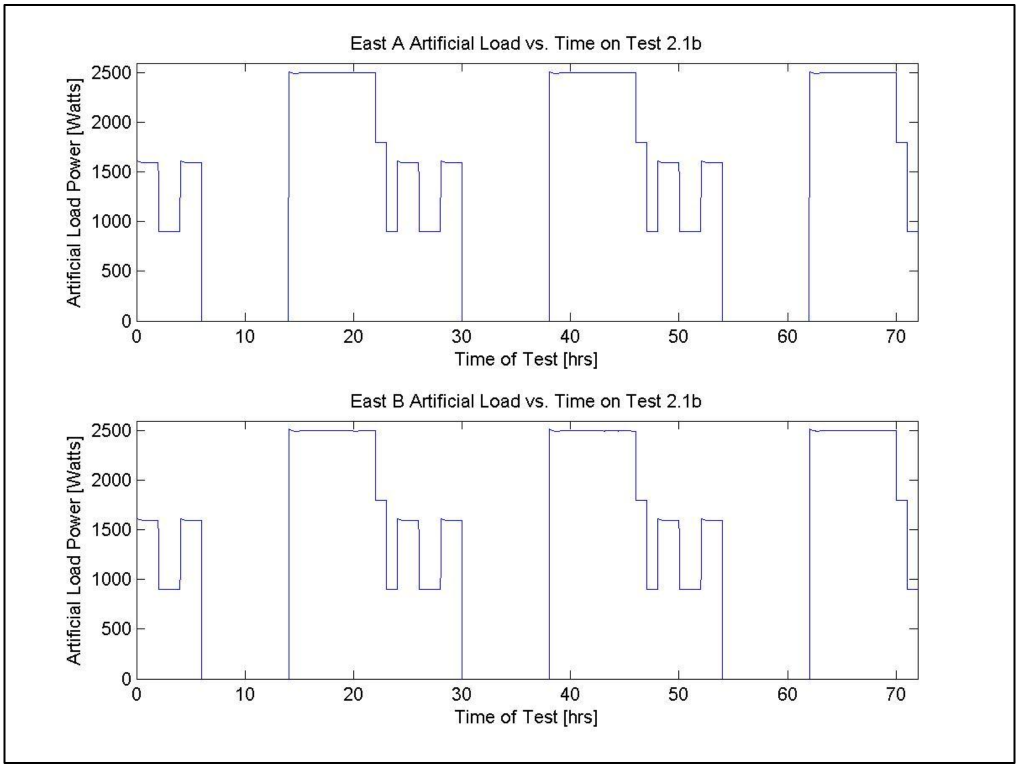
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 32.24026 |
| | variance | 83.76938 |
| AHUB | mean | 33.20001 |
| | variance | 53.17159 |
| difference | | -0.95975 |

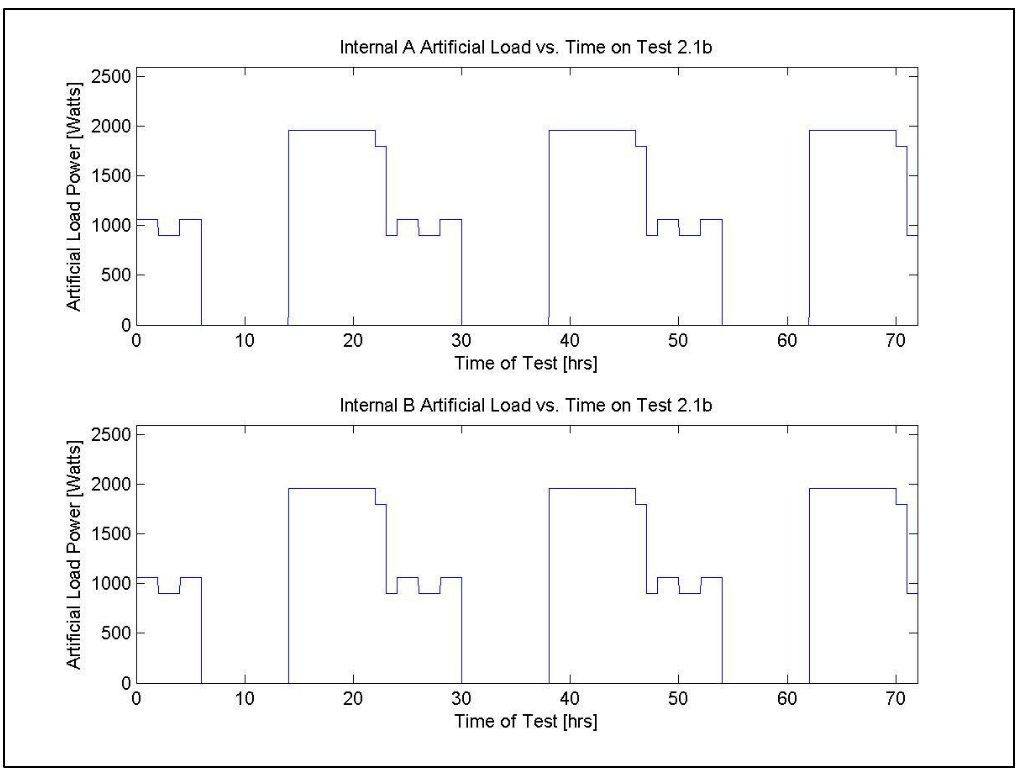
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 21.2845 | 27.52158 | 29.63938 | 26.14849 | 18.86503 |
| | Internal | 33.00925 | 26.13458 | 14.15325 | 24.43236 | 91.06035 |
| | South | 37.29592 | 44.36321 | 43.22033 | 41.62649 | 14.39191 |
| | West | 41.76133 | 37.04075 | 31.45904 | 36.75371 | 26.5961 |
| | mean | 33.33775 | 33.76503 | 29.618 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 26.48442 | 28.85196 | 41.16142 | 32.16593 | 62.09039 |
| | Internal | 24.27017 | 27.28858 | 21.05738 | 24.20538 | 9.710138 |
| | South | 38.74638 | 39.49233 | 42.93004 | 40.38958 | 4.97956 |
| | West | 34.47179 | 37.93458 | 35.71108 | 36.03915 | 3.078454 |
| | mean | 30.99319 | 33.39186 | 35.21498 | | |

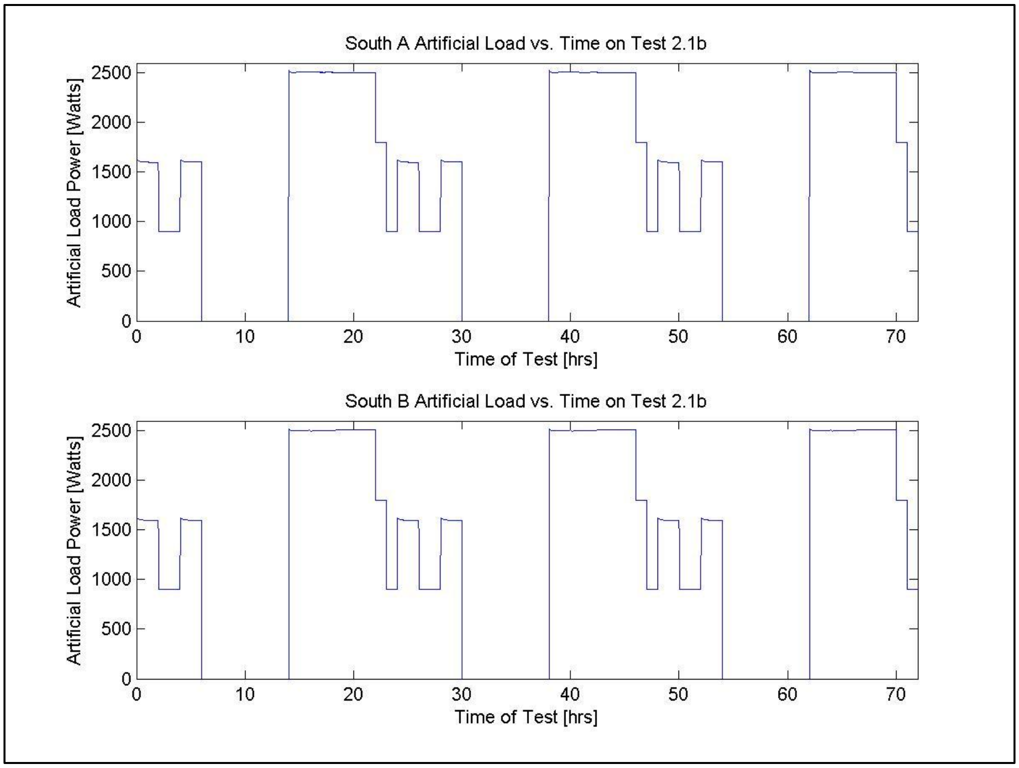
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -13.7087 |
| | variance | 3437.039 |
| AHUB | mean | -11.086 |
| | variance | 2207.948 |
| difference | | -2.62271 |

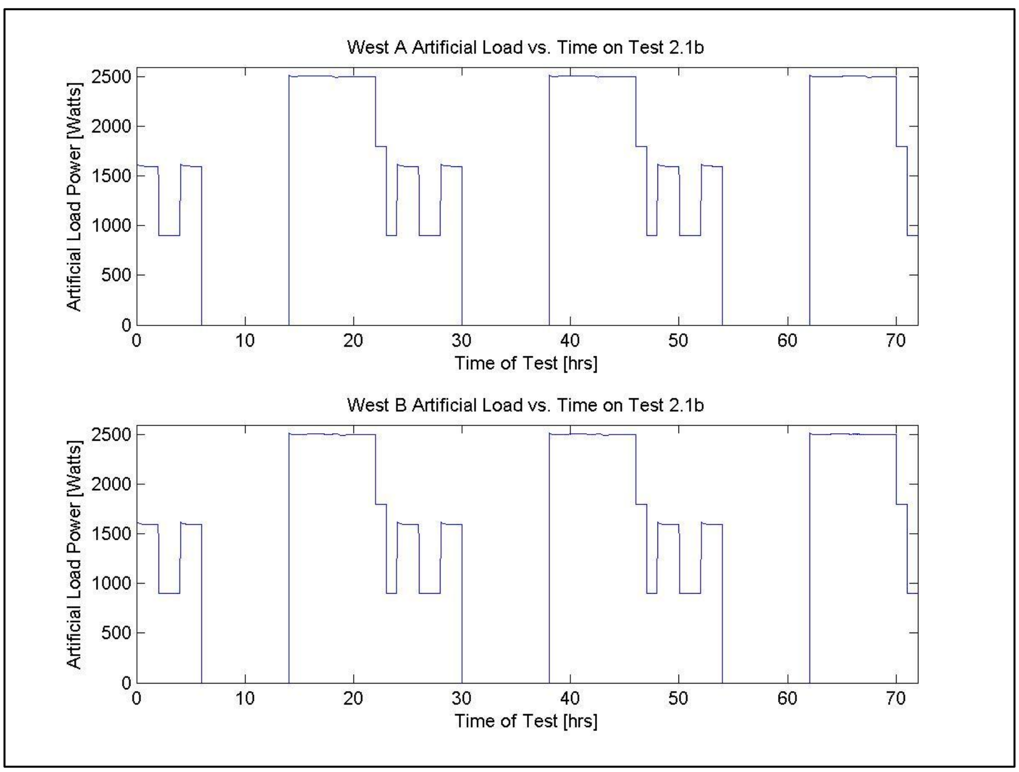
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.348264 | 0.131076 | -0.01884 | 0.153501 |
| | Internal | 0.024913 | -0.09063 | -31.8426 | -10.6361 |
| | South | 0.032378 | -11.8666 | -47.5324 | -19.7889 |
| | West | 0.322569 | -16.8204 | -57.1924 | -24.5634 |
| | mean | 0.182031 | -7.16163 | -34.1466 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.027951 | -0.0092 | -0.05252 | -0.01126 |
| | Internal | -16.2343 | -14.0319 | -16.0853 | -15.4505 |
| | South | -17.3107 | -17.9207 | -16.5897 | -17.2737 |
| | West | -10.6937 | -13.5887 | -10.5435 | -11.6086 |
| | mean | -11.0527 | -11.3876 | -10.8178 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 20.96178 | 20.63289 | 17.5402 | 19.71162 |
| | Internal | 14.93457 | 16.68892 | 1716.918 | 582.8471 |
| | South | 25.66868 | 2109.855 | 13860.49 | 5332.005 |
| | West | 168.7664 | 2804.371 | 15777.54 | 6250.226 |
| | mean | 57.58287 | 1237.887 | 7843.122 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 12.69191 | 12.86247 | 17.60509 | 14.38649 |
| | Internal | 1133.735 | 1135.091 | 1089.068 | 1119.298 |
| | South | 5706.922 | 5891.892 | 5289.796 | 5629.537 |
| | West | 1490.965 | 2241.786 | 1938.867 | 1890.539 |
| | mean | 2086.079 | 2320.408 | 2083.834 | |


East A Artificial Load vs. Time on Test 2.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
Time of Test [hrs]
0
10
20
30
40
50
60
70
East B Artificial Load vs. Time on Test 2.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
Time of Test [hrs]
0
10
20
30
40
50
60
70


Internal A Artificial Load vs. Time on Test 2.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
Time of Test [hrs]
0
10
20
30
40
50
60
70
Internal B Artificial Load vs. Time on Test 2.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
Time of Test [hrs]
0
10
20
30
40
50
60
70


South A Artificial Load vs. Time on Test 2.1b
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 2.1b
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 2.1b
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 2.1b
Artificial Load Power [Watts]
Time of Test [hrs]

# TEST 2.2a

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-6 |
| AHUA | 43.17386232 |
| AHUB | 49.95628943 |
| % difference | -15.71% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 13.70022 | 13.85255 | 15.62108 | 14.39129 | 1.140102 |
| AHUB | 19.81637 | 16.61398 | 13.52594 | 16.6521 | 9.893473 |
| % difference | -44.64% | -19.93% | 13.41% | -15.71% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -0.78368 |
| | variance | 1.730546 |
| AHUB | mean [$^{o}$F] | -0.83947 |
| | variance | 1.424626 |
| difference | | 0.055787 |

| Temperature Control [°F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.05637 | -0.91524 | -0.90533 | -0.95898 |
| | Internal | 0.054262 | -0.02777 | 0.112494 | 0.04633 |
| | South | -1.13992 | -1.04487 | -0.99561 | -1.06013 |
| | West | -1.21538 | -1.17852 | -1.09193 | -1.16194 |
| | mean | -0.83935 | -0.7916 | -0.72009 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.27477 | -1.19252 | -1.16993 | -1.21241 |
| | Internal | -0.31576 | -0.36135 | 0.066168 | -0.20365 |
| | South | -1.10079 | -0.95893 | -0.89613 | -0.98528 |
| | West | -1.03334 | -0.99348 | -0.84278 | -0.95653 |
| | mean | -0.93117 | -0.87657 | -0.71067 | |

| Temperature Control [°F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.963202 | 0.947471 | 0.954135 | 0.954936 |
| | Internal | 3.107815 | 2.787878 | 3.007746 | 2.967813 |
| | South | 0.973376 | 0.938761 | 0.964437 | 0.958858 |
| | West | 1.031218 | 1.040186 | 1.201101 | 1.090835 |
| | mean | 1.518903 | 1.428574 | 1.531855 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.039133 | 0.986431 | 0.977294 | 1.000953 |
| | Internal | 1.65428 | 1.551016 | 2.824462 | 2.00992 |
| | South | 1.013025 | 0.965227 | 0.959744 | 0.979332 |
| | West | 0.998117 | 1.073035 | 1.169847 | 1.080333 |
| | mean | 1.176139 | 1.143927 | 1.482837 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.880486 |
| | variance | 0.000722 |
| AHUB | mean | 1.082097 |
| | variance | 0.127418 |
| difference | | -0.20161 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 0.907291667 | 0.853542 | 0.880625 | 0.880486 | 0.000722 |
| AHUB | 1.469208333 | 1.011125 | 0.765958 | 1.082097 | 0.127418 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.002702 |
| | variance | 0.00071 |
| AHUB | mean | -0.0001 |
| | variance | 0.000436 |
| difference | | 0.002804 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.002542 | 0.003097 | 2.47E-03 | 0.002702 |
| | variance | 0.000826 | 0.000562 | 0.000743 | |
| AHUB | mean | -0.00011 | 0.000128 | -0.00032 | -0.0001 |
| | variance | 0.000525 | 0.000413 | 0.000371 | |

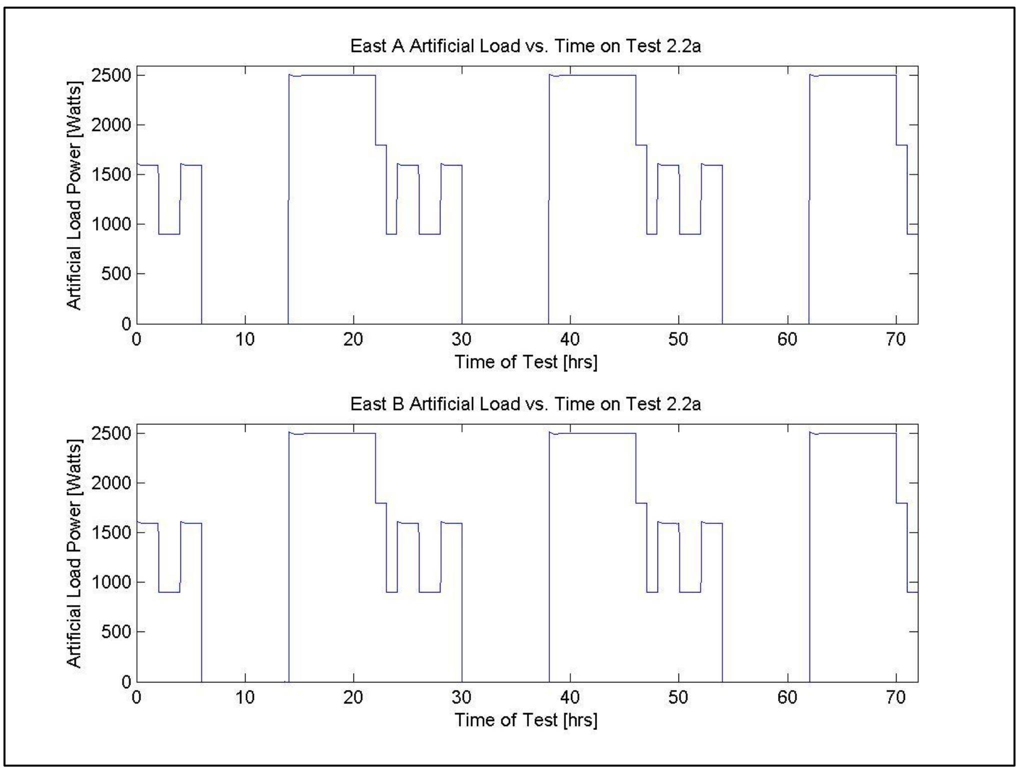
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 36.71073 |
| | variance | 75.36977 |
| AHUB | mean | 34.71182 |
| | variance | 82.63293 |
| difference | | 1.998903 |

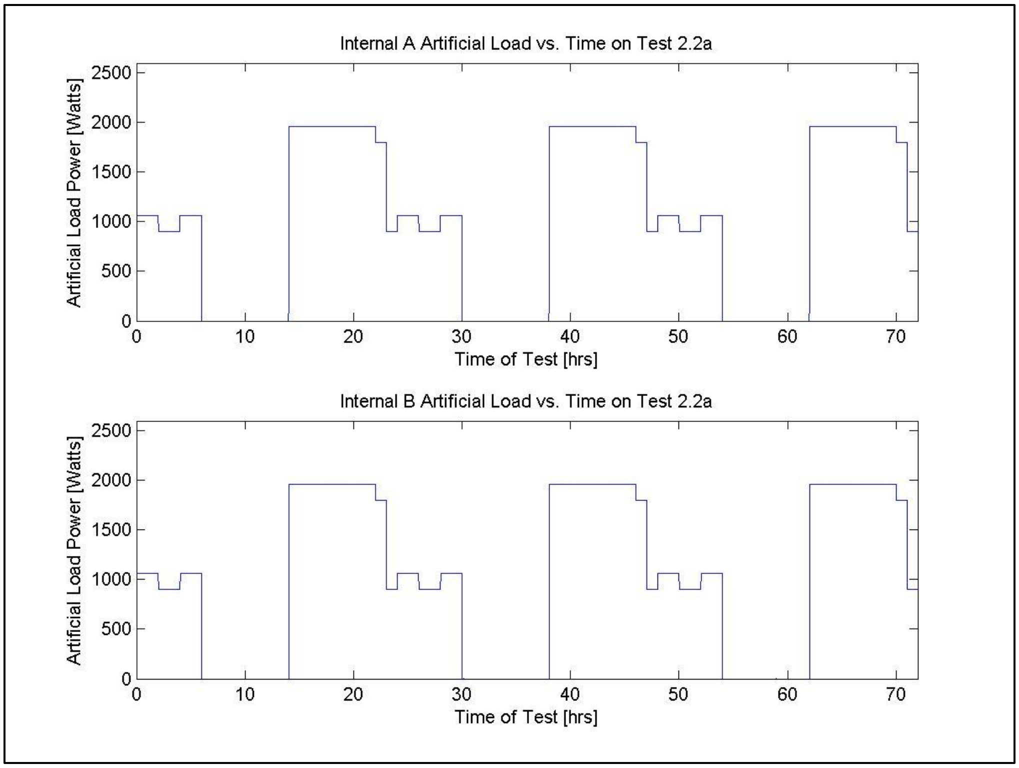
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 33.27504 | 40.88092 | 30.03596 | 34.73064 | 30.99235 |
| | Internal | 42.68175 | 37.60925 | 37.68875 | 39.32658 | 8.444438 |
| | South | 24.82713 | 23.3935 | 45.956 | 31.39221 | 159.5918 |
| | West | 29.51221 | 43.07213 | 51.59608 | 41.39347 | 124.0378 |
| | mean | 32.57403 | 36.23895 | 41.3192 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 36.28454 | 42.01575 | 23.96742 | 34.08924 | 85.05011 |
| | Internal | 40.19867 | 34.02792 | 10.565 | 28.26386 | 244.4568 |
| | South | 36.72404 | 35.18108 | 35.1985 | 35.70121 | 0.784717 |
| | West | 43.18096 | 39.43229 | 39.76571 | 40.79299 | 4.3046 |
| | mean | 39.09705 | 37.66426 | 27.37416 | | |

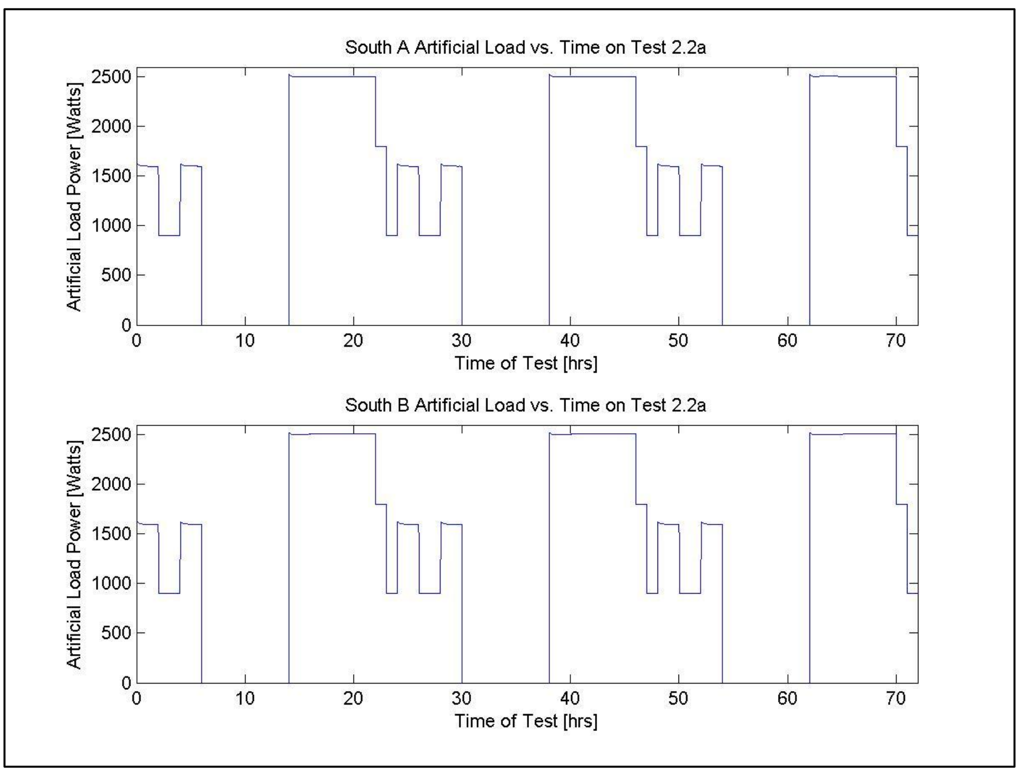
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.28218 |
| | variance | 134.6213 |
| AHUB | mean | -5.22099 |
| | variance | 1037.286 |
| difference | | 4.938809 |

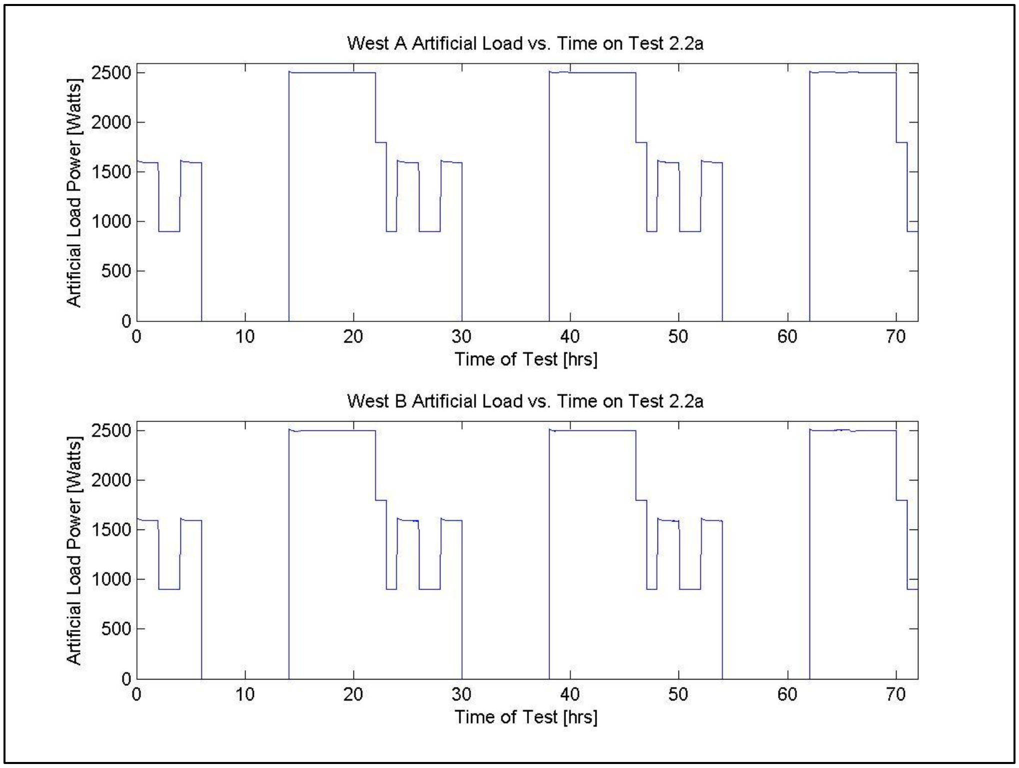
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.006337 | -0.00399 | -0.00148 | 0.000289 |
| | Internal | -0.77231 | -0.43464 | -0.53082 | -0.57925 |
| | South | 0.013455 | -0.01345 | 0.055469 | 0.01849 |
| | West | 0.014497 | -0.07101 | -1.64818 | -0.56823 |
| | mean | -0.18451 | -0.13077 | -0.53125 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.07023 | 0.003906 | -0.06215 | -0.04282 |
| | Internal | 0.054688 | -0.03672 | -32.814 | -10.932 |
| | South | 0.104253 | -0.00234 | -0.13403 | -0.01071 |
| | West | -0.00443 | 0.002604 | -29.6934 | -9.89841 |
| | mean | 0.021072 | -0.00814 | -15.6759 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 31.81249 | 26.74575 | 28.01026 | 28.85617 |
| | Internal | 299.6458 | 210.9455 | 207.533 | 239.3747 |
| | South | 19.75285 | 17.76916 | 71.21946 | 36.24716 |
| | West | 22.26604 | 31.06319 | 646.8821 | 233.4038 |
| | mean | 93.3693 | 71.63089 | 238.4112 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 17.1943 | 16.50479 | 10.05855 | 14.58588 |
| | Internal | 21.76477 | 29.75867 | 1908.745 | 653.423 |
| | South | 19.34053 | 17.06177 | 36.70451 | 24.36894 |
| | West | 16.5252 | 16.48247 | 8712.691 | 2915.233 |
| | mean | 18.7062 | 19.95193 | 2667.05 | |




Internal A Artificial Load vs. Time on Test 2.2a
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 2.2a
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 2.2a
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]
South B Artificial Load vs. Time on Test 2.2a
Artificial Load Power [Watts]
Time of Test [hrs]




## TEST 2.2b

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-6 |
| AHUA | 66.43631352 |
| AHUB | 60.76872032 |
| % difference | 8.53% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 23.64715 | 19.09068 | 23.69849 | 22.14544 | 6.999325 |
| AHUB | 19.33787 | 20.64526 | 20.78558 | 20.25624 | 0.637471 |
| % difference | 18.22% | -8.14% | 12.29% | 8.53% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -0.64428 |
| | variance | 1.866947 |
| AHUB | mean [$^{o}$F] | -0.77496 |
| | variance | 1.290087 |
| difference | | 0.13068 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.10152 | -0.69212 | -0.45981 | -0.75115 |
| | Internal | -0.14757 | 0.289559 | -0.04208 | 0.033303 |
| | South | -1.1341 | -0.73649 | -0.6262 | -0.83227 |
| | West | -1.28375 | -0.82595 | -0.97136 | -1.02702 |
| | mean | -0.91674 | -0.49125 | -0.52486 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.20753 | -0.93353 | -0.7164 | -0.95249 |
| | Internal | -0.34277 | -0.28126 | -0.31646 | -0.3135 |
| | South | -0.94345 | -0.68835 | -0.58348 | -0.73843 |
| | West | -1.40268 | -0.98258 | -0.90105 | -1.09544 |
| | mean | -0.97411 | -0.72143 | -0.62935 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 1.015458 | 0.789902 | 0.793645 | 0.866335 |
| | Internal | 2.348499 | 3.984606 | 2.769605 | 3.034236 |
| | South | 0.973181 | 1.222881 | 0.988639 | 1.061567 |
| | West | 1.217878 | 2.494079 | 1.293035 | 1.66833 |
| | mean | 1.388754 | 2.122867 | 1.461231 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.075268 | 0.968202 | 0.76351 | 0.93566 |
| | Internal | 1.62E+00 | 1.74E+00 | 1.72E+00 | 1.691676 |
| | South | 0.873569 | 0.866859 | 0.850235 | 0.863555 |
| | West | 1.52E+00 | 1.069032 | 1.05E+00 | 1.211748 |
| | mean | 1.272235 | 1.160353 | 1.094391 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.756556 |
| | variance | 0.226402 |
| AHUB | mean | 2.068583 |
| | variance | 0.006575 |
| difference | | -0.31203 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 2.2845 | 1.360833 | 1.624333 | 1.756556 | 0.226402 |
| AHUB | 2.149833333 | 1.987667 | 2.06825 | 2.068583 | 0.006575 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.00057 |
| | variance | 0.001778 |
| AHUB | mean | 0.039629 |
| | variance | 0.009451 |
| difference | | -0.0402 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00186 | -8.19E-05 | 2.37E-04 | -0.00057 |
| | variance | 0.001843 | 0.001692 | 0.0018 | |
| AHUB | mean | 0.062438 | 0.008733 | 0.047717 | 0.039629 |
| | variance | 0.013512 | 0.003767 | 0.009546 | |

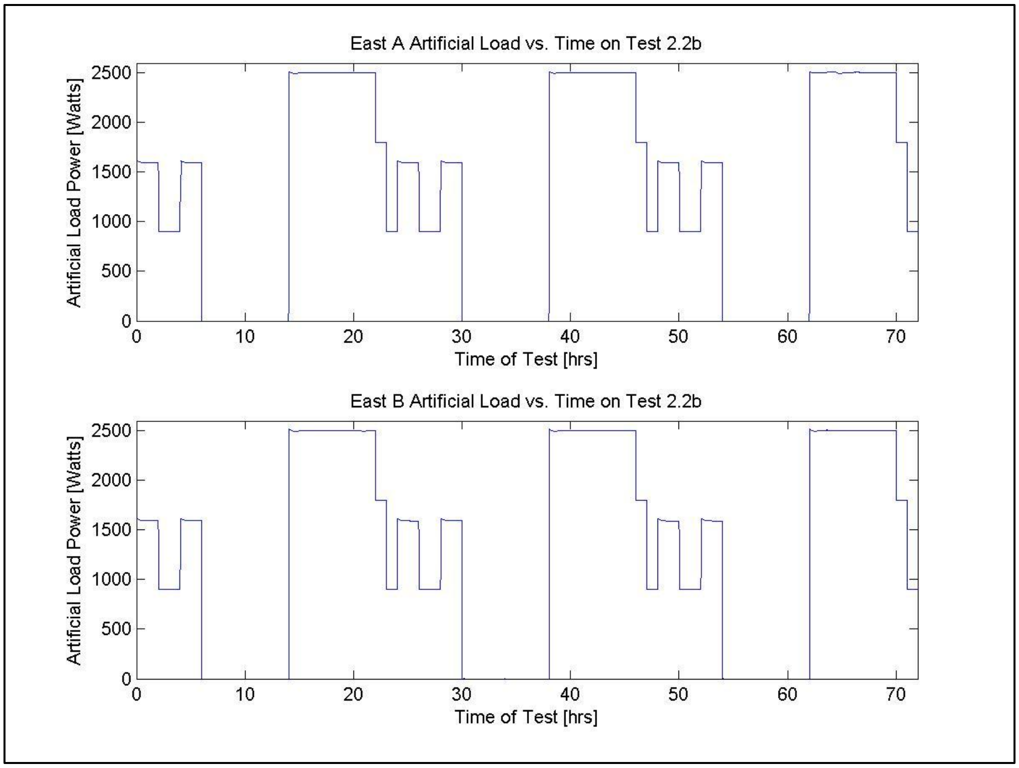
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 34.18119 |
| | variance | 62.01452 |
| AHUB | mean | 45.15715 |
| | variance | 60.99215 |
| difference | | -10.976 |

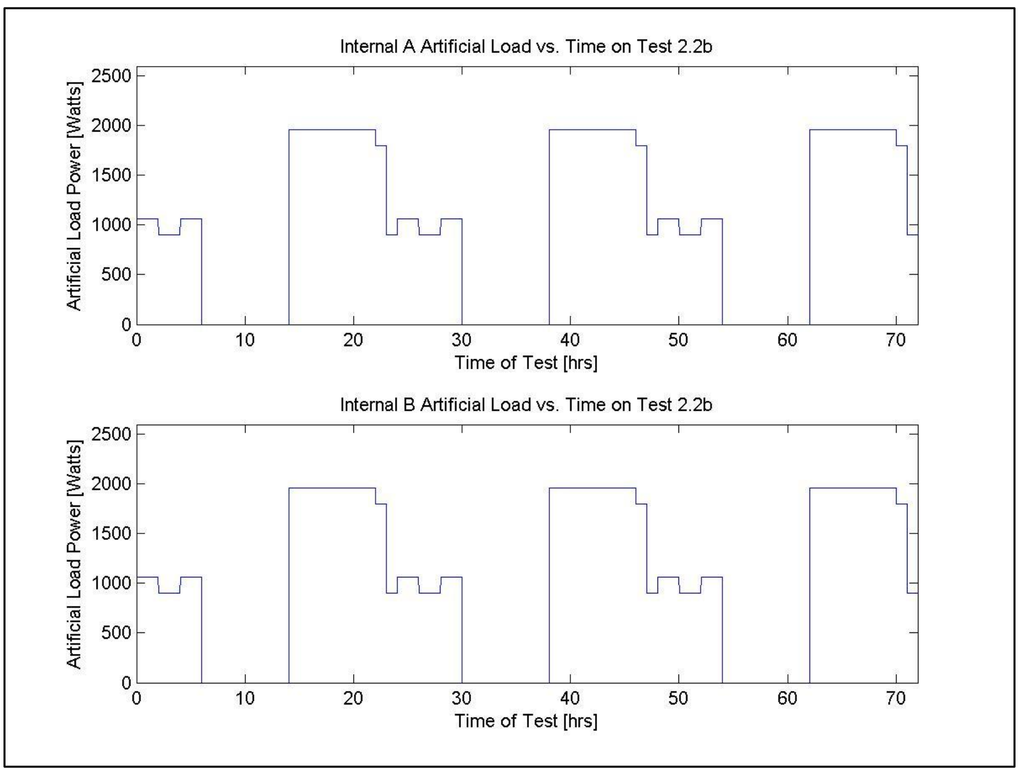
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 22.81529 | 38.95096 | 39.01829 | 33.59485 | 87.15025 |
| | Internal | 28.61779 | 25.51025 | 29.43313 | 27.85372 | 4.285089 |
| | South | 27.33538 | 33.4065 | 47.29288 | 36.01158 | 104.6653 |
| | West | 35.16704 | 36.01921 | 46.60758 | 39.26461 | 40.62098 |
| | mean | 28.48388 | 33.47173 | 40.58797 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 39.66958 | 40.16629 | 39.87417 | 39.90335 | 0.062318 |
| | Internal | 59.50738 | 55.88392 | 57.87354 | 57.75494 | 3.292912 |
| | South | 41.49163 | 42.9405 | 45.09988 | 43.17733 | 3.296935 |
| | West | 39.84842 | 40.31358 | 39.21688 | 39.79296 | 0.302999 |
| | mean | 45.12925 | 44.82607 | 45.51611 | | |

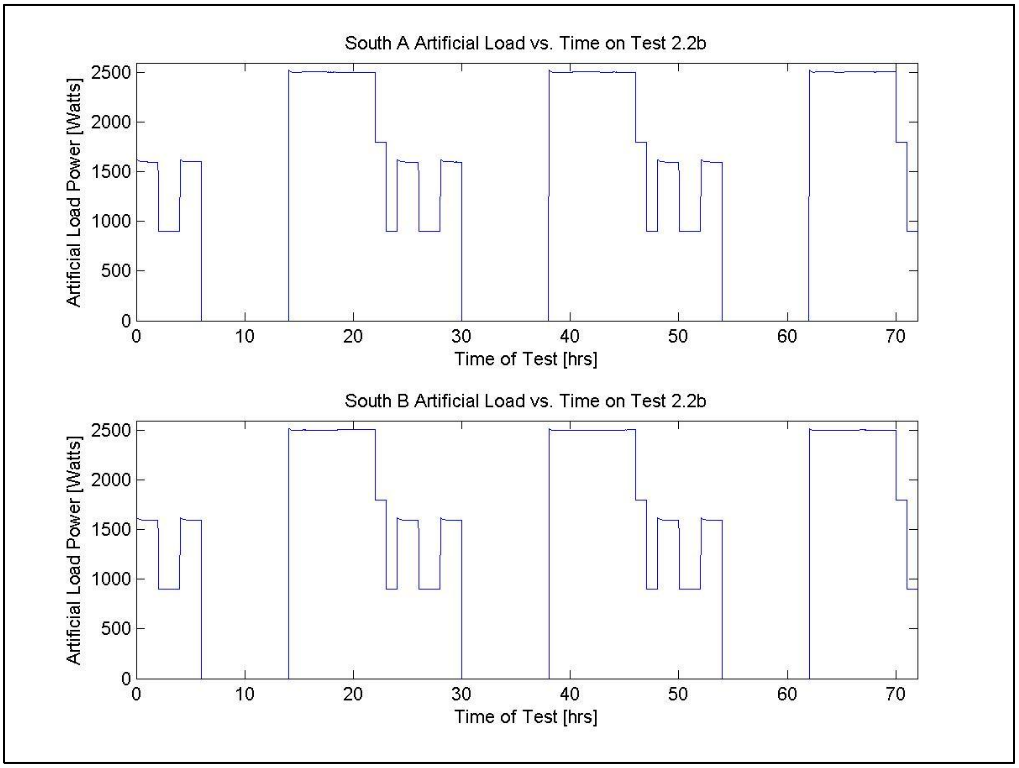
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -13.5117 |
| | variance | 3545.013 |
| AHUB | mean | -0.26632 |
| | variance | 111.8046 |
| difference | | -13.2454 |

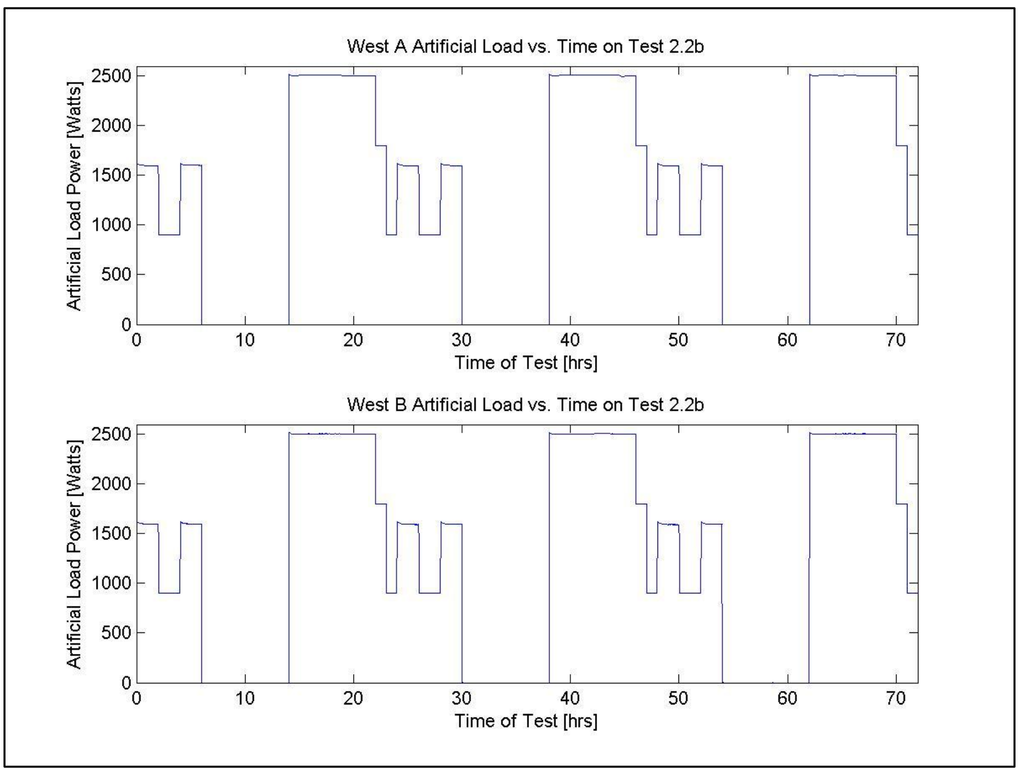
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.2553 | -1.31189 | -2.90538 | -1.49086 |
| | Internal | -0.01328 | -30.356 | 0.228385 | -10.047 |
| | South | 0.217622 | -51.5637 | -3.27179 | -18.206 |
| | West | -0.01563 | -73.1066 | 0.212674 | -24.3032 |
| | mean | -0.01664 | -39.0845 | -1.43403 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.08125 | 0.094184 | -0.06849 | -0.01852 |
| | Internal | -2.31493 | -0.08264 | -0.42726 | -0.94161 |
| | South | -0.06016 | 0.022743 | -0.20061 | -0.07934 |
| | West | 0.040365 | 0.007986 | -0.12578 | -0.02581 |
| | mean | -0.60399 | 0.010569 | -0.20553 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 21.06683 | 85.88994 | 550.4591 | 219.1386 |
| | Internal | 10.19489 | 1579.355 | 30.67936 | 540.0765 |
| | South | 20.40688 | 13814.54 | 520.0111 | 4784.987 |
| | West | 18.25091 | 18971.67 | 184.8898 | 6391.603 |
| | mean | 17.47988 | 8612.865 | 321.5098 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 3.68E+01 | 3.17E+01 | 3.57E+01 | 34.74846 |
| | Internal | 404.6781 | 196.8273 | 197.5917 | 266.3657 |
| | South | 7.06E+01 | 9.07E+01 | 1.22E+02 | 94.34995 |
| | West | 52.65765 | 52.2141 | 46.46353 | 50.44509 |
| | mean | 141.1947 | 92.86229 | 100.3749 | |


East A Artificial Load vs. Time on Test 2.2b
Artificial Load Power [Watts]
Time of Test [hrs]
East B Artificial Load vs. Time on Test 2.2b
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 2.2b
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 2.2b
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 2.2b
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 2.2b
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 2.2b
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 2.2b
Artificial Load Power [Watts]
Time of Test [hrs]

**TEST 2.3a**

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-6 |
| AHUA | 59.39611958 |
| AHUB | 60.23032318 |
| % difference | -1.40% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 21.76851 | 19.64311 | 17.9845 | 19.79871 | 3.597846 |
| AHUB | 24.02777 | 19.31117 | 16.89139 | 20.07677 | 13.17158 |
| % difference | -10.38% | 1.69% | 6.08% | -1.40% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -0.54509 |
| | variance | 1.588596 |
| AHUB | mean [$^{o}$F] | -0.70901 |
| | variance | 1.353481 |
| difference | | 0.163919 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.67543 | -0.75839 | -0.86248 | -0.76543 |
| | Internal | -0.01024 | 0.052819 | 0.063453 | 0.035346 |
| | South | -0.65223 | -0.25079 | -0.21425 | -0.37242 |
| | West | -1.07327 | -1.13378 | -1.02652 | -1.07786 |
| | mean | -0.60279 | -0.52253 | -0.50995 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.87014 | -1.03661 | -1.04021 | -0.98232 |
| | Internal | -0.38415 | -0.28469 | 0.137198 | -0.17721 |
| | South | -0.64831 | -0.75257 | -0.81287 | -0.73792 |
| | West | -0.9501 | -0.98484 | -0.88082 | -0.93859 |
| | mean | -0.71318 | -0.76468 | -0.64918 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.788068 | 0.803015 | 0.976093 | 0.855725 |
| | Internal | 2.742947 | 2.857626 | 2.989699 | 2.863424 |
| | South | 1.277374 | 0.441602 | 0.483198 | 0.734058 |
| | West | 1.168364 | 1.179908 | 1.123879 | 1.157383 |
| | mean | 1.494188 | 1.320538 | 1.393217 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.83465 | 0.957573 | 0.950812 | 0.914345 |
| | Internal | 1.51E+00 | 1.75E+00 | 3.13E+00 | 2.127015 |
| | South | 0.817047 | 0.851013 | 0.937134 | 0.868398 |
| | West | 1.08E+00 | 1.016826 | 9.96E-01 | 1.032375 |
| | mean | 1.060486 | 1.143036 | 1.503077 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.970722 |
| | variance | 0.048847 |
| AHUB | mean | 1.194278 |
| | variance | 0.106322 |
| difference | | 0.776444 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 2.069541667 | 1.717542 | 2.125083 | 1.970722 | 0.048847 |
| AHUB | 1.54325 | 1.142208 | 0.897375 | 1.194278 | 0.106322 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.39133 |
| | variance | 0.077616 |
| AHUB | mean | 0.059137 |
| | variance | 0.013835 |
| difference | | -0.45047 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.36292 | -4.12E-01 | -3.99E-01 | -0.39133 |
| | variance | 0.086945 | 0.074386 | 0.070327 | |
| AHUB | mean | -0.0002 | 0.001058 | 0.176554 | 0.059137 |
| | variance | 0.000655 | 0.000871 | 0.019302 | |

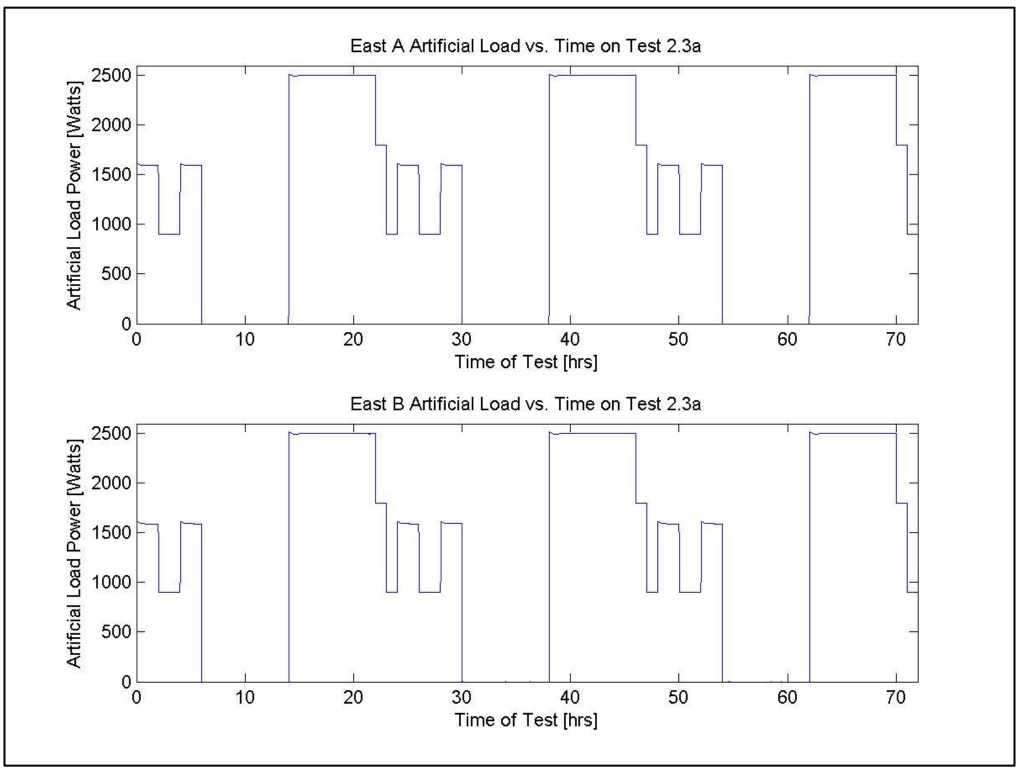
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 60.88244 |
| | variance | 297.5042 |
| AHUB | mean | 36.14549 |
| | variance | 52.08469 |
| difference | | 24.73695 |

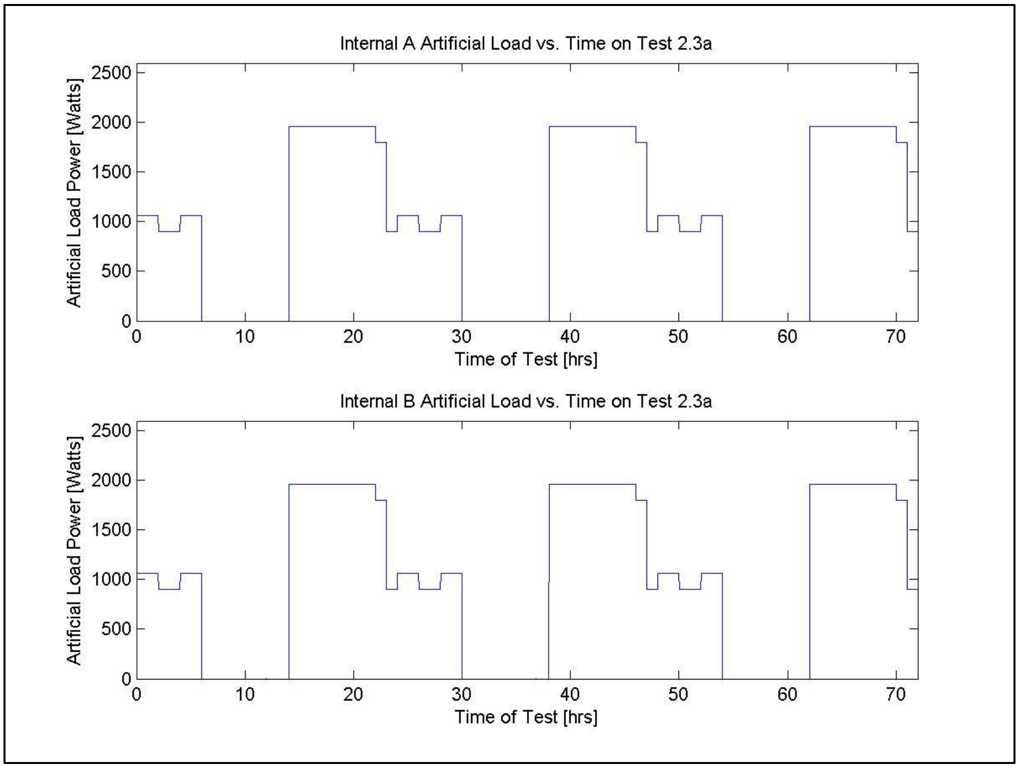
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 46.00571 | 43.23392 | 49.66996 | 46.30319 | 10.42203 |
| | Internal | 83.77471 | 83.83362 | 95.25967 | 87.62267 | 43.74369 |
| | South | 47.88354 | 55.15837 | 62.07558 | 55.03917 | 50.36417 |
| | West | 60.63679 | 50.25821 | 52.79925 | 54.56475 | 29.26649 |
| | mean | 59.57519 | 58.12103 | 64.95111 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 42.15054 | 22.69875 | 45.18308 | 36.67746 | 148.8523 |
| | Internal | 39.10433 | 30.18888 | 25.25813 | 31.51711 | 49.25253 |
| | South | 40.38321 | 40.98538 | 35.59188 | 38.98682 | 8.734887 |
| | West | 42.34871 | 38.69921 | 31.15383 | 37.40058 | 32.59613 |
| | mean | 40.9967 | 33.14305 | 34.29673 | | |

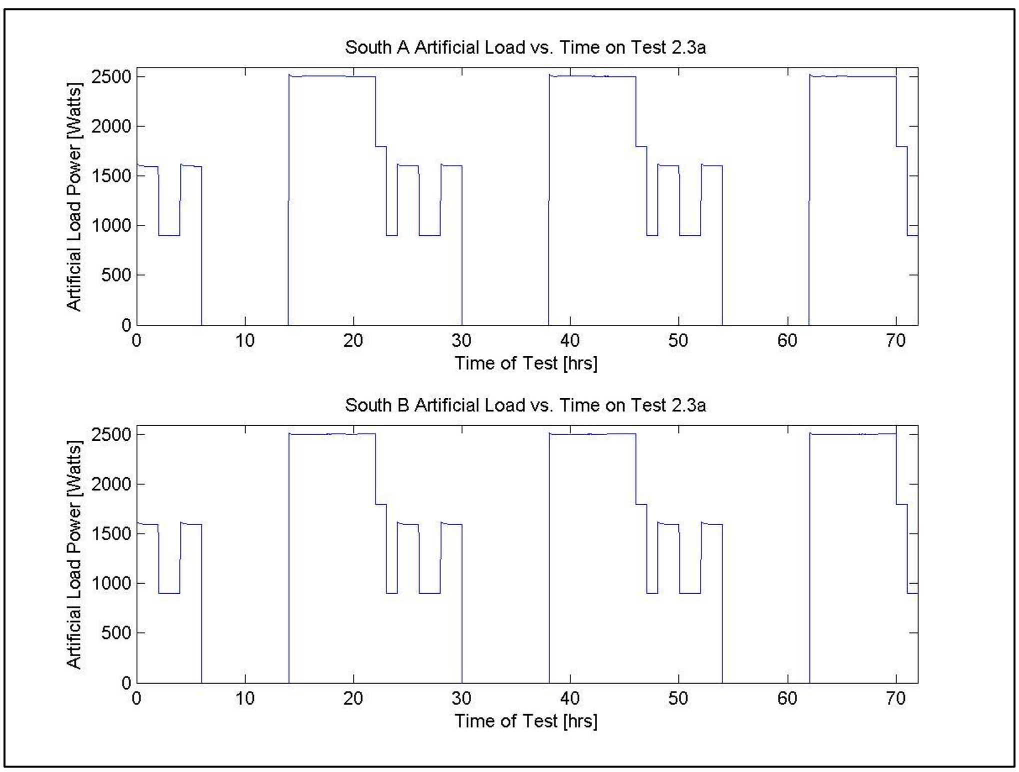
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -4.31157 |
| | variance | 1304.072 |
| AHUB | mean | -2.57493 |
| | variance | 229.5735 |
| difference | | -1.73664 |

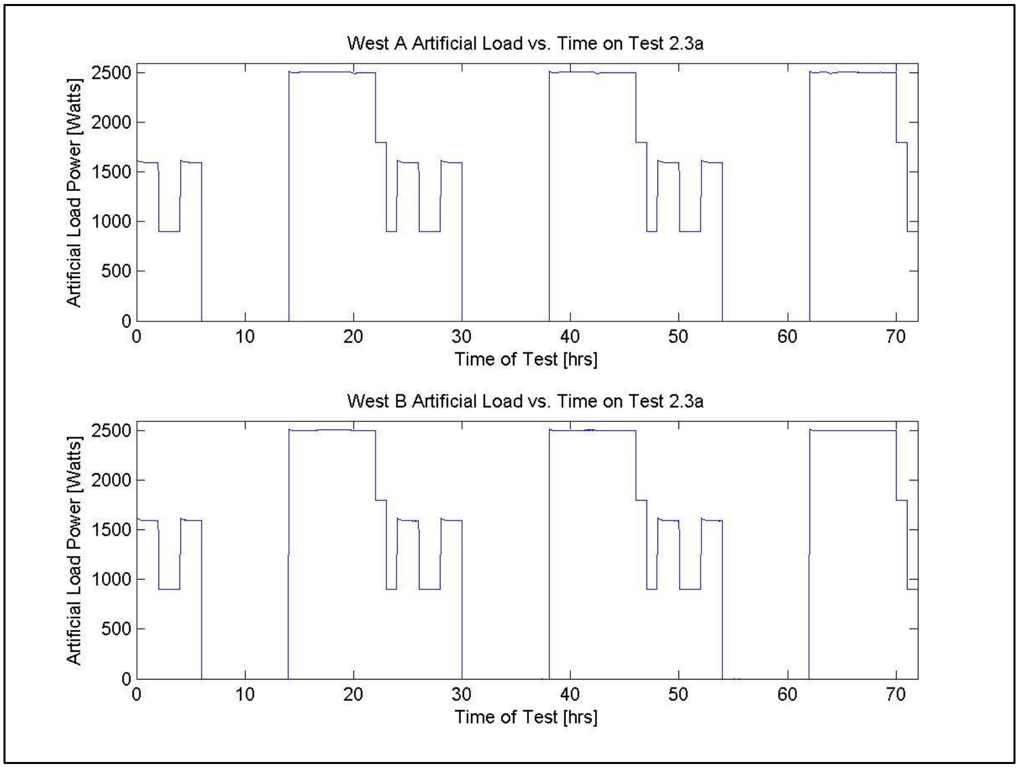
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.01441 | -0.11936 | -0.0375 | -0.04748 |
| | Internal | -5.62465 | -3.45755 | -6.15781 | -5.08001 |
| | South | -16.6488 | -4.98325 | -12.7946 | -11.4755 |
| | West | -0.99783 | -0.10686 | -0.82509 | -0.64326 |
| | mean | -5.81421 | -2.16675 | -4.95375 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.058941 | -0.01667 | -0.12813 | -0.02862 |
| | Internal | 0.026649 | -0.05113 | -30.778 | -10.2675 |
| | South | 0.114931 | -0.12101 | -0.01936 | -0.00848 |
| | West | 0.024219 | 0.042708 | -0.05234 | 0.004861 |
| | mean | 0.056185 | -0.03652 | -7.74447 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 82.36013 | 74.74891 | 108.5702 | 88.55974 |
| | Internal | 747.7918 | 622.5505 | 796.7213 | 722.3545 |
| | South | 6818.37 | 809.2978 | 4489.815 | 4039.161 |
| | West | 350.8116 | 225.2385 | 206.476 | 260.842 |
| | mean | 1999.833 | 432.9589 | 1400.396 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.92E+01 | 1.10E+01 | 2.05E+01 | 16.91028 |
| | Internal | 25.31399 | 27.11317 | 1649.448 | 567.2917 |
| | South | 1.95E+01 | 2.34E+01 | 3.04E+01 | 24.41767 |
| | West | 22.44051 | 17.71462 | 22.23889 | 20.79801 |
| | mean | 21.61095 | 19.80764 | 430.6446 | |




Internal A Artificial Load vs. Time on Test 2.3a
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 2.3a
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 2.3a
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 2.3a
Artificial Load Power [Watts]
Time of Test [hrs]




## TEST 2.3b

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-6 |
| AHUA | 73.7513365 |
| AHUB | 71.97171942 |
| % difference | 2.41% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 26.65218 | 26.79202 | 20.30714 | 24.58378 | 13.72214 |
| AHUB | 19.60263 | 19.34109 | 33.028 | 23.99057 | 61.27343 |
| % difference | 26.45% | 27.81% | -62.64% | 2.41% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -0.31833 |
| | variance | 1.899286 |
| AHUB | mean [$^oF$] | -0.57651 |
| | variance | 1.611803 |
| difference | | 0.258186 |

| Temperature Control [$^oF$ Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.90937 | -0.63005 | -0.17284 | -0.57076 |
| | Internal | -0.20054 | 0.082469 | 0.490589 | 0.124173 |
| | South | -0.28098 | -0.17007 | 0.209785 | -0.08042 |
| | West | -1.06425 | -0.9286 | -0.24606 | -0.74631 |
| | mean | -0.61379 | -0.41156 | 0.070368 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.05671 | -0.88798 | -0.46851 | -0.8044 |
| | Internal | -0.39488 | -0.29733 | 0.323717 | -0.12283 |
| | South | -0.6847 | -0.55719 | -0.46036 | -0.56742 |
| | West | -1.00724 | -0.91252 | -0.51445 | -0.81141 |
| | mean | -0.78588 | -0.66375 | -0.2799 | |

| Temperature Control [$^oF$ Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.957362 | 0.803458 | 1.13539 | 0.965403 |
| | Internal | 2.207746 | 3.023132 | 4.938586 | 3.389821 |
| | South | 0.356414 | 0.277085 | 0.556459 | 0.396653 |
| | West | 1.138118 | 1.525787 | 3.351775 | 2.005227 |
| | mean | 1.16491 | 1.407366 | 2.495553 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.958224 | 0.85217 | 0.912969 | 0.907788 |
| | Internal | 1.60E+00 | 1.79E+00 | 4.57E+00 | 2.651063 |
| | South | 1.07882 | 1.071172 | 0.998281 | 1.049424 |
| | West | 1.12E+00 | 1.048203 | 1.77E+00 | 1.313191 |
| | mean | 1.188348 | 1.189736 | 2.063016 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.464347 |
| | variance | 0.323475 |
| AHUB | mean | 1.419611 |
| | variance | 0.009765 |
| difference | | 0.044736 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 2.055125 | 1.417375 | 0.920542 | 1.464347 | 0.323475 |
| AHUB | 1.483541667 | 1.4695 | 1.305792 | 1.419611 | 0.009765 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.00078 |
| | variance | 0.001621 |
| AHUB | mean | 0.206906 |
| | variance | 0.060646 |
| difference | | -0.20768 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00167 | 1.31E-03 | -1.98E-03 | -0.00078 |
| | variance | 0.001823 | 0.001634 | 0.001401 | |
| AHUB | mean | 0.222226 | 0.145131 | 0.253361 | 0.206906 |
| | variance | 0.02777 | 0.04177 | 0.106269 | |

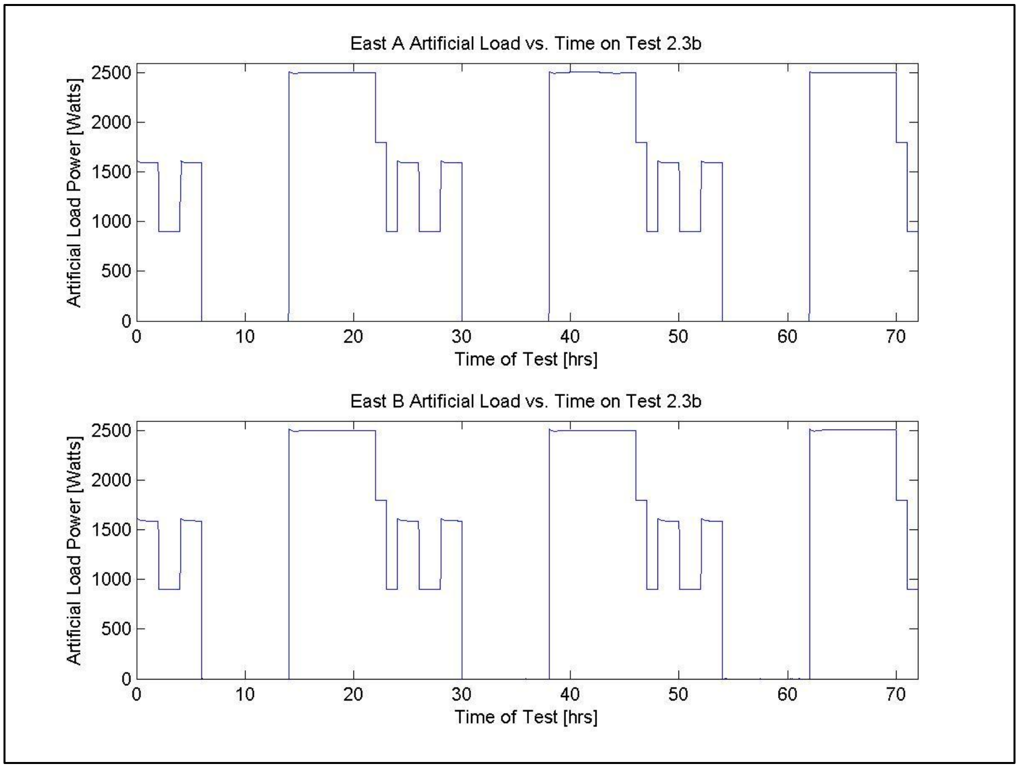
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 31.13845 |
| | variance | 18.26055 |
| AHUB | mean | 48.13082 |
| | variance | 65.2177 |
| difference | | -16.9924 |

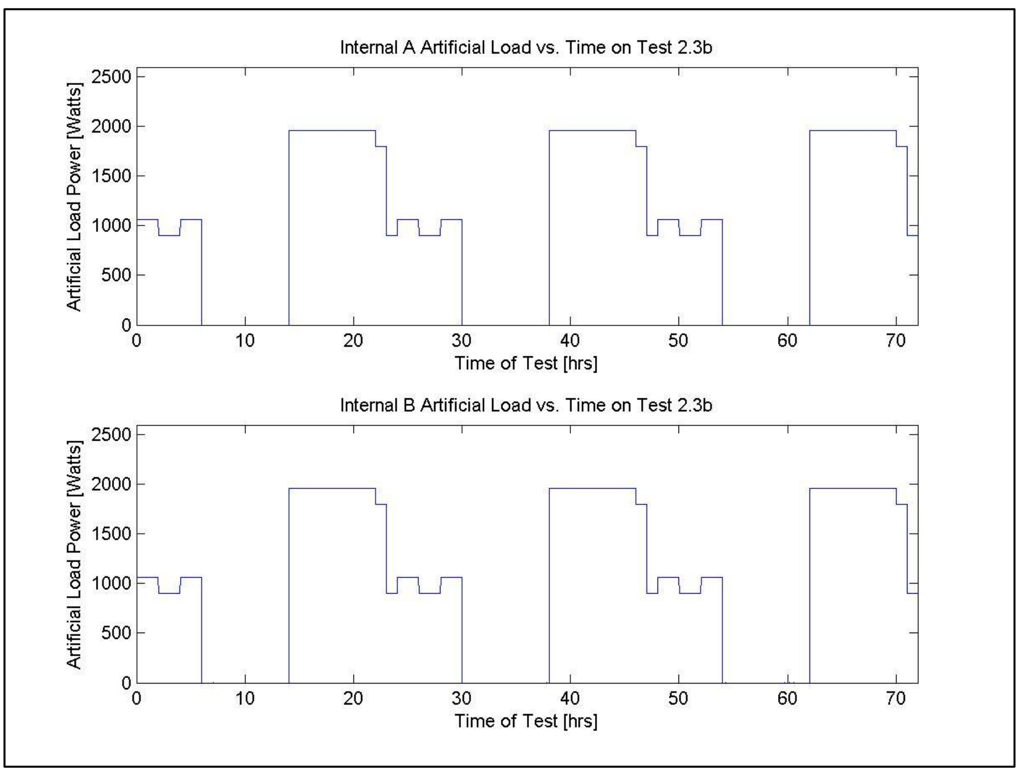
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 36.86633 | 30.30892 | 29.34617 | 32.17381 | 16.74658 |
| | Internal | 34.10938 | 26.53208 | 21.06896 | 27.23681 | 42.88559 |
| | South | 30.57163 | 34.30383 | 29.47371 | 31.44972 | 6.410818 |
| | West | 33.77458 | 33.57971 | 33.72613 | 33.69347 | 0.010294 |
| | mean | 33.83048 | 31.18114 | 28.40374 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 34.564 | 45.04808 | 41.93771 | 40.5166 | 28.99367 |
| | Internal | 56.45 | 54.06896 | 37.87192 | 49.46363 | 102.1931 |
| | South | 53.37233 | 55.11846 | 38.91817 | 49.13632 | 79.07022 |
| | West | 57.51108 | 53.05971 | 49.64938 | 53.40672 | 15.54193 |
| | mean | 50.47435 | 51.8238 | 42.09429 | | |

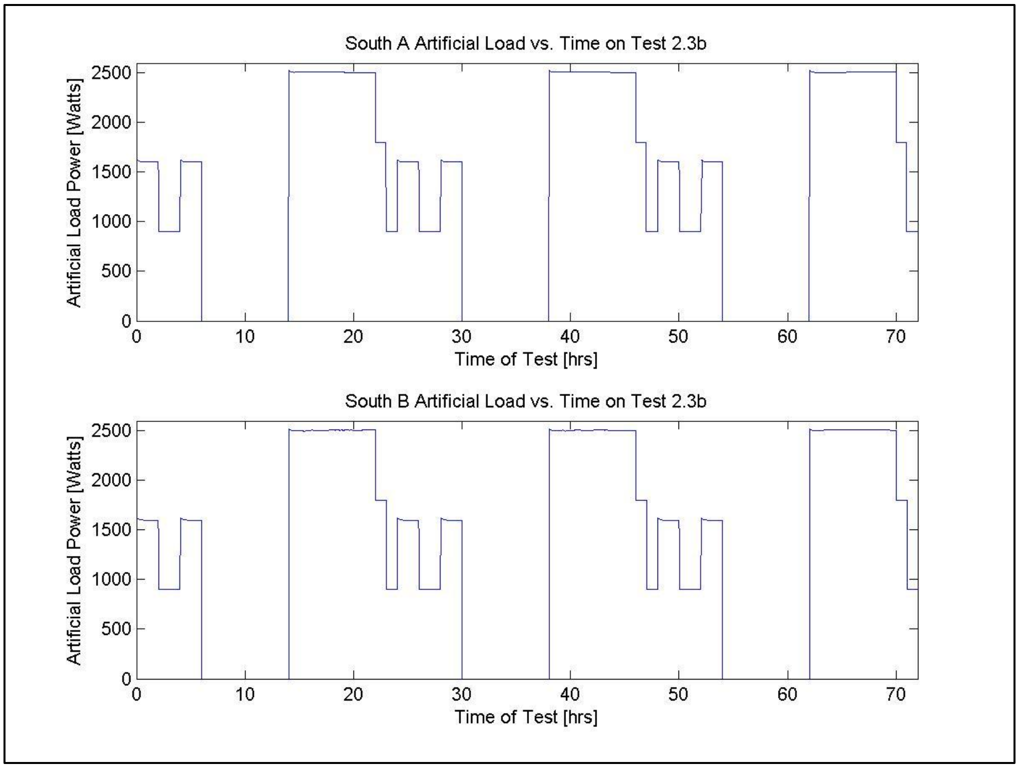
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -29.1655 |
| | variance | 7631.059 |
| AHUB | mean | -3.79814 |
| | variance | 1153.311 |
| difference | | -25.3673 |

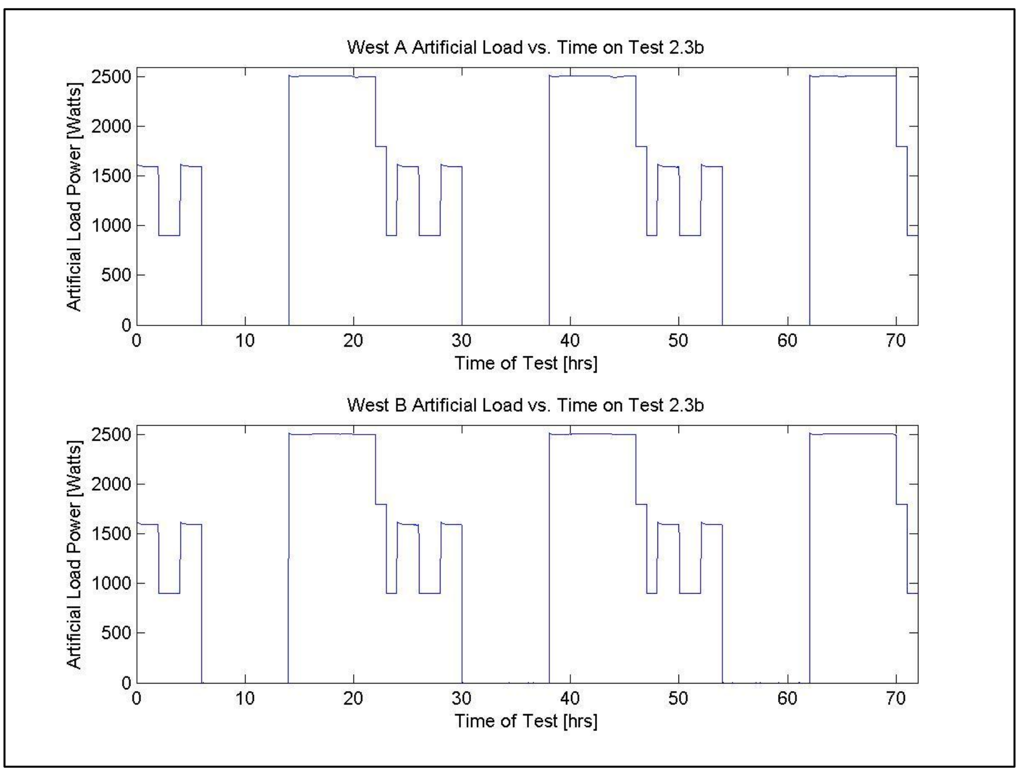
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.142188 | -6.61875 | -101.379 | -35.9519 |
| | Internal | 0.473264 | -0.06311 | -30.5978 | -10.0626 |
| | South | 0.052257 | -8.65295 | -89.0573 | -32.5527 |
| | West | 0.198438 | -19.0255 | -95.4573 | -38.0948 |
| | mean | 0.216536 | -8.59008 | -79.1229 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.06658 | -0.09557 | 0.130295 | -0.01062 |
| | Internal | -3.7303 | -2.30208 | -1.53325 | -2.52188 |
| | South | -4.49931 | -10.3853 | -13.8827 | -9.58912 |
| | West | -3.55894 | -1.87899 | -3.77491 | -3.07095 |
| | mean | -2.96378 | -3.66549 | -4.76515 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 20.95925 | 526.1203 | 24343.76 | 8296.946 |
| | Internal | 30.90475 | 17.77906 | 1454.512 | 501.0652 |
| | South | 20.14318 | 881.2618 | 21199.13 | 7366.844 |
| | West | 69.07254 | 2468.488 | 22055.35 | 8197.638 |
| | mean | 35.26993 | 973.4123 | 17263.19 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 3.14E+01 | 4.75E+01 | 1.09E+02 | 62.64352 |
| | Internal | 610.3688 | 473.9028 | 182.1285 | 422.1334 |
| | South | 9.12E+02 | 4.16E+03 | 5.16E+03 | 3409.743 |
| | West | 649.6552 | 411.6541 | 903.7748 | 655.028 |
| | mean | 550.7441 | 1272.279 | 1589.138 | |


East A Artificial Load vs. Time on Test 2.3b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
East B Artificial Load vs. Time on Test 2.3b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 2.3b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 2.3b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


South A Artificial Load vs. Time on Test 2.3b
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 2.3b
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 2.3b
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 2.3b
Artificial Load Power [Watts]
Time of Test [hrs]

# APPENDIX C: TEST SERIES 3 TABLES AND GRAPHS

## TEST 3.1

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 48.2534336 |
| AHUB | 40.73122578 |
| % difference | 15.59% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 20.06565 | 16.68424 | 11.50354 | 16.08448 | 18.59721 |
| AHUB | 14.45781 | 13.85701 | 12.4164 | 13.57708 | 1.100609 |
| % difference | 27.95% | 16.95% | -7.94% | 15.59% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.37664 |
| | variance | 2.766387 |
| AHUB | mean [$^{o}$F] | -1.35769 |
| | variance | 2.728751 |
| difference | | -0.01895 |

| Temperature Control [$^oF$ Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.47691 | -0.32567 | -1.3336 | -0.71206 |
| | Internal | -1.65682 | -1.59395 | -1.55515 | -1.60197 |
| | South | -1.51056 | -1.38783 | -1.55306 | -1.48382 |
| | West | -1.75481 | -1.65144 | -1.71985 | -1.7087 |
| | mean | -1.34978 | -1.23972 | -1.54041 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.78025 | -0.58133 | -1.6019 | -0.98783 |
| | Internal | -1.74119 | -1.6816 | -1.66165 | -1.69481 |
| | South | -1.26669 | -1.15666 | -1.41096 | -1.27811 |
| | West | -1.50407 | -1.43909 | -1.4669 | -1.47002 |
| | mean | -1.32305 | -1.21467 | -1.53535 | |

| Temperature Control [$^oF$ Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.508068 | 0.357923 | 2.87586 | 1.247284 |
| | Internal | 2.963019 | 3.114001 | 3.180904 | 3.085975 |
| | South | 2.699359 | 2.649635 | 3.096886 | 2.815293 |
| | West | 3.078306 | 3.163263 | 3.069869 | 3.103813 |
| | mean | 2.312188 | 2.321206 | 3.05588 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.812989 | 0.562283 | 2.940219 | 1.438497 |
| | Internal | 2.83E+00 | 2.96E+00 | 2.94E+00 | 2.909236 |
| | South | 2.656772 | 2.451029 | 3.25044 | 2.78608 |
| | West | 3.32E+00 | 3.365505 | 3.24E+00 | 3.310579 |
| | mean | 2.406584 | 2.334218 | 3.092492 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.345847 |
| | variance | 0.530433 |
| AHUB | mean | 0.798958 |
| | variance | 0.008289 |
| difference | | 0.546889 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.944917 | 1.557458 | 0.535167 | 1.345847 | 0.530433 |
| AHUB | 0.901042 | 0.769667 | 0.726167 | 0.798958 | 0.008289 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.000505 |
| | variance | 0.000694 |
| AHUB | mean | -0.00059 |
| | variance | 0.000431 |
| difference | | 0.001093 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00019 | 5.64E-04 | 1.14E-03 | 0.000505 |
| | variance | 0.000952 | 0.000847 | 0.000283 | |
| AHUB | mean | -0.00038 | -0.00013 | -0.00126 | -0.00059 |
| | variance | 0.000719 | 0.000385 | 0.000188 | |

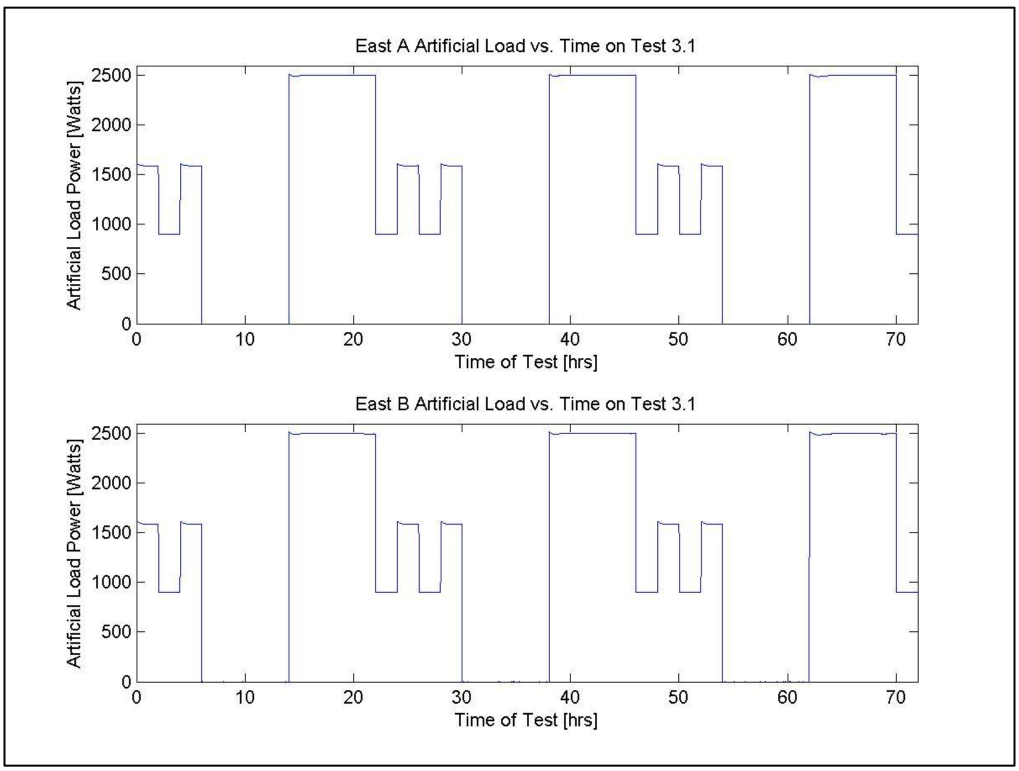
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 31.96239 |
| | variance | 74.51218 |
| AHUB | mean | 32.52723 |
| | variance | 144.0868 |
| difference | | -0.56483 |

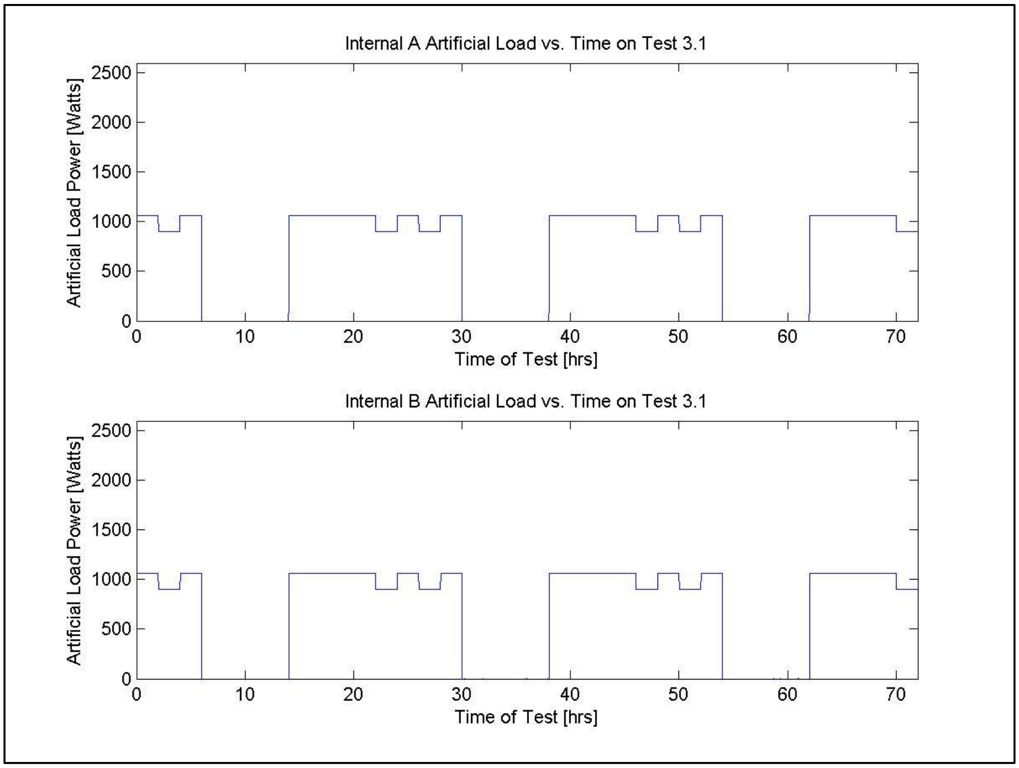
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 27.122 | 31.74146 | 41.07242 | 33.31196 | 50.50338 |
| | Internal | 19.9315 | 30.496 | 14.11196 | 21.51315 | 68.98542 |
| | South | 36.45804 | 35.029 | 36.11208 | 35.86638 | 0.555819 |
| | West | 31.592 | 33.88554 | 45.99671 | 37.15808 | 59.90605 |
| | mean | 28.77589 | 32.788 | 34.32329 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 44.55079 | 37.12208 | 44.45646 | 42.04311 | 18.16461 |
| | Internal | 17.64004 | 12.84583 | 12.92929 | 14.47172 | 7.530427 |
| | South | 43.53096 | 28.76554 | 40.91167 | 37.73606 | 62.06776 |
| | West | 40.19704 | 30.78592 | 36.59108 | 35.85801 | 22.54536 |
| | mean | 36.47971 | 27.37984 | 33.72213 | | |

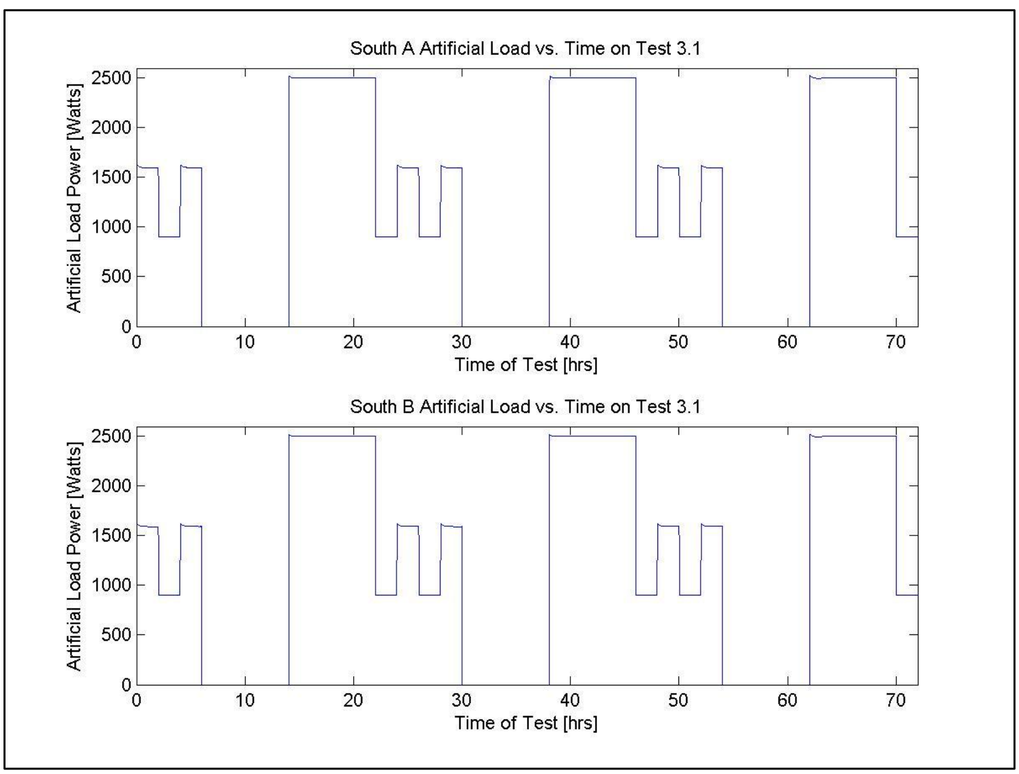
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.00635 |
| | variance | 17.86463 |
| AHUB | mean | -1.43197 |
| | variance | 261.6922 |
| difference | | 1.425615 |

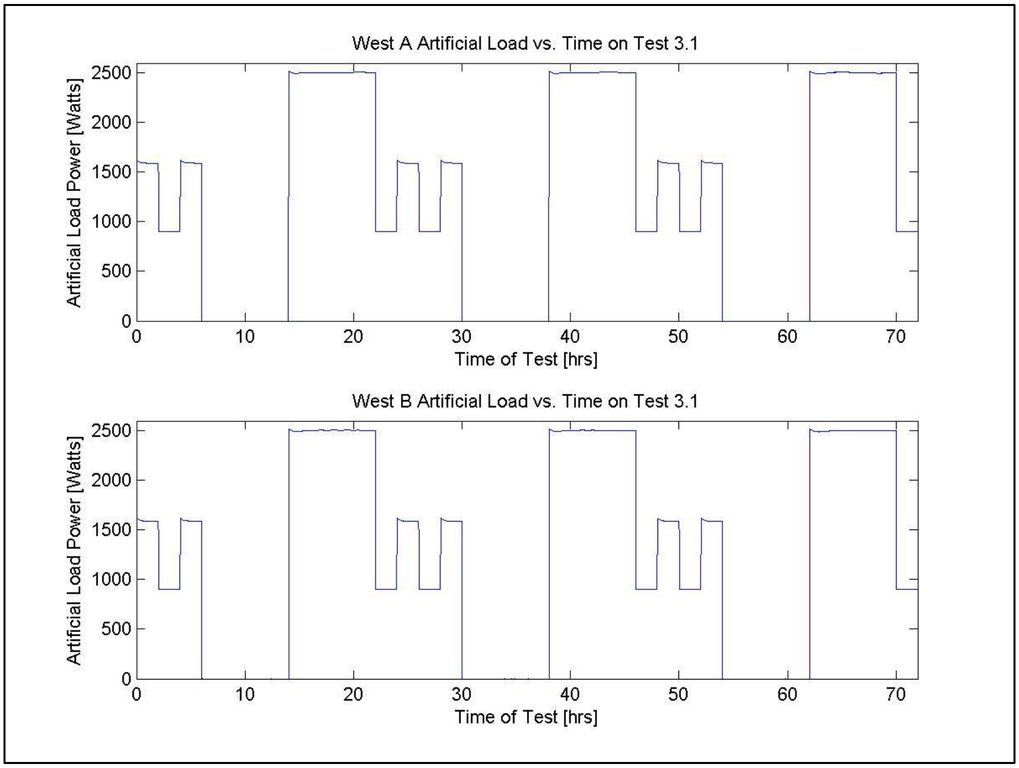
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.214757 | 0.084635 | 0.000694 | 0.100029 |
| | Internal | 0.010938 | -0.04653 | -0.0678 | -0.03446 |
| | South | 0.032986 | -0.02995 | -0.00226 | 0.00026 |
| | West | -0.2434 | 0.032552 | -0.06285 | -0.09123 |
| | mean | 0.003819 | 0.010178 | -0.03305 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.023958 | -0.02752 | -0.00226 | -0.00194 |
| | Internal | 0.018924 | 0.002431 | -0.01701 | 0.001447 |
| | South | 0.031684 | -0.0237 | -0.00911 | -0.00038 |
| | West | -14.126 | -3.10964 | 0.054688 | -5.727 |
| | mean | -3.51287 | -0.78961 | 0.006576 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 20.63544 | 24.41992 | 21.93381 | 22.32972 |
| | Internal | 4.937901 | 8.527021 | 4.980253 | 6.148392 |
| | South | 20.57029 | 18.7798 | 15.84987 | 18.39999 |
| | West | 23.21636 | 25.42603 | 25.10941 | 24.58393 |
| | mean | 17.34 | 19.28819 | 16.96833 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 2.78E+01 | 2.22E+01 | 1.81E+01 | 22.67513 |
| | Internal | 10.10851 | 5.337425 | 3.508505 | 6.318145 |
| | South | 4.29E+01 | 3.21E+01 | 2.36E+01 | 32.87287 |
| | West | 2399.912 | 352.1714 | 19.88074 | 923.9882 |
| | mean | 620.1872 | 102.9316 | 16.27199 | |




Internal A Artificial Load vs. Time on Test 3.1
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 3.1
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 3.1
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 3.1
Artificial Load Power [Watts]
Time of Test [hrs]




## TEST 3.2

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 51.85688927 |
| AHUB | 42.44829728 |
| % difference | 18.14% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 19.98839 | 18.36137 | 13.50714 | 17.28563 | 11.36956 |
| AHUB | 13.34386 | 15.28453 | 13.81991 | 14.14943 | 1.022983 |
| % difference | 33.24% | 16.76% | -2.32% | 18.14% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.25112 |
| | variance | 2.808963 |
| AHUB | mean [$^{o}$F] | -1.21254 |
| | variance | 2.547241 |
| difference | | -0.03858 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.19297 | -0.20988 | -0.5569 | -0.65325 |
| | Internal | -1.68331 | -1.59421 | -1.59135 | -1.62296 |
| | South | -1.33996 | -1.13133 | -1.35279 | -1.2747 |
| | West | -1.44768 | -1.44097 | -1.47202 | -1.45356 |
| | mean | -1.41598 | -1.0941 | -1.24327 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.37573 | -0.35317 | -0.80333 | -0.84408 |
| | Internal | -1.75272 | -1.64335 | -1.7452 | -1.71375 |
| | South | -1.01892 | -0.76042 | -0.97844 | -0.91926 |
| | West | -1.38723 | -1.375 | -1.35697 | -1.37307 |
| | mean | -1.38365 | -1.03299 | -1.22098 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 2.759413 | 0.273322 | 0.825044 | 1.285926 |
| | Internal | 2.908971 | 3.098667 | 3.086653 | 3.03143 |
| | South | 3.202929 | 2.410487 | 3.095029 | 2.902815 |
| | West | 3.328096 | 3.26989 | 3.323219 | 3.307068 |
| | mean | 3.049852 | 2.263092 | 2.582486 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 3.023517 | 0.335931 | 1.158859 | 1.506102 |
| | Internal | 2.79E+00 | 2.96E+00 | 2.77E+00 | 2.83712 |
| | South | 2.275933 | 1.41357 | 1.884818 | 1.858107 |
| | West | 3.29E+00 | 3.295174 | 3.32E+00 | 3.304253 |
| | mean | 2.844976 | 2.000906 | 2.283305 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.039569 |
| | variance | 0.28333 |
| AHUB | mean | 0.708264 |
| | variance | 9.58E-06 |
| difference | | 0.331306 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.590667 | 0.999708 | 0.528333 | 1.039569 | 0.28333 |
| AHUB | 0.7115 | 0.705333 | 0.707958 | 0.708264 | 9.58E-06 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.002787 |
| | variance | 0.000496 |
| AHUB | mean | -0.00039 |
| | variance | 0.000279 |
| difference | | 0.003173 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.003212 | 2.95E-03 | 2.20E-03 | 0.002787 |
| | variance | 0.000758 | 0.000435 | 0.000295 | |
| AHUB | mean | -0.00138 | 0.000704 | -0.00048 | -0.00039 |
| | variance | 0.000234 | 0.000341 | 0.00026 | |

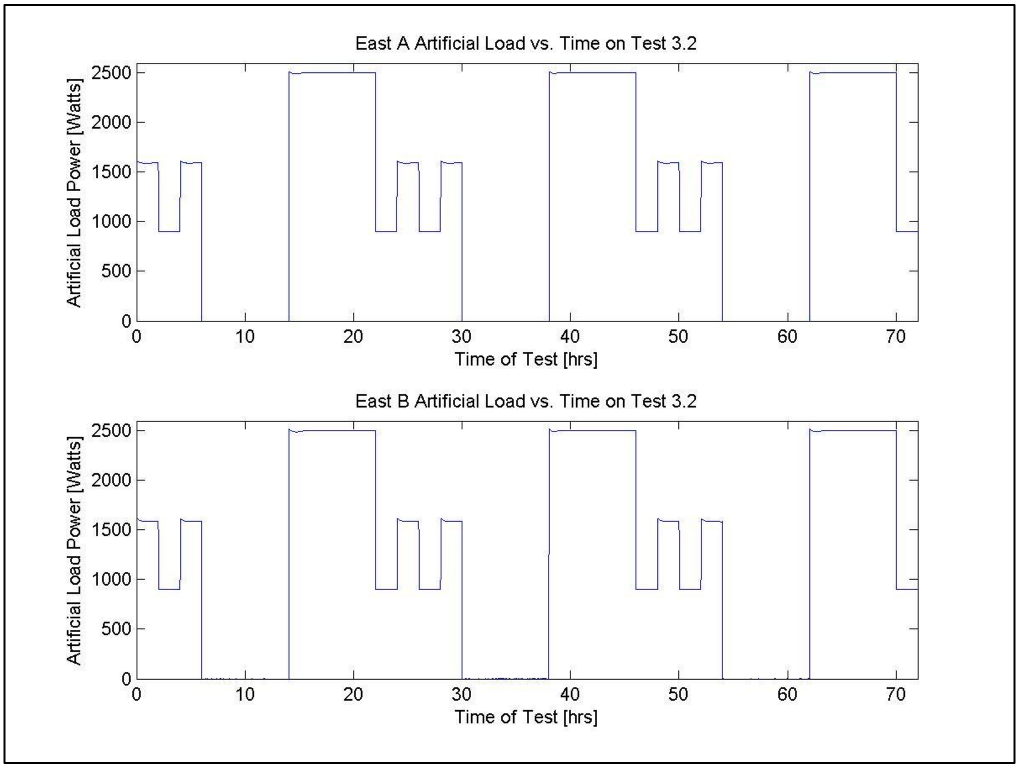
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 31.68802 |
| | variance | 65.65034 |
| AHUB | mean | 30.85588 |
| | variance | 147.3069 |
| difference | | 0.832146 |

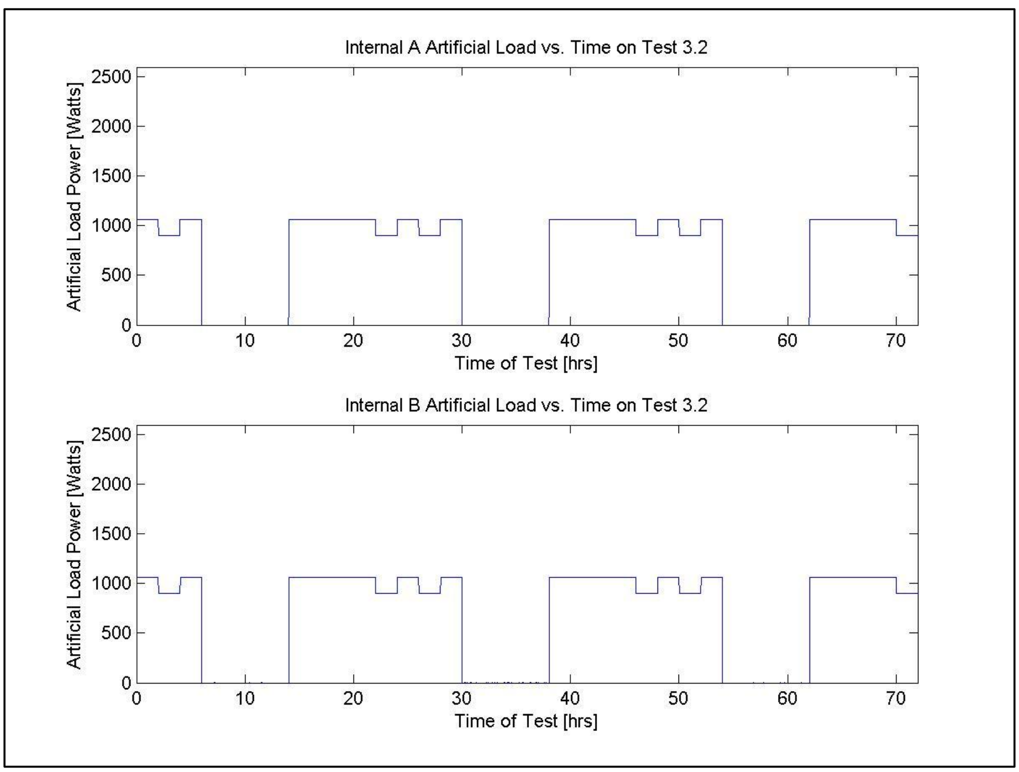
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 26.03662 | 33.91446 | 35.64479 | 31.86529 | 26.22853 |
| | Internal | 46.36721 | 27.65254 | 13.72942 | 29.24972 | 268.2196 |
| | South | 26.86638 | 32.69042 | 32.74554 | 30.76744 | 11.41452 |
| | West | 29.01438 | 35.77708 | 39.81742 | 34.86963 | 29.79404 |
| | mean | 32.07115 | 32.50863 | 30.48429 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 31.25113 | 34.47283 | 38.96121 | 34.89506 | 14.99505 |
| | Internal | 12.05125 | 13.19467 | 11.59438 | 12.2801 | 0.679512 |
| | South | 34.921 | 44.58975 | 37.52338 | 39.01138 | 25.03179 |
| | West | 29.90121 | 46.02479 | 35.78492 | 37.23697 | 66.57383 |
| | mean | 27.03115 | 34.57051 | 30.96597 | | |

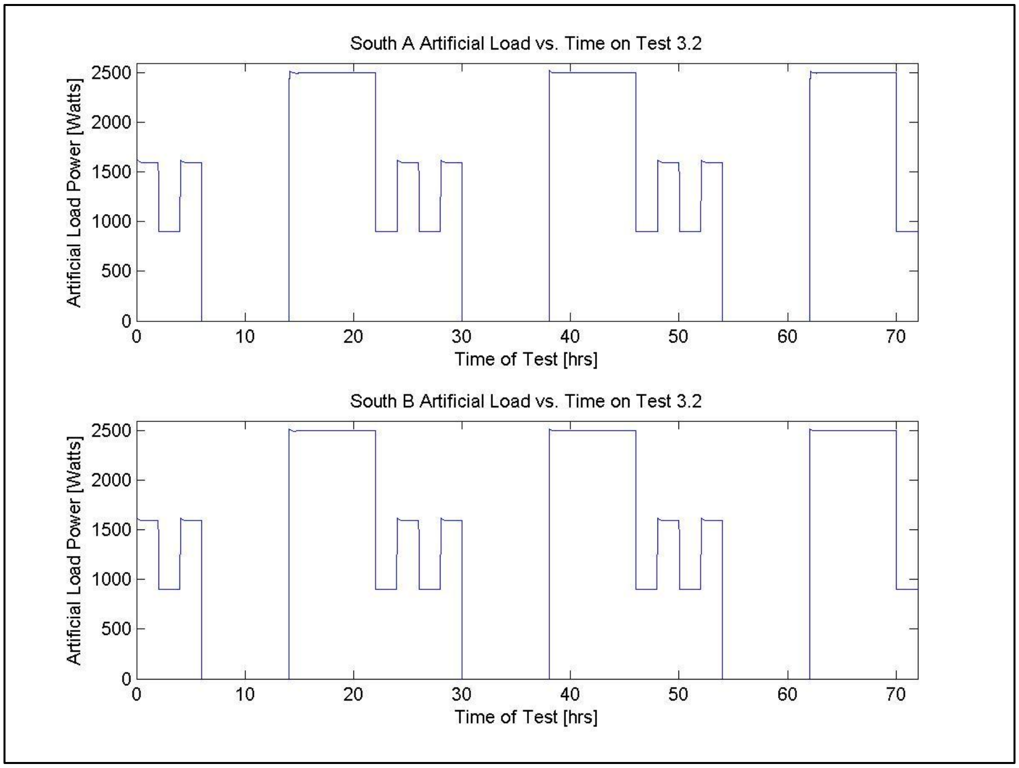
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -2.11998 |
| | variance | 499.5541 |
| AHUB | mean | -0.00668 |
| | variance | 26.75235 |
| difference | | -2.1133 |

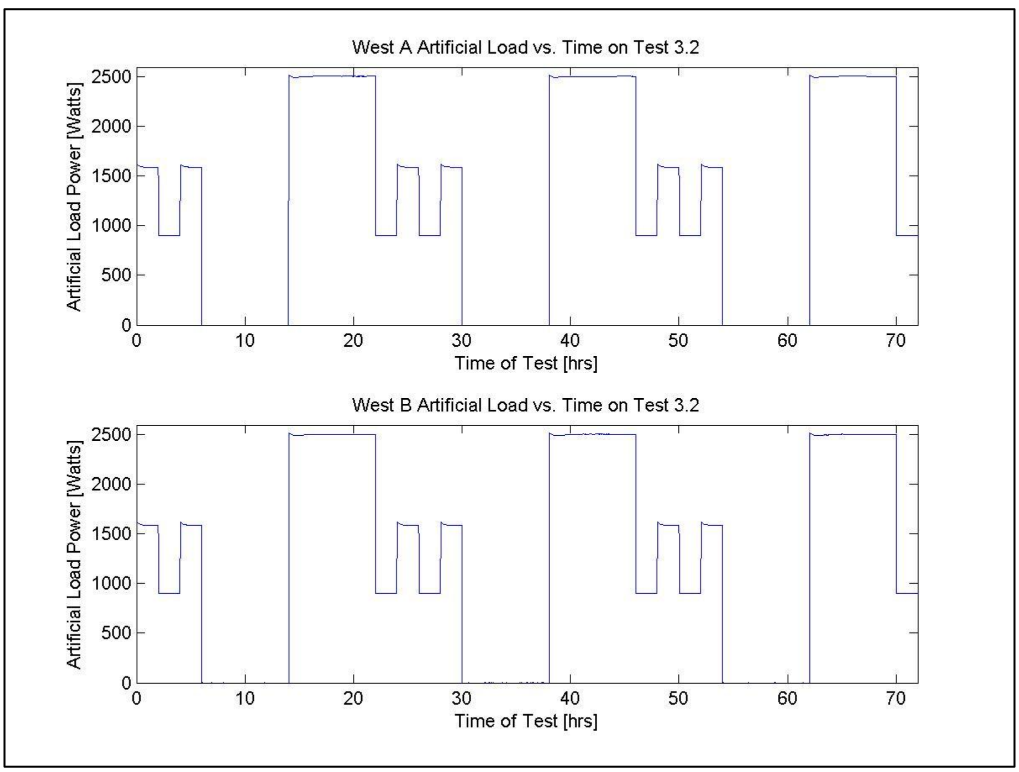
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.28464 | -0.01345 | -0.04488 | -0.11432 |
| | Internal | 0.032465 | -0.02865 | -0.06589 | -0.02069 |
| | South | 0.173785 | -0.18134 | -0.07066 | -0.02607 |
| | West | 0.094618 | 0.034462 | -25.0856 | -8.31884 |
| | mean | 0.004058 | -0.04724 | -6.31675 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.03802 | -0.06788 | 0.04401 | -0.02063 |
| | Internal | 0.011198 | 0.005295 | -0.00391 | 0.004196 |
| | South | 0.008247 | 0.014236 | 0.035764 | 0.019416 |
| | West | -0.04453 | 0.033941 | -0.07856 | -0.02972 |
| | mean | -0.01578 | -0.0036 | -0.00067 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 19.47751 | 27.95453 | 31.05659 | 26.16287 |
| | Internal | 12.34176 | 8.11015 | 4.983441 | 8.478451 |
| | South | 20.18303 | 19.33919 | 17.15171 | 18.89131 |
| | West | 20.40053 | 22.31916 | 5219.228 | 1753.982 |
| | mean | 18.10071 | 19.43076 | 1318.105 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.62E+01 | 2.05E+01 | 2.03E+01 | 19.02306 |
| | Internal | 3.162542 | 4.220231 | 3.51296 | 3.631911 |
| | South | 2.92E+01 | 3.46E+01 | 3.60E+01 | 33.26009 |
| | West | 16.0415 | 89.27666 | 48.15091 | 51.15636 |
| | mean | 16.15249 | 37.16929 | 26.98178 | |


East A Artificial Load vs. Time on Test 3.2
Artificial Load Power [Watts]
Time of Test [hrs]
East B Artificial Load vs. Time on Test 3.2
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 3.2
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 3.2
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 3.2
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 3.2
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 3.2
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 3.2
Artificial Load Power [Watts]
Time of Test [hrs]

**TEST 3.3**

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 54.00671753 |
| AHUB | 39.71534922 |
| % difference | 26.46% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 21.37976 | 18.34327 | 14.28369 | 18.00224 | 12.67578 |
| AHUB | 13.06779 | 13.25516 | 13.3924 | 13.23845 | 0.026552 |
| % difference | 38.88% | 27.74% | 6.24% | 26.46% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -1.151 |
| | variance | 2.699326 |
| AHUB | mean [$^oF$] | -1.15133 |
| | variance | 2.477233 |
| difference | | 0.000335 |

| Temperature Control [$^oF$ Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.21317 | -0.18163 | -0.17355 | -0.18945 |
| | Internal | -1.68252 | -1.61274 | -1.57959 | -1.62495 |
| | South | -1.36612 | -1.37184 | -1.30443 | -1.34746 |
| | West | -1.56445 | -1.55907 | -1.20289 | -1.44213 |
| | mean | -1.20656 | -1.18132 | -1.06511 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.51567 | -0.47958 | -0.40477 | -0.46667 |
| | Internal | -1.74982 | -1.62463 | -1.65426 | -1.67624 |
| | South | -1.13034 | -1.07134 | -1.05739 | -1.08636 |
| | West | -1.43355 | -1.33321 | -1.36144 | -1.37607 |
| | mean | -1.20735 | -1.12719 | -1.11946 | |

| Temperature Control [$^oF$ Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.241931 | 0.20905 | 0.210382 | 0.220454 |
| | Internal | 2.939737 | 3.063252 | 3.104153 | 3.035714 |
| | South | 2.53926 | 2.527929 | 2.568836 | 2.545341 |
| | West | 3.241117 | 3.252798 | 4.598654 | 3.697523 |
| | mean | 2.240511 | 2.263257 | 2.620506 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.468345 | 0.510068 | 0.387423 | 0.455278 |
| | Internal | 2.75E+00 | 3.11E+00 | 2.91E+00 | 2.923195 |
| | South | 2.28595 | 2.349708 | 2.173489 | 2.269716 |
| | West | 3.37E+00 | 3.604105 | 3.41E+00 | 3.459712 |
| | mean | 2.219167 | 2.392567 | 2.219192 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.314556 |
| | variance | 0.58982 |
| AHUB | mean | 1.502458 |
| | variance | 0.005329 |
| difference | | -0.1879 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 2.01975 | 1.427625 | 0.496292 | 1.314556 | 0.58982 |
| AHUB | 1.418167 | 1.544708 | 1.5445 | 1.502458 | 0.005329 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.001182 |
| | variance | 0.000799 |
| AHUB | mean | -0.21328 |
| | variance | 0.062185 |
| difference | | 0.214466 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.000726 | -3.33E-04 | 3.15E-03 | 0.001182 |
| | variance | 0.001128 | 0.000903 | 0.000362 | |
| AHUB | mean | -0.20994 | -0.21535 | -0.21456 | -0.21328 |
| | variance | 0.057018 | 0.070253 | 0.059353 | |

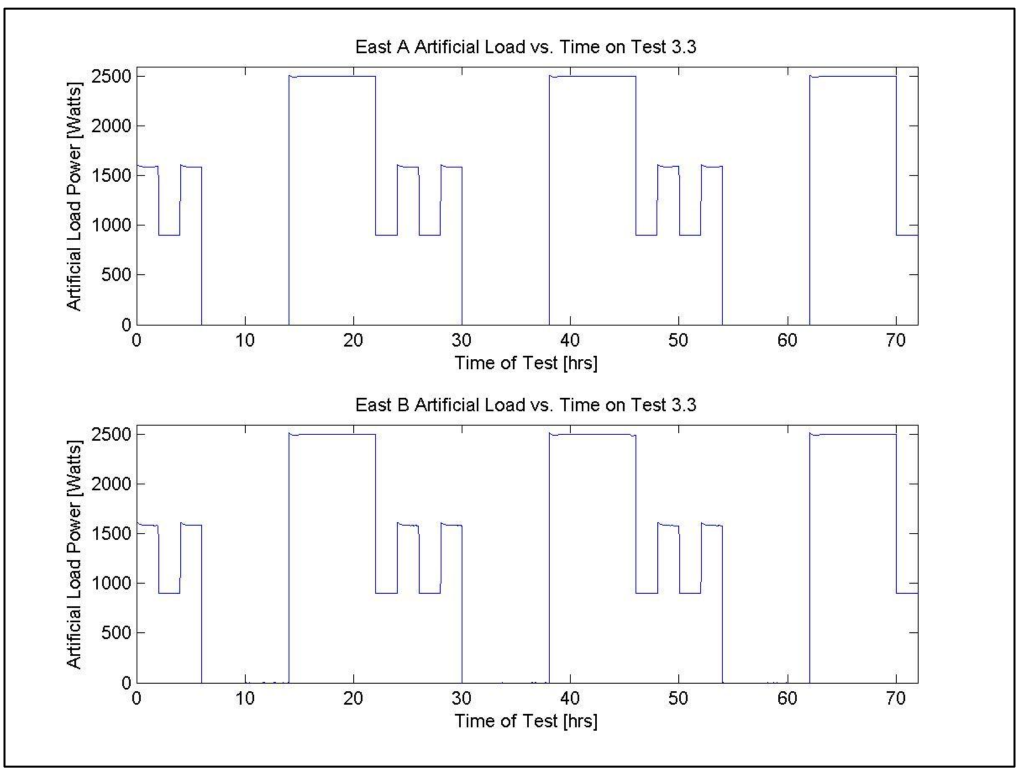
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 29.35234 |
| | variance | 36.21918 |
| AHUB | mean | 81.41971 |
| | variance | 178.5497 |
| difference | | -52.0674 |

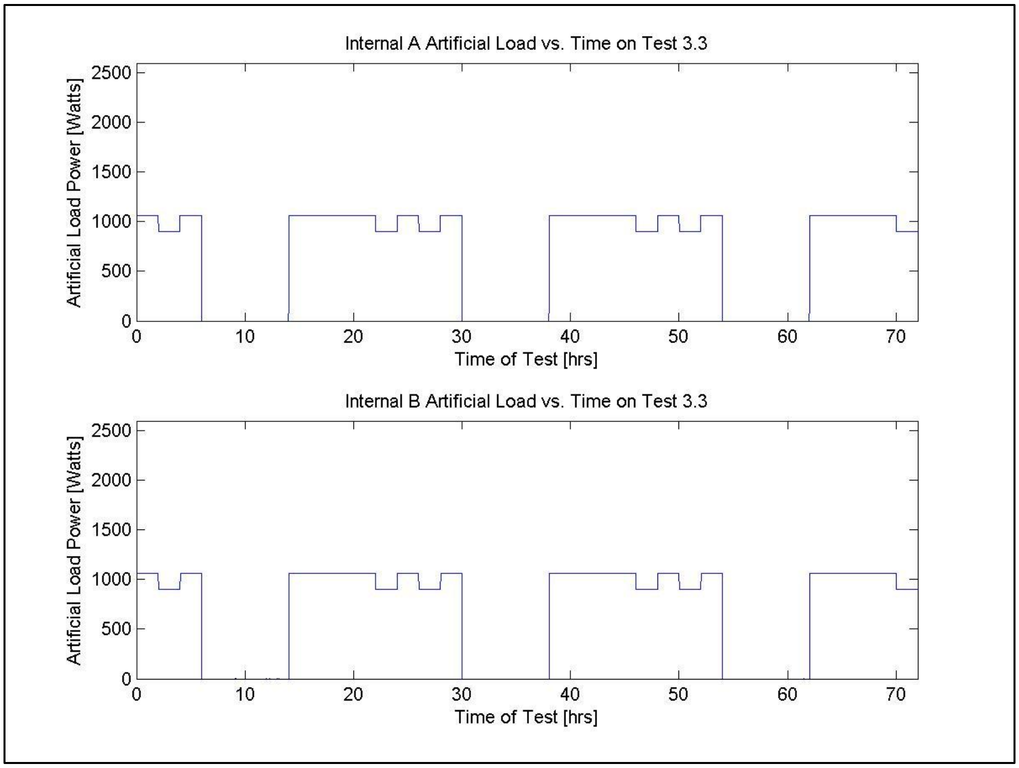
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 32.37254 | 36.02067 | 31.61117 | 33.33479 | 5.555366 |
| | Internal | 19.52267 | 30.85208 | 17.37954 | 22.58476 | 52.40967 |
| | South | 25.06958 | 31.76096 | 31.67521 | 29.50192 | 14.73602 |
| | West | 26.84438 | 32.63088 | 36.48838 | 31.98788 | 23.56177 |
| | mean | 25.95229 | 32.81615 | 29.28857 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 62.55892 | 68.32267 | 72.75167 | 67.87775 | 26.1215 |
| | Internal | 98.27483 | 92.91767 | 97.00404 | 96.06551 | 7.835434 |
| | South | 66.867 | 70.62625 | 76.80179 | 71.43168 | 25.16156 |
| | West | 90.95063 | 82.38246 | 97.57858 | 90.30389 | 58.04425 |
| | mean | 79.66284 | 78.56226 | 86.03402 | | |

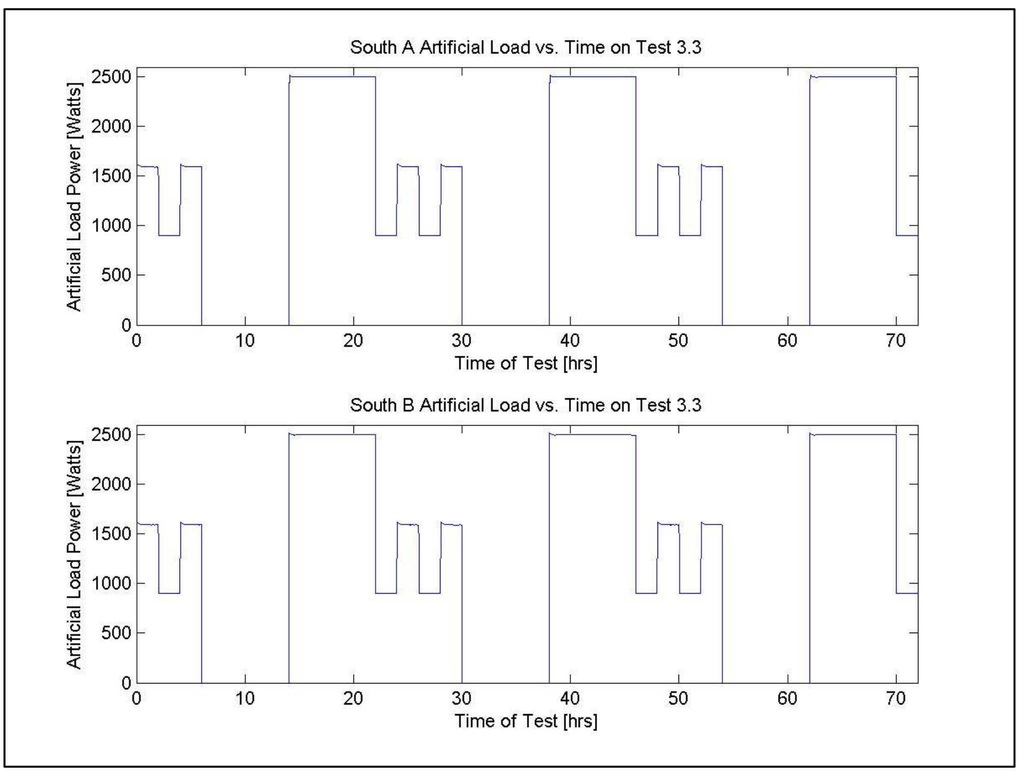
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -7.76748 |
| | variance | 2449.27 |
| AHUB | mean | -10.1012 |
| | variance | 4589.19 |
| difference | | 2.333715 |

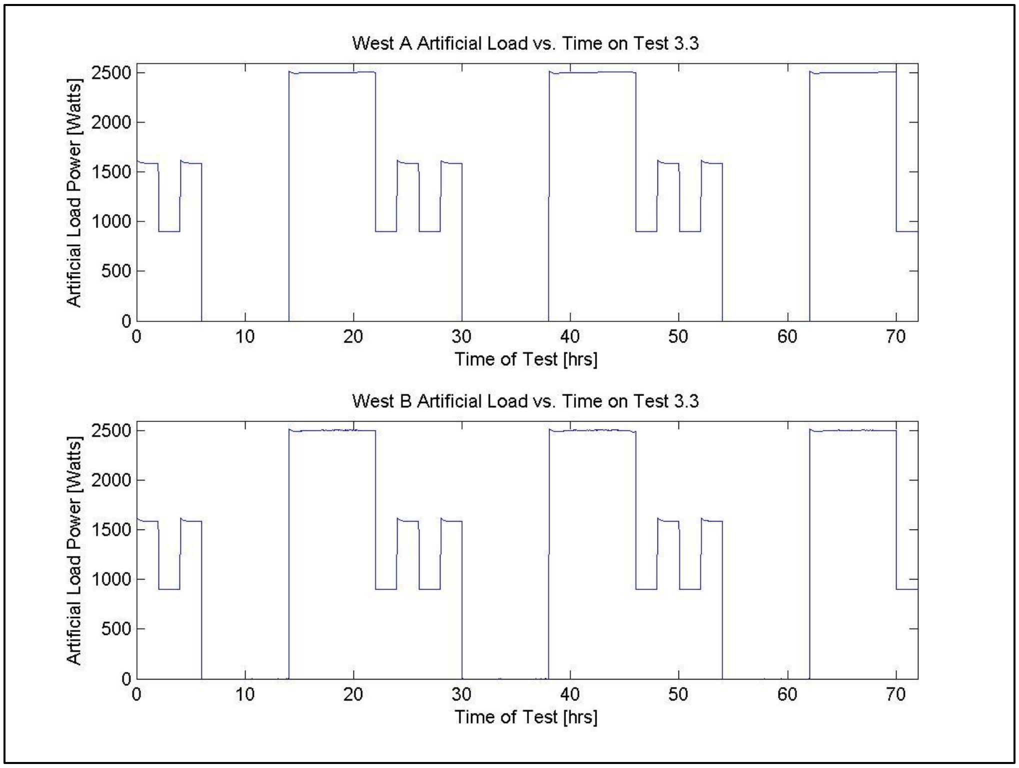
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.32543 | -0.24106 | -5.78924 | -2.11858 |
| | Internal | -0.02977 | -0.09696 | -0.06354 | -0.06343 |
| | South | 0.158333 | -0.18134 | -0.03837 | -0.02046 |
| | West | -0.04861 | -1.21233 | -85.3415 | -28.8675 |
| | mean | -0.06137 | -0.43292 | -22.8082 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.21545 | -16.2352 | -0.20556 | -5.55205 |
| | Internal | -2.39714 | -13.4685 | -7.24622 | -7.70396 |
| | South | -0.90234 | -31.7096 | -0.5513 | -11.0544 |
| | West | -1.16762 | -43.949 | -3.16641 | -16.0944 |
| | mean | -1.17064 | -26.3406 | -2.79237 | |

| | Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 23.3134 | 26.07896 | 506.5586 | 185.317 |
| | Internal | 4.671987 | 8.096188 | 6.383512 | 6.383896 |
| | South | 17.84331 | 19.72709 | 16.39768 | 17.98936 |
| | West | 21.33682 | 73.68297 | 22086.91 | 7393.975 |
| | mean | 16.79138 | 31.8963 | 5654.061 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.96E+02 | 5.59E+03 | 2.69E+02 | 2018.351 |
| | Internal | 562.2149 | 1851.635 | 879.2602 | 1097.703 |
| | South | 3.52E+02 | 1.71E+04 | 3.47E+02 | 5920.569 |
| | West | 544.5958 | 24323.16 | 897.7485 | 8588.502 |
| | mean | 413.7901 | 12206.71 | 598.3439 | |




Internal A Artificial Load vs. Time on Test 3.3
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 3.3
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]


South A Artificial Load vs. Time on Test 3.3
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]
South B Artificial Load vs. Time on Test 3.3
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]




## TEST 3.4

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 52.25118787 |
| AHUB | 43.00119755 |
| % difference | 17.70% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 21.05823 | 17.13417 | 14.05878 | 17.41706 | 12.30811 |
| AHUB | 14.13462 | 14.23076 | 14.63581 | 14.33373 | 0.07075 |
| % difference | 32.88% | 16.95% | -4.10% | 17.70% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.24793 |
| | variance | 2.687683 |
| AHUB | mean [$^{o}$F] | -1.23187 |
| | variance | 2.424431 |
| difference | | -0.01605 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.18836 | -0.87521 | -0.2124 | -0.42532 |
| | Internal | -1.62935 | -1.61545 | -1.60255 | -1.61578 |
| | South | -1.32646 | -1.39643 | -1.37052 | -1.36447 |
| | West | -1.53044 | -1.59915 | -1.6288 | -1.58613 |
| | mean | -1.16865 | -1.37156 | -1.20357 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.43359 | -1.17354 | -0.51434 | -0.70716 |
| | Internal | -1.74587 | -1.76177 | -1.77387 | -1.76051 |
| | South | -0.9643 | -1.11804 | -1.10113 | -1.06116 |
| | West | -1.3382 | -1.40638 | -1.45143 | -1.39867 |
| | mean | -1.12049 | -1.36493 | -1.21019 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.222264 | 1.690015 | 0.217709 | 0.709996 |
| | Internal | 3.037289 | 3.042231 | 3.074312 | 3.051277 |
| | South | 2.565679 | 2.826755 | 2.654804 | 2.682413 |
| | West | 3.194486 | 3.185804 | 3.427506 | 3.269265 |
| | mean | 2.25493 | 2.686201 | 2.343583 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.343956 | 1.940576 | 0.432732 | 0.905755 |
| | Internal | 2.79E+00 | 2.75E+00 | 2.70E+00 | 2.747989 |
| | South | 1.753756 | 2.282923 | 2.233002 | 2.089894 |
| | West | 3.10E+00 | 3.262335 | 3.34E+00 | 3.231134 |
| | mean | 1.996834 | 2.558063 | 2.176182 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.186167 |
| | variance | 0.556997 |
| AHUB | mean | 0.714972 |
| | variance | 0.00051 |
| difference | | 0.471194 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.9875 | 1.060083 | 0.510917 | 1.186167 | 0.556997 |
| AHUB | 0.689375 | 0.7235 | 0.732042 | 0.714972 | 0.00051 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.001624 |
| | variance | 0.000731 |
| AHUB | mean | 0.000263 |
| | variance | 0.000265 |
| difference | | 0.001361 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00097 | 2.92E-03 | 2.92E-03 | 0.001624 |
| | variance | 0.001138 | 0.000655 | 0.00039 | |
| AHUB | mean | 0.000269 | 0.000577 | -5.69E-05 | 0.000263 |
| | variance | 0.000242 | 0.00026 | 0.000292 | |

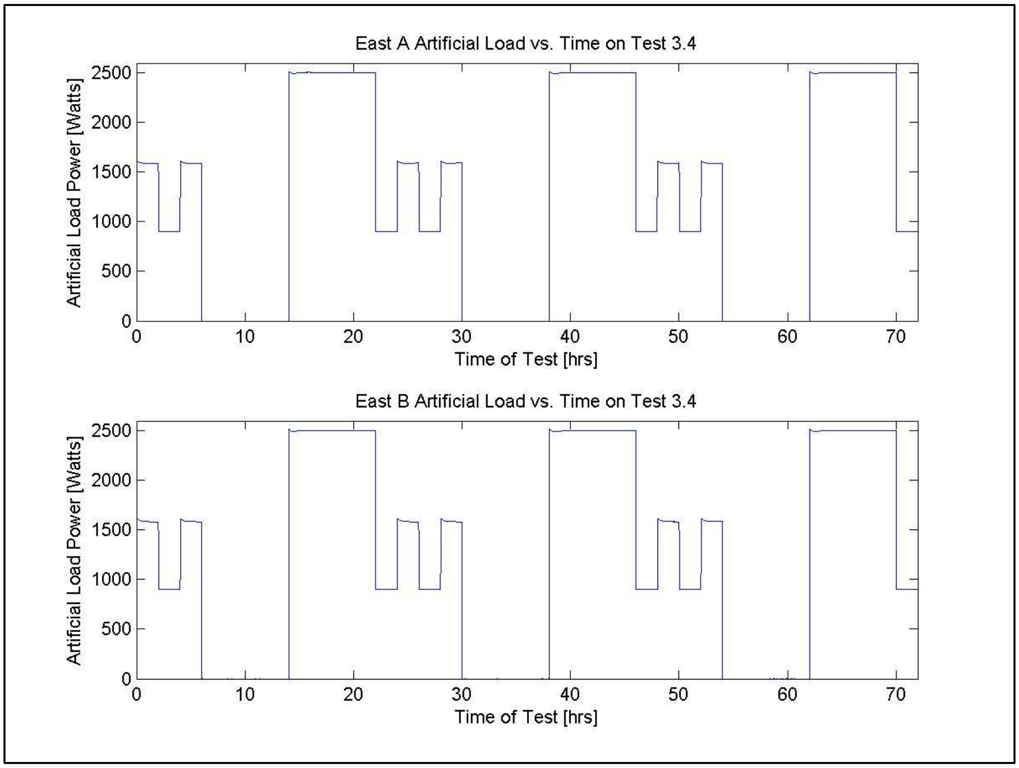
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 30.80696 |
| | variance | 68.74676 |
| AHUB | mean | 31.45037 |
| | variance | 153.7411 |
| difference | | -0.64341 |

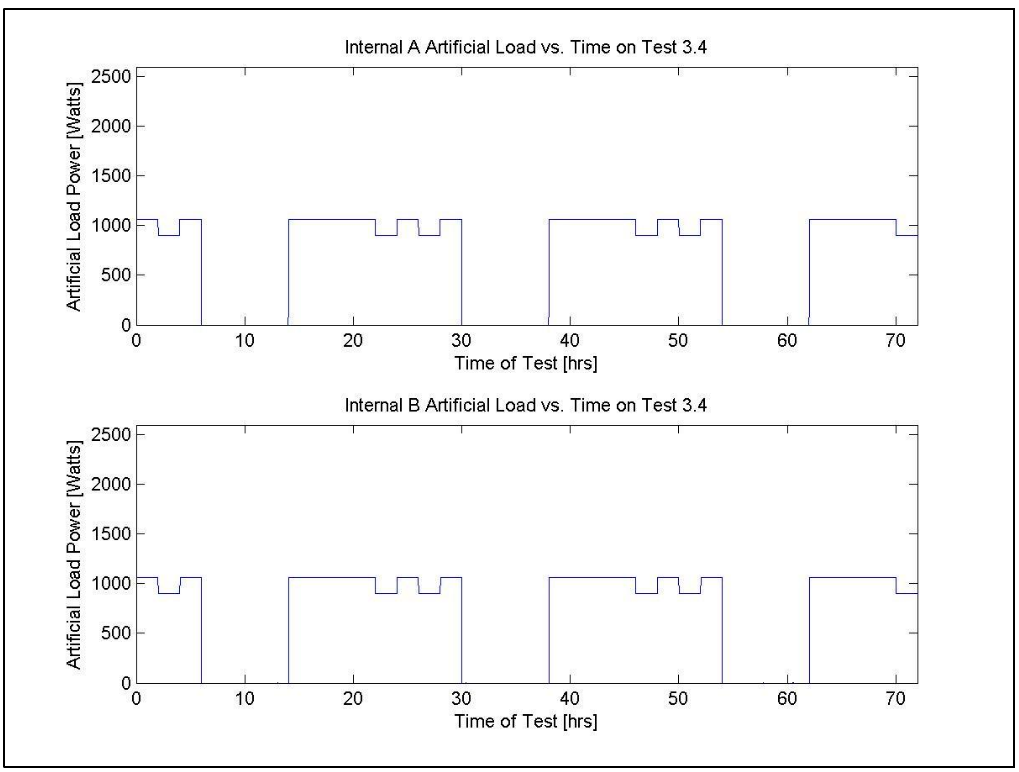
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 32.41796 | 38.56704 | 34.16738 | 35.05079 | 10.03813 |
| | Internal | 43.42233 | 16.67129 | 15.86329 | 25.31897 | 245.962 |
| | South | 33.78542 | 26.49088 | 31.58058 | 30.61896 | 13.99613 |
| | West | 38.15325 | 31.84258 | 26.7215 | 32.23911 | 32.78915 |
| | mean | 36.94474 | 28.39295 | 27.08319 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 34.91246 | 41.99108 | 39.26604 | 38.72319 | 12.74775 |
| | Internal | 10.99375 | 11.4755 | 11.10729 | 11.19218 | 0.063425 |
| | South | 37.37875 | 39.53429 | 38.27696 | 38.39667 | 1.172338 |
| | West | 40.26667 | 38.04854 | 34.15308 | 37.48943 | 9.578429 |
| | mean | 30.88791 | 32.76235 | 30.70084 | | |

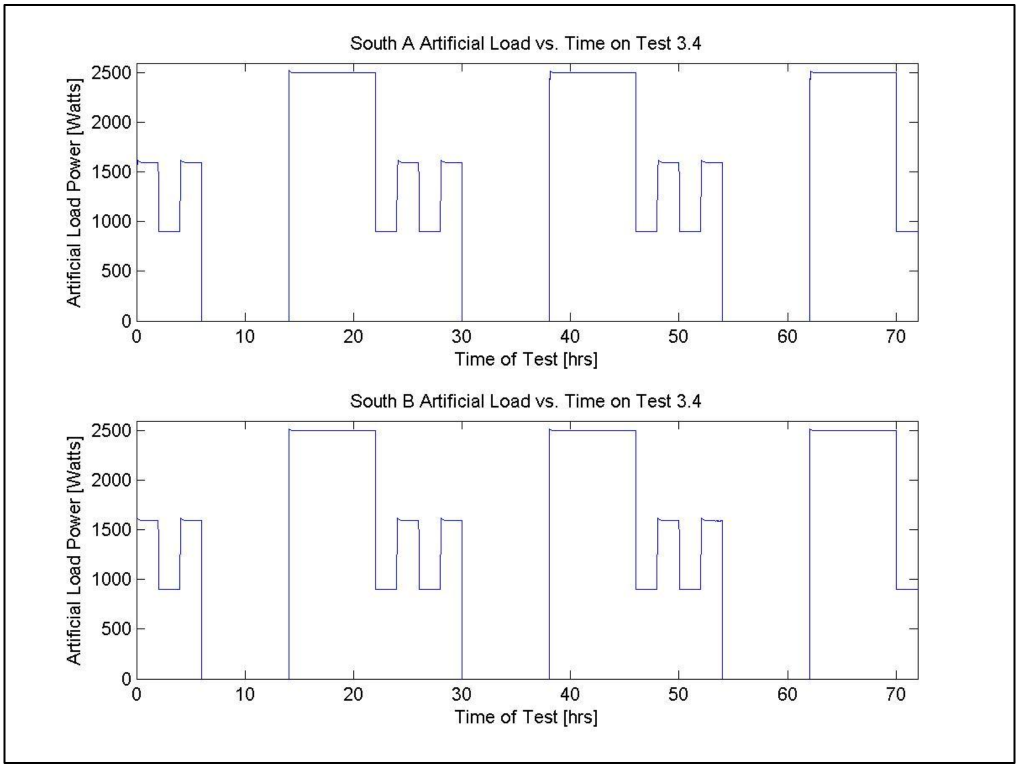
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -5.22313 |
| | variance | 1575.419 |
| AHUB | mean | 0.717975 |
| | variance | 851.9381 |
| difference | | -5.94111 |

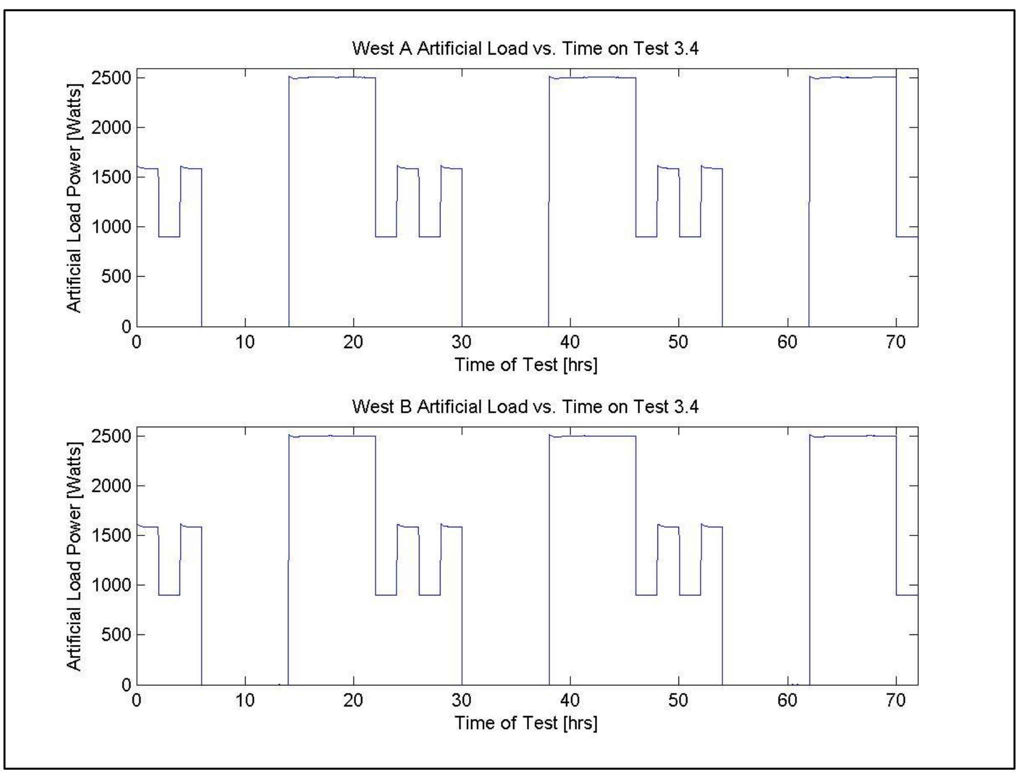
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.189497 | -0.01901 | -2.54167 | -0.79039 |
| | Internal | -0.01953 | -0.02352 | -0.05885 | -0.03397 |
| | South | -0.15521 | -0.01311 | -0.04887 | -0.0724 |
| | West | 0.193229 | -0.07465 | -60.1059 | -19.9958 |
| | mean | 0.051997 | -0.03257 | -15.6888 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.067708 | 0.002257 | 0.025 | 0.031655 |
| | Internal | -0.01215 | 0.017969 | 8.340705 | 2.782174 |
| | South | 0.005556 | -0.00443 | -0.00521 | -0.00136 |
| | West | 0.038976 | 0.112153 | 0.02717 | 0.059433 |
| | mean | 0.025022 | 0.031988 | 2.096917 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 23.03985 | 23.88038 | 155.6468 | 67.52234 |
| | Internal | 11.55429 | 4.997959 | 5.878114 | 7.476787 |
| | South | 19.56007 | 20.89658 | 14.73733 | 18.39799 |
| | West | 20.92544 | 20.16138 | 15301.59 | 5114.224 |
| | mean | 18.76991 | 17.48407 | 3869.462 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.95E+01 | 1.92E+01 | 2.40E+01 | 20.91058 |
| | Internal | 2.705355 | 3.033305 | 9932.951 | 3312.897 |
| | South | 2.66E+01 | 2.65E+01 | 2.45E+01 | 25.87179 |
| | West | 27.40563 | 33.90702 | 25.97399 | 29.09555 |
| | mean | 19.05222 | 20.67293 | 2501.856 | |


East A Artificial Load vs. Time on Test 3.4
Artificial Load Power [Watts]
Time of Test [hrs]
East B Artificial Load vs. Time on Test 3.4
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 3.4
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 3.4
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 3.4
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 3.4
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 3.4
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 3.4
Artificial Load Power [Watts]
Time of Test [hrs]

# APPENDIX D: TEST SERIES 4 TABLES AND GRAPHS

## TEST 4.1a

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 56.34772258 |
| AHUB | 53.21972252 |
| % difference | 5.55% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 19.75555 | 18.05292 | 18.53925 | 18.78257 | 0.769138 |
| AHUB | 18.15891 | 17.47309 | 17.58772 | 17.73991 | 0.134961 |
| % difference | 8.08% | 3.21% | 5.13% | 5.55% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -0.97268 |
| | variance | 3.115125 |
| AHUB | mean [$^{o}$F] | -0.9624 |
| | variance | 2.654684 |
| difference | | -0.01027 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.59163 | -0.423 | -0.19753 | -0.40405 |
| | Internal | -0.88158 | -0.86481 | -0.91562 | -0.88734 |
| | South | -1.18881 | -1.18479 | -1.27373 | -1.21578 |
| | West | -1.34692 | -1.37529 | -1.42844 | -1.38355 |
| | mean | -1.00224 | -0.96197 | -0.95383 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.73559 | -0.57832 | -0.21015 | -0.50802 |
| | Internal | -1.1049 | -1.09652 | -1.11805 | -1.10649 |
| | South | -0.93921 | -0.95891 | -1.0521 | -0.98341 |
| | West | -1.24231 | -1.20878 | -1.30402 | -1.2517 |
| | mean | -1.0055 | -0.96063 | -0.92108 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 1.332003 | 1.272833 | 0.379562 | 0.994799 |
| | Internal | 4.585736 | 4.743012 | 4.564125 | 4.630958 |
| | South | 2.811289 | 2.714358 | 2.826636 | 2.784094 |
| | West | 3.552111 | 3.400816 | 3.458002 | 3.47031 |
| | mean | 3.070285 | 3.032755 | 2.807081 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.432944 | 1.136685 | 0.183668 | 0.917766 |
| | Internal | 4.12E+00 | 4.22E+00 | 4.06E+00 | 4.13266 |
| | South | 1.989927 | 1.919344 | 2.082412 | 1.997227 |
| | West | 3.25E+00 | 3.071199 | 3.32E+00 | 3.213687 |
| | mean | 2.698205 | 2.586744 | 2.411055 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.909069 |
| | variance | 0.000309 |
| AHUB | mean | 0.9875 |
| | variance | 4.9E-06 |
| difference | | -0.07843 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 0.909625 | 0.926375 | 0.891208 | 0.909069 | 0.000309 |
| AHUB | 0.987333 | 0.985375 | 0.989792 | 0.9875 | 4.9E-06 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.000229 |
| | variance | 0.000958 |
| AHUB | mean | -0.00132 |
| | variance | 0.000746 |
| difference | | 0.001546 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.000133 | -2.39E-04 | 7.93E-04 | 0.000229 |
| | variance | 0.000726 | 0.000628 | 0.00152 | |
| AHUB | mean | -0.00124 | -0.00095 | -1.76E-03 | -0.00132 |
| | variance | 0.000524 | 0.000464 | 0.001251 | |

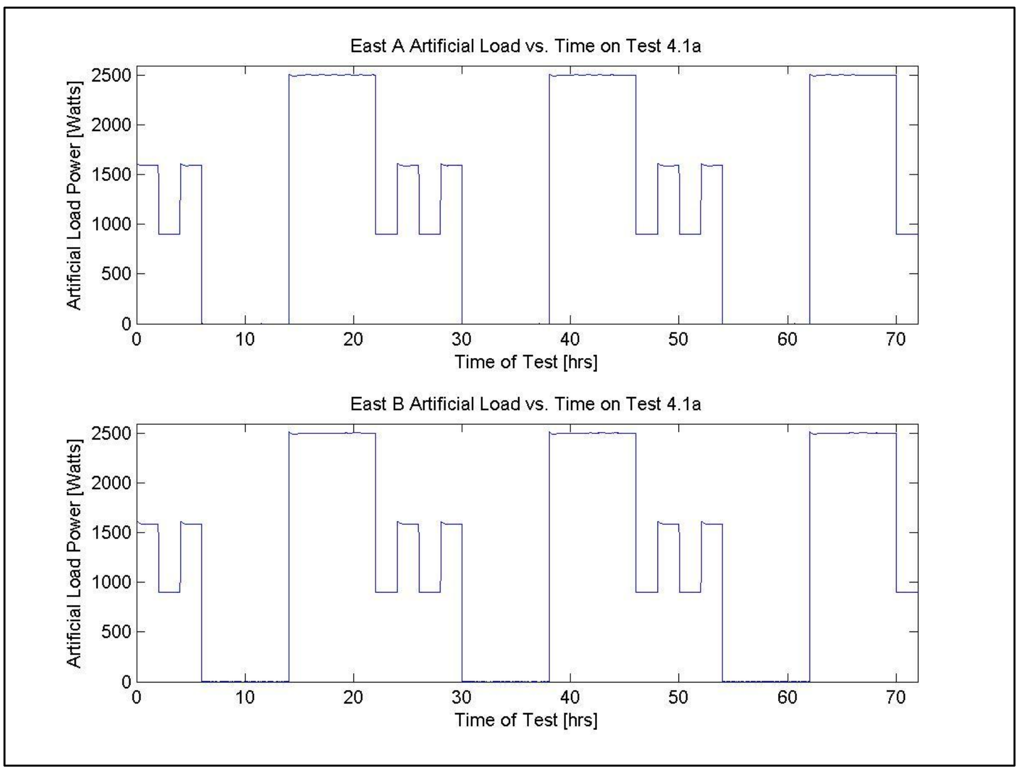
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 39.93172 |
| | variance | 21.93456 |
| AHUB | mean | 40.5007 |
| | variance | 25.42171 |
| difference | | -0.56898 |

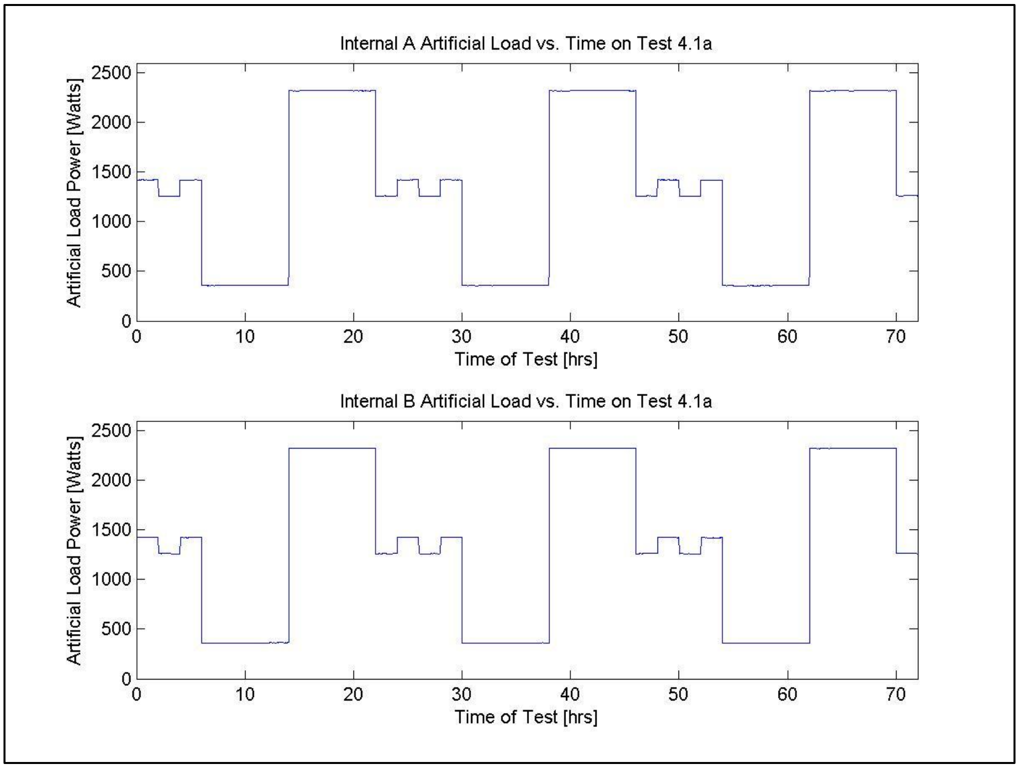
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 39.51879 | 44.38413 | 45.97683 | 43.29325 | 11.31908 |
| | Internal | 34.97879 | 35.46854 | 33.90992 | 34.78575 | 0.635277 |
| | South | 38.05525 | 38.54583 | 40.22383 | 38.94164 | 1.293185 |
| | West | 45.67329 | 35.64588 | 46.79958 | 42.70625 | 37.7038 |
| | mean | 39.55653 | 38.51109 | 41.72754 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 43.75683 | 41.83738 | 41.01633 | 42.20351 | 1.978128 |
| | Internal | 32.51208 | 32.72846 | 32.51921 | 32.58658 | 0.015109 |
| | South | 43.53729 | 47.23654 | 41.84583 | 44.20656 | 7.60087 |
| | West | 43.25213 | 41.51763 | 44.24871 | 43.00615 | 1.910081 |
| | mean | 40.76458 | 40.83 | 39.90752 | | |

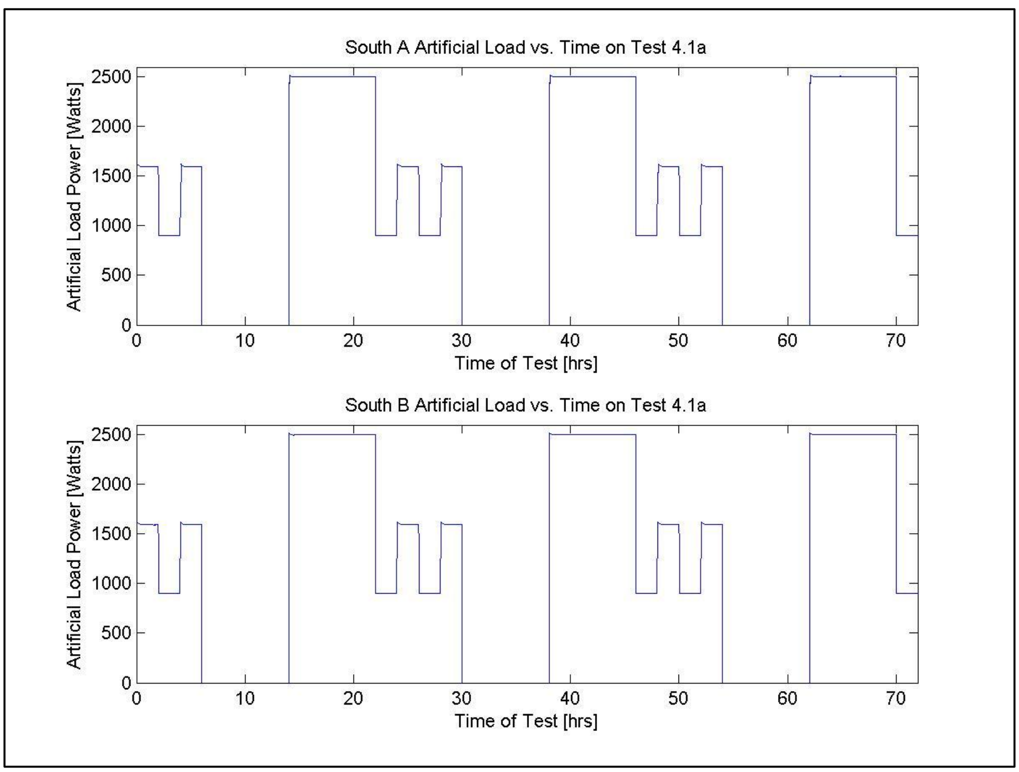
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -13.2475 |
| | variance | 2734.49 |
| AHUB | mean | -5.92564 |
| | variance | 889.9999 |
| difference | | -7.3219 |

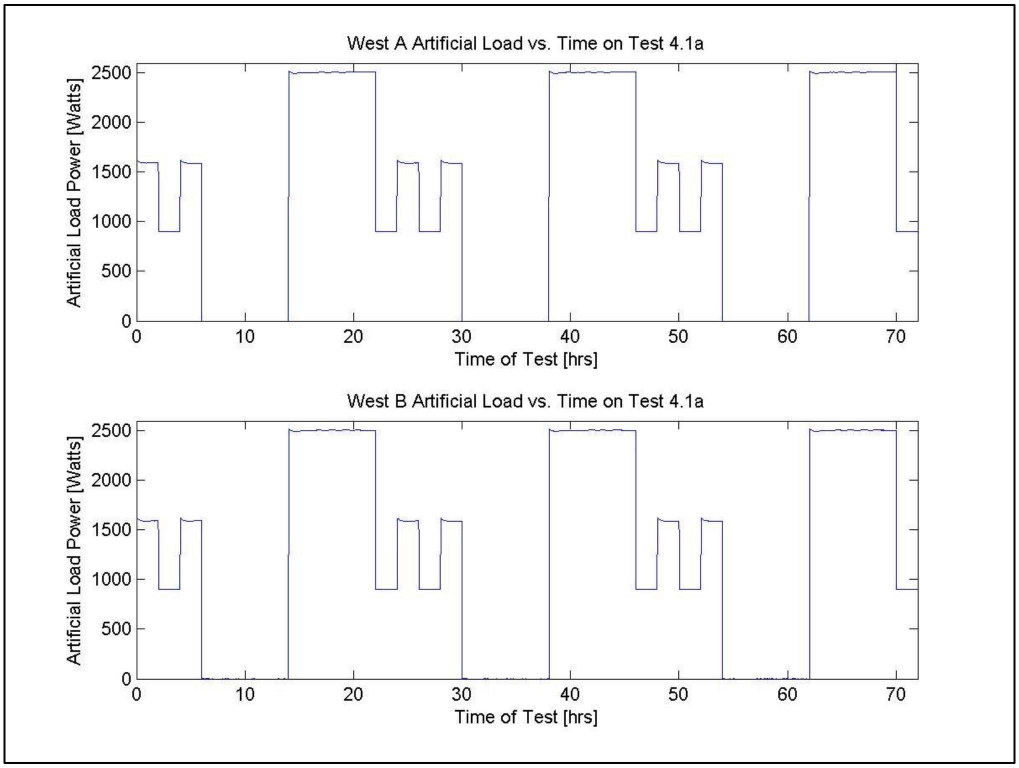
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -19.0931 | -31.8579 | -15.3075 | -22.0861 |
| | Internal | -10.5212 | -12.3261 | -10.7319 | -11.1931 |
| | South | 0.031684 | 0.073177 | -0.14809 | -0.01441 |
| | West | -22.0691 | -16.676 | -20.3444 | -19.6965 |
| | mean | -12.9129 | -15.1967 | -11.633 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.096094 | -0.01684 | -0.19149 | -0.03741 |
| | Internal | -10.0003 | -10.6592 | -9.52786 | -10.0624 |
| | South | 0.042708 | 0.056076 | 0.049913 | 0.049566 |
| | West | -15.377 | -8.84132 | -16.7385 | -13.6523 |
| | mean | -6.30961 | -4.86532 | -6.60197 | |

| | | | | | |
|---|---|---|---|---|---|
| Flow Rate Control [CFM Variance] | | | | | |
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 3743.272 | 8566.534 | 3358.666 | 5222.824 |
| | Internal | 1004.008 | 1101.375 | 1040.002 | 1048.461 |
| | South | 43.27463 | 36.69384 | 41.69491 | 40.55446 |
| | West | 5051.421 | 3155.032 | 4627.392 | 4277.948 |
| | mean | 2460.494 | 3214.909 | 2266.939 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 3.92E+01 | 4.18E+01 | 4.25E+01 | 41.16318 |
| | Internal | 869.9885 | 925.7432 | 859.9827 | 885.2382 |
| | South | 4.95E+01 | 6.74E+01 | 4.95E+01 | 55.49104 |
| | West | 2768.934 | 1363.645 | 3130.318 | 2420.966 |
| | mean | 931.9062 | 599.6553 | 1020.582 | |




Internal A Artificial Load vs. Time on Test 4.1a
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.1a
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.1a
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.1a
Artificial Load Power [Watts]
Time of Test [hrs]




# TEST 4.1b

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 51.39672352 |
| AHUB | 48.31388003 |
| % difference | 6.00% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 17.4311 | 16.97613 | 16.9895 | 17.13224 | 0.067032 |
| AHUB | 16.27643 | 16.13734 | 15.90012 | 16.10463 | 0.036204 |
| % difference | 6.62% | 4.94% | 6.41% | 6.00% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.1066 |
| | variance | 202.5038 |
| AHUB | mean [$^{o}$F] | -1.07594 |
| | variance | 202.2545 |
| difference | | -0.03067 |

| Temperature Control [$^{o}$F Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -0.23528 | -0.97153 | -0.11976 | -0.44219 |
| | Internal | -0.63976 | -1.38394 | -0.97491 | -0.99954 |
| | South | -1.35808 | -2.09733 | -1.31681 | -1.59074 |
| | West | -1.40337 | -1.41662 | -1.36184 | -1.39395 |
| | mean | -0.90912 | -1.46736 | -0.94333 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.2996 | -1.02535 | -0.27329 | -0.53274 |
| | Internal | -0.81606 | -1.62526 | -1.17003 | -1.20379 |
| | South | -1.20345 | -1.79613 | -0.99576 | -1.33178 |
| | West | -1.26994 | -1.21801 | -1.21837 | -1.23544 |
| | mean | -0.89726 | -1.41619 | -0.91436 | |

| Temperature Control [$^{o}$F Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.433286 | 798.1092 | 0.466688 | 266.3364 |
| | Internal | 5.544835 | 802.4705 | 4.772342 | 270.9292 |
| | South | 2.804134 | 798.9868 | 2.985921 | 268.259 |
| | West | 3.812947 | 3.775985 | 4.026692 | 3.871875 |
| | mean | 3.148801 | 600.8356 | 3.062911 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.28715 | 797.9039 | 0.274598 | 266.1552 |
| | Internal | 5.01E+00 | 8.02E+02 | 4.26E+00 | 270.3789 |
| | South | 2.652628 | 799.1158 | 2.715222 | 268.1612 |
| | West | 4.03E+00 | 4.170052 | 4.06E+00 | 4.088553 |
| | mean | 2.99479 | 600.765 | 2.828085 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.43975 |
| | variance | 0.004797 |
| AHUB | mean | 1.464722 |
| | variance | 0.010685 |
| difference | | -0.02497 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 1.478167 | 1.481292 | 1.359792 | 1.43975 | 0.004797 |
| AHUB | 1.460083 | 1.570333 | 1.36375 | 1.464722 | 0.010685 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.0009 |
| | variance | 0.002665 |
| AHUB | mean | -0.00094 |
| | variance | 0.002278 |
| difference | | 4.44E-05 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00023 | -1.52E-03 | -9.48E-04 | -0.0009 |
| | variance | 0.002853 | 0.002331 | 0.002813 | |
| AHUB | mean | -0.00108 | -0.0007 | -1.05E-03 | -0.00094 |
| | variance | 0.002442 | 0.002357 | 0.002038 | |

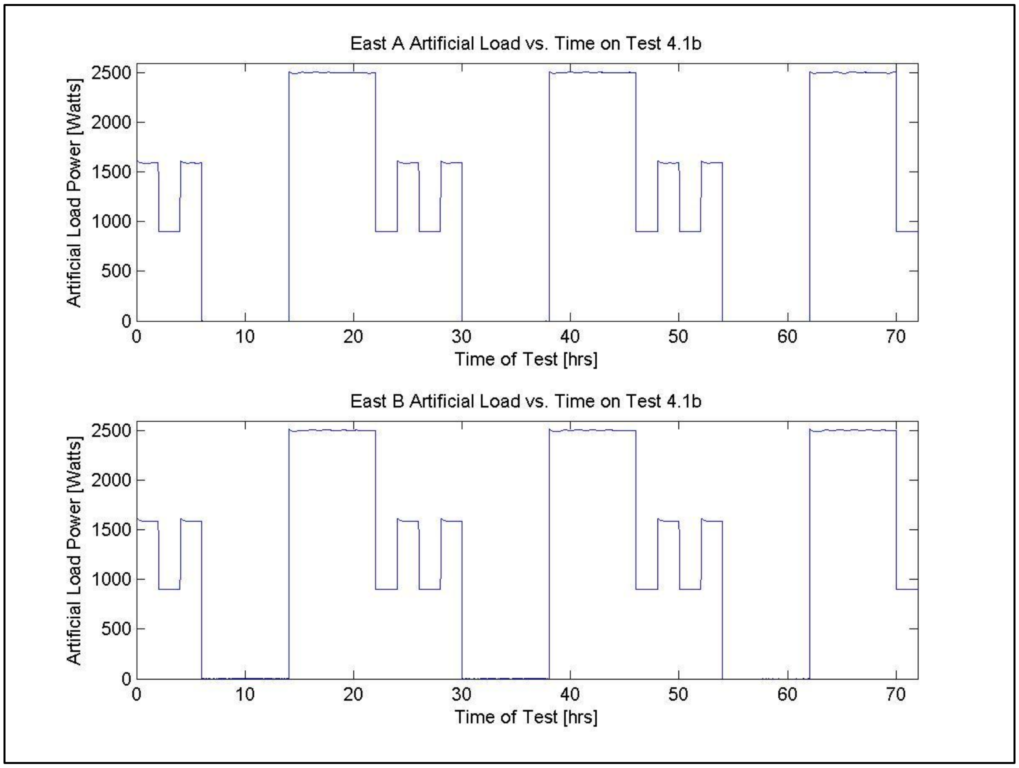
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 89.99852 |
| | variance | 2003.322 |
| AHUB | mean | 87.74868 |
| | variance | 2198.443 |
| difference | | 2.249844 |

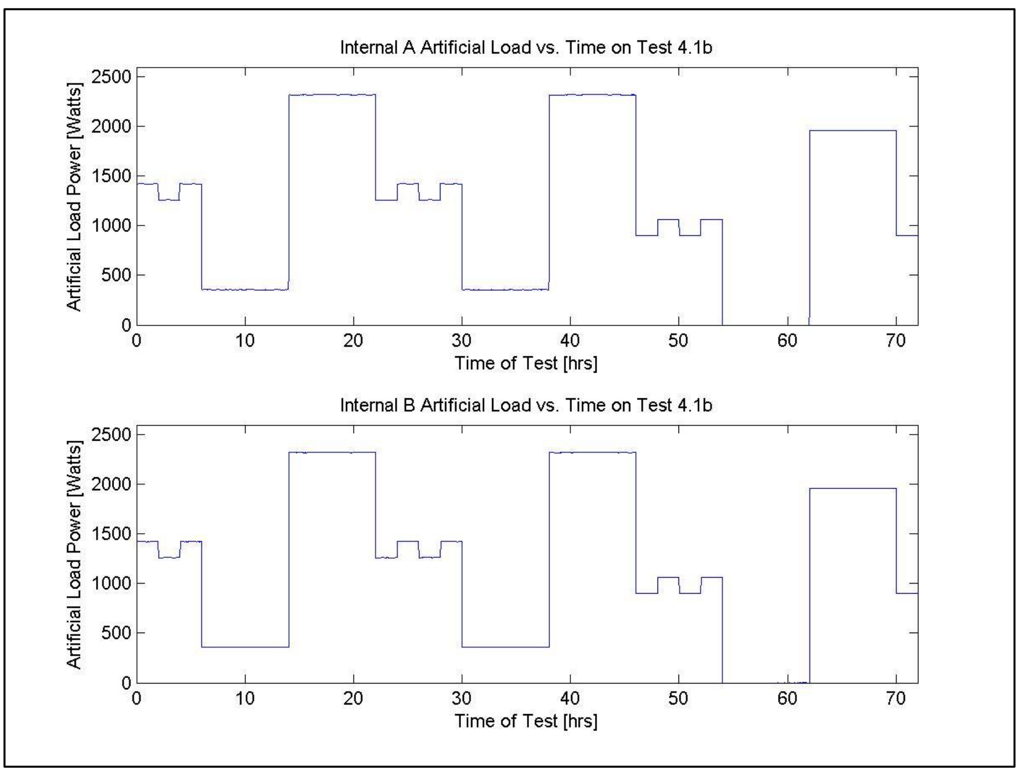
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 59.61092 | 156.9106 | 67.71146 | 94.74433 | 2914.891 |
| | Internal | 74.35392 | 161.7648 | 80.34087 | 105.4865 | 2384.396 |
| | South | 50.12929 | 140.5679 | 56.14563 | 82.28093 | 2557.075 |
| | West | 46.54463 | 134.4978 | 51.40446 | 77.48229 | 2443.98 |
| | mean | 57.65969 | 148.4353 | 63.9006 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 50.1685 | 142.1885 | 50.10992 | 80.82231 | 2824.358 |
| | Internal | 72.87425 | 166.0988 | 76.91642 | 105.2965 | 2776.775 |
| | South | 53.20113 | 150.1995 | 60.79796 | 88.06621 | 2909.841 |
| | West | 46.32825 | 138.6351 | 45.46583 | 76.80972 | 2866.967 |
| | mean | 55.64303 | 149.2805 | 58.32253 | | |

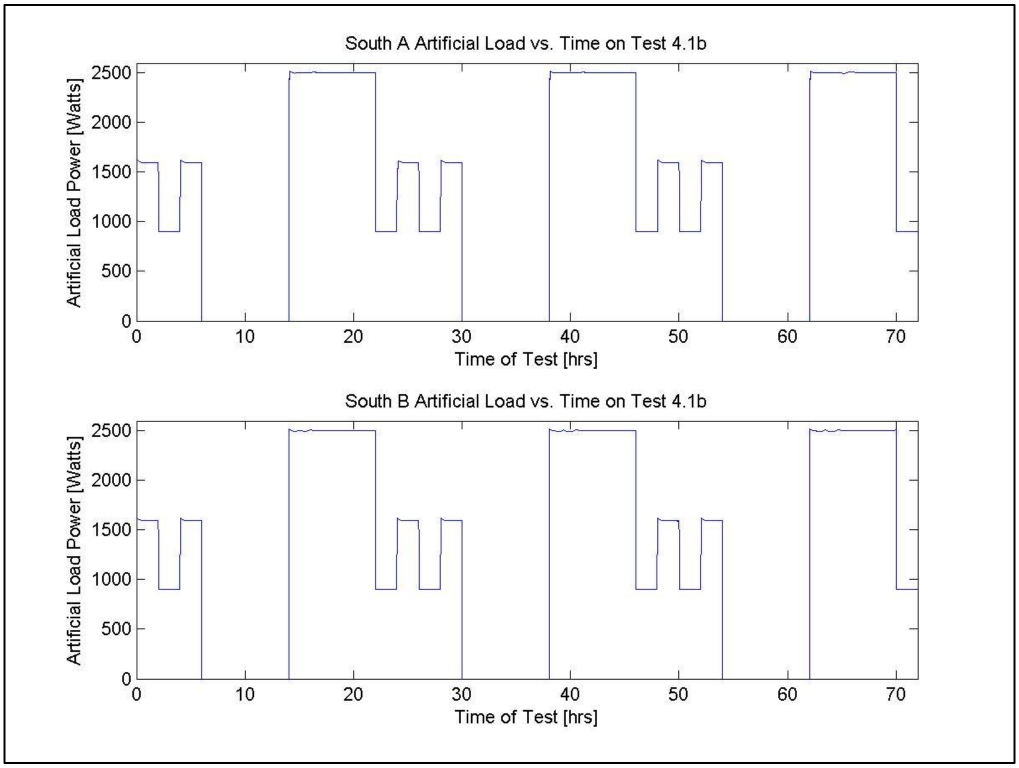
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -33.4244 |
| | variance | 8485.344 |
| AHUB | mean | -29.8458 |
| | variance | 8379.542 |
| difference | | -3.5786 |

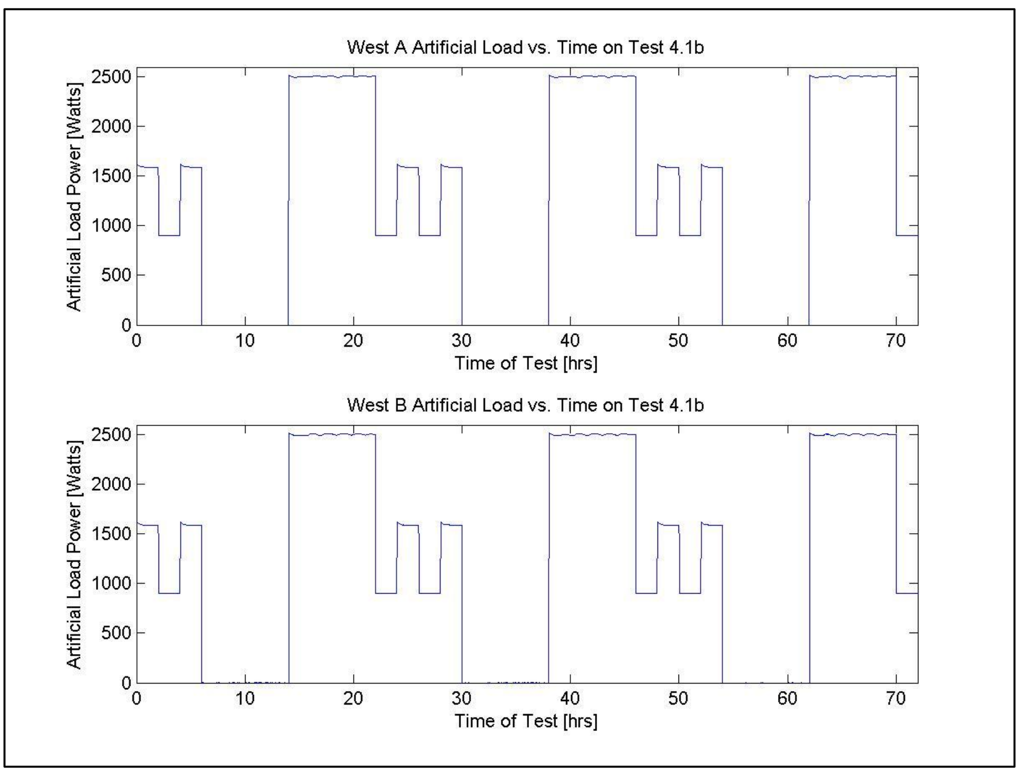
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -32.9665 | -31.9953 | -45.5311 | -36.831 |
| | Internal | -52.1966 | -54.5765 | -45.752 | -50.8417 |
| | South | -1.89948 | -1.17309 | -5.82517 | -2.96591 |
| | West | -46.0259 | -41.2778 | -41.8731 | -43.0589 |
| | mean | -33.2721 | -32.2557 | -34.7453 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -5.69236 | -6.86137 | -7.14922 | -6.56765 |
| | Internal | -45.62 | -47.8917 | -34.4743 | -42.662 |
| | South | -13.4344 | -22.6951 | -23.8511 | -19.9935 |
| | West | -48.0765 | -51.7481 | -50.6552 | -50.1599 |
| | mean | -28.2058 | -32.299 | -29.0325 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 7849.482 | 8028.164 | 14757.86 | 10211.83 |
| | Internal | 5847.792 | 7260.885 | 4968.136 | 6025.604 |
| | South | 411.3045 | 1642.893 | 1569.376 | 1207.858 |
| | West | 14685.52 | 15119.11 | 15557.42 | 15120.69 |
| | mean | 7198.526 | 8012.763 | 9213.198 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.51E+03 | 2.70E+03 | 1.50E+03 | 1900.768 |
| | Internal | 4678.947 | 6101.382 | 3716.1 | 4832.143 |
| | South | 3.54E+03 | 9.38E+03 | 9.10E+03 | 7341.129 |
| | West | 16897.17 | 19934.3 | 17738.1 | 18189.86 |
| | mean | 6656.023 | 9530.319 | 8011.582 | |


East A Artificial Load vs. Time on Test 4.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
East B Artificial Load vs. Time on Test 4.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 4.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
Time of Test [hrs]
0
10
20
30
40
50
60
70
South B Artificial Load vs. Time on Test 4.1b
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 4.1b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
Time of Test [hrs]
0
10
20
30
40
50
60
70
West B Artificial Load vs. Time on Test 4.1b
Artificial Load Power [Watts]
Time of Test [hrs]

# TEST 4.1c

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-2 |
| AHUA | 31.01263 |
| AHUB | 30.9361475 |
| % difference | 0.25% |

| Fan Power Consumed [kW-hr] | | | | |
|---|---|---|---|---|
| | 1 | 2 | mean | variance |
| AHUA | 15.57445 | 15.43818 | 15.50631 | 0.009284 |
| AHUB | 15.56419 | 15.37196 | 15.46807 | 0.018477 |
| % difference | 0.07% | 0.43% | 0.25% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.36387 |
| | variance | 3.340368 |
| AHUB | mean [$^{o}$F] | -1.36993 |
| | variance | 3.231102 |
| difference | | 0.006063 |

| Temperature Control [$^{o}$F Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -1.21375 | -1.32414 | -1.26895 |
| | Internal | -1.31111 | -1.33866 | -1.32488 |
| | South | -1.35822 | -1.39516 | -1.37669 |
| | West | -1.4381 | -1.53179 | -1.48495 |
| | mean | -1.33029 | -1.39744 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -1.33135 | -1.41232 | -1.37184 |
| | Internal | -1.46173 | -1.48154 | -1.47164 |
| | South | -1.23082 | -1.33995 | -1.28539 |
| | West | -1.32771 | -1.374 | -1.35085 |
| | mean | -1.3379 | -1.40195 | |

| Temperature Control [$^{o}$F Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 2.915824 | 3.184161 | 3.049993 |
| | Internal | 3.781909 | 3.661397 | 3.721653 |
| | South | 3.336152 | 3.243533 | 3.289842 |
| | West | 3.330652 | 3.22327 | 3.276961 |
| | mean | 3.341134 | 3.32809 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 3.207228 | 3.210826 | 3.209027 |
| | Internal | 3.35E+00 | 3.33E+00 | 3.338058 |
| | South | 2.935326 | 3.15035 | 3.042838 |
| | West | 3.32E+00 | 3.322274 | 3.319217 |
| | mean | 3.202081 | 3.252488 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.976521 |
| | variance | 0.000384 |
| AHUB | mean | 1.032438 |
| | variance | 0.001524 |
| difference | | -0.05592 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | |
|---|---|---|---|---|
| Day | 1 | 2 | mean | variance |
| AHUA | 0.962667 | 0.990375 | 0.976521 | 0.000384 |
| AHUB | 1.004833 | 1.060042 | 1.032438 | 0.001524 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 4.48E-05 |
| | variance | 0.00103 |
| AHUB | mean | -0.00064 |
| | variance | 0.000758 |
| difference | | 0.000682 |

| Static Pressure Control [inches w.g.] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | mean | 0.000216 | -1.26E-04 | 4.48E-05 |
| | variance | 0.001098 | 0.000962 | |
| AHUB | mean | -0.00071 | -0.00057 | -0.00064 |
| | variance | 0.000815 | 0.000702 | |

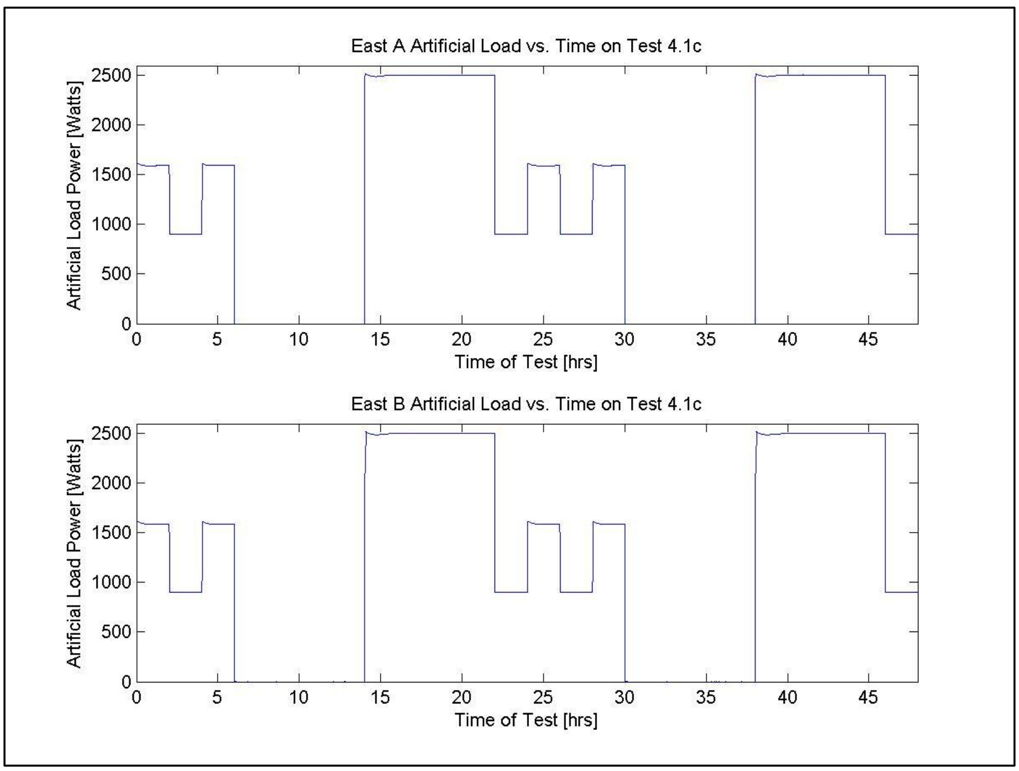
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 40.98771 |
| | variance | 46.88475 |
| AHUB | mean | 36.5662 |
| | variance | 21.97815 |
| difference | | 4.421516 |

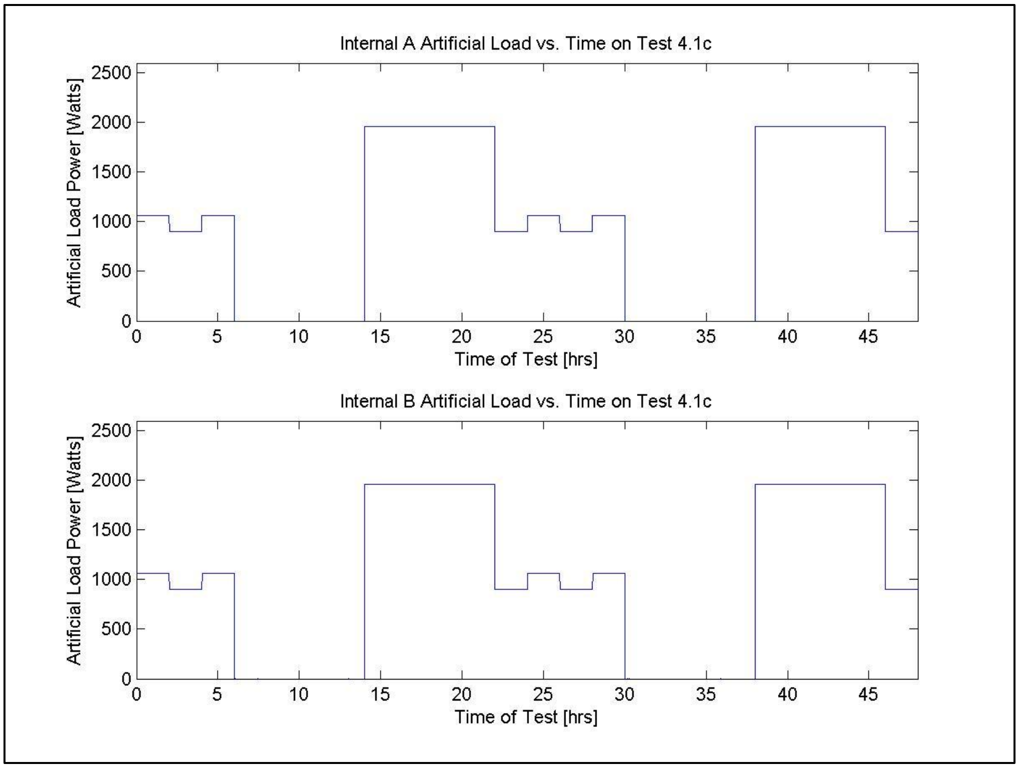
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | mean | variance |
| AHUA | East | 48.22854 | 52.40892 | 50.31873 | 8.737768 |
| | Internal | 36.48371 | 37.35858 | 36.92115 | 0.382703 |
| | South | 30.87667 | 41.40925 | 36.14296 | 55.46766 |
| | West | 42.70108 | 38.43496 | 40.56802 | 9.099911 |
| | mean | 39.5725 | 42.40293 | | |
| | Day | 1 | 2 | mean | variance |
| AHUB | East | 37.93792 | 36.81892 | 37.37842 | 0.62608 |
| | Internal | 32.94504 | 32.8255 | 32.88527 | 0.007145 |
| | South | 45.33963 | 35.23379 | 40.28671 | 51.06393 |
| | West | 40.4365 | 30.99229 | 35.7144 | 44.59654 |
| | mean | 39.16477 | 33.96763 | | |

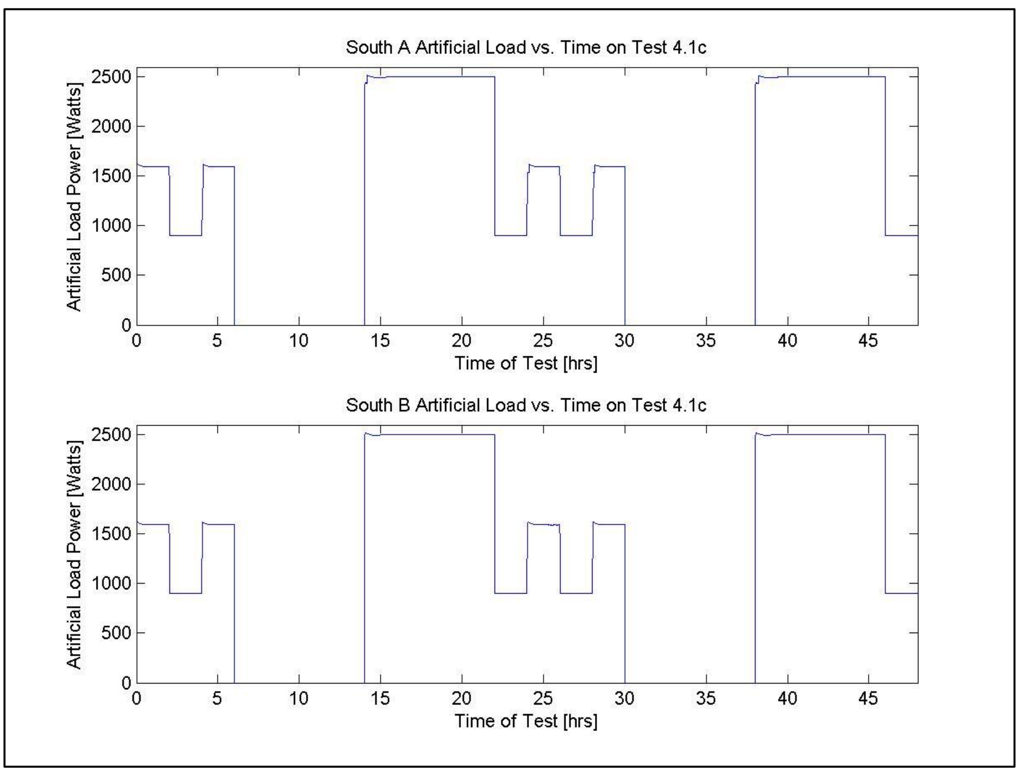
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -2.55207 |
| | variance | 381.971 |
| AHUB | mean | -0.31606 |
| | variance | 101.7396 |
| difference | | -2.23601 |

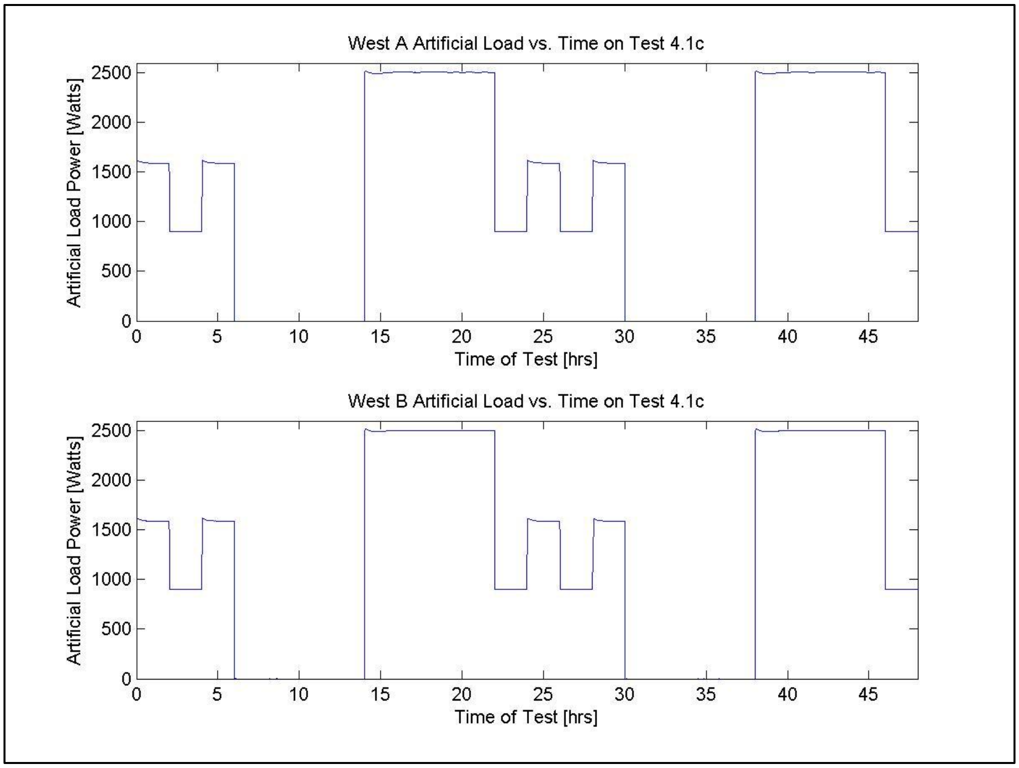
| Flow Rate Control [CFM Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -3.56441 | -3.63932 | -3.60187 |
| | Internal | -6.61684 | -6.54028 | -6.57856 |
| | South | -0.02188 | -0.00599 | -0.01393 |
| | West | 0.004861 | -0.03273 | -0.01393 |
| | mean | -2.54957 | -2.55458 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.0487 | -0.0428 | -0.04575 |
| | Internal | -1.28194 | -1.10165 | -1.1918 |
| | South | -0.03854 | 0.034028 | -0.00226 |
| | West | -0.01762 | -0.03125 | -0.02444 |
| | mean | -0.3467 | -0.28542 | |

| Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 568.4115 | 591.3169 | 579.8642 |
| | Internal | 808.6745 | 790.7184 | 799.6965 |
| | South | 40.13462 | 39.29569 | 39.71515 |
| | West | 85.04723 | 73.5809 | 79.31406 |
| | mean | 375.567 | 373.728 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 3.53E+01 | 3.62E+01 | 3.58E+01 |
| | Internal | 273.1308 | 257.844 | 2.65E+02 |
| | South | 5.27E+01 | 4.99E+01 | 5.13E+01 |
| | West | 51.78125 | 55.42456 | 5.36E+01 |
| | mean | 103.2433 | 99.84274 | |




Internal A Artificial Load vs. Time on Test 4.1c
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.1c
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.1c
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.1c
Artificial Load Power [Watts]
Time of Test [hrs]




## TEST 4.1d

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-2 |
| AHUA | 32.69675108 |
| AHUB | 30.87736553 |
| % difference | 5.56% |

| Fan Power Consumed [kW-hr] | | | | |
|---|---|---|---|---|
| | 1 | 2 | mean | variance |
| AHUA | 15.8392 | 16.85755 | 16.34838 | 0.518519 |
| AHUB | 15.14598 | 15.73138 | 15.43868 | 0.171346 |
| % difference | 4.38% | 6.68% | 5.56% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [°F] | -1.19361 |
| | variance | 2.793741 |
| AHUB | mean [°F] | -1.15296 |
| | variance | 2.593475 |
| difference | | -0.04064 |

| Temperature Control [°F Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -1.04862 | -0.32481 | -0.68672 |
| | Internal | -1.4084 | -1.42025 | -1.41432 |
| | South | -1.26462 | -1.18048 | -1.22255 |
| | West | -1.43222 | -1.46947 | -1.45084 |
| | mean | -1.28847 | -1.09875 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -1.20993 | -0.36238 | -0.78615 |
| | Internal | -1.51277 | -1.51801 | -1.51539 |
| | South | -1.04618 | -0.97527 | -1.01072 |
| | West | -1.27318 | -1.326 | -1.29959 |
| | mean | -1.26051 | -1.04541 | |

| Temperature Control [°F Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 2.069123 | 0.494618 | 1.281871 |
| | Internal | 3.503351 | 3.429765 | 3.466558 |
| | South | 2.844959 | 2.487799 | 2.666379 |
| | West | 3.23197 | 3.289648 | 3.260809 |
| | mean | 2.912351 | 2.425458 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 2.535394 | 0.437327 | 1.486361 |
| | Internal | 3.34E+00 | 3.32E+00 | 3.331887 |
| | South | 2.059938 | 1.820263 | 1.9401 |
| | West | 3.04E+00 | 3.228495 | 3.132338 |
| | mean | 2.744117 | 2.201227 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.676479 |
| | variance | 0.000283 |
| AHUB | mean | 0.733646 |
| | variance | 0.001269 |
| difference | | -0.05717 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | |
|---|---|---|---|---|
| Day | 1 | 2 | mean | variance |
| AHUA | 0.688375 | 0.664583 | 0.676479 | 0.000283 |
| AHUB | 0.758833 | 0.708458 | 0.733646 | 0.001269 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -6.84E-05 |
| | variance | 0.000557 |
| AHUB | mean | -0.00157 |
| | variance | 0.000334 |
| difference | | 0.001503 |

| Static Pressure Control [inches w.g.] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | mean | -0.00044 | 3.05E-04 | -6.8E-05 |
| | variance | 0.000641 | 0.000474 | |
| AHUB | mean | -0.00134 | -0.0018 | -0.00157 |
| | variance | 0.000343 | 0.000325 | |

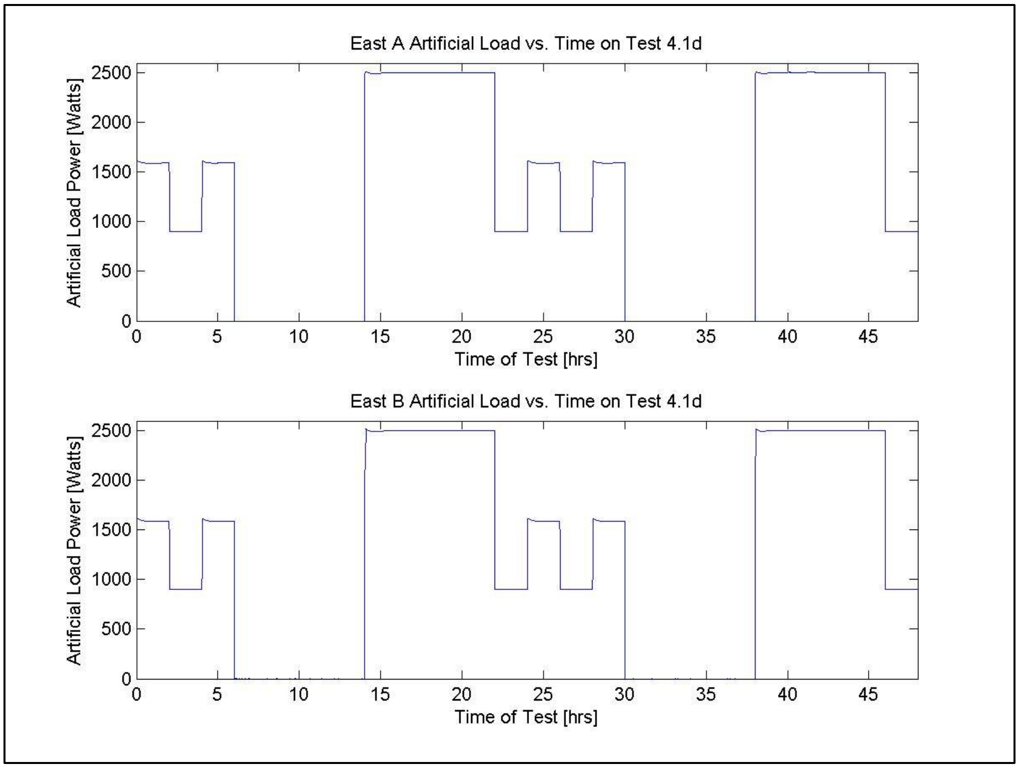
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 35.14702 |
| | variance | 58.39895 |
| AHUB | mean | 33.59019 |
| | variance | 65.3987 |
| difference | | 1.556823 |

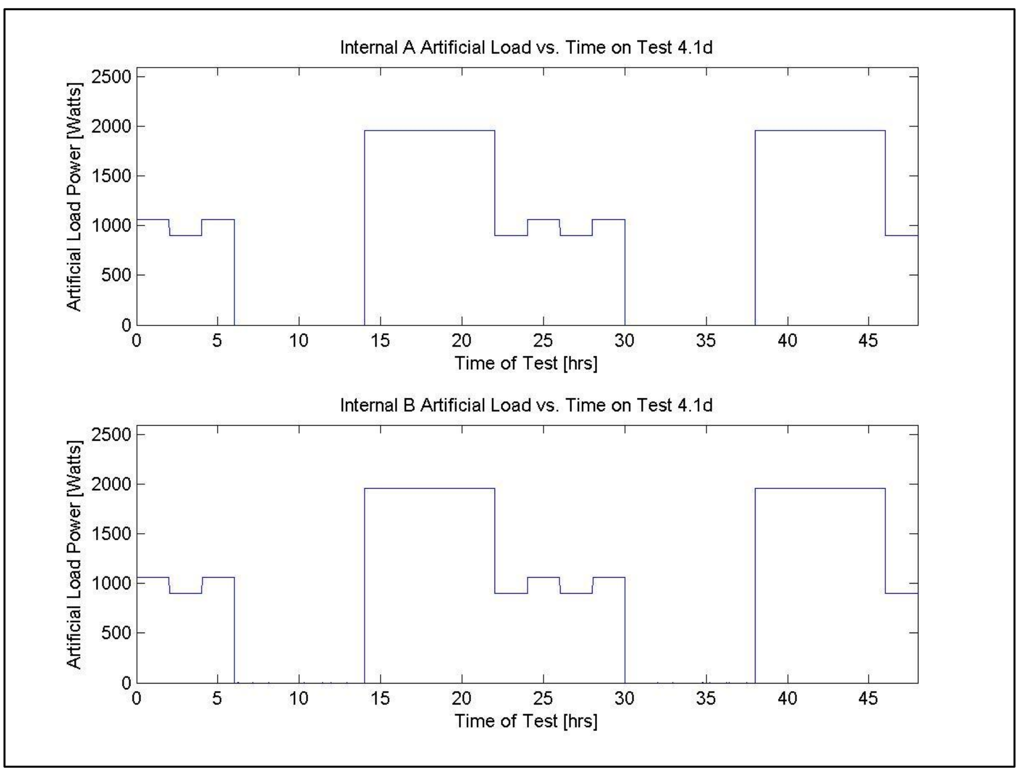
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | mean | variance |
| AHUA | East | 46.79888 | 40.40246 | 43.60067 | 20.45707 |
| | Internal | 24.99521 | 30.31471 | 27.65496 | 14.14854 |
| | South | 30.5175 | 30.76463 | 30.64106 | 0.030535 |
| | West | 43.85054 | 33.53221 | 38.69138 | 53.234 |
| | mean | 36.54053 | 33.7535 | | |
| | Day | 1 | 2 | mean | variance |
| AHUB | East | 43.17588 | 36.66988 | 39.92288 | 21.16402 |
| | Internal | 22.76633 | 24.90571 | 23.83602 | 2.288463 |
| | South | 45.82196 | 32.04171 | 38.93183 | 94.94765 |
| | West | 30.17721 | 33.16288 | 31.67004 | 4.457103 |
| | mean | 35.48534 | 31.69504 | | |

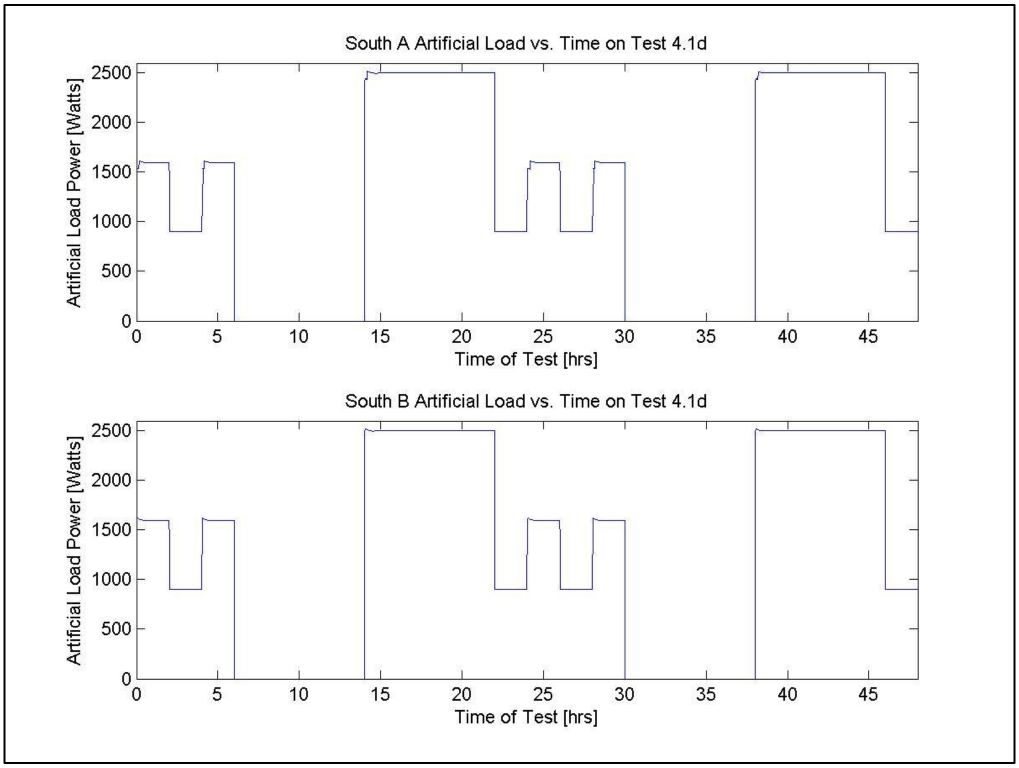
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -2.05917 |
| | variance | 308.0243 |
| AHUB | mean | -0.35662 |
| | variance | 48.83776 |
| difference | | -1.70255 |

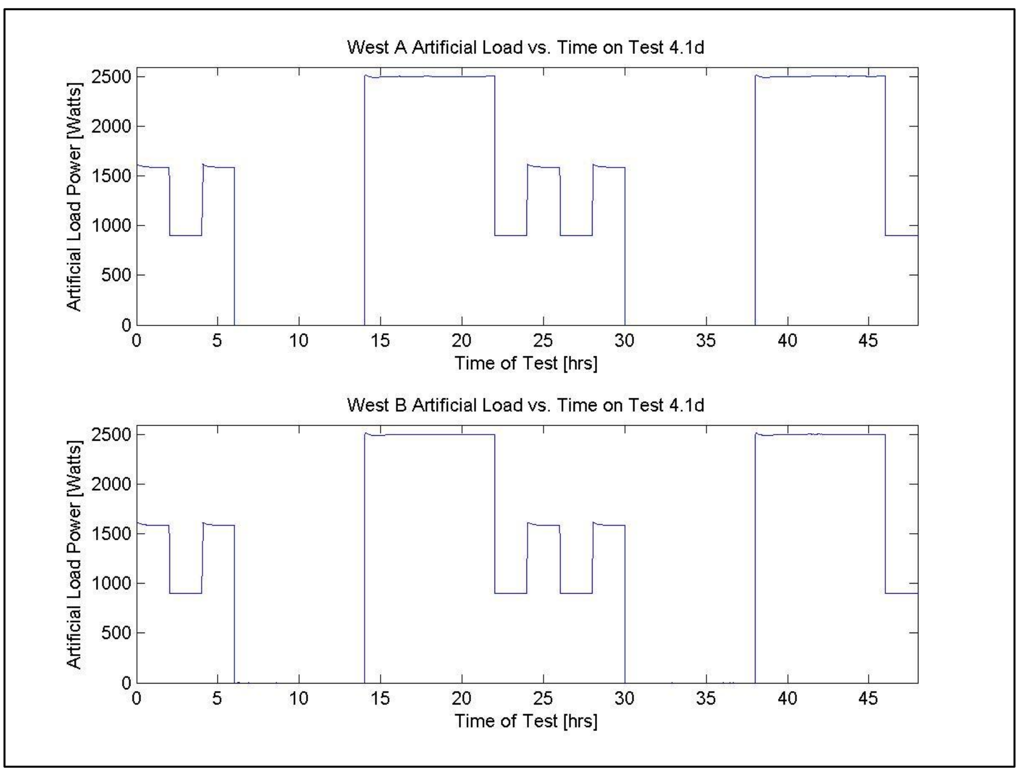
| Flow Rate Control [CFM Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -1.39948 | -9.15356 | -5.27652 |
| | Internal | -3.64635 | -2.38203 | -3.01419 |
| | South | 0.067014 | -0.00955 | 0.028733 |
| | West | 0.05434 | -0.00373 | 0.025304 |
| | mean | -1.23112 | -2.88722 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 0.026389 | 0.031858 | 0.029123 |
| | Internal | -1.24748 | -1.29566 | -1.27157 |
| | South | 0.01684 | -0.05182 | -0.01749 |
| | West | -0.08967 | -0.2434 | -0.16654 |
| | mean | -0.32348 | -0.38976 | |

| Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 194.6189 | 1554.05 | 874.3344 |
| | Internal | 315.4444 | 222.7887 | 269.1166 |
| | South | 21.62841 | 17.84253 | 19.73547 |
| | West | 38.83793 | 29.6306 | 34.23426 |
| | mean | 142.6324 | 456.0779 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 2.49E+01 | 1.83E+01 | 2.16E+01 |
| | Internal | 100.4941 | 107.7642 | 1.04E+02 |
| | South | 3.29E+01 | 2.13E+01 | 2.71E+01 |
| | West | 28.46955 | 54.44063 | 4.15E+01 |
| | mean | 46.70346 | 50.45868 | |


East A Artificial Load vs. Time on Test 4.1d
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
5
10
15
20
25
30
35
40
45
Time of Test [hrs]
East B Artificial Load vs. Time on Test 4.1d
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 4.1d
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
0
5
10
15
20
25
30
35
40
45
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.1d
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.1d
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.1d
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 4.1d
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 4.1d
Artificial Load Power [Watts]
Time of Test [hrs]

**TEST 4.2a**

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-2 |
| AHUA | 35.97204708 |
| AHUB | 35.14246025 |
| % difference | 2.31% |

| Fan Power Consumed [kW-hr] | | | | |
|---|---|---|---|---|
| | 1 | 2 | mean | variance |
| AHUA | 18.26069 | 17.71135 | 17.98602 | 0.150888 |
| AHUB | 18.0869 | 17.05556 | 17.57123 | 0.53183 |
| % difference | 0.95% | 3.70% | 2.31% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.1825 |
| | variance | 2.993841 |
| AHUB | mean [$^{o}$F] | -1.12159 |
| | variance | 2.784856 |
| difference | | -0.06091 |

| Temperature Control [$^{o}$F Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -0.19705 | -1.19737 | -0.69721 |
| | Internal | -1.39778 | -1.38871 | -1.39325 |
| | South | -1.20646 | -1.29676 | -1.25161 |
| | West | -1.40247 | -1.37343 | -1.38795 |
| | mean | -1.05094 | -1.31407 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.19677 | -1.30282 | -0.74979 |
| | Internal | -1.44943 | -1.45248 | -1.45095 |
| | South | -0.9347 | -1.14537 | -1.04004 |
| | West | -1.23759 | -1.25355 | -1.24557 |
| | mean | -0.95462 | -1.28856 | |

| Temperature Control [$^{o}$F Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 0.299213 | 2.840906 | 1.570059 |
| | Internal | 3.474829 | 3.539355 | 3.507092 |
| | South | 2.747192 | 3.133636 | 2.940414 |
| | West | 3.388881 | 3.381794 | 3.385337 |
| | mean | 2.477529 | 3.223923 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 0.191309 | 3.084004 | 1.637656 |
| | Internal | 3.42E+00 | 3.39E+00 | 3.406406 |
| | South | 1.889488 | 2.663882 | 2.276685 |
| | West | 3.19E+00 | 3.290161 | 3.239307 |
| | mean | 2.173016 | 3.107011 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.659875 |
| | variance | 0.000177 |
| AHUB | mean | 0.778271 |
| | variance | 0.00115 |
| difference | | -0.1184 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | |
|---|---|---|---|---|
| Day | 1 | 2 | mean | variance |
| AHUA | 0.669292 | 0.650458 | 0.659875 | 0.000177 |
| AHUB | 0.80225 | 0.754292 | 0.778271 | 0.00115 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.000932 |
| | variance | 0.000378 |
| AHUB | mean | -0.0004 |
| | variance | 0.000325 |
| difference | | 0.001332 |

| Static Pressure Control [inches w.g.] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | mean | 0.000637 | 1.23E-03 | 0.000932 |
| | variance | 0.000416 | 0.000341 | |
| AHUB | mean | -0.00026 | -0.00054 | -0.0004 |
| | variance | 0.000362 | 0.000287 | |

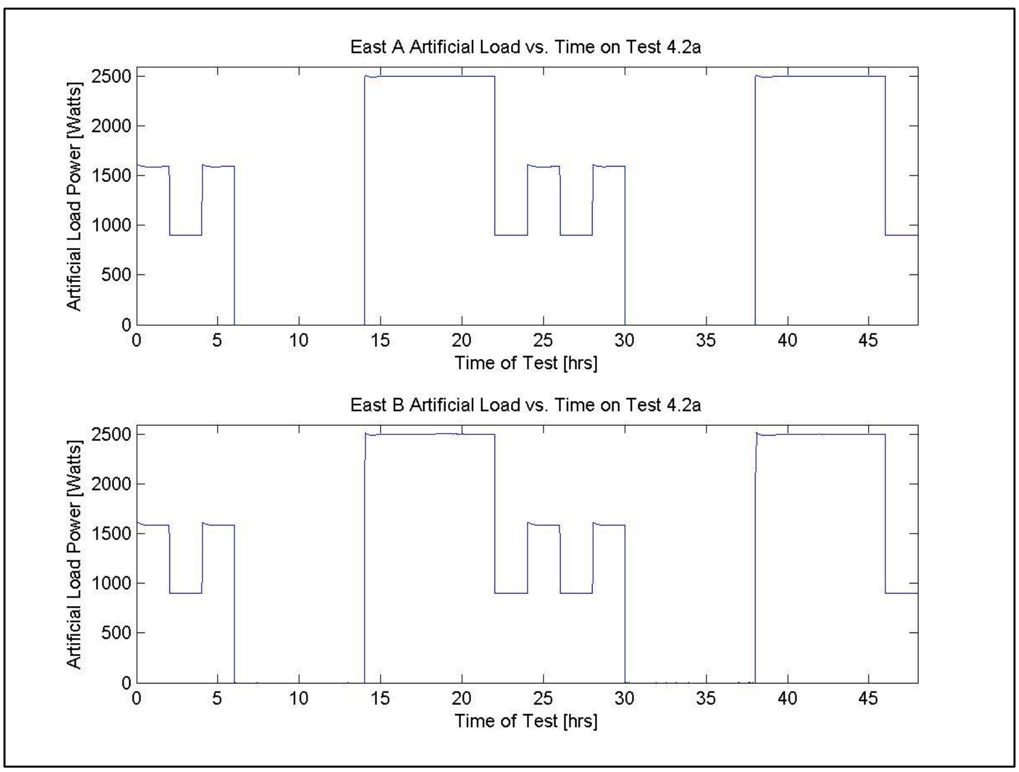
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 37.23197 |
| | variance | 70.95583 |
| AHUB | mean | 33.19678 |
| | variance | 108.6441 |
| difference | | 4.035193 |

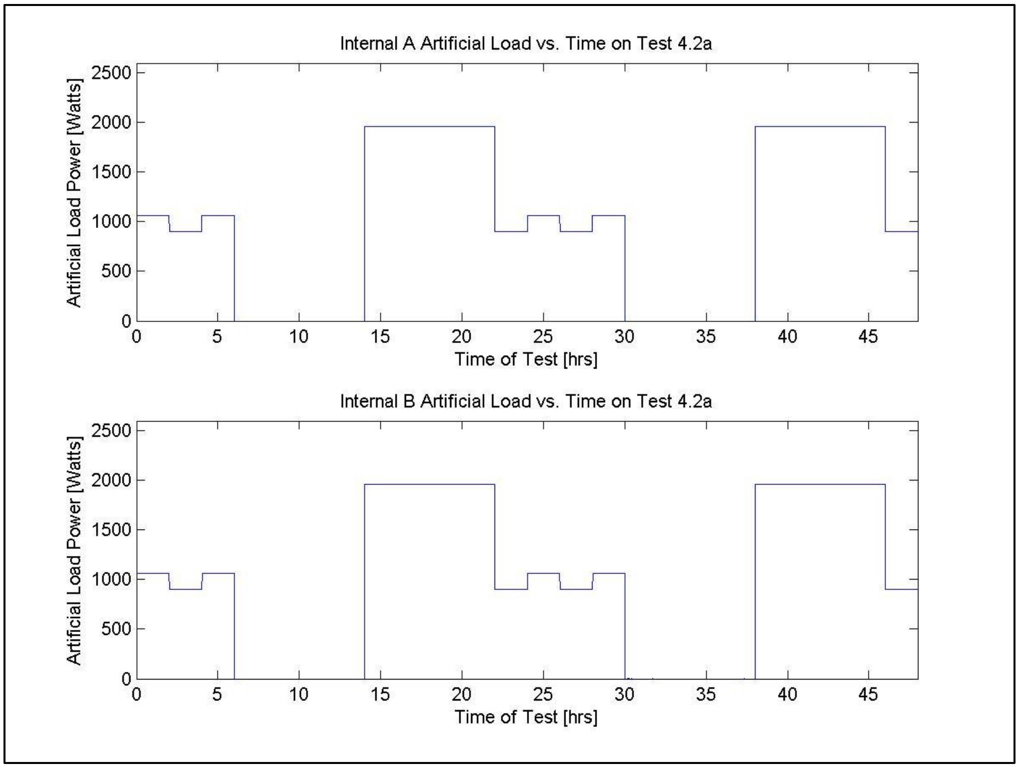
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | mean | variance |
| AHUA | East | 43.59633 | 41.24942 | 42.42288 | 2.754009 |
| | Internal | 24.79371 | 26.66121 | 25.72746 | 1.743778 |
| | South | 37.36304 | 33.21388 | 35.28846 | 8.607792 |
| | West | 48.735 | 42.24321 | 45.4891 | 21.07168 |
| | mean | 38.62202 | 35.84193 | | |
| | Day | 1 | 2 | mean | variance |
| AHUB | East | 37.17463 | 38.58754 | 37.88108 | 0.998167 |
| | Internal | 16.33113 | 18.16233 | 17.24673 | 1.676662 |
| | South | 41.06588 | 43.95596 | 42.51092 | 4.176291 |
| | West | 31.99879 | 38.298 | 35.1484 | 19.84001 |
| | mean | 31.6426 | 34.75096 | | |

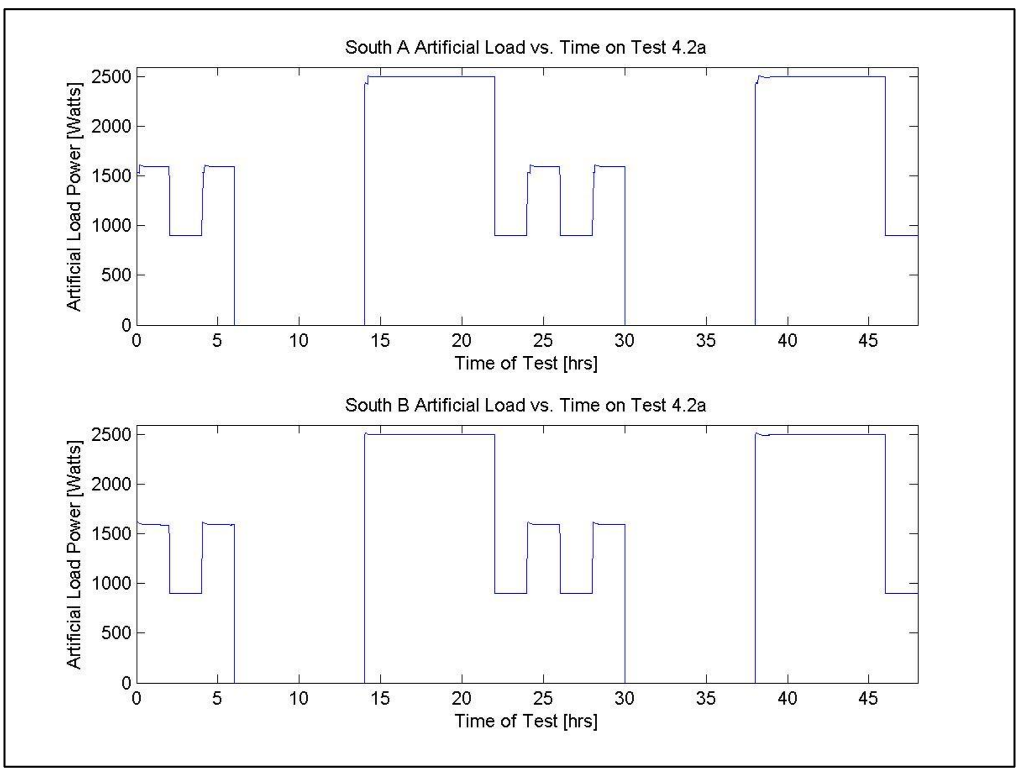
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.089 |
| | variance | 75.17751 |
| AHUB | mean | -0.03422 |
| | variance | 30.2512 |
| difference | | -0.05477 |

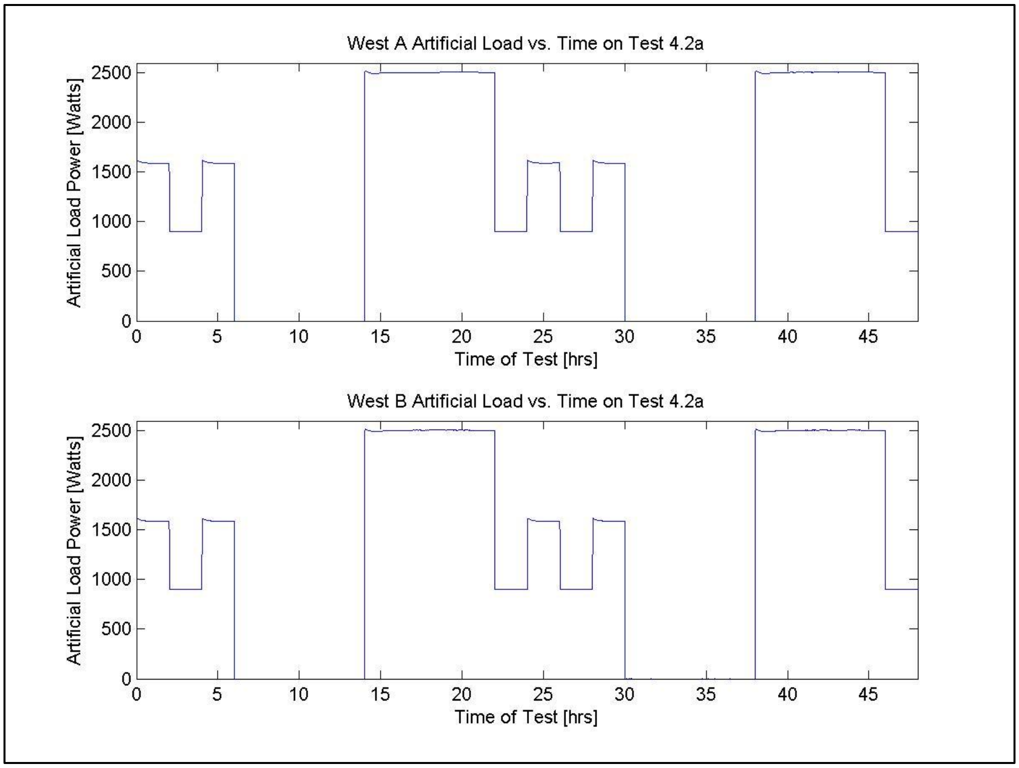
| Flow Rate Control [CFM Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -0.58012 | -0.12717 | -0.35365 |
| | Internal | -0.0967 | 0.002517 | -0.04709 |
| | South | 0.014149 | 0.008073 | 0.011111 |
| | West | 0.023264 | 0.04401 | 0.033637 |
| | mean | -0.15985 | -0.01814 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.09306 | 0.057552 | -0.01775 |
| | Internal | 0.013889 | 0.000868 | 0.007378 |
| | South | 0.061372 | -0.1263 | -0.03247 |
| | West | -0.17109 | -0.01701 | -0.09405 |
| | mean | -0.04722 | -0.02122 | |

| Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 159.696 | 77.07145 | 118.3837 |
| | Internal | 86.32217 | 92.98257 | 89.65237 |
| | South | 26.05899 | 21.41258 | 23.73578 |
| | West | 79.66707 | 58.27326 | 68.97016 |
| | mean | 87.93606 | 62.43497 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 2.28E+01 | 1.83E+01 | 2.05E+01 |
| | Internal | 15.58548 | 12.60743 | 1.41E+01 |
| | South | 3.70E+01 | 3.07E+01 | 3.38E+01 |
| | West | 75.66549 | 29.45767 | 5.26E+01 |
| | mean | 37.76238 | 22.76377 | |




Internal A Artificial Load vs. Time on Test 4.2a
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.2a
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.2a
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.2a
Artificial Load Power [Watts]
Time of Test [hrs]




## TEST 4.2b

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-2 |
| AHUA | 36.45458538 |
| AHUB | 33.50292815 |
| % difference | 8.10% |

| Fan Power Consumed [kW-hr] | | | | |
|---|---|---|---|---|
| | 1 | 2 | mean | variance |
| AHUA | 18.54501 | 17.90958 | 18.22729 | 0.201887 |
| AHUB | 16.86351 | 16.63942 | 16.75146 | 0.025106 |
| % difference | 9.07% | 7.09% | 8.10% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -1.08214 |
| | variance | 2.576609 |
| AHUB | mean [$^oF$] | -1.01009 |
| | variance | 2.253421 |
| difference | | -0.07205 |

| Temperature Control [$^oF$ Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -0.5054 | -0.47599 | -0.49069 |
| | Internal | -1.42061 | -1.41679 | -1.4187 |
| | South | -1.00037 | -1.08674 | -1.04355 |
| | West | -1.36509 | -1.38616 | -1.37563 |
| | mean | -1.07286 | -1.09142 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.60568 | -0.5288 | -0.56724 |
| | Internal | -1.50262 | -1.49926 | -1.50094 |
| | South | -0.7157 | -0.82914 | -0.77242 |
| | West | -1.12541 | -1.27413 | -1.19977 |
| | mean | -0.98735 | -1.03283 | |

| Temperature Control [$^oF$ Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 0.825407 | 0.778105 | 0.801756 |
| | Internal | 3.505019 | 3.428667 | 3.466843 |
| | South | 2.073031 | 2.291298 | 2.182165 |
| | West | 3.274231 | 3.343087 | 3.308659 |
| | mean | 2.419422 | 2.460289 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 0.891533 | 0.798265 | 0.844899 |
| | Internal | 3.32E+00 | 3.32E+00 | 3.319762 |
| | South | 1.269568 | 1.512544 | 1.391056 |
| | West | 2.61E+00 | 3.2402 | 2.923329 |
| | mean | 2.022304 | 2.217219 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.602521 |
| | variance | 5.91E-05 |
| AHUB | mean | 0.756 |
| | variance | 0.000268 |
| difference | | -0.15348 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | |
|---|---|---|---|---|
| Day | 1 | 2 | mean | variance |
| AHUA | 0.597083 | 0.607958 | 0.602521 | 5.91E-05 |
| AHUB | 0.744417 | 0.767583 | 0.756 | 0.000268 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.00198 |
| | variance | 0.000292 |
| AHUB | mean | 0.001202 |
| | variance | 0.000355 |
| difference | | 0.000778 |

| Static Pressure Control [inches w.g.] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | mean | 0.001248 | 2.71E-03 | 0.00198 |
| | variance | 0.000296 | 0.000288 | |
| AHUB | mean | 0.001121 | 0.001284 | 0.001202 |
| | variance | 0.00037 | 0.000339 | |

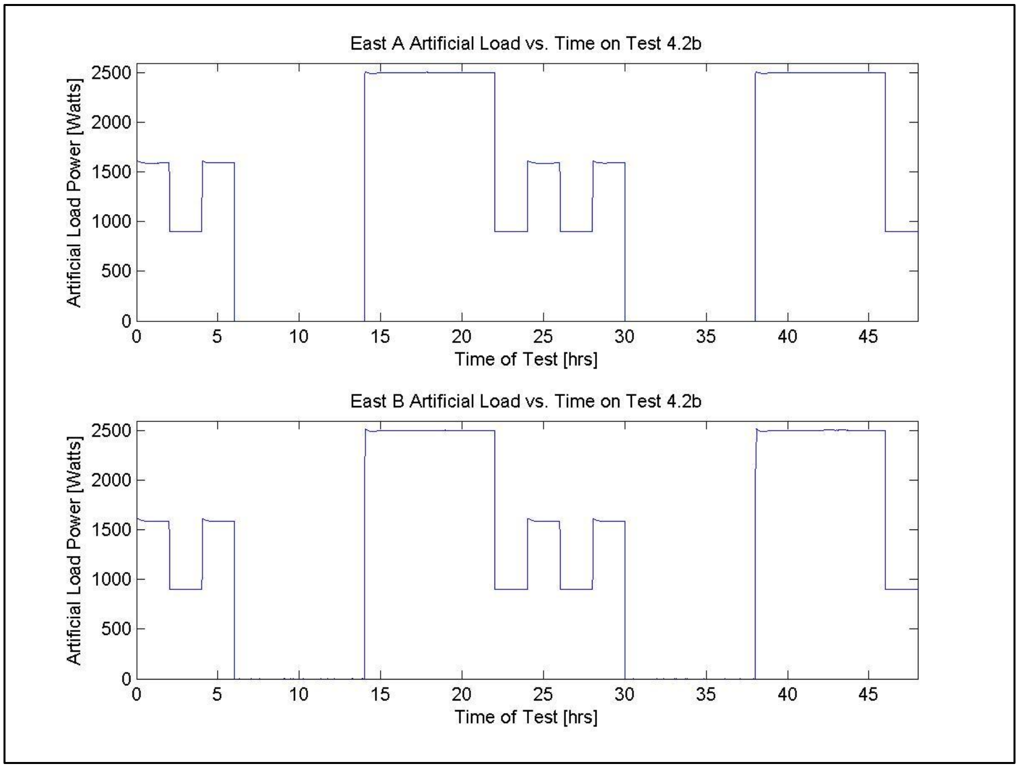
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 34.0223 |
| | variance | 110.9106 |
| AHUB | mean | 35.04188 |
| | variance | 62.04854 |
| difference | | -1.01958 |

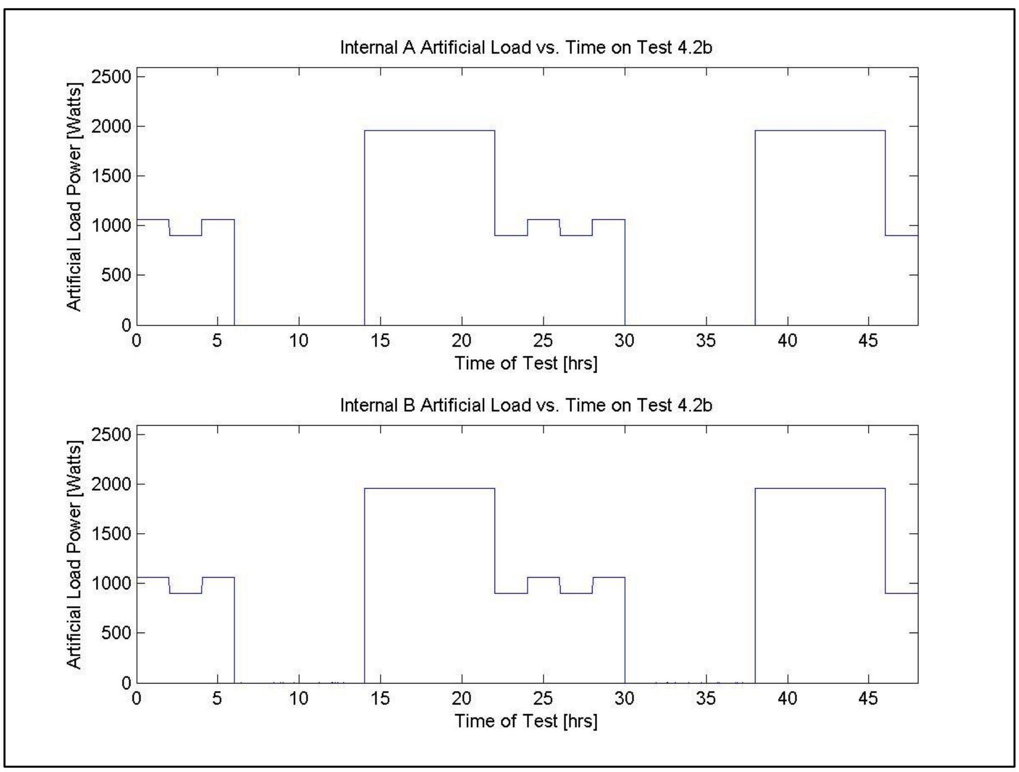
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | mean | variance |
| AHUA | East | 45.94888 | 45.924 | 45.93644 | 0.000309 |
| | Internal | 20.05092 | 20.84992 | 20.45042 | 0.319201 |
| | South | 28.46708 | 30.95096 | 29.70902 | 3.084818 |
| | West | 37.52658 | 42.46004 | 39.99331 | 12.16951 |
| | mean | 32.99836 | 35.04623 | | |
| | Day | 1 | 2 | mean | variance |
| AHUB | East | 38.22446 | 37.96275 | 38.0936 | 0.034246 |
| | Internal | 20.63046 | 24.39771 | 22.51408 | 7.096086 |
| | South | 38.67967 | 40.7625 | 39.72108 | 2.169097 |
| | West | 38.67404 | 41.00346 | 39.83875 | 2.713091 |
| | mean | 34.05216 | 36.0316 | | |

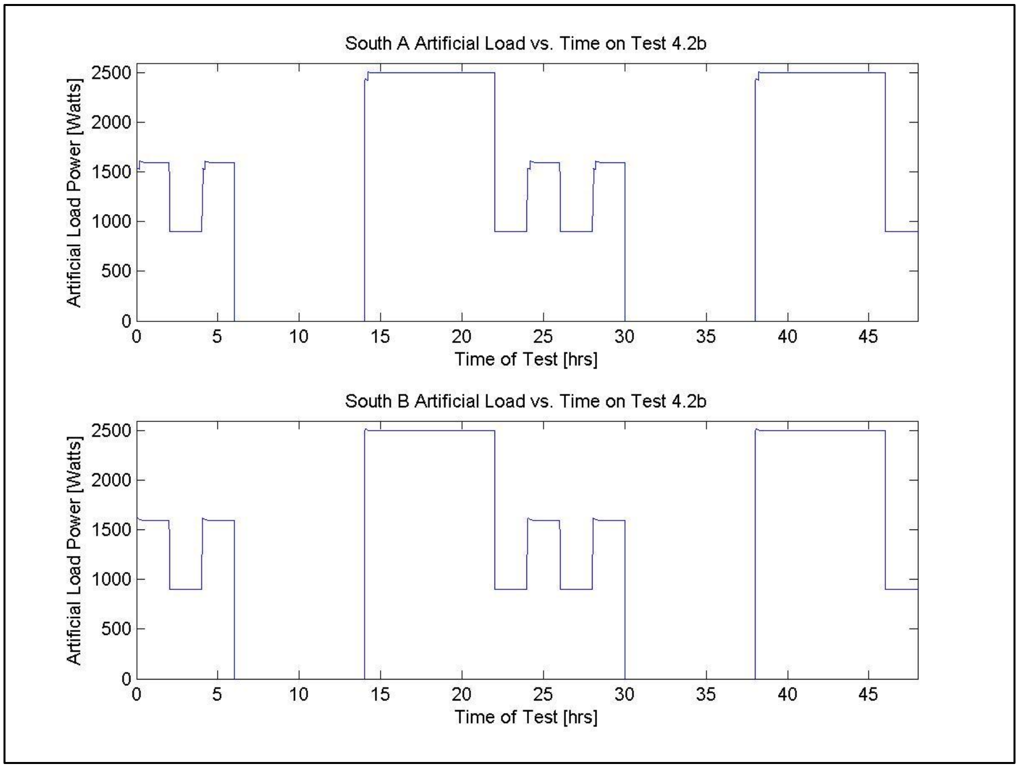
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.0073 |
| | variance | 46.97225 |
| AHUB | mean | -0.0418 |
| | variance | 47.32815 |
| difference | | 0.034494 |

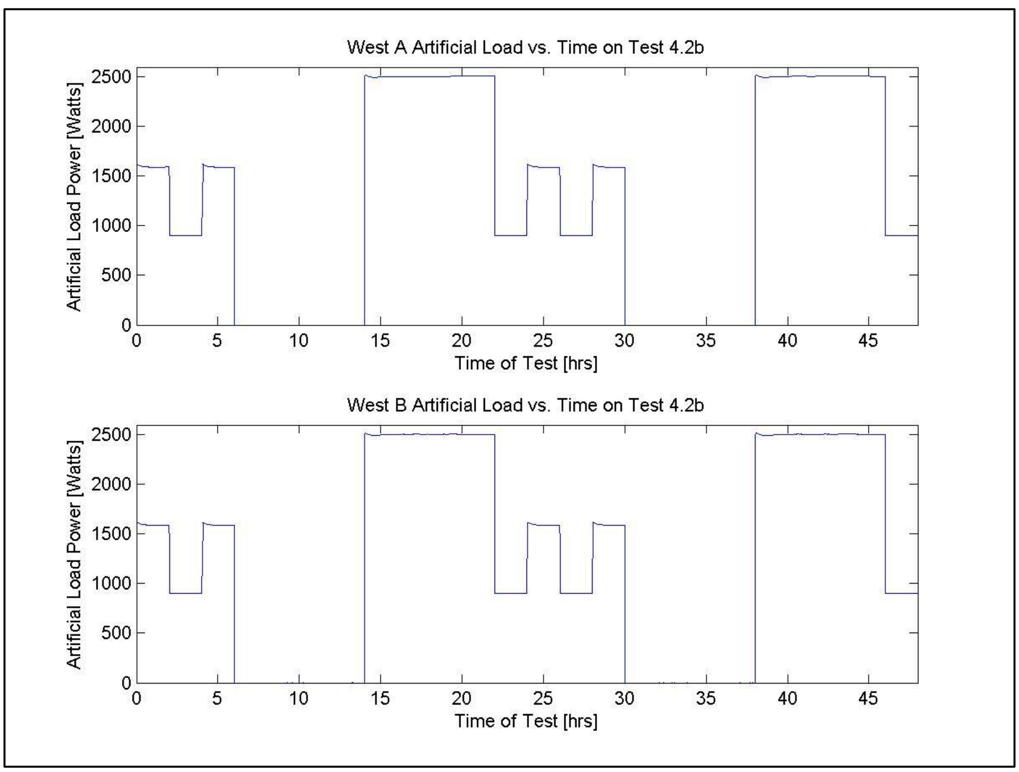
| Flow Rate Control [CFM Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 0.059983 | 0.009375 | 0.034679 |
| | Internal | 0.033767 | -0.1263 | -0.04627 |
| | South | 0.068229 | -0.09488 | -0.01332 |
| | West | -0.00182 | -0.00677 | -0.0043 |
| | mean | 0.040039 | -0.05464 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 0.034115 | 0.012066 | 0.02309 |
| | Internal | -0.02734 | 0.004514 | -0.01141 |
| | South | -0.06892 | -0.03056 | -0.04974 |
| | West | -0.20877 | -0.04948 | -0.12912 |
| | mean | -0.06773 | -0.01586 | |

| Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 102.7602 | 88.49205 | 95.62615 |
| | Internal | 44.58343 | 38.39877 | 41.4911 |
| | South | 19.83579 | 20.72228 | 20.27904 |
| | West | 26.83792 | 34.34197 | 30.58994 |
| | mean | 48.50435 | 45.48877 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 2.14E+01 | 2.11E+01 | 2.12E+01 |
| | Internal | 52.31511 | 57.92343 | 5.51E+01 |
| | South | 2.80E+01 | 3.02E+01 | 2.91E+01 |
| | West | 92.24972 | 75.71867 | 8.40E+01 |
| | mean | 48.46969 | 46.2342 | |


East A Artificial Load vs. Time on Test 4.2b
Artificial Load Power [Watts]
Time of Test [hrs]
East B Artificial Load vs. Time on Test 4.2b
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 4.2b
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.2b
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.2b
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.2b
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 4.2b
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 4.2b
Artificial Load Power [Watts]
Time of Test [hrs]

**TEST 4.3a**

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-2 |
| AHUA | 30.58512665 |
| AHUB | 28.52858767 |
| % difference | 6.72% |

| Fan Power Consumed [kW-hr] | | | | |
|---|---|---|---|---|
| | 1 | 2 | mean | variance |
| AHUA | 15.63479 | 14.95034 | 15.29256 | 0.234237 |
| AHUB | 14.18808 | 14.3405 | 14.26429 | 0.011616 |
| % difference | 9.25% | 4.08% | 6.72% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.22916 |
| | variance | 2.897678 |
| AHUB | mean [$^{o}$F] | -1.20688 |
| | variance | 2.75153 |
| difference | | -0.02229 |

| Temperature Control [$^{o}$F Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -0.97602 | -0.92736 | -0.95169 |
| | Internal | -1.38392 | -1.37203 | -1.37797 |
| | South | -1.19571 | -1.21545 | -1.20558 |
| | West | -1.34327 | -1.41953 | -1.3814 |
| | mean | -1.22473 | -1.2336 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -1.18674 | -1.10116 | -1.14395 |
| | Internal | -1.46745 | -1.44985 | -1.45865 |
| | South | -0.95647 | -1.02569 | -0.99108 |
| | West | -1.1933 | -1.27435 | -1.23382 |
| | mean | -1.20099 | -1.21276 | |

| Temperature Control [$^{o}$F Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 2.036157 | 1.810364 | 1.92326 |
| | Internal | 3.500661 | 3.483995 | 3.492328 |
| | South | 2.895207 | 2.740523 | 2.817865 |
| | West | 3.209953 | 3.268394 | 3.239174 |
| | mean | 2.910494 | 2.825819 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 2.629553 | 2.138705 | 2.384129 |
| | Internal | 3.39E+00 | 3.42E+00 | 3.406496 |
| | South | 2.008958 | 2.107784 | 2.058371 |
| | West | 2.98E+00 | 3.112791 | 3.044345 |
| | mean | 2.751564 | 2.695106 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.305729 |
| | variance | 0.126316 |
| AHUB | mean | 0.886333 |
| | variance | 0.009293 |
| difference | | 0.419396 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | |
|---|---|---|---|---|
| Day | 1 | 2 | mean | variance |
| AHUA | 1.557042 | 1.054417 | 1.305729 | 0.126316 |
| AHUB | 0.9545 | 0.818167 | 0.886333 | 0.009293 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.86222 |
| | variance | 0.096945 |
| AHUB | mean | -0.92681 |
| | variance | 0.069078 |
| difference | | 0.064582 |

| Static Pressure Control [inches w.g.] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | mean | -0.85124 | -8.73E-01 | -0.86222 |
| | variance | 0.110962 | 0.082753 | |
| AHUB | mean | -0.92576 | -0.92785 | -0.92681 |
| | variance | 0.069917 | 0.068284 | |

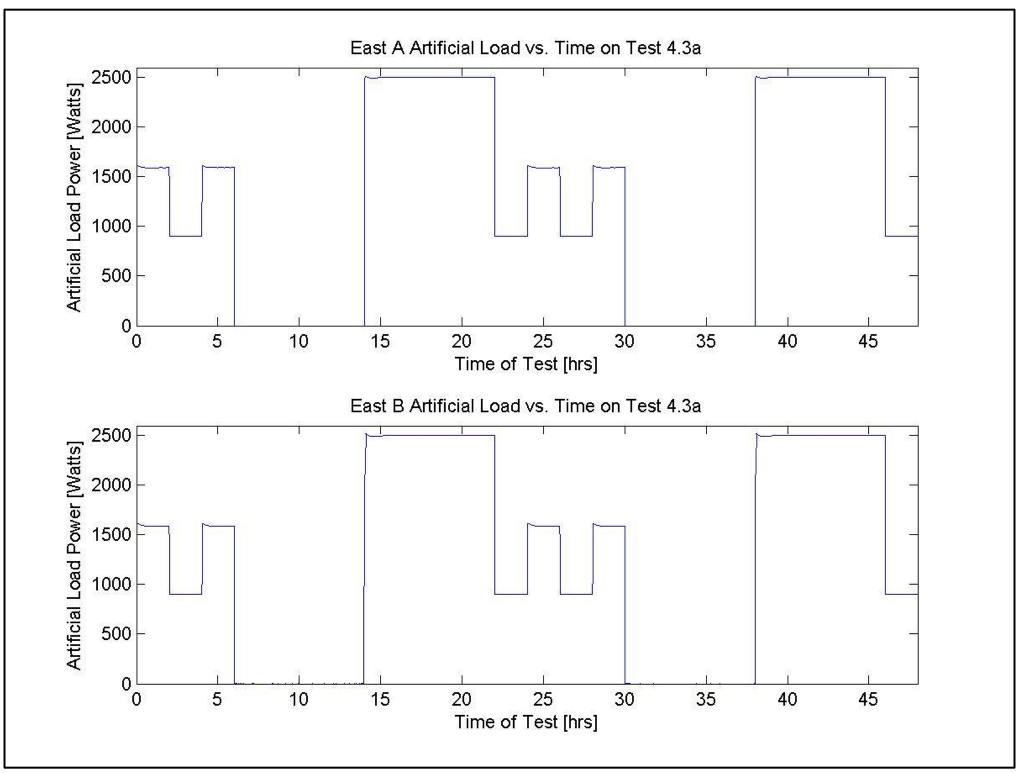
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 75.5819 |
| | variance | 382.9235 |
| AHUB | mean | 40.36169 |
| | variance | 24.67393 |
| difference | | 35.2202 |

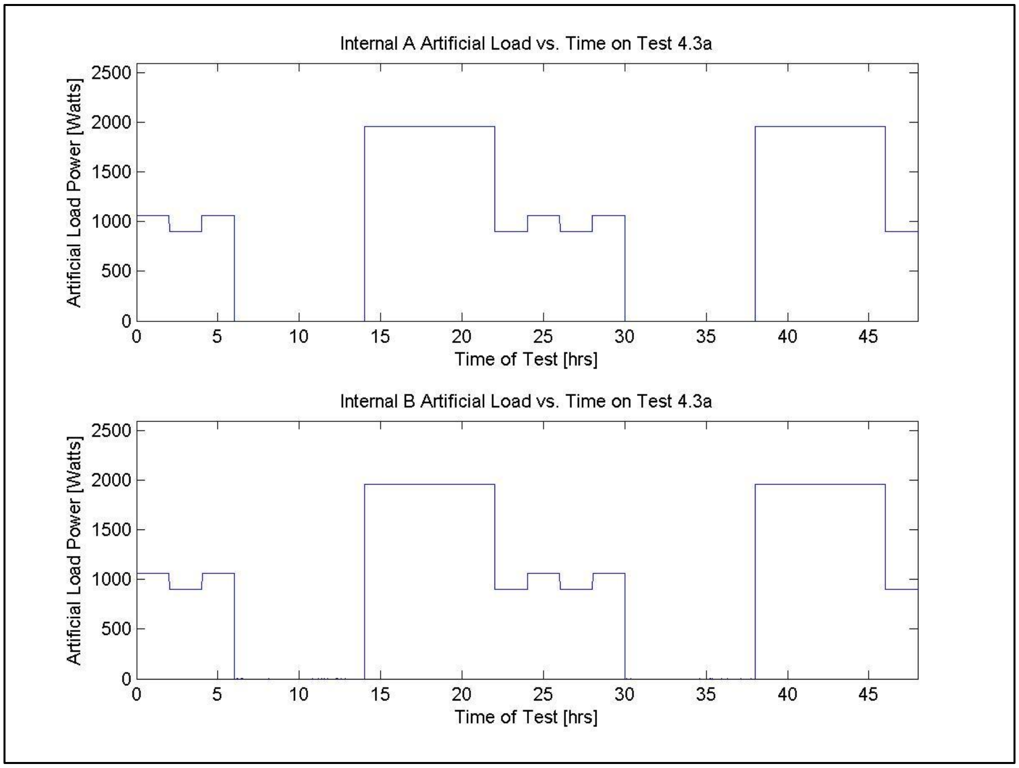
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | mean | variance |
| AHUA | East | 87.76567 | 64.67721 | 76.22144 | 266.5385 |
| | Internal | 114.635 | 80.68687 | 97.66096 | 576.239 |
| | South | 76.63821 | 57.15912 | 66.89867 | 189.7173 |
| | West | 69.52779 | 53.56525 | 61.54652 | 127.4014 |
| | mean | 87.14168 | 64.02211 | | |
| | Day | 1 | 2 | mean | variance |
| AHUB | East | 39.076 | 35.94321 | 37.5096 | 4.907192 |
| | Internal | 50.69038 | 36.75558 | 43.72298 | 97.08921 |
| | South | 43.09471 | 37.94017 | 40.51744 | 13.28465 |
| | West | 42.66646 | 36.72704 | 39.69675 | 17.63834 |
| | mean | 43.88189 | 36.8415 | | |

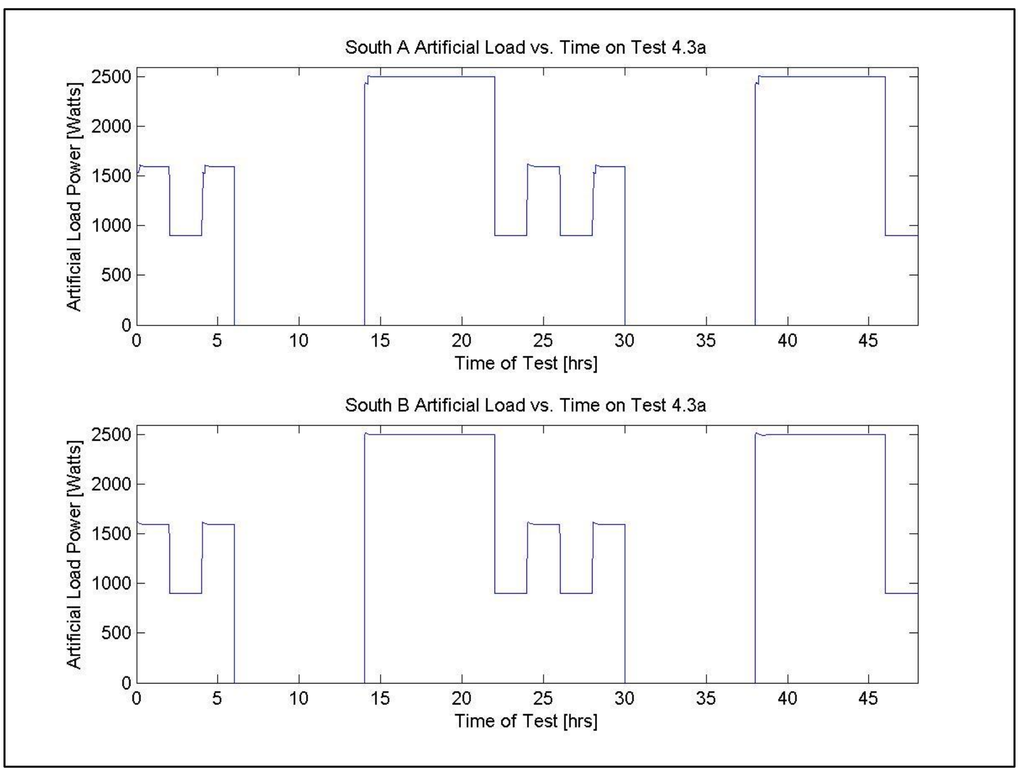
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -1.25157 |
| | variance | 527.4422 |
| AHUB | mean | -0.18787 |
| | variance | 120.9634 |
| difference | | -1.06369 |

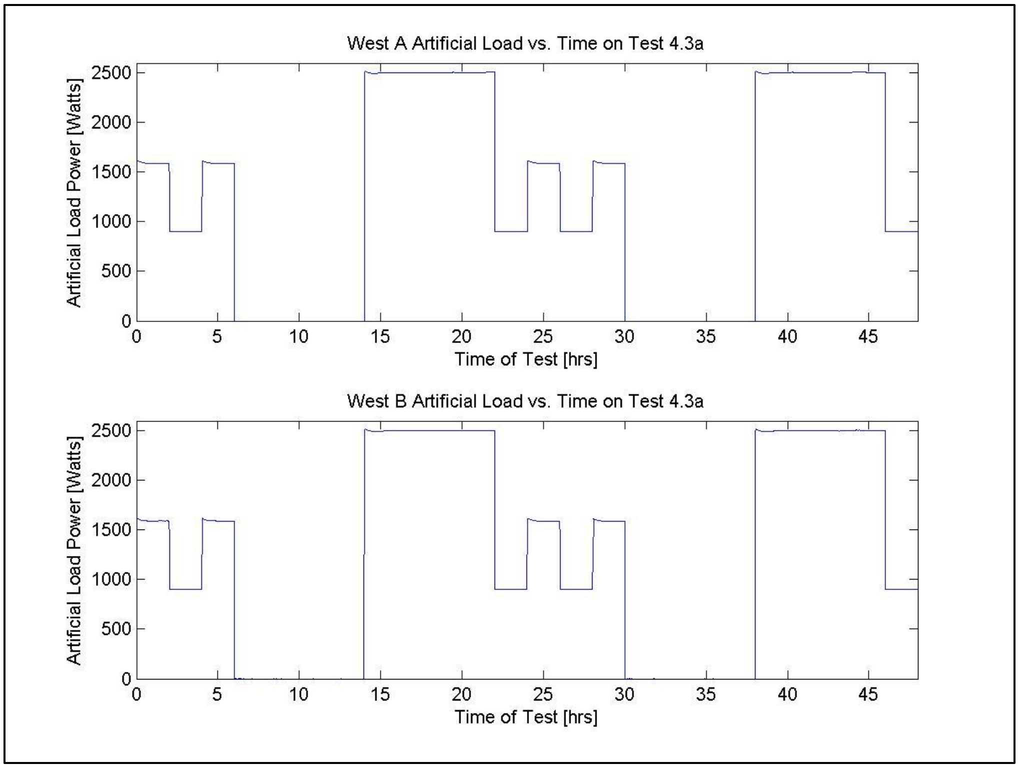
| Flow Rate Control [CFM Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -0.33576 | -0.14366 | -0.23971 |
| | Internal | -6.27902 | -2.65199 | -4.46551 |
| | South | -0.05061 | -0.21476 | -0.13268 |
| | West | -0.17986 | -0.15686 | -0.16836 |
| | mean | -1.71131 | -0.79182 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.02491 | 0.025521 | 0.000304 |
| | Internal | -0.4684 | -0.84249 | -0.65545 |
| | South | -0.10017 | -0.06849 | -0.08433 |
| | West | -0.01172 | -0.01233 | -0.01202 |
| | mean | -0.1513 | -0.22445 | |

| Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 599.5291 | 302.5846 | 451.0568 |
| | Internal | 1519.467 | 579.2919 | 1049.379 |
| | South | 439.8053 | 230.9677 | 335.3865 |
| | West | 329.7476 | 186.5195 | 258.1336 |
| | mean | 722.1372 | 324.8409 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 7.62E+01 | 6.53E+01 | 7.07E+01 |
| | Internal | 233.9023 | 199.8086 | 2.17E+02 |
| | South | 1.07E+02 | 8.57E+01 | 9.65E+01 |
| | West | 116.8365 | 82.69328 | 9.98E+01 |
| | mean | 133.5291 | 108.379 | |




Internal A Artificial Load vs. Time on Test 4.3a
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.3a
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.3a
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.3a
Artificial Load Power [Watts]
Time of Test [hrs]




## TEST 4.3b

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-2 |
| AHUA | 33.1032527 |
| AHUB | 30.05533768 |
| % difference | 9.21% |

| Fan Power Consumed [kW-hr] | | | | |
|---|---|---|---|---|
| | 1 | 2 | mean | variance |
| AHUA | 15.83754 | 17.26571 | 16.55163 | 1.019835 |
| AHUB | 14.49899 | 15.55635 | 15.02767 | 0.559 |
| % difference | 8.45% | 9.90% | 9.21% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.00514 |
| | variance | 2.745071 |
| AHUB | mean [$^{o}$F] | -0.99034 |
| | variance | 2.40773 |
| difference | | -0.0148 |

| Temperature Control [$^{o}$F Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -0.2049 | -0.07644 | -0.14067 |
| | Internal | -1.38571 | -1.37463 | -1.38017 |
| | South | -1.16674 | -1.04835 | -1.10755 |
| | West | -1.41521 | -1.36914 | -1.39217 |
| | mean | -1.04314 | -0.96714 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.4329 | -0.24045 | -0.33668 |
| | Internal | -1.4448 | -1.45007 | -1.44744 |
| | South | -0.96408 | -0.83148 | -0.89778 |
| | West | -1.30357 | -1.25536 | -1.27946 |
| | mean | -1.03634 | -0.94434 | |

| Temperature Control [$^{o}$F Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 0.781644 | 0.394009 | 0.587827 |
| | Internal | 3.518991 | 3.508907 | 3.513949 |
| | South | 2.579825 | 2.374191 | 2.477008 |
| | West | 3.30778 | 3.39425 | 3.351015 |
| | mean | 2.54706 | 2.417839 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 0.54815 | 0.300616 | 0.424383 |
| | Internal | 3.41E+00 | 3.43E+00 | 3.422284 |
| | South | 1.897074 | 1.652685 | 1.774879 |
| | West | 3.28E+00 | 3.260282 | 3.272093 |
| | mean | 2.285928 | 2.160892 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 1.68075 |
| | variance | 0.005253 |
| AHUB | mean | 1.613021 |
| | variance | 6.66E-05 |
| difference | | 0.067729 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | |
|---|---|---|---|---|
| Day | 1 | 2 | mean | variance |
| AHUA | 1.6295 | 1.732 | 1.68075 | 0.005253 |
| AHUB | 1.60725 | 1.618792 | 1.613021 | 6.66E-05 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.83342 |
| | variance | 0.096828 |
| AHUB | mean | -0.97784 |
| | variance | 0.062496 |
| difference | | 0.144422 |

| Static Pressure Control [inches w.g.] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | mean | -0.85719 | -8.10E-01 | -0.83342 |
| | variance | 0.089261 | 0.103331 | |
| AHUB | mean | -0.98743 | -0.96825 | -0.97784 |
| | variance | 0.056123 | 0.068728 | |

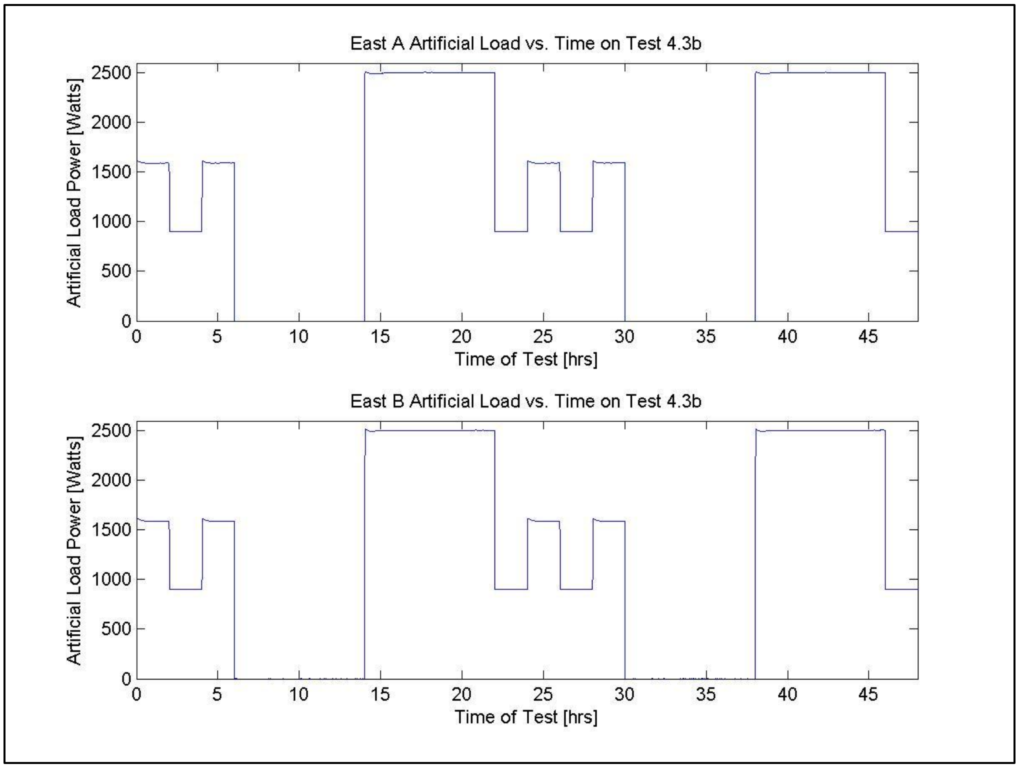
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 92.36976 |
| | variance | 540.1814 |
| AHUB | mean | 86.41214 |
| | variance | 494.2623 |
| difference | | 5.95762 |

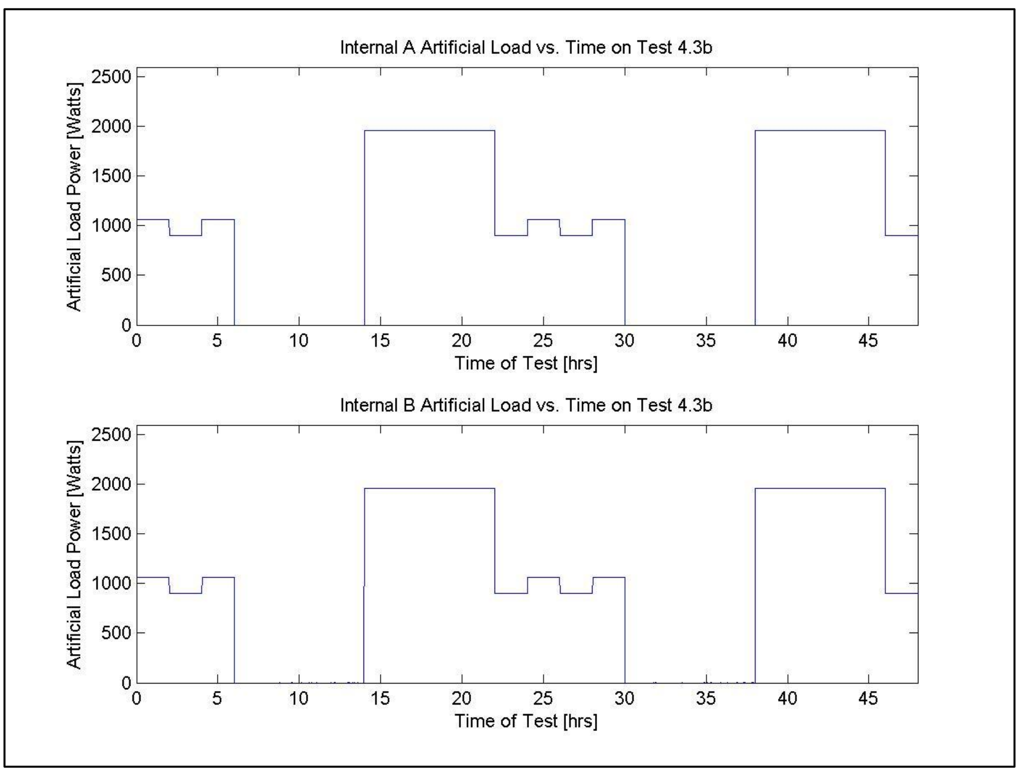
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | mean | variance |
| AHUA | East | 84.77958 | 98.02488 | 91.40223 | 87.71888 |
| | Internal | 132.7485 | 121.9439 | 127.3462 | 58.36951 |
| | South | 73.76571 | 71.69225 | 72.72898 | 2.149615 |
| | West | 77.833 | 78.17033 | 78.00167 | 0.056897 |
| | mean | 92.28169 | 92.45783 | | |
| | Day | 1 | 2 | mean | variance |
| AHUB | East | 66.37746 | 68.95108 | 67.66427 | 3.311773 |
| | Internal | 123.6677 | 115.9545 | 119.8111 | 29.74679 |
| | South | 69.91388 | 71.82421 | 70.86904 | 1.824687 |
| | West | 85.53721 | 89.07117 | 87.30419 | 6.244431 |
| | mean | 86.37405 | 86.45023 | | |

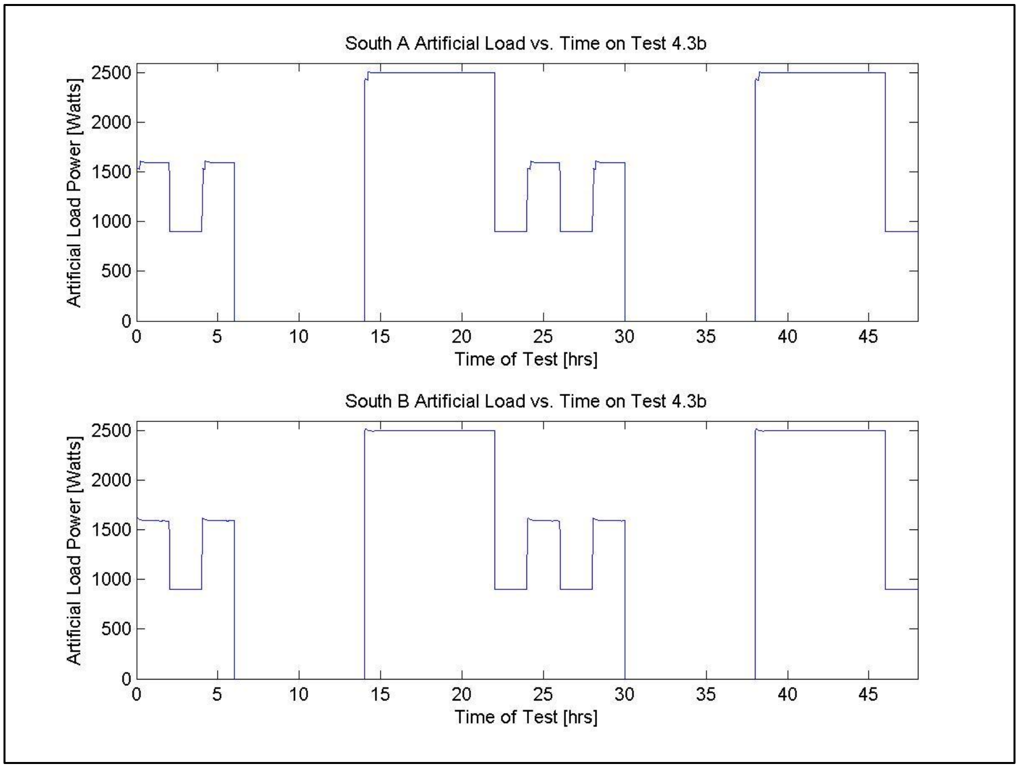
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -12.7742 |
| | variance | 3742.455 |
| AHUB | mean | -1.4528 |
| | variance | 478.2099 |
| difference | | -11.3214 |

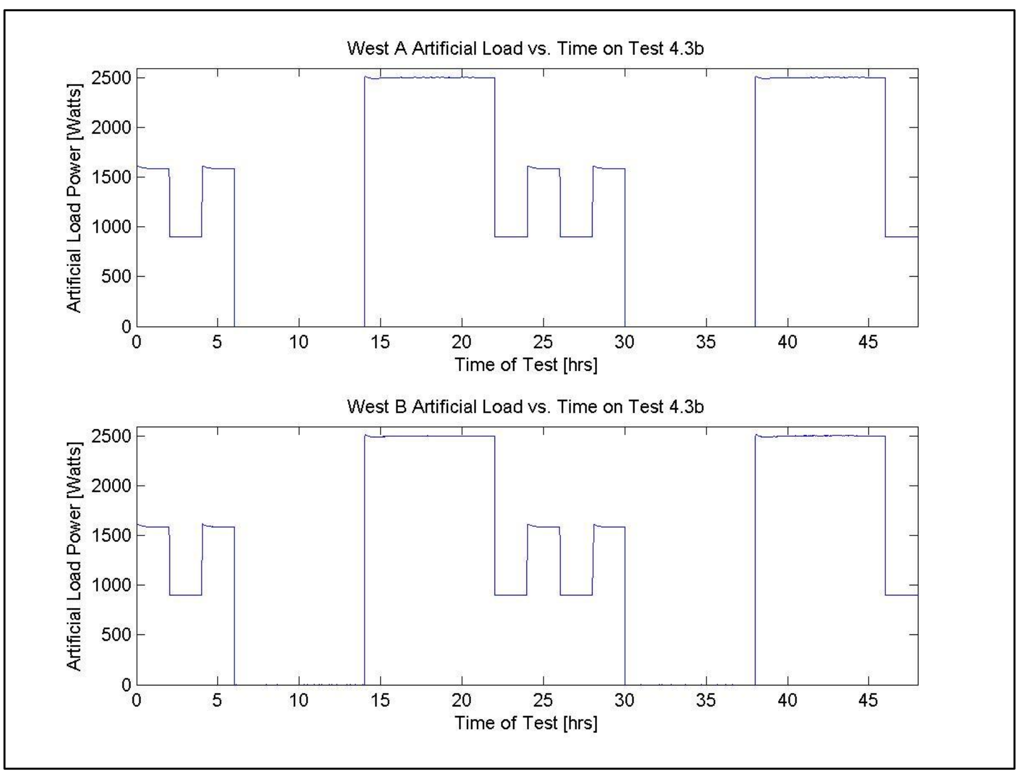
| Flow Rate Control [CFM Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -46.4865 | -42.1711 | -44.3288 |
| | Internal | -5.98008 | -6.5954 | -6.28774 |
| | South | -0.26337 | -0.45512 | -0.35924 |
| | West | -0.10113 | -0.14063 | -0.12088 |
| | mean | -13.2078 | -12.3406 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.02899 | -0.04036 | -0.03468 |
| | Internal | -4.1191 | -3.69462 | -3.90686 |
| | South | -0.91944 | -1.54609 | -1.23277 |
| | West | -0.62509 | -0.6487 | -0.63689 |
| | mean | -1.42316 | -1.48244 | |

| Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 13453.5 | 10455.28 | 11954.39 |
| | Internal | 1044.626 | 1020.557 | 1032.591 |
| | South | 287.5744 | 304.1621 | 295.8683 |
| | West | 324.289 | 352.435 | 338.362 |
| | mean | 3777.497 | 3033.109 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 2.07E+02 | 2.39E+02 | 2.23E+02 |
| | Internal | 823.0779 | 763.3326 | 7.93E+02 |
| | South | 3.72E+02 | 4.51E+02 | 4.11E+02 |
| | West | 465.0295 | 489.6911 | 4.77E+02 |
| | mean | 466.747 | 485.8059 | |


East A Artificial Load vs. Time on Test 4.3b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
Time of Test [hrs]
0
5
10
15
20
25
30
35
40
45
East B Artificial Load vs. Time on Test 4.3b
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 4.3b
Artificial Load Power [Watts]
0
500
1000
1500
2000
2500
Time of Test [hrs]
0
5
10
15
20
25
30
35
40
45
Internal B Artificial Load vs. Time on Test 4.3b
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.3b
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.3b
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 4.3b
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 4.3b
Artificial Load Power [Watts]
Time of Test [hrs]

**TEST 4.4a**

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-2 |
| AHUA | 36.03336572 |
| AHUB | 34.43465765 |
| % difference | 4.44% |

| Fan Power Consumed [kW-hr] | | | | |
|---|---|---|---|---|
| | 1 | 2 | mean | variance |
| AHUA | 18.91424 | 17.11912 | 18.01668 | 1.611226 |
| AHUB | 17.5611 | 16.87356 | 17.21733 | 0.236361 |
| % difference | 7.15% | 1.43% | 4.44% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -1.05669 |
| | variance | 2.6482 |
| AHUB | mean [$^oF$] | -0.98907 |
| | variance | 2.30264 |
| difference | | -0.06762 |

| Temperature Control [°F Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -0.16568 | -0.58919 | -0.37744 |
| | Internal | -1.42667 | -1.42215 | -1.42441 |
| | South | -1.04725 | -1.09425 | -1.07075 |
| | West | -1.36393 | -1.3444 | -1.35416 |
| | mean | -1.00088 | -1.1125 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.18372 | -0.70626 | -0.44499 |
| | Internal | -1.50869 | -1.50468 | -1.50669 |
| | South | -0.7964 | -0.86167 | -0.82904 |
| | West | -1.20649 | -1.14464 | -1.17557 |
| | mean | -0.92382 | -1.05431 | |

| Temperature Control [°F Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 0.294507 | 0.984524 | 0.639515 |
| | Internal | 3.443256 | 3.473184 | 3.45822 |
| | South | 2.298709 | 2.470028 | 2.384369 |
| | West | 3.371347 | 3.400349 | 3.385848 |
| | mean | 2.351955 | 2.582021 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 0.243964 | 1.160971 | 0.702467 |
| | Internal | 3.33E+00 | 3.35E+00 | 3.33851 |
| | South | 1.50907 | 1.656658 | 1.582864 |
| | West | 3.07E+00 | 2.720651 | 2.897202 |
| | mean | 2.039526 | 2.220995 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.720167 |
| | variance | 0.001634 |
| AHUB | mean | 0.8265 |
| | variance | 0.004705 |
| difference | | -0.10633 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | |
|---|---|---|---|---|
| Day | 1 | 2 | mean | variance |
| AHUA | 0.691583 | 0.74875 | 0.720167 | 0.001634 |
| AHUB | 0.778 | 0.875 | 0.8265 | 0.004705 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.000527 |
| | variance | 0.000553 |
| AHUB | mean | 0.000112 |
| | variance | 0.00061 |
| difference | | 0.000415 |

| Static Pressure Control [inches w.g.] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | mean | 0.000444 | 6.10E-04 | 0.000527 |
| | variance | 0.00039 | 0.000717 | |
| AHUB | mean | -6.25E-06 | 0.000231 | 0.000112 |
| | variance | 0.00037 | 0.00085 | |

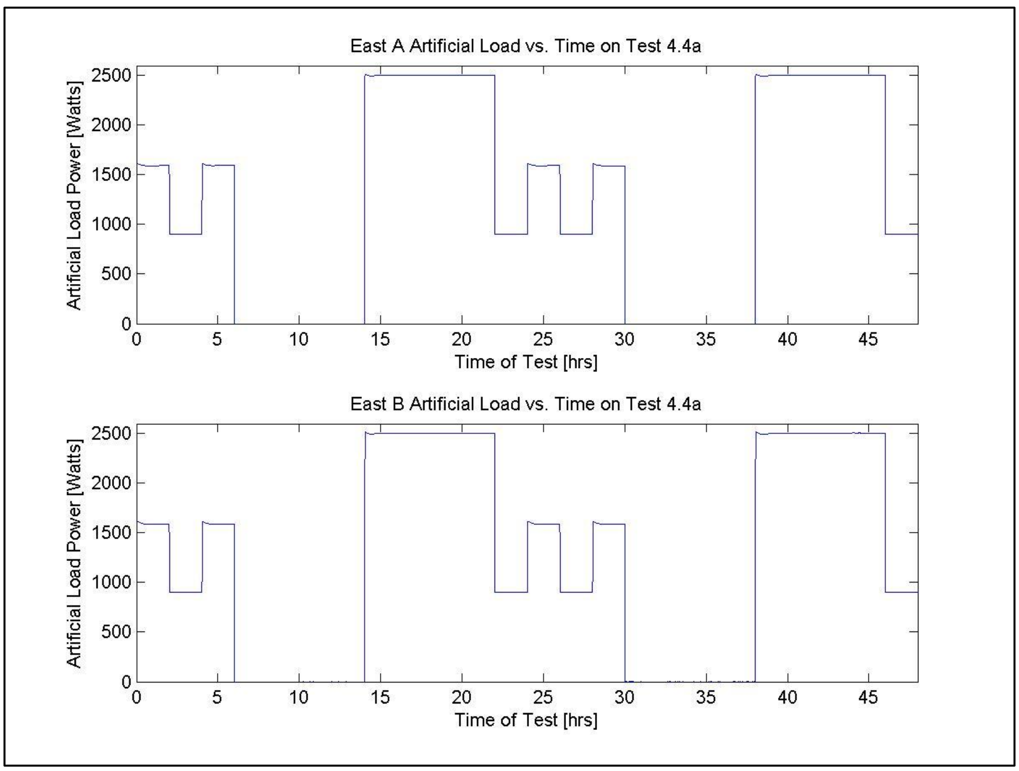
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 36.13379 |
| | variance | 102.763 |
| AHUB | mean | 35.14722 |
| | variance | 96.51685 |
| difference | | 0.986562 |

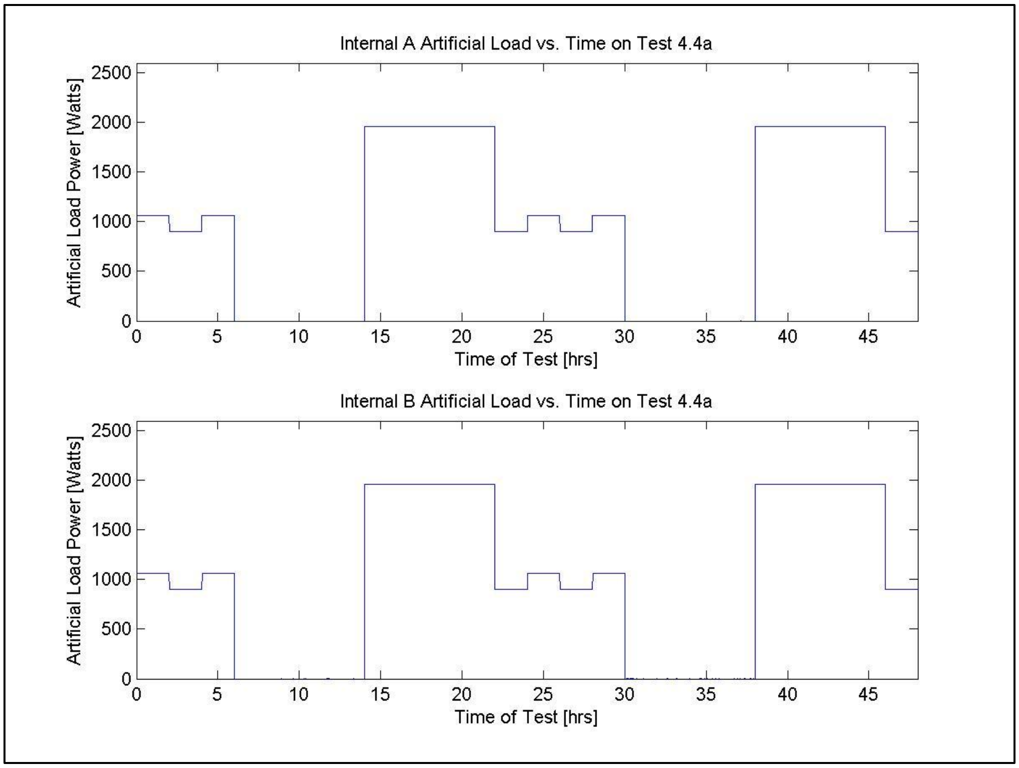
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | mean | variance |
| AHUA | East | 39.22733 | 40.06996 | 39.64865 | 0.355008 |
| | Internal | 20.8205 | 19.76213 | 20.29131 | 0.560079 |
| | South | 39.00867 | 39.30708 | 39.15787 | 0.044526 |
| | West | 45.04771 | 45.82692 | 45.43731 | 0.303583 |
| | mean | 36.02605 | 36.24152 | | |
| | Day | 1 | 2 | mean | variance |
| AHUB | East | 42.138 | 39.11638 | 40.62719 | 4.565109 |
| | Internal | 19.68492 | 20.31142 | 19.99817 | 0.196251 |
| | South | 41.01454 | 44.35863 | 42.68658 | 5.591447 |
| | West | 33.85192 | 40.702 | 37.27696 | 23.46182 |
| | mean | 34.17234 | 36.1221 | | |

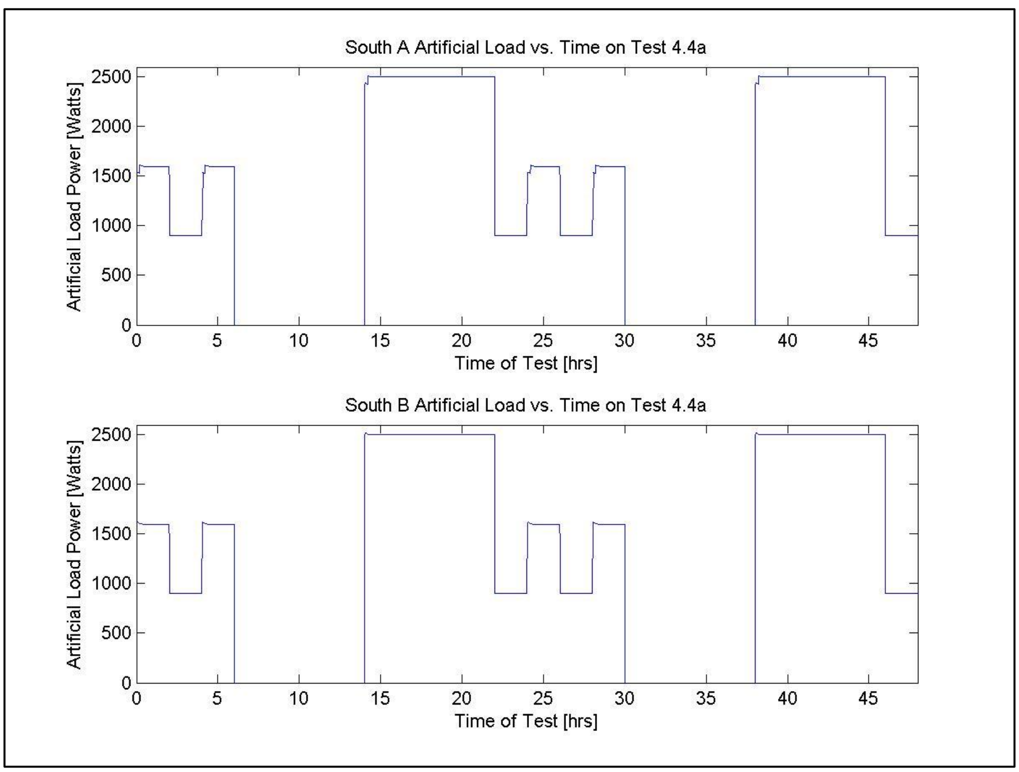
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.0473 |
| | variance | 35.13936 |
| AHUB | mean | 0.003125 |
| | variance | 32.62534 |
| difference | | -0.05042 |

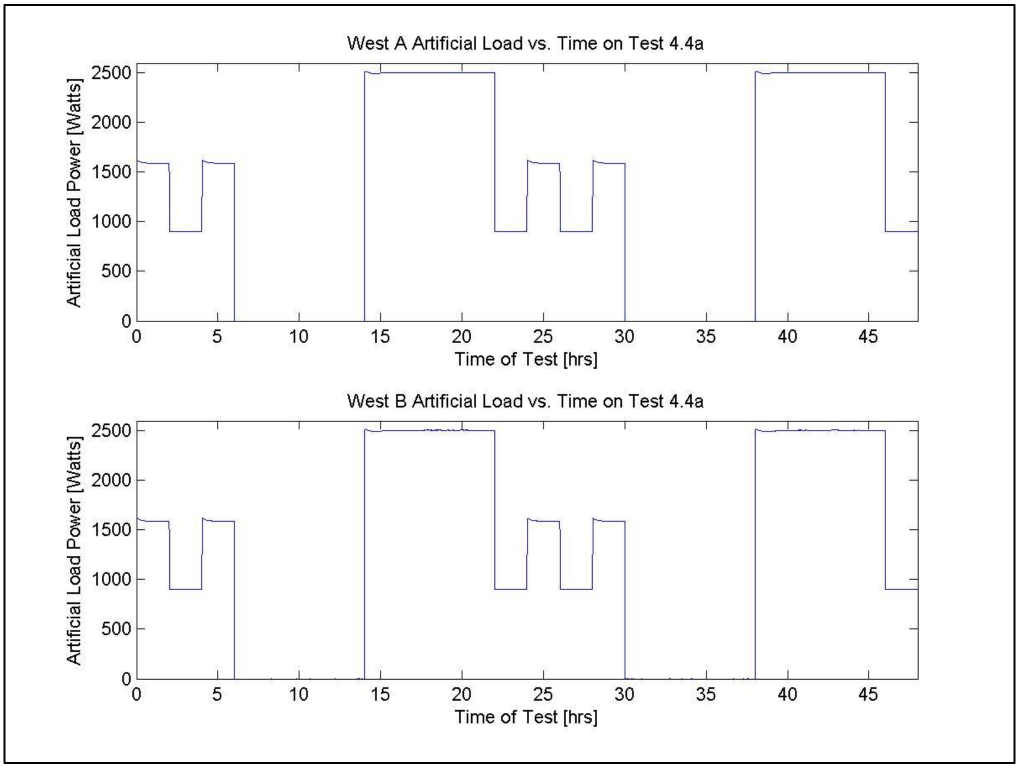
| Flow Rate Control [CFM Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -0.17543 | -0.09167 | -0.13355 |
| | Internal | 0.001128 | -0.04102 | -0.01994 |
| | South | -0.12196 | -0.01879 | -0.07038 |
| | West | 0.052257 | 0.017101 | 0.034679 |
| | mean | -0.061 | -0.03359 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 0.090017 | -0.08646 | 0.00178 |
| | Internal | 0.029514 | -0.02786 | 0.000825 |
| | South | 0.103733 | -0.03993 | 0.031901 |
| | West | 0.009288 | -0.0533 | -0.02201 |
| | mean | 0.058138 | -0.05189 | |

| Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 83.30104 | 35.40722 | 59.35413 |
| | Internal | 17.55567 | 17.1142 | 17.33493 |
| | South | 30.69226 | 26.93116 | 28.81171 |
| | West | 41.74223 | 28.50083 | 35.12153 |
| | mean | 43.3228 | 26.98835 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 3.23E+01 | 2.72E+01 | 2.97E+01 |
| | Internal | 19.01898 | 30.24645 | 2.46E+01 |
| | South | 2.91E+01 | 4.49E+01 | 3.70E+01 |
| | West | 32.90967 | 45.46849 | 3.92E+01 |
| | mean | 28.33426 | 36.94799 | |




Internal A Artificial Load vs. Time on Test 4.4a
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.4a
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.4a
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.4a
Artificial Load Power [Watts]
Time of Test [hrs]




# TEST 4.4b

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-2 |
| AHUA | 34.20974293 |
| AHUB | 32.76051893 |
| % difference | 4.24% |

| Fan Power Consumed [kW-hr] | | | | |
|---|---|---|---|---|
| | 1 | 2 | mean | variance |
| AHUA | 16.7731 | 17.43664 | 17.10487 | 0.220145 |
| AHUB | 16.16981 | 16.59071 | 16.38026 | 0.088579 |
| % difference | 3.60% | 4.85% | 4.24% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [°F] | -1.22367 |
| | variance | 2.965734 |
| AHUB | mean [°F] | -1.20456 |
| | variance | 2.691385 |
| difference | | -0.01911 |

| Temperature Control [°F Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -1.21731 | -0.54179 | -0.87955 |
| | Internal | -1.34672 | -1.42542 | -1.38607 |
| | South | -1.28793 | -1.19319 | -1.24056 |
| | West | -1.39383 | -1.38315 | -1.38849 |
| | mean | -1.31145 | -1.13589 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -1.35993 | -0.65098 | -1.00545 |
| | Internal | -1.51227 | -1.52061 | -1.51644 |
| | South | -1.13753 | -0.94996 | -1.04375 |
| | West | -1.29187 | -1.21331 | -1.25259 |
| | mean | -1.3254 | -1.08371 | |

| Temperature Control [°F Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 2.751629 | 0.702744 | 1.727187 |
| | Internal | 3.757307 | 3.429922 | 3.593615 |
| | South | 2.952028 | 2.638569 | 2.795299 |
| | West | 3.577839 | 3.349564 | 3.463702 |
| | mean | 3.259701 | 2.5302 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 2.972693 | 0.749425 | 1.861059 |
| | Internal | 3.30E+00 | 3.32E+00 | 3.309404 |
| | South | 2.542619 | 1.835735 | 2.189177 |
| | West | 3.27E+00 | 2.954611 | 3.111143 |
| | mean | 3.021063 | 2.214328 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.886625 |
| | variance | 0.147515 |
| AHUB | mean | 0.905354 |
| | variance | 0.021021 |
| difference | | -0.01873 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | |
|---|---|---|---|---|
| Day | 1 | 2 | mean | variance |
| AHUA | 1.158208 | 0.615042 | 0.886625 | 0.147515 |
| AHUB | 1.007875 | 0.802833 | 0.905354 | 0.021021 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.00039 |
| | variance | 0.001436 |
| AHUB | mean | -0.001 |
| | variance | 0.0011 |
| difference | | 0.000619 |

| Static Pressure Control [inches w.g.] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | mean | -0.0017 | 9.28E-04 | -0.00039 |
| | variance | 0.002375 | 0.000494 | |
| AHUB | mean | -0.00202 | 8.33E-06 | -0.001 |
| | variance | 0.001589 | 0.00061 | |

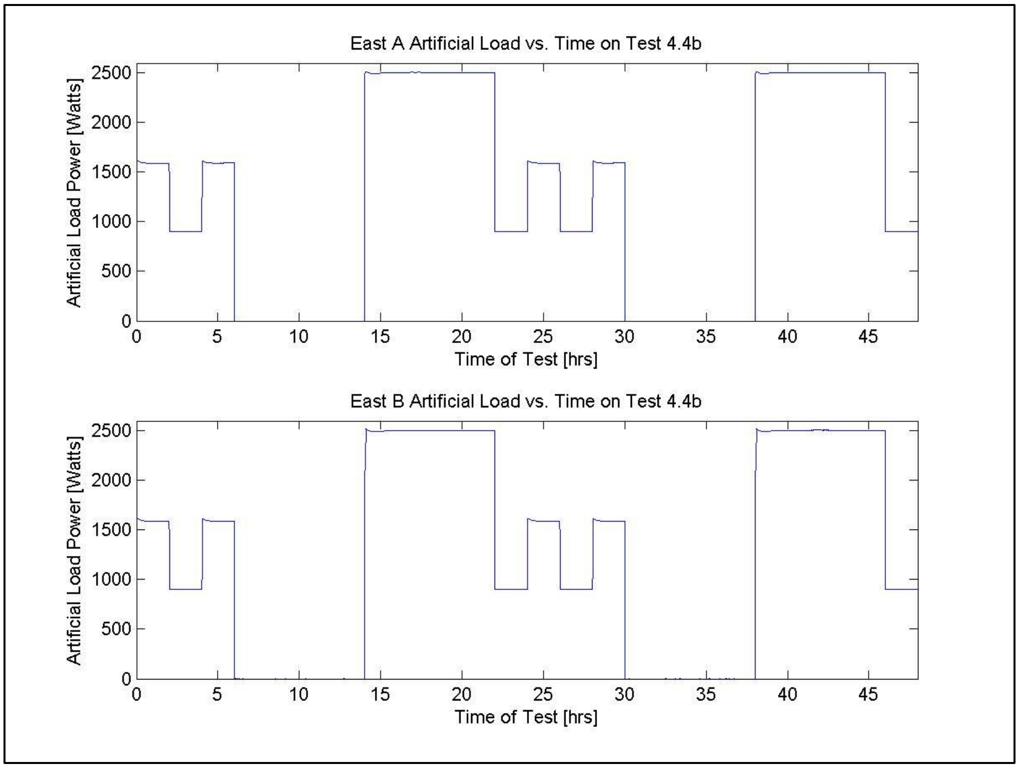
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 40.77022 |
| | variance | 189.3917 |
| AHUB | mean | 37.39457 |
| | variance | 83.86508 |
| difference | | 3.375646 |

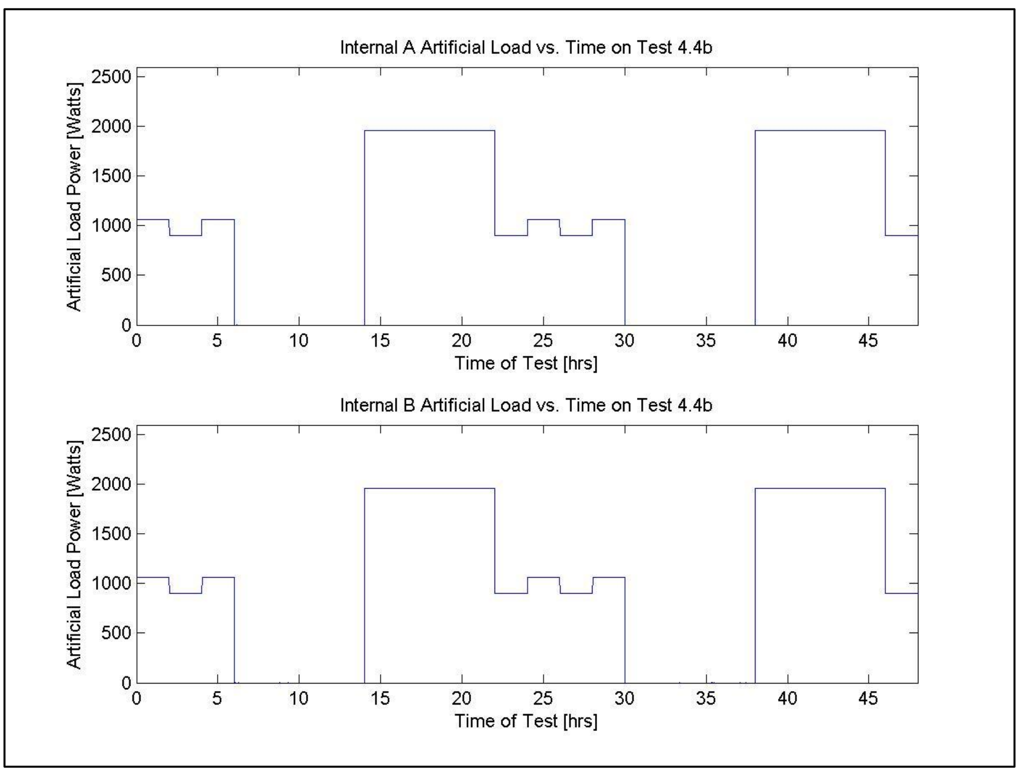
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | mean | variance |
| AHUA | East | 57.07617 | 43.99942 | 50.53779 | 85.5007 |
| | Internal | 26.16133 | 18.42592 | 22.29363 | 29.91834 |
| | South | 48.51354 | 32.37767 | 40.4456 | 130.1832 |
| | West | 54.44796 | 45.15975 | 49.80385 | 43.13541 |
| | mean | 46.54975 | 34.99069 | | |
| | Day | 1 | 2 | mean | variance |
| AHUB | East | 44.67363 | 37.92258 | 41.2981 | 22.78828 |
| | Internal | 32.13379 | 17.92563 | 25.02971 | 100.936 |
| | South | 45.40042 | 40.50713 | 42.95377 | 11.97215 |
| | West | 44.56579 | 36.02763 | 40.29671 | 36.45015 |
| | mean | 41.69341 | 33.09574 | | |

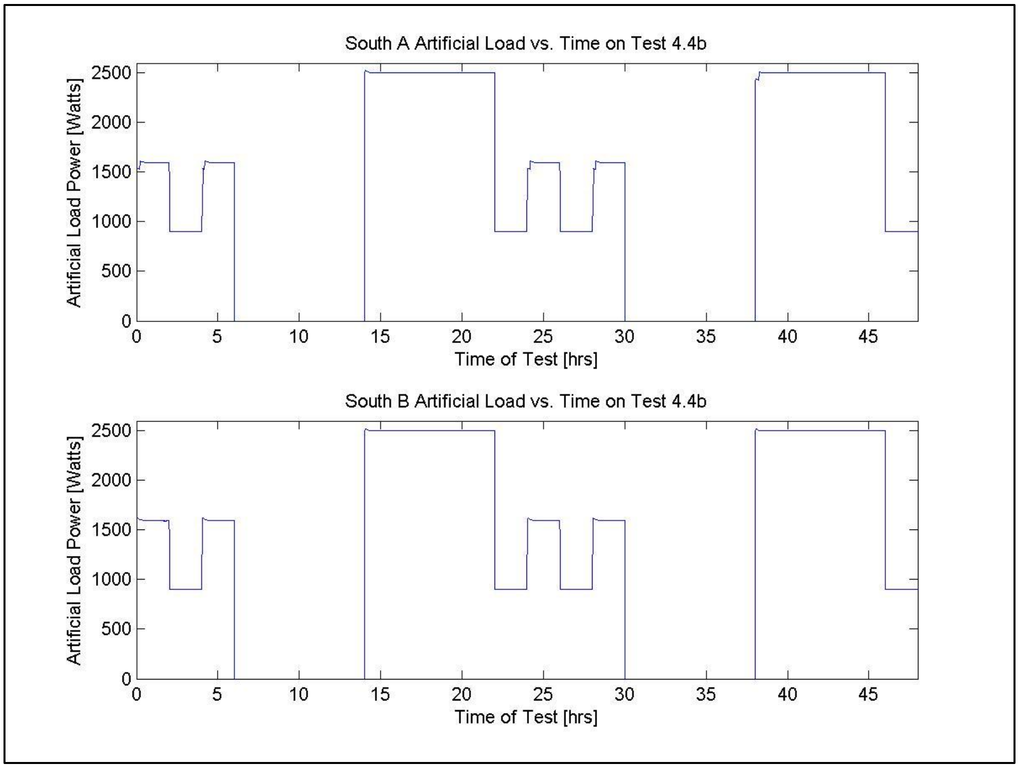
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -8.04198 |
| | variance | 1909.628 |
| AHUB | mean | -0.46089 |
| | variance | 113.4307 |
| difference | | -7.58109 |

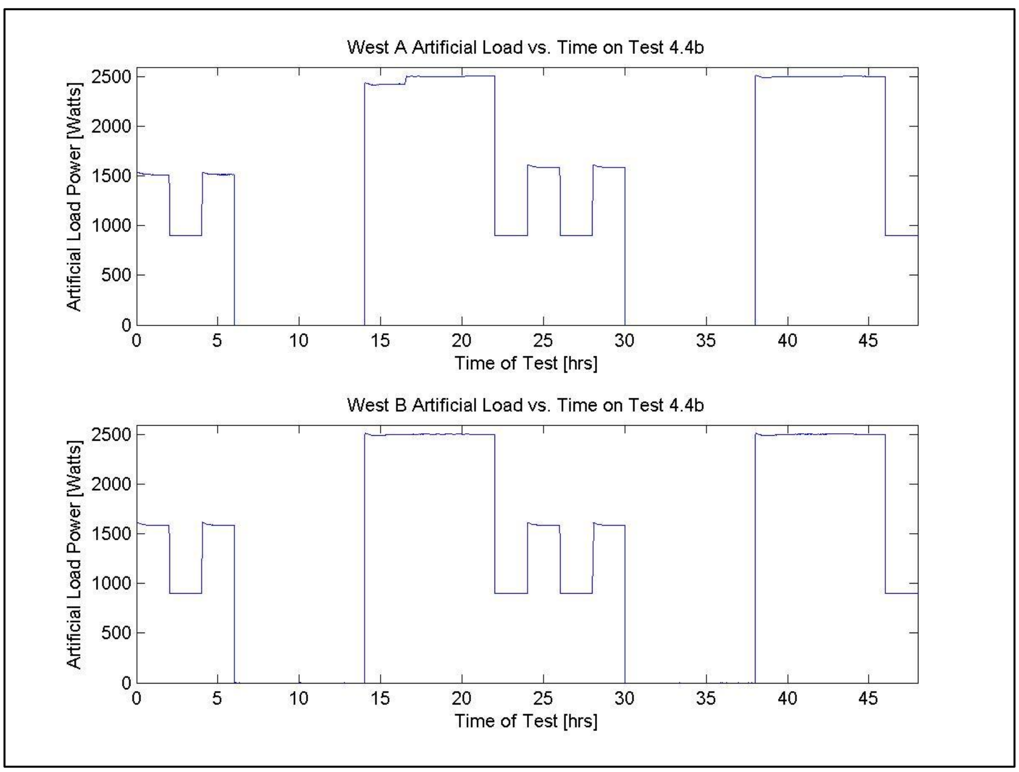
| Flow Rate Control [CFM Average] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | -14.9737 | -0.19722 | -7.58546 |
| | Internal | -11.369 | 0.040104 | -5.66445 |
| | South | -0.10469 | 0.007899 | -0.04839 |
| | West | -37.7496 | 0.01033 | -18.8696 |
| | mean | -16.0492 | -0.03472 | |
| | Day | 1 | 2 | mean |
| AHUB | East | -0.05095 | 0.020399 | -0.01528 |
| | Internal | -0.85686 | -0.01589 | -0.43637 |
| | South | -0.05078 | -0.00833 | -0.02956 |
| | West | -2.69141 | -0.03333 | -1.36237 |
| | mean | -0.9125 | -0.00929 | |

| Flow Rate Control [CFM Variance] | | | | |
|---|---|---|---|---|
| | Day | 1 | 2 | mean |
| AHUA | East | 3433.388 | 53.16697 | 1743.277 |
| | Internal | 864.118 | 13.77028 | 438.9441 |
| | South | 101.6558 | 21.55298 | 61.6044 |
| | West | 9495.959 | 40.66621 | 4768.312 |
| | mean | 3473.78 | 32.28911 | |
| | Day | 1 | 2 | mean |
| AHUB | East | 7.67E+01 | 2.19E+01 | 4.93E+01 |
| | Internal | 166.884 | 13.86718 | 9.04E+01 |
| | South | 9.75E+01 | 2.53E+01 | 6.14E+01 |
| | West | 471.782 | 27.7645 | 2.50E+02 |
| | mean | 203.2209 | 22.206 | |


East A Artificial Load vs. Time on Test 4.4b
Artificial Load Power [Watts]
Time of Test [hrs]
East B Artificial Load vs. Time on Test 4.4b
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 4.4b
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 4.4b
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 4.4b
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 4.4b
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 4.4b
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 4.4b
Artificial Load Power [Watts]
Time of Test [hrs]

# APPENDIX E: TEST SERIES 5 TABLES AND GRAPHS

## TEST 5.5f

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 35.13192463 |
| AHUB | 54.76945332 |
| % difference | -55.90% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 12.94391 | 10.98268 | 11.20533 | 11.71064 | 1.153112 |
| AHUB | 19.11389 | 17.76895 | 17.88661 | 18.25648 | 0.554822 |
| % difference | -47.67% | -61.79% | -59.63% | | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^{o}$F] | -1.67271 |
| | variance | 4.633502 |
| AHUB | mean [$^{o}$F] | -1.82679 |
| | variance | 4.739998 |
| difference | | 0.15408 |

| Temperature Control [$^oF$ Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -1.60396 | -1.83413 | -1.87212 | -1.77007 |
| | Internal | -1.22189 | -1.15228 | -1.19226 | -1.18881 |
| | South | -1.41064 | -1.81512 | -1.8272 | -1.68432 |
| | West | -2.03919 | -2.01727 | -2.08647 | -2.04764 |
| | mean | -1.56892 | -1.7047 | -1.74451 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -1.86726 | -1.94349 | -1.98909 | -1.93328 |
| | Internal | -1.35238 | -1.34692 | -1.36731 | -1.35554 |
| | South | -1.46152 | -1.83378 | -1.83421 | -1.70984 |
| | West | -2.1095 | -2.1415 | -2.67454 | -2.30851 |
| | mean | -1.69767 | -1.81642 | -1.96629 | |

| Temperature Control [$^oF$ Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 4.848311 | 4.180625 | 4.347457 | 4.458797 |
| | Internal | 4.717095 | 4.876458 | 4.753026 | 4.782193 |
| | South | 4.173302 | 4.163415 | 4.26967 | 4.202129 |
| | West | 4.656246 | 4.581208 | 4.757202 | 4.664886 |
| | mean | 4.598738 | 4.450426 | 4.531839 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 4.01979 | 3.892834 | 3.957601 | 3.956742 |
| | Internal | 3.96E+00 | 3.99E+00 | 3.95E+00 | 3.967097 |
| | South | 4.048176 | 4.257464 | 4.282091 | 4.19591 |
| | West | 5.61E+00 | 5.579971 | 7.63E+00 | 6.272178 |
| | mean | 4.408611 | 4.430557 | 4.954778 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.796944 |
| | variance | 0.000176 |
| AHUB | mean | 1.615111 |
| | variance | 0.00845 |
| difference | | -0.81817 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 0.789667 | 0.81225 | 0.788917 | 0.796944 | 0.000176 |
| AHUB | 1.509042 | 1.66475 | 1.671542 | 1.615111 | 0.00845 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -0.00145 |
| | variance | 0.000597 |
| AHUB | mean | -0.00045 |
| | variance | 0.000658 |
| difference | | -0.001 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | -0.00138 | -1.76E-03 | -1.22E-03 | -0.00145 |
| | variance | 0.000677 | 0.000554 | 0.000561 | |
| AHUB | mean | 6.04E-05 | -0.00129 | -1.22E-04 | -0.00045 |
| | variance | 0.000596 | 0.000698 | 0.000679 | |

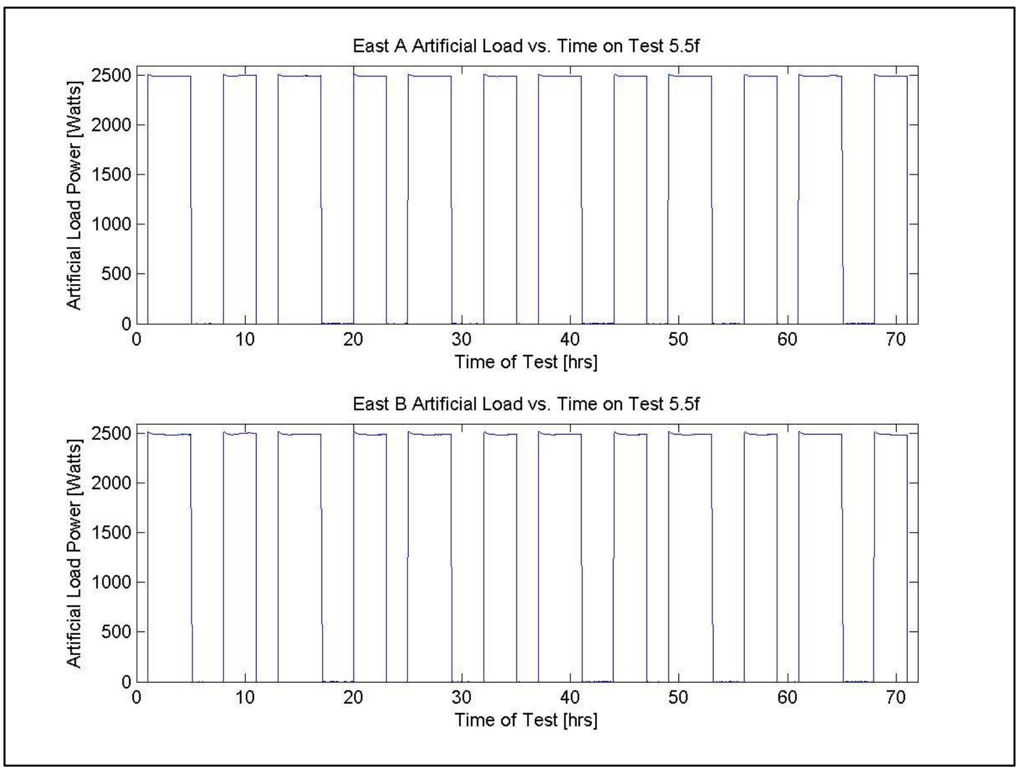
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 32.46584 |
| | variance | 19.87183 |
| AHUB | mean | 29.82643 |
| | variance | 27.27984 |
| difference | | 2.63941 |

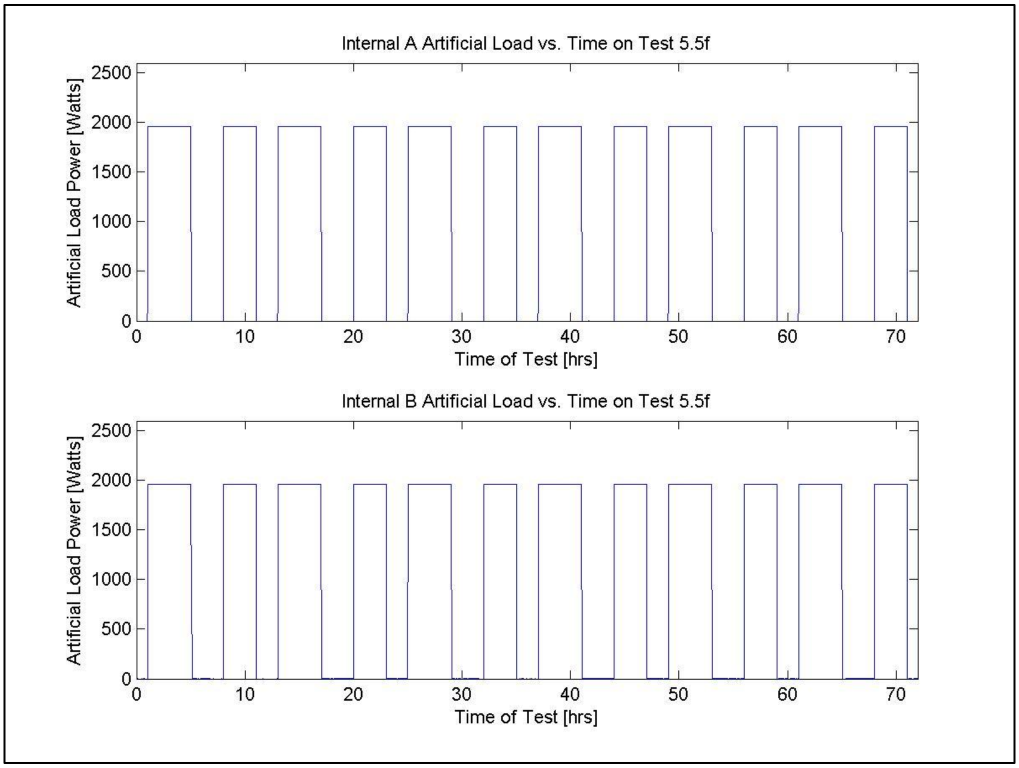
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 40.03888 | 34.44467 | 33.5715 | 36.01835 | 12.31409 |
| | Internal | 27.21788 | 29.35217 | 29.09529 | 28.55511 | 1.357647 |
| | South | 40.77367 | 34.59396 | 27.38533 | 34.25099 | 44.90009 |
| | West | 30.12763 | 30.86613 | 32.123 | 31.03892 | 1.017773 |
| | mean | 34.53951 | 32.31423 | 30.54378 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 29.55783 | 27.36567 | 26.43838 | 27.78729 | 2.566081 |
| | Internal | 24.71483 | 26.49483 | 26.91567 | 26.04178 | 1.364861 |
| | South | 36.07996 | 27.74146 | 22.59538 | 28.8056 | 46.30779 |
| | West | 36.29254 | 37.22625 | 36.49438 | 36.67106 | 0.241365 |
| | mean | 31.66129 | 29.70705 | 28.11095 | | |

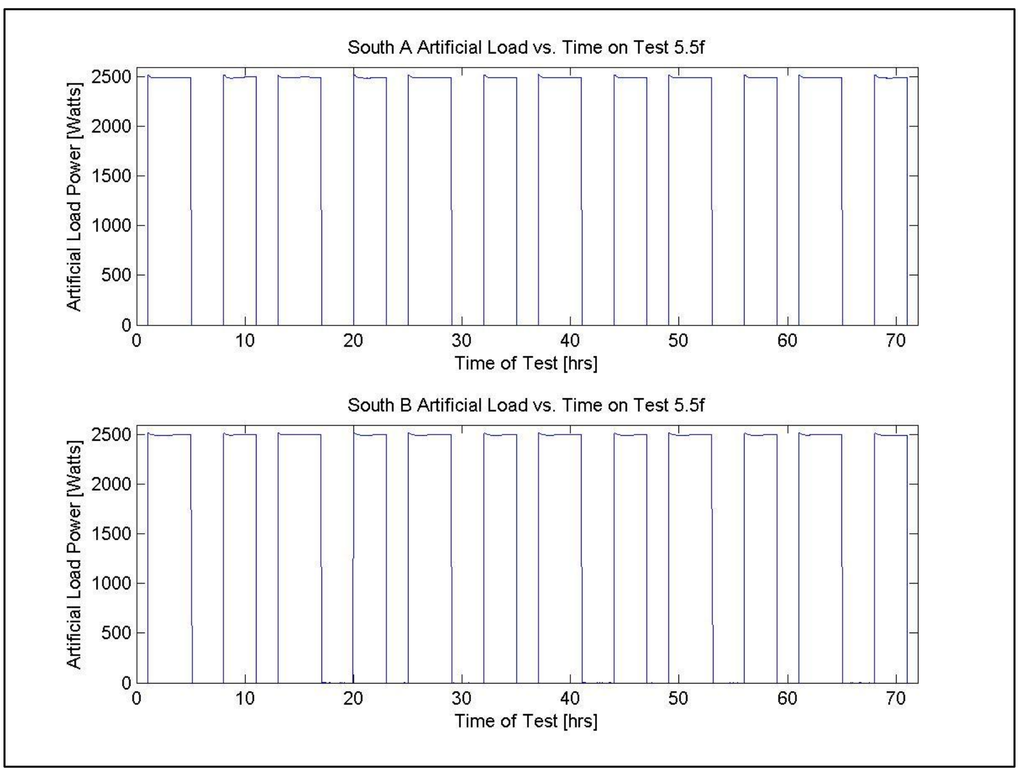
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | -4.5353 |
| | variance | 772.1749 |
| AHUB | mean | 0.019604 |
| | variance | 16.49232 |
| difference | | -4.5549 |

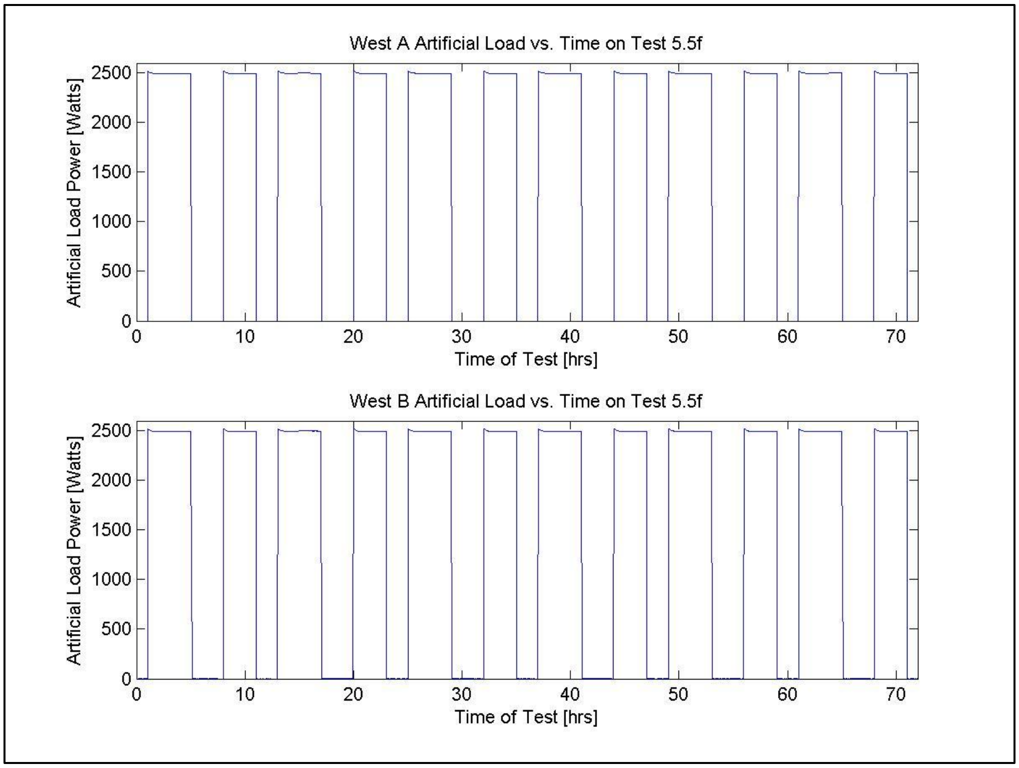
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -19.889 | -0.08576 | -0.01276 | -6.6625 |
| | Internal | -7.5178 | -12.0512 | -10.1934 | -9.9208 |
| | South | -4.73845 | 0.024219 | 0.002431 | -1.5706 |
| | West | 0.000868 | 0.035503 | 0.001736 | 0.012703 |
| | mean | -8.03609 | -3.01931 | -2.5505 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 0.08559 | 0.075868 | 0.124306 | 0.095255 |
| | Internal | 0.00599 | -0.05243 | -0.02179 | -0.02274 |
| | South | 0.059028 | -0.25139 | 0.263542 | 0.023727 |
| | West | 0.013281 | -0.07205 | 0.005295 | -0.01782 |
| | mean | 0.040972 | -0.075 | 0.092839 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 6014.887 | 23.18518 | 24.42367 | 2020.832 |
| | Internal | 523.6258 | 805.2102 | 671.1331 | 666.6564 |
| | South | 654.7429 | 16.28085 | 14.4902 | 228.5047 |
| | West | 16.9909 | 13.78341 | 16.05611 | 15.61014 |
| | mean | 1802.562 | 214.6149 | 181.5258 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.53E+01 | 1.40E+01 | 1.33E+01 | 14.21566 |
| | Internal | 13.73807 | 15.79092 | 17.40348 | 15.64416 |
| | South | 1.85E+01 | 2.16E+01 | 2.18E+01 | 20.62407 |
| | West | 14.97532 | 15.30327 | 16.1348 | 15.47113 |
| | mean | 15.64703 | 16.65502 | 17.16421 | |




Internal A Artificial Load vs. Time on Test 5.5f
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 5.5f
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]


South A Artificial Load vs. Time on Test 5.5f
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]
South B Artificial Load vs. Time on Test 5.5f
Artificial Load Power [Watts]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
Time of Test [hrs]




## TEST 5.5g

| Total Fan Consumption [kW-hr] | |
|---|---|
| Days | 1-3 |
| AHUA | 54.42497252 |
| AHUB | 34.99376257 |
| % difference | 35.70% |

| Fan Power Consumed [kW-hr] | | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | mean | variance |
| AHUA | 17.7529 | 17.88859 | 18.78349 | 18.14166 | 0.313561 |
| AHUB | 11.5088 | 11.71569 | 11.76928 | 11.66459 | 0.018921 |
| % difference | 35.17% | 34.51% | 37.34% | 35.70% | |

| Temperature Control Aggregate Values | | |
|---|---|---|
| AHUA | mean [$^oF$] | -1.78046 |
| | variance | 4.608779 |
| AHUB | mean [$^oF$] | -1.84259 |
| | variance | 4.834749 |
| difference | | 0.062138 |

| Temperature Control [$^oF$ Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | -2.00837 | -1.92396 | -1.80189 | -1.91141 |
| | Internal | -1.32383 | -1.28666 | -1.30577 | -1.30542 |
| | South | -1.88745 | -1.85121 | -1.70208 | -1.81358 |
| | West | -2.15476 | -2.02561 | -2.09387 | -2.09141 |
| | mean | -1.8436 | -1.77186 | -1.7259 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -2.17973 | -2.10085 | -1.9361 | -2.07223 |
| | Internal | -1.33381 | -1.25555 | -1.2441 | -1.27782 |
| | South | -1.88395 | -1.86726 | -1.66866 | -1.80662 |
| | West | -2.01338 | -1.82913 | -2.79859 | -2.2137 |
| | mean | -1.85272 | -1.7632 | -1.91186 | |

| Temperature Control [$^oF$ Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 4.955437 | 4.566498 | 4.363921 | 4.628619 |
| | Internal | 4.396381 | 4.354891 | 4.356941 | 4.369404 |
| | South | 4.503073 | 4.311024 | 4.144567 | 4.319555 |
| | West | 4.97537 | 4.572336 | 4.767692 | 4.771799 |
| | mean | 4.707565 | 4.451187 | 4.40828 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 4.344038 | 4.09258 | 3.938091 | 4.124903 |
| | Internal | 4.34E+00 | 4.36E+00 | 4.47E+00 | 4.387729 |
| | South | 4.494354 | 4.337305 | 4.020798 | 4.284152 |
| | West | 5.18E+00 | 4.495604 | 7.86E+00 | 5.845158 |
| | mean | 4.589204 | 4.320664 | 5.071589 | |

| Static Pressure Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 2.051333 |
| | variance | 0.010682 |
| AHUB | mean | 1.030347 |
| | variance | 0.001517 |
| difference | | 1.020986 |

| Static Pressure Travel per Hour [inches w.g. per hour] | | | | | |
|---|---|---|---|---|---|
| Day | 1 | 2 | 3 | mean | variance |
| AHUA | 2.087333 | 2.131875 | 1.934792 | 2.051333 | 0.010682 |
| AHUB | 1.053375 | 1.052292 | 0.985375 | 1.030347 | 0.001517 |

| Static Pressure Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.000617 |
| | variance | 0.00111 |
| AHUB | mean | -0.00168 |
| | variance | 0.000877 |
| difference | | 0.002294 |

| Static Pressure Control [inches w.g.] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | mean | 0.000331 | 8.16E-04 | 7.03E-04 | 0.000617 |
| | variance | 0.001127 | 0.001167 | 0.001037 | |
| AHUB | mean | -0.00212 | -0.00171 | -1.20E-03 | -0.00168 |
| | variance | 0.000852 | 0.00088 | 0.000901 | |

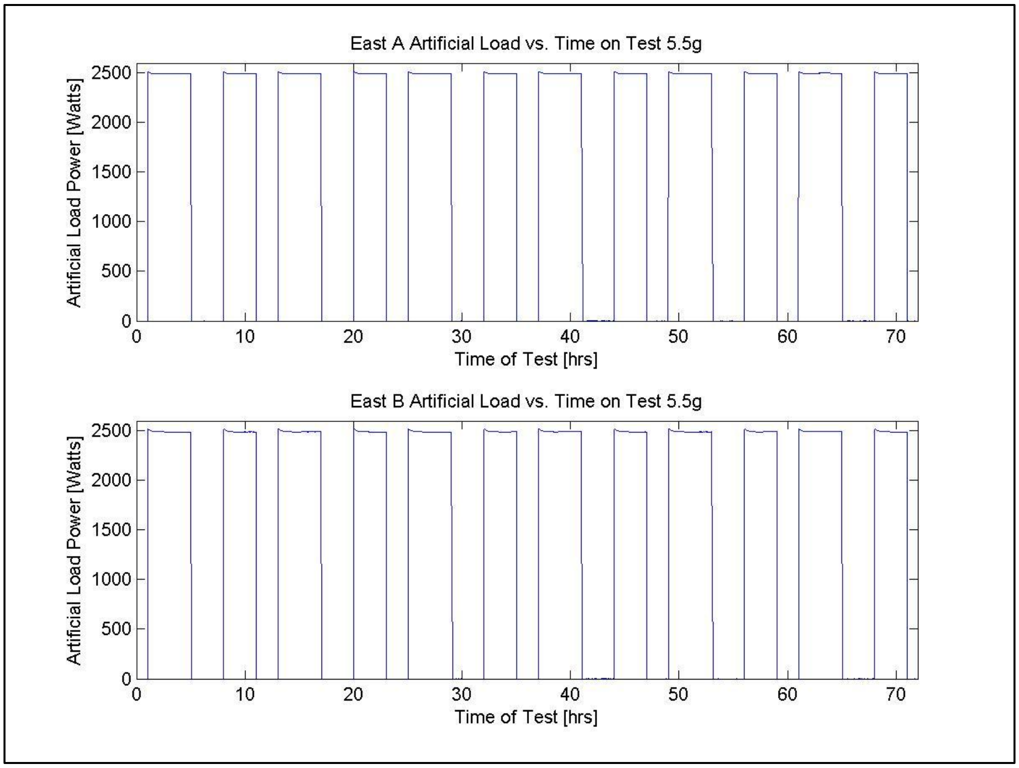
| Damper Travel Aggregate Values | | |
|---|---|---|
| AHUA | mean | 28.616 |
| | variance | 22.2862 |
| AHUB | mean | 30.82015 |
| | variance | 15.8787 |
| difference | | -2.20415 |

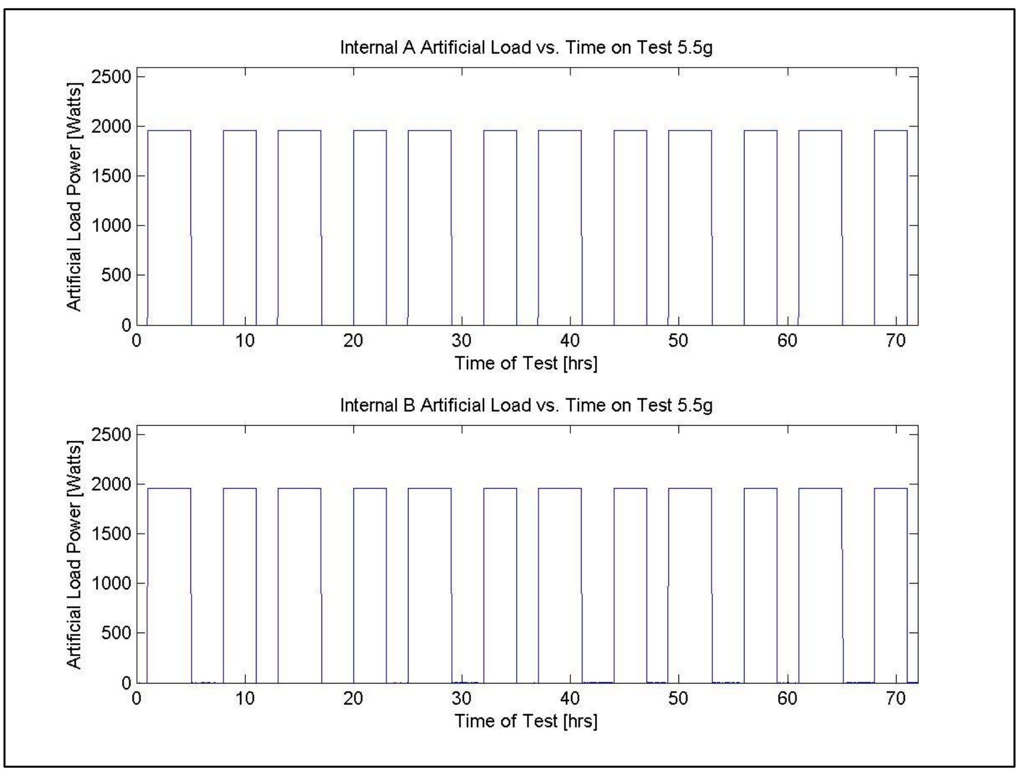
| Damper Travel per Hour [% of Maximum Damper Position per Hour] | | | | | | |
|---|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean | variance |
| AHUA | East | 26.08867 | 25.42146 | 28.79788 | 26.76933 | 3.197528 |
| | Internal | 31.73458 | 26.68654 | 35.22992 | 31.21701 | 18.44822 |
| | South | 24.44433 | 22.24275 | 37.53296 | 28.07335 | 68.32492 |
| | West | 25.72483 | 33.12733 | 26.36075 | 28.40431 | 16.83134 |
| | mean | 26.9981 | 26.86952 | 31.98038 | | |
| | Day | 1 | 2 | 3 | mean | variance |
| AHUB | East | 29.33204 | 32.6365 | 35.41842 | 32.46232 | 9.283744 |
| | Internal | 26.96629 | 28.47171 | 23.89692 | 26.44497 | 5.43601 |
| | South | 34.0805 | 33.15529 | 38.239 | 35.15826 | 7.332204 |
| | West | 28.50042 | 29.787 | 29.35767 | 29.21503 | 0.429084 |
| | mean | 29.71981 | 31.01263 | 31.728 | | |

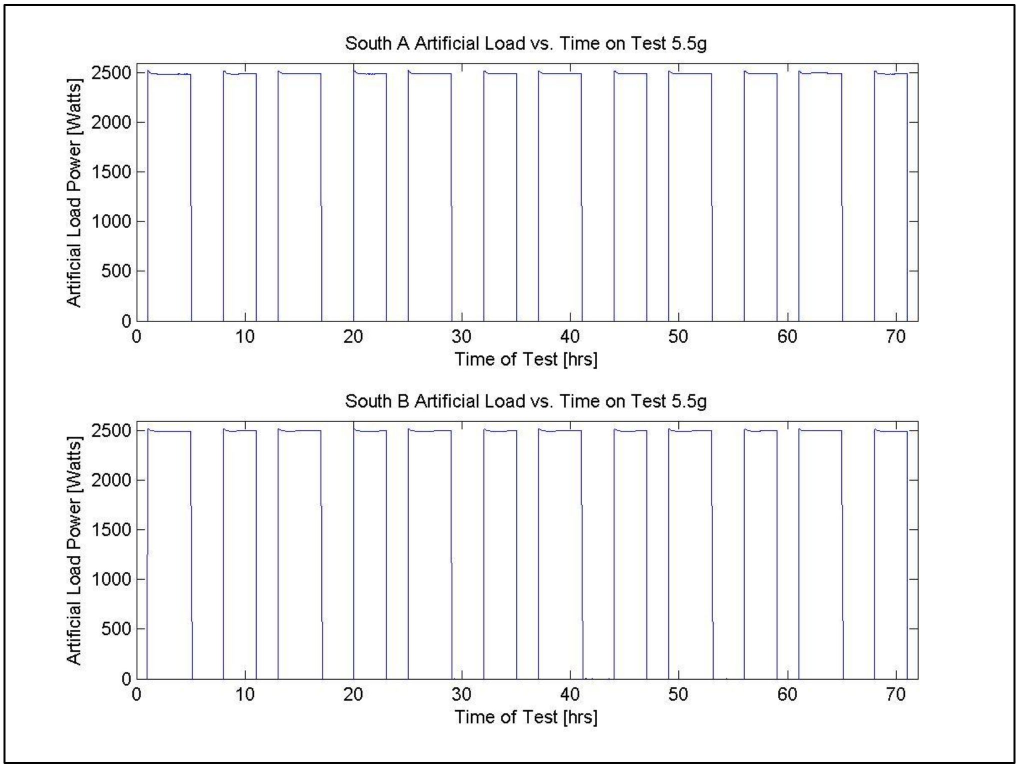
| Flow Rate Control Aggregate Values | | |
|---|---|---|
| AHUA | mean | 0.0199 |
| | variance | 28.44045 |
| AHUB | mean | -3.48764 |
| | variance | 248.4191 |
| difference | | 3.507538 |

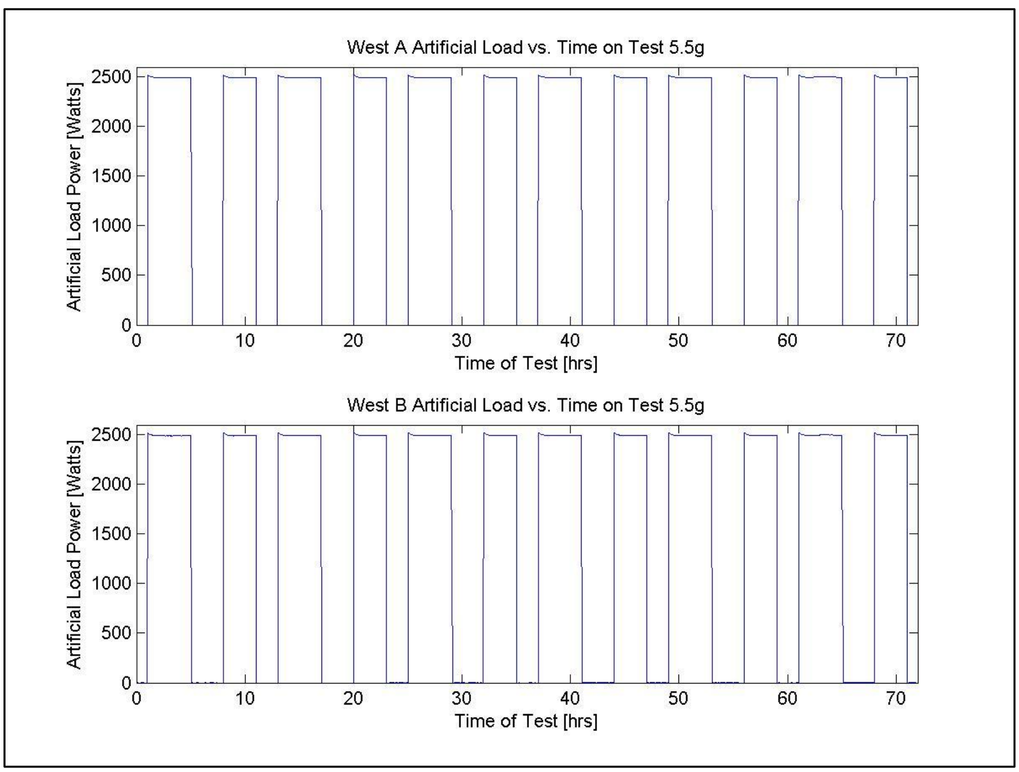
| Flow Rate Control [CFM Average] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 0.063108 | 0.28151 | -0.23993 | 0.034896 |
| | Internal | 0.03342 | 0.051215 | -0.02517 | 0.019821 |
| | South | -0.02813 | 0.091146 | -0.07109 | -0.00269 |
| | West | 0.23342 | 0.144965 | -0.29566 | 0.027575 |
| | mean | 0.075456 | 0.142209 | -0.15796 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | -0.10851 | 0.050174 | -0.0421 | -0.03348 |
| | Internal | -12.2892 | -13.4293 | -16.0691 | -13.9292 |
| | South | -0.08576 | 0.06684 | -0.03299 | -0.0173 |
| | West | -0.02995 | 0.097309 | 0.02092 | 0.029427 |
| | mean | -3.12836 | -3.30373 | -4.03082 | |

| Flow Rate Control [CFM Variance] | | | | | |
|---|---|---|---|---|---|
| | Day | 1 | 2 | 3 | mean |
| AHUA | East | 23.96145 | 22.31143 | 24.95236 | 23.74175 |
| | Internal | 49.54975 | 58.25954 | 37.40394 | 48.40441 |
| | South | 19.84585 | 19.52617 | 22.94355 | 20.77186 |
| | West | 21.87658 | 19.70007 | 20.85435 | 20.81033 |
| | mean | 28.80841 | 29.9493 | 26.53855 | |
| | Day | 1 | 2 | 3 | mean |
| AHUB | East | 1.34E+01 | 1.61E+01 | 2.18E+01 | 17.09272 |
| | Internal | 645.3543 | 771.0503 | 925.0781 | 780.4942 |
| | South | 2.39E+01 | 2.39E+01 | 4.86E+01 | 32.14707 |
| | West | 13.23111 | 16.48139 | 20.04261 | 16.58504 |
| | mean | 173.9598 | 206.8963 | 253.8832 | |


East A Artificial Load vs. Time on Test 5.5g
Artificial Load Power [Watts]
Time of Test [hrs]
East B Artificial Load vs. Time on Test 5.5g
Artificial Load Power [Watts]
Time of Test [hrs]


Internal A Artificial Load vs. Time on Test 5.5g
Artificial Load Power [Watts]
Time of Test [hrs]
Internal B Artificial Load vs. Time on Test 5.5g
Artificial Load Power [Watts]
Time of Test [hrs]


South A Artificial Load vs. Time on Test 5.5g
Artificial Load Power [Watts]
Time of Test [hrs]
South B Artificial Load vs. Time on Test 5.5g
Artificial Load Power [Watts]
Time of Test [hrs]


West A Artificial Load vs. Time on Test 5.5g
Artificial Load Power [Watts]
Time of Test [hrs]
West B Artificial Load vs. Time on Test 5.5g
Artificial Load Power [Watts]
Time of Test [hrs]