# ABSTRACT

RAPER, GARRETT MATTHEW. North Carolina Performance Enhanced Relocatable Classroom Project: An Evaluation of Design Changes to a Typical Relocatable Classroom. (Under the direction of Dr. James W. Leach and Dr. Herbert M. Eckerlin)

In this study, the energy consumption of two relocatable classrooms located on the southern portion of the campus of Chapel Hill High School in Chapel Hill, NC is investigated. One classroom, the control, was specified and purchased by the Chapel Hill-Carrboro City School System. The other is a performance enhanced classroom designed by the Florida Solar Energy Center and purchased by the North Carolina Solar Center. Both classrooms are 24’ by 40’ modular structures, completely underpinned, and located adjacent to one another for a side by side comparison. The energy consumption and indoor conditions of each classroom are monitored by a data-logging system that also records outdoor conditions via a weather station.

The performance enhanced classroom is equipped with a 3 ton, SEER 12 heat pump controlled by a Bard CS2000 unit, six skylights, increased insulation and envelope sealing, a demand control ventilation system with an energy recovery wheel, and a day lighting system controlled by occupancy sensors. The control classroom is equipped with a wall-mounted 10 kW electric furnace/air conditioning system. A programmable thermostat was also installed in the control classroom after two months of data was collected. A building model is prepared using the Energy-10 software package to estimate the impact the various design changes have on the energy consumption of each classroom.

# NORTH CAROLINA PERFORMANCE ENHANCED RELOCATABLE CLASSROOM PROJECT:  AN EVALUATION OF DESIGN CHANGES TO A TYPICAL RELOCATABLE CLASSROOM

By

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# DEDICATION

This thesis is dedicated to my mother and father, whose love and guidance followed me and focused my efforts every step of the way.  Their commitment to me and my education have truly made this thesis possible.  Thanks Mom and Dad, I love you both!

# BIOGRAPHY

Garrett Matthew Raper was born in Concord, NC on December 30, 1980. After living in Kannapolis for several years, he and his family moved to nearby China Grove, NC in 1984. He received his primary and secondary education in the Rowan-Salisbury School System. In May of 1999, he graduated from South Rowan High School as the Salutatorian and was accepted to attend North Carolina State University. His interest in all things mechanical, especially automobiles, inspired him to major in Mechanical Engineering. In May of 2003, he graduated Cum Laude with a Bachelor of Science in Mechanical Engineering from North Carolina State University.

After graduation, he worked as a research assistant with the Industrial Assessment Center performing energy assessments at manufacturing facilities recommending measures to reduce energy consumption and cost, reduce waste, and improve productivity. In August 2003, he began his education in the Mechanical Engineering Graduate program at North Carolina State University and continued his work with the Industrial Assessment Center. While in the Mechanical Engineering Graduate program, he studied thermodynamics and heat transfer.

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Also, recognition is due to both the North Carolina Solar Center and the Florida Solar Energy Center for their support of the project. A special thanks is due Danny Parker, Stephanie Thomas-Rees, and John Sherwin from the Florida Solar Energy Center for instrumenting the classroom and making the data available online. I also wish to thank Mr. Kurt Creamer for his work setting up the project and helping adjust the systems. The Roger Carter Corporation’s cooperation in constructing the performance enhanced classroom was invaluable to the success of the project.

The cooperation of the Chapel Hill-Carrboro City School System as well as Chapel Hill High School was critical to the completion of this project. Special recognition of Assistant Principals Jeff Thomas and Mervin Jenkins is warranted for their help with any questions during the project and allowing access to their school campus. Special thanks is also given to Pat Lewis and David Miller, the teachers in the classrooms, who allowed unrestricted access to their classrooms and answered any questions that were encountered about the classrooms during the study period.

The guidance of Dr. James Leach and Dr. Herbert Eckerlin is greatly appreciated. Their guidance was critical to the successful completion of this project. Both were available to answer any and all questions that I had regarding the project and to discuss the complications along the way. And finally, I would like to acknowledge the efforts of Mr. Stephen Terry for his help in setting up additional data-logging equipment and for his help in analyzing the project data.

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## 1.0 OBJECTIVE

The purpose of this project is to compare the operating costs of a standard relocatable classroom as purchased by a local school system to that of a performance enhanced relocatable classroom within the climate of central North Carolina. Modifications to the performance enhanced relocatable classroom, including those made to the HVAC, lighting, and building envelope, were designed to either reduce the energy consumption of the classroom or improve the learning environment for the occupants when compared to the standard relocatable classroom. Although the environmental concerns are as highly important to the school system as operating costs, this project focuses primarily on the energy component of the performance enhanced relocatable classroom. The end result of this project is an estimate of the impact on energy consumption and operating costs attributed to each of the modifications based on both measured data and a building model.

## 2.0 INTRODUCTION

In school systems throughout North Carolina and other states, the installation of relocatable classrooms has become common practice. Estimates indicate that one-quarter of the schools within the United States are overcrowded[1], a fact that, compounded by the current initiatives to reduce class size, has resulted in the need for more classrooms than are currently available [1]. Many school systems are utilizing relocatable classrooms to alleviate this problem. Advantages to relocatable classrooms include the minimization of classroom disruption because of their ability to be delivered and installed with relative speed, they can often be installed during academic school year breaks such as the summer, and they are

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[1] A facility is considered overcrowded when the number of pupils exceeds 105% of the capacity of the permanent structures on campus [1].

usually less costly than permanent structures [2]. The relocatable classroom is often intended as a temporary solution until permanent facilities are constructed, but the units are seldom removed and often become permanent [3].

The Modular Building Institute, a trade association for the Commercial Factory-Built Structures Industry, estimates that 220,000 relocatable units are utilized by public schools throughout the United States [2]. According to data collected in 1999, relocatable classrooms are located at 36% of the nation's schools [1]. The relocatable classrooms utilized in this study are among the ten located at Chapel Hill High School in Chapel Hill, North Carolina. The Chapel Hill-Carrboro City School System, of which Chapel Hill High School is a part, utilized 42 relocatable classrooms throughout its school district during the 2003-2004 school year [4].

The large number of relocatable classrooms makes their design with regard to energy efficiency while also keeping initial costs as low as possible important. Some school systems specify the buildings to be constructed as inexpensively as possible, seeing them as a temporary solution to the problems created by overcrowding and reduced class sizes. Other school systems specify marginally more efficient systems in an effort to reduce operating costs. However, as temporary relocatable classrooms evolve into permanent fixtures, the initial cost savings realized by installing less efficient systems may be overshadowed by the increased operating costs of a less costly constructed classroom. In addition to being large energy users, relocatable classrooms are often blamed for indoor air quality problems and are perceived as a sub-standard learning environment [3]. As these classrooms become even more prevalent at schools nationwide, the issues surrounding life-cycle costs and public perception must be addressed through more energy efficient and learning conducive designs while maintaining the portability, low maintenance, and relative low costs of the current designs.

## 2.1 PROJECT BACKGROUND

This thesis project is conducted by the North Carolina Solar Center (NCSC) in partnership with the Florida Solar Energy Center (FSEC). Sponsorship for the project is provided by the State Energy Office of North Carolina, the Department of Energy (DOE), and the National Association of State Energy Officials (NASEO). FSEC has designed a series of performance enhanced relocatable classrooms and has previously installed them in both the warm climate of Florida and the cold climate of New York. Looking for an intermediate climate in which to test their design, such as that provided by central North Carolina, FSEC agreed to place a unit in Chapel Hill, NC, and work with the NCSC to help investigate the design. The two centers work independently of one another to evaluate the project in North Carolina. Additionally, FSEC continues to monitor their designs in both New York and Florida.

The project evaluates the design of the performance enhanced relocatable classroom when compared to a control, a standard relocatable classroom as purchased by the Chapel Hill-Carrboro City School System. It is important to note that specifications of relocatable classrooms vary widely across the state of North Carolina, and the measured results herein are specific to the particular control classroom’s design. Modifications to the enhanced classroom are intended to reduce the energy consumption, improve indoor conditions, or both as compared to the control unit.  The impact of these modifications will depend greatly upon the specific design of the control classroom.

Although of great importance, the design changes intended to improve the learning environment of the control classroom are not within the scope of this thesis or its ability to measure results.  An evaluation of these design changes would require far more investigation than has currently been completed.  This thesis will focus primarily on the design changes intended to improve the relocatable classroom's energy efficiency.  The result is an estimate of the impact of each design change based upon measured data as well as a building model prepared using the Energy-10 software package.

## 2.2  PROJECT DESCRIPTION

Two relocatable classrooms are located in Chapel Hill, NC, on the southern portion of Chapel Hill High School's campus.  The classrooms are part of a ten-unit cluster located at the school.  Classroom 10 is a standard relocatable classroom specified and purchased by the Chapel Hill-Carrboro City School System.  Classroom 9 is a performance enhanced relocatable classroom designed by FSEC and purchased by the NCSC.  The two relocatable classrooms are located adjacent to one another for a side-by-side comparison, as depicted in Figure 2.2.1.  Each relocatable classroom is a 24' by 40' modular structure, completely underpinned, and with a wall mounted HVAC system.  The particular specifications of each classroom are depicted in Table 2.2.1.  The impacts of these differences with regard to the energy consumption of the two classrooms are discussed in upcoming sections.

Classroom 10 - Control

Classroom 9 - Experimental

**Figure 2.2.1: Units Located Side-by-Side**

Some of the key features of the performance enhanced classroom are within its HVAC system. The experimental classroom is equipped with a 3 ton, SEER 12 heat pump that is more efficient than the 10 kW electric furnace/air conditioner found on the control classroom. Additionally, the heat pump is equipped with a demand control ventilation system and an energy recovery wheel. The system is controlled by the Bard CS2000 occupancy sensor, which also controls the setback temperatures of the classroom during unoccupied periods. Building construction modifications that include more insulation, better envelope sealing, low-e glazing, and lighter roofing tiles help to lower the load on the HVAC system.

### Table 2.2.1: Building Construction Comparison [3]

| Characteristic | Standard Relocatable | PERC |
|---|---|---|
| Floor Insulation | R-11, standard | R-15 Formaldehyde Free |
| Wall Insulation | R-11, standard | R- 15 Formaldehyde Free insulation w/ R-7 isocyanurate |
| Exterior Door | Honeycomb core R= 1.626 | Polystyrene core R= 4.8 |
| Ceiling Insulation | R- 19 batt insulation | R-38 blown |
| Roof | Dark colored asphalt shingle | Light colored asphalt shingle w/ Techshield radiant barrier decking by Louisiana Pacific |
| Windows | Single pane, aluminum frame (U= 1.10, SHGC= 0.86, Vt=0.90) | Low-E Argon gas filled, vinyl framed by Reynolds 200 Series (U=0.35, SHGC = 0.38, Vt=0.58) |
| Lighting | 16 fixtures @ (2) T12 34W lamps; 16 ballasts; Other: Bathroom (1) 60W incandescent bulb plus (2) outdoor lights @ 60W | 10 fixtures @ (3) T8 32W lamps; 20 ballasts; Other: Bathroom (1) 13W CFL plus (2) outdoor lights @ 13W CFL |
| Light Controls | Manual | Sensor switch photosensor controls continuous dimming ballast with manual override |
| Outdoor Light | Manually controlled | Photosensor controlled |
| Skylights | None | (6) SunOptics Skylights |
| Interior Floor Finish | Roll carpeting | Non-permeable backing, Interface Cubic carpet tile, low VOC glue |
| Interior Wall Finish | Vinyl covered gypsum | Harmony Low Odor Latex Paint |
| Heating System | 10 kW electric resistance heat strip | Bard SH Series Heat Pump, HSPF 7.5, 5 kW auxiliary heat strip |
| Cooling System | Bard WA423A1D Air Conditioner | 3 ton Bard SH Series Heat Pump with ERV, SEER 12, SH381-A1DR |
| Ventilation System | Fixed CFM during occupancy | CO 2 control for ventilation with 3-step fan speed with ERV |
| HVAC controls | Manual t-stat; replaced with a Honeywell Model CT8602C 7-day programmable unit in March, 2004 | Bard CS2000 Energy Monitor |
| Bathroom Exhaust Fan | Broan, 4 sone, 100 CFM | Broan Ultrasilent model #S80LU, 0.3 sone, 50 CFM |
| Duct Leakage | CFM25out = 197 | CFM25out = 182 |
| Building Leakage | ACH50 = 9.08 | ACH50 = 4.83 |

Another outstanding feature of the experimental classroom is the integration of the lighting system with the skylights. Ten three bulb, continuously dimmable, T8 fixtures replace the sixteen two bulb, T12 fixtures in the control classroom. Six skylights provide natural light from the sun during daylight hours. A photocell senses the amount of sunlight gained through the skylights and allows the T8 fixtures to be dimmed, maintaining a consistent level of light at the desktops while reducing energy consumption. Occupancy sensors are also employed to ensure the lights are turned off during unoccupied periods.

Both classrooms are connected to a data-logging system, part of which is depicted in Figure 2.2.2, that collects data at fifteen-minute intervals. The data-logger transmits the results from the previous day to FSEC each morning via a telephone modem. This data is posted to a website accessible at http://www.logger.fsec.ucf.edu/cgi-bin/wg40.exe?user=baihppsp.

**Figure 2.2.2: Data-Logging System, Control Classroom**

The data-logging system was installed in October of 2003; however, usable data was not available until December of the same year because of small adjustments required to the classrooms' systems.  The data set used for the calculations in upcoming sessions utilizes data collected during the 2004 calendar year, unless otherwise specified.

Average Watts over fifteen-minute intervals are recorded by the data-logging system using amperage readings from current transducers and voltage measurements taken in the individual classroom's breaker box.  Thermocouple wires are used to record the temperature of the supply air, return air, crawl space, attic, lighting fixture, and thermostat area in each relocatable classroom at every fifteen-minute interval.  Additional temperatures are measured in the top and bottom of the skylight openings in the experimental classroom for each interval.  The data-logger also records the indoor lighting level (lux/m$^2$), $CO_2$ concentration (ppm), and relative humidity (%) in each classroom at every interval.  An outdoor weather station mounted to the side of the experimental classroom is pictured in Figure 2.2.3.  This unit transmits the outdoor temperature, relative humidity, wind speed, and solar insolation to the data-logger at each interval.

**Figure 2.2.3:  Weather Station**

The control classroom is utilized to teach English and literature classes while the experimental classroom is utilized to teach mathematics. These differences are the primary reason that design changes intended to improve the learning environment of relocatable classrooms cannot be analyzed with the current data set. Later sections will also show how the differing uses may effect the energy consumption of the individual classrooms.

## 3.0 MEASURED RESULTS

The data-logging system records the electrical energy consumption of four circuits within each classroom: the total usage of the classroom as well as the individual usage of the HVAC, lighting, and domestic hot water systems. The electrical energy consumption of the remaining circuits represents the plug loads, the consumption of the equipment connected to the classroom's wall sockets, and is calculated by the difference between the total consumption of the classroom and the sum of the other three monitored circuits. Table 3.0.1 and Table 3.0.2 illustrate the data collected by the data-logger during the 2004 calendar year.

**Table 3.0.1: Experimental Measured Electrical Energy Use**

| Month | Experimental – Classroom 9 | | | | |
|---|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Lights (kWh) | Hot Water (kWh) | Plug Loads[*] (kWh) |
| **Jan**[**] | 1,243 | 1,004 | 136 | 29 | 74 |
| **Feb** | 791 | 580 | 109 | 29 | 73 |
| **Mar** | 576 | 342 | 119 | 27 | 88 |
| **Apr** | 473 | 283 | 70 | 23 | 97 |
| **May** | 633 | 451 | 81 | 20 | 81 |
| **Jun** | 481 | 351 | 40 | 16 | 74 |
| **Jul** | 446 | 377 | 8 | 13 | 48 |
| **Aug** | 647 | 451 | 85 | 17 | 94 |
| **Sep** | 644 | 410 | 123 | 18 | 93 |
| **Oct** | 520 | 240 | 140 | 21 | 119 |
| **Nov** | 551 | 325 | 112 | 22 | 92 |
| **Dec** | 966 | 731 | 97 | 26 | 112 |
| **Tot** | 7,971 | 5,545 | 1,120 | 261 | 1,045 |

[*] **Values Not Directly Measured by the Data-Logging System**
[**] **Period Prior to Adjustment of Dimming Control System**

The data in Table 3.0.1 for January is prior to the adjustment of the dimming control system for the lights. When installed, the settings on the dimming control relay for the dimmable T8 fixtures were adjusted to settings indicated by the manufacturer's setup sheet. Data indicated that the lighting level in the experimental classroom was higher than expected using these settings, and the teacher in the classroom expressed concern because of the noticeable dimming rate. The settings were adjusted to slow the dimming response as well as to provide 50 ft-candles of light at the darkest desktop. The remaining data in Table 3.0.1 reflects this change.

**Table 3.0.2: Control Measured Electrical Energy Use**

| Month | Control – Classroom 10 | | | | |
|---|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Lights (kWh) | Hot Water (kWh) | Plug Loads* (kWh) |
| **Jan**** | 2,715 | 2,556 | 105 | 34 | 20 |
| **Feb**** | 2,164 | 1,993 | 115 | 31 | 25 |
| **Mar** | 972 | 757 | 142 | 31 | 42 |
| **Apr** | 525 | 324 | 135 | 27 | 39 |
| **May** | 518 | 323 | 110 | 22 | 63 |
| **Jun** | 377 | 225 | 76 | 19 | 57 |
| **Jul** | 316 | 195 | 55 | 16 | 50 |
| **Aug** | 457 | 285 | 104 | 19 | 49 |
| **Sep** | 549 | 327 | 141 | 21 | 60 |
| **Oct** | 409 | 190 | 135 | 27 | 57 |
| **Nov** | 651 | 446 | 119 | 31 | 55 |
| **Dec** | 1,836 | 1,676 | 79 | 34 | 47 |
| **Tot** | 11,489 | 9,297 | 1,316 | 312 | 564 |

*** Values Not Directly Measured by the Data-Logging System**
**** Period Prior to Installation of the Programmable Thermostat**

The data in Table 3.0.2 for January and February is prior to the installation of the programmable thermostat in the control classroom. The HVAC system in the control classroom was operated by a manual thermostat with a sliding temperature control during this period. Initially, the teacher in the control classroom attempted to set the thermostat back manually during nights and weekends; however, the morning recovery time of the classroom was too lengthy for comfort and the thermostat remained set within a few degrees of the occupied setting during unoccupied periods.

A programmable thermostat was installed in the control classroom at the beginning of March to setback the temperature during unoccupied periods. The programmable thermostat is manufactured by the same company as the thermostat in the experimental classroom to provide as near as possible set-point control logic in each classroom. The programmable thermostat is capable of returning the classroom to the occupied temperature by the time the occupied period begins. This eliminated the uncomfortable morning recovery periods and provides a better comparison to the experimental classroom, which automatically sets itself back during unoccupied periods. The remainder of the data in Table 3.0.2 reflects the change to the programmable thermostat. Savings from the installation of this unit are estimated by a building model in a later section.

Comparing the plug loads expressed in Tables 3.0.1 and 3.0.2, it can be seen that the plug loads in the experimental classroom are significantly higher than those in the control classroom. It is speculated that part of this difference is due to the differing classes taught in each of the classrooms; the experimental classroom is used to teach mathematics while the control classroom is used to teach English and literature classes. While both classrooms are equipped with an overhead projector, it is speculated that the teacher in the experimental classroom uses the overhead projector more often than the teacher in the control classroom because of the nature of the mathematics versus English and literature curriculums. Indeed, during a day of collecting data while the classrooms were occupied, it was noted that the overhead projector was being used in the experimental classroom and not in the control.

Additionally, the experimental classroom is equipped with a CRT style computer monitor while the control is equipped with an LCD display that consumes less energy. Observations during unoccupied periods show that the computer system in the experimental classroom is commonly left operating while the system in the control classroom is shut down. These two factors appear to be the primary contributors to the plug load differences.

The matter of differing plug loads from one classroom to another is important when comparing the HVAC loads from the classrooms. The discrepancy cannot be reconciled by subtracting their difference from the experimental classroom's plug loads and adding it back to its HVAC usage. Because the classrooms are contained, closed systems, all the electrical energy consumed by equipment through the wall sockets is converted to heat and dissipated into the classroom space. The conversion efficiency of this energy to heat is 100%. The control classroom is equipped with a 10 kW electric furnace that is also essentially 100% efficient. Any heat from equipment within the classroom space such as lights, overhead projectors, and computers reduces the power the HVAC system must provide to heat the control classroom by the amount of electrical energy consumed by this equipment. This is true because the conversion efficiency of electrical energy to heat is the same for all of these, 100%.

However, space heating in the experimental classroom is provided by a heat pump. Heat pumps have the ability to supply the classroom with more energy in the form of heat than they consume in electrical energy. This makes the efficiency of the heat pump, commonly referred to as the coefficient of performance (COP), higher than 100%. Because the heat from energy consumed by equipment within the classroom is produced at a lower efficiency than can be provided by the HVAC system, the total consumption of electrical energy within the experimental classroom is higher than it would be if all the heat were provided by the

HVAC system. The reason the plug loads cannot be reconciled by simply subtracting the difference from the experimental classroom's plug loads and adding it back to the HVAC usage is the differing efficiencies.

A similar case is true during the cooling season, except the heat created by the equipment within the building must be removed by the air conditioner. Like a heat pump, an air conditioner can remove more heat from the classroom than it consumes in electrical energy; however, since both classrooms are equipped with air conditioning units, the difference in the plug loads is less significant. Additionally, because the experimental classroom's air conditioning unit is more efficient than the control's, the difference is even less significant than if the two units were the same efficiency.

## 3.1 MEASURED ENERGY AND COST SAVINGS

Table 4 lists the energy savings of the experimental classroom for each of the measured circuits. Negative values indicate that the control classroom used less energy than the experimental. Both the experimental and control classrooms are on Duke Power's Schedule G (NC) General Service rate schedule. At their current levels of usage under this rate schedule, the classrooms are not billed for demand and are charged 9.6487 cents per kWh [5].

**Table 3.1.1: Summary of Measured Energy Savings**

| Month | Experimental Savings | | | | |
|---|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Lights (kWh) | Hot Water (kWh) | Plug Loads (kWh) |
| **Jan** | 1,472 | 1,552 | -31 | 5 | -54 |
| **Feb** | 1,373 | 1,413 | 6 | 2 | -48 |
| **Mar** | 396 | 415 | 23 | 4 | -46 |
| **Apr** | 52 | 41 | 65 | 4 | -58 |
| **May** | -115 | -128 | 29 | 2 | -18 |
| **Jun** | -104 | -126 | 36 | 3 | -17 |
| **Jul** | -130 | -182 | 47 | 3 | 2 |
| **Aug** | -190 | -166 | 19 | 2 | -45 |
| **Sep** | -95 | -83 | 18 | 3 | -33 |
| **Oct** | -111 | -50 | -5 | 6 | -62 |
| **Nov** | 100 | 121 | 7 | 9 | -37 |
| **Dec** | 870 | 945 | -18 | 8 | -65 |
| **Tot** | 3,518 | 3,752 | 196 | 51 | -481 |

During the 2004 calendar year, the experimental classroom’s overall energy consumption was 3,518 kWh less than the control classroom, a 30.6% reduction in energy use. This equates to a total cost savings of $339.44 for this time period. Measured results from the HVAC system indicate savings of 3,752 kWh and $362.02 in the experimental classroom, a 40.4% reduction. The day lighting and T8 conversion resulted in savings of 227 kWh and $21.90 after the controls were adjusted in January, a savings of 18.7%.

Table 3.1.1 indicates that the experimental classroom actually uses more energy during the months dominated by air conditioning loads than does the control classroom. There are several explanations that together may explain this finding. One is that there is more ventilation in the experimental classroom than in the control. ASHRAE Standard 62-1989 indicates that classrooms should have a minimum ventilation rate of 15 cfm of outside air per occupant [6]. Studies indicate that many relocatable classrooms do not meet this minimum requirement [7].

Investigations conducted by FSEC among relocatable classrooms in Florida show that nearly all relocatable classrooms are shipped with the HVAC system's outside air dampers closed, and that these dampers are either not opened when the classrooms are installed or only opened to the minimum position of approximately 150 cfm, the equivalent rate for ten occupants [8]. Further investigations performed for a project with the North Carolina State University Industrial Assessment Center (NCSU IAC) found only six of twenty-three outside air dampers operating properly at two locations within Wake County, North Carolina [9]. These findings indicate that the control classroom's ventilation rate most likely falls below the minimum requirement.

Figure 3.1.1 shows the $CO_2$ concentration profile for a day chosen at random during the study period. The concentrations peak at 2,293 ppm in the control and 1,424 in the experimental. Since the two classrooms contain approximately the same number of occupants, this indicates that the control classroom's ventilation rate is lower than that of the experimental classroom. Table 3.1.2 illustrates the relationship between indoor $CO_2$ concentrations and ventilation rates for enclosed buildings during steady occupancy. Correlating the data from Figure 3.1.1 and Table 3.1.2, the ventilation rates for the control and experimental classrooms could be as low as five and ten cfm per person, respectively.

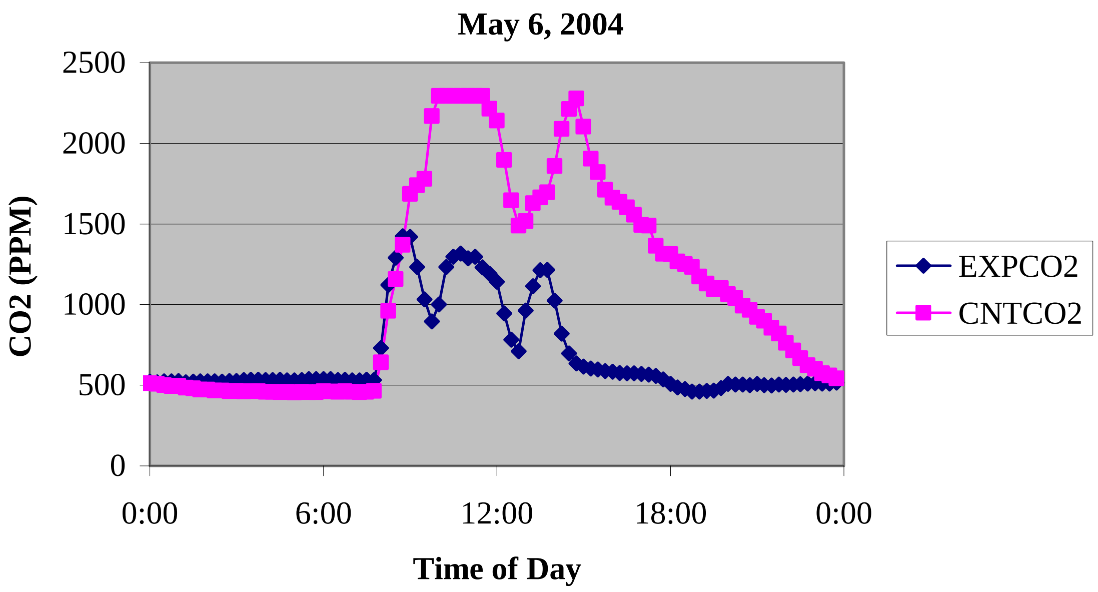

**Figure 3.1.1: Sample Day $CO_2$ Concentration**

**Table 3.1.2: Ventilation Rate and Resultant $CO_2$ Concentrations (at 350 ppm outdoor concentration) [10]**

| **Indoor $CO_2$ (ppm, approximate)** | **Outside Air Ventilation (cfm per person)** | **$CO_2$ Differential (Inside - Outside)** |
|---:|---:|---:|
| 800 | 20 | 500 |
| 1,000 | 15 | 650 |
| 1,400 | 10 | 1,050 |
| 2,400 | 5 | 2,050 |

The increased ventilation rate in the experimental classroom leads to increased energy consumption within the HVAC system to condition the outdoor air. This may explain why the experimental classroom's HVAC system consumes more energy than the control classroom during the months dominated by cooling. But why is this not observed during the heating season? As discussed earlier, the heat pump in the experimental classroom is more efficient than the electric furnace in the control classroom. More heat is added to the ventilation air in the experimental classroom than in the control during the heating season; but, because of the differences in efficiencies, the HVAC system in the experimental classroom does not consume as much energy as the control classroom's system even though it supplies more energy to the incoming ventilation air.  The difference is only apparent during the cooling months because the efficiencies of the classrooms' cooling system are more comparable than their heating systems.

Although the ventilation rate in the experimental classroom is higher than the ventilation rate in the control, both appear to be below the minimum ASHRAE recommendation.  The reasons for this as well as an estimated cost of the increased infiltration will be discussed in a later section.

In addition to an increased level of ventilation, the experimental classroom is outfitted with six skylights.  Although the skylights are glazed to reduce the amount of solar radiation that passes through them, the amount of radiation that infiltrates the room may be enough to significantly increase the cooling load during the cooling season.  However, the increased load on the cooling system may be offset by the benefits of the solar radiation during the heating season.  The Energy-10 building model will be used to investigate the skylights and their effect on the HVAC system in a later section.

Additionally, the increased internal load in the experimental classroom may contribute to the increased energy consumption of the experimental classroom's HVAC system during the cooling season.  The plug loads, discussed earlier, are significantly higher in the experimental classroom than in the control. During the cooling season, this increased energy created in the classroom must be removed by the cooling system in addition to the heat created by the occupants, ventilation, and lighting system. The difference in the plug loads is approximately 2.5 times higher than the savings from the day lighting system alone. The significance of these increased plug loads will also be investigated in an upcoming section.

## 4.0 ENERGY-10 MODEL [11]

A model of both the control and experimental classrooms was prepared using the Energy-10 software package. Because many changes were made to the design of the control classroom and the systems are interdependent upon one another, the model is used to isolate the design changes and estimate their individual impacts on the control classroom's design.

The Energy-10 software utilizes typical meteorological year (TMY) data to estimate the expected energy consumption of a specified building. Building parameters are given to the software such as building size and shape, location and orientation, infiltration and ventilation, internal gains, envelope conductance, and HVAC system type and design. The software calculates the expected energy consumption of the building and compares the results to a second building, similar to the first but specified by the software to maximize energy efficiency. This second building represents a best case scenario when specified by the software and can be modified to represent an actual building. For this project, the first building was specified as the control classroom and the second was modified to represent the experimental, performance enhanced relocatable classroom. Most of the parameters used in the software to complete the model are listed in Table 4.0.1.

**Table 4.0.1: Energy-10 Parameters**

| | **Control Classroom** | **Experimental Classroom** |
|---|---|---|
| **Location** | Chapel Hill, NC | Chapel Hill, NC |
| **North Wall** | 320 $ft^2$; R = 11.11; Solar Abs = 0.5; Orient = 0; Tilt = 90; 1 - 3040 double, wood window; 1 - foamcore door | 320 $ft^2$; R = 14.30; Solar Abs = 0.5; Orient = 0; Tilt = 90; 1 - 3040 double, low-e window; 1 - foamcore door |
| **East Wall** | 192 $ft^2$; R = 11.11; Solar Abs = 0.5; Orient = 90; Tilt = 90 | 192 $ft^2$; R =14.30; Solar Abs = 0.5; Orient = 90; Tilt = 90 |
| **South Wall** | 320 $ft^2$; R = 11.11; Solar Abs = 0.5; Orient = 180; Tilt = 90; 1 - 3040 double, wood window; 1 - foamcore door | 320 $ft^2$; R = 14.30; Solar Abs = 0.5; Orient = 180; Tilt = 90; 1 - 3040 double, low-e window; 1 - foamcore door |
| **West Wall** | 192 $ft^2$; R = 11.11; Solar Abs = 0.5; Orient = 270; Tilt = 90 | 192 $ft^2$; R = 14.30; Solar Abs = 0.5; Orient = 270; Tilt = 90 |
| **Roof** | 960 $ft^2$; R = 20, Solar Abs = 0.5; Orient = 0; Tilt = 0 | 960 $ft^2$; R = 33.33, Solar Abs = 0.5; Orient = 0; Tilt = 0; 6 - 3040 double, low-e windows |
| **Floors** | 960 $ft^2$, R = 11.11; Type = Crawl Space; f Factor = 0.4 | 960 $ft^2$, R = 14.33; Type = Crawl Space; f Factor = 0.4 |
| **Partitions** | Furniture = 500 $ft^2$; Walls (Interior) = 480 $ft^2$ | Furniture = 500 $ft^2$; Walls (Interior) = 480 $ft^2$ |
| **Infiltration** | 0.47 Air Changes per Hour | 0.25 Air Changes per Hour |
| **HVAC System** | Type = DX Cooling with Elect Furn; Output = 34,130 BTU/h, Supply Air Temperature = 85 F; Efficiency = 100%; Sensible Output 33,600 BTU/h; Total Output = 42,000 BTU/h; EER = 8.0, Supply Air Temperature = 53 F; Air Flow = 750 cfm, MOOA = 200 cfm; Autosize Off | Air Source Heat Pump/ER Backup; Output = 17,065 BTU/hr; Supply Air Temperature = 89 F; COP@47F = 3.6; COP@17F = 2.3; Capacity@47F = 33,000BTU/h; Capacity@17F = 16,500 BTU/h; Electrical Resistance = 17,065 BTU/h; Sensible Output = 28,400 BTU/h; Total Output = 35,500 BTU/h; EER = 10.8; Supply Air Temperature = 53 F; Air Flow = 1,000 cfm, MOOA = 300 cfm; Autosize Off [12] |
| **HVAC Controls** | Workday = Control Point 7AM to 4 PM, Setback Remainder; Non-Workday = Always on Setback; Occupancy = Same as Workday | Workday = Control Point 7AM to 4 PM, Setback Remainder; Non-Workday = Always on Setback; Occupancy = Same as Workday |
| **Heating Setpoints** | Comfort = 68 F, Setback/Setup = 60 F | Comfort = 68 F, Setback/Setup = 63 F |
| **Cooling Setpoints** | Comfort = 74 F, Setback/Setup = 85 F | Comfort = 74 F, Setback/Setup = 79 F |

The model assumes that each classroom is continuously occupied by 20 persons throughout the occupied periods, although this is not truly the case. Average hourly values for lighting Wattage within the model were derived from measured data within the control classroom and used for both classrooms. Savings from day lighting are estimated from these values within the experimental classroom by specifying continuously dimmable ballasts and from TMY insolation data. Hot water usage and other internal gains were computed individually for each classroom using measured data. This accounted for the experimental classroom's increased plug loads within the model.

Another important assumption within the model is a dual set-point thermostat, one that can automatically switch between cooling and heating modes. The experimental classroom is outfitted with this type of thermostat; however, a suitable dual set-point, programmable thermostat could not be found for the control classroom. The thermostat used in the control classroom must be manually switched between heating and cooling modes, representing a possible source for error in the model. Additionally, the model assumes that all weekdays are occupied, assumes the thermostat set-points are constant, and cannot account for teacher workdays and school holidays. These account for other sources of error within the model. The resulting calculations from the Energy-10 model are depicted in Table 4.0.2 for the control and Table 4.0.3 for the experimental and compared to their respective measured data.

**Table 4.0.2: Comparison of Control Classroom Model and Measured Data**

| Month | Model | | | Measured | | |
|---|---|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Lights (kWh) | Total (kWh) | HVAC (kWh) | Lights (kWh) |
| **Jan** | 1,777 | 1,586 | 119 | 2,715 | 2,556 | 105 |
| **Feb** | 1,520 | 1,347 | 108 | 2,164 | 1,993 | 115 |
| **Mar** | 840 | 649 | 119 | 972 | 757 | 142 |
| **Apr** | 684 | 487 | 126 | 525 | 324 | 135 |
| **May** | 550 | 353 | 125 | 518 | 323 | 110 |
| **Jun** | 662 | 478 | 113 | 377 | 225 | 76 |
| **Jul** | 855 | 657 | 125 | 316 | 195 | 55 |
| **Aug** | 833 | 635 | 125 | 457 | 285 | 104 |
| **Sep** | 490 | 307 | 113 | 549 | 327 | 141 |
| **Oct** | 554 | 355 | 125 | 409 | 190 | 135 |
| **Nov** | 783 | 606 | 108 | 651 | 446 | 119 |
| **Dec** | 1,573 | 1,381 | 119 | 1,836 | 1,676 | 79 |

**Table 4.0.3: Comparison of Experimental Classroom Model and Measured Data**

| Month | Model | | | Measured | | |
|---|---|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Lights (kWh) | Total (kWh) | HVAC (kWh) | Lights (kWh) |
| **Jan** | 1,283 | 1,064 | 105 | 1,243 | 1,004 | 136 |
| **Feb** | 1,127 | 930 | 95 | 791 | 580 | 109 |
| **Mar** | 527 | 310 | 103 | 576 | 342 | 119 |
| **Apr** | 598 | 379 | 105 | 473 | 283 | 70 |
| **May** | 683 | 462 | 105 | 633 | 451 | 81 |
| **Jun** | 883 | 679 | 95 | 481 | 351 | 40 |
| **Jul** | 1,067 | 846 | 105 | 446 | 377 | 8 |
| **Aug** | 1,038 | 819 | 103 | 647 | 451 | 85 |
| **Sep** | 654 | 449 | 96 | 644 | 410 | 123 |
| **Oct** | 516 | 275 | 125 | 520 | 240 | 140 |
| **Nov** | 487 | 287 | 94 | 551 | 325 | 112 |
| **Dec** | 1,106 | 886 | 107 | 966 | 731 | 97 |

## 5.0 INDIVIDUAL IMPACTS OF DESIGN CHANGES

This section discusses the individual impacts on the energy consumption of the classrooms due to the individual design changes. The measured results as well as the Energy-10 model are used to isolate the individual design changes in an attempt to estimate their impact independently of the other changes. This section also discusses, in more detail than previous sections, the design changes as well as their intended impact and unforeseen issues with the performance enhanced design, if any.

## 5.1 IMPACT OF INCREASED INSULATION AND ENVELOPE SEALING

The performance enhanced classroom is fitted with materials that better insulate and seal the building envelope. These materials also produce fewer emissions for better indoor air quality; however, these benefits are beyond the scope of this project. The wall conductance values representing increased insulation are taken from data sheets located within the classrooms. These values are presented in Table 4.0.1 along with the number of natural air changes per hour, a measurement indicating how well the classroom is sealed. The impact of the increased insulation values and better sealing with regard to the energy consumption of the control classroom are presented in Table 5.1.1.

**Table 5.1.1: Impact of Increased Insulation and Better Envelope Sealing on the Control Classroom's Energy Consumption**

| Month | Standard Insulation, Natural Air Changes per Hour = 0.47 | | Increased Insulation, Natural Air Changes per Hour = 0.25 | |
|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) |
| **Jan** | 1,777 | 1,586 | 1,273 | 1,081 |
| **Feb** | 1,520 | 1,347 | 1,090 | 916 |
| **Mar** | 840 | 649 | 568 | 376 |
| **Apr** | 684 | 487 | 560 | 363 |
| **May** | 550 | 353 | 498 | 300 |
| **Jun** | 662 | 478 | 642 | 458 |
| **Jul** | 855 | 657 | 819 | 621 |
| **Aug** | 833 | 635 | 798 | 600 |
| **Sep** | 490 | 307 | 488 | 304 |
| **Oct** | 554 | 355 | 417 | 218 |
| **Nov** | 783 | 606 | 525 | 349 |
| **Dec** | 1,573 | 1,381 | 1,154 | 963 |
| **Tot** | 11,121 | 8,841 | 8,832 | 6,549 |

The values represented in Table 5.1.1 use the building model for the control classroom, only modifying the values for the insulation and air changes per hour. As expected, the values during the months dominated by cooling do not differ significantly, while the months dominated by heating do change significantly. As discussed in previous sections, this is most likely do to the differences in the efficiencies of the heating and cooling systems. The savings for a classroom equipped with a heat pump system would be different than those expressed in Table 5.1.1. These differences will be shown in an upcoming section.

Table 5.1.1 indicates a total yearly energy savings of 21.4%. This value is likely conservative because it includes the summer months that were not typically occupied during the study period and in which little savings occur.  A reduction of this amount to the measured energy consumed during the study period would result in a yearly savings of 2,460 kWh and $237.

## 5.2  IMPACT OF T8 FIXTURES AND DAY LIGHTING

The performance enhanced relocatable classroom is fitted with ten three bulb, continuously dimmable T8 fixtures instead of the sixteen two bulb, non-dimmable T12 fixtures installed in the control classroom.  Each dimmable T8 fixture is controlled by two ballasts while each T12 fixture is controlled by a single ballast.  The experimental classroom utilizes two occupancy sensors to control the operation of the fixtures while the control classroom utilizes two standard switches, each controlling half of the fixtures.  Figure 5.2.1 shows the lighting profile from the same random day in Figure 3.1.1.

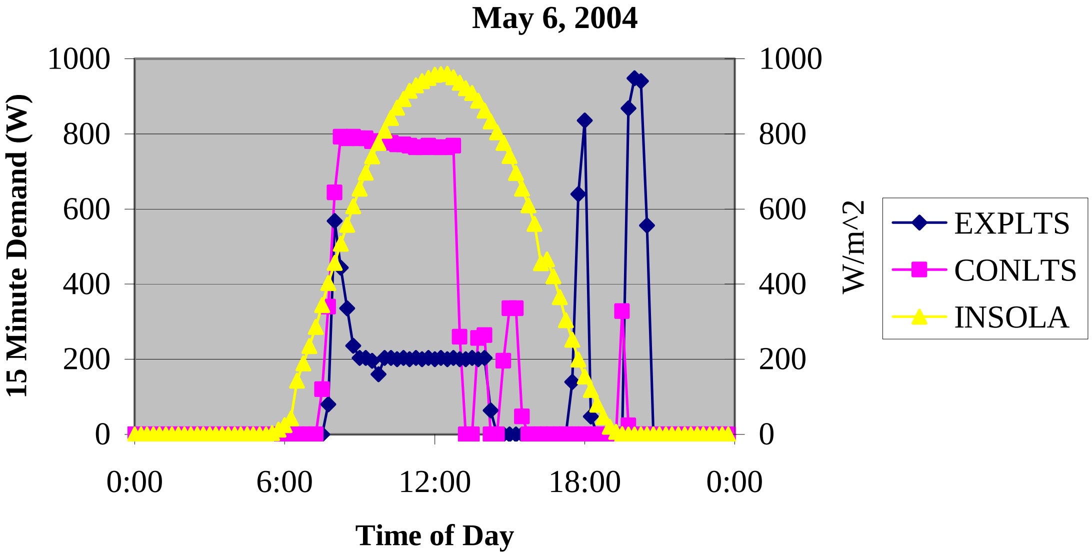

**Figure 5.2.1:  Sample Day Lighting Profile**

The performance enhanced experimental classroom is also fitted with six skylights that provide natural light during daylight hours. A photocell senses the amount of light that enters through the skylights and sends a signal to a control box which, in turn, dims the lights to maintain a constant level of lighting at the desktop. The location of this sensor as well as one of the skylights is depicted in Figure 5.2.2. When the lights are dimmed, they also use less energy than when they are fully illuminated. This can be observed in Figure 5.2.1. Additionally, the ambient light from the skylights may provide better indoor conditions that are more conducive to learning; however, the evaluation of this statement is not within the scope of this thesis project.

**Figure 5.2.2: Skylight View and Photocell Location**

Louvers located in the skylights allow the room to be darkened when necessary. The louvers are controlled by a timer pictured in Figure 5.2.3. The lights can also be dimmed or brightened with the dimming switch, also pictured in Figure 5.2.3.

**Figure 5.2.3: Dimming Switch and Louver Timer**

When initially installed, the dimming control unit was adjusted to the factory suggested settings for the classroom application. However, data showed that the lights in the experimental unit were actually using more energy than the lights in the control. Also, the teacher in the experimental classroom was concerned that the noticeable dimming rate of the lights may have been disrupting students. The control unit was adjusted at the end of January, 2004 using a hand-held photometer to provide 50 ft-candles of light at the darkest desk within the room. The dimming rate of the lights was also adjusted to provide a dimming response that was less noticeable, but slower.

Measurements indicate that the T8 fixtures utilized in the experimental classroom have a 19.7% higher demand than the fixtures in the control classroom. If the experimental unit was equipped with ten three bulb, single ballast T8 fixtures, the total demand would be 23.6% lower than the T12 fixtures in the control [13]. The only logical explanation for this difference is the ten additional ballasts utilized in the experimental classroom. Table 5.2.1 shows the results from the Energy-10 model for energy savings due to the T8 conversion and for the case of a T8 conversion utilizing single ballast fixtures. Again, these values are based upon the control classroom's design and would differ if a heat pump were used. The latter will be discussed in an upcoming section. The savings from day lighting cannot be estimated for this case because of limitations within the Energy-10 software package.

**Table 5.2.1: Impact of T8 Conversion**

| Month | 16 - 2 Bulb, T12 Fixtures, No Day Lighting | | | 10 - 3 Bulb, T8 Fixtures, 2 Ballasts per Fixture, No Day Lighting | | | 10 - 3 Bulb, T8 Fixtures, 1 Ballast per Fixture, No Day Lighting | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Total (kWh)** | **HVAC (kWh)** | **Lights (kWh)** | **Total (kWh)** | **HVAC (kWh)** | **Lights (kWh)** | **Total (kWh)** | **HVAC (kWh)** | **Lights (kWh)** |
| **Jan** | 1,777 | 1,586 | 119 | 1,779 | 1,563 | 142 | 1,775 | 1,612 | 91 |
| **Feb** | 1,520 | 1,347 | 108 | 1,529 | 1,335 | 129 | 1,510 | 1,362 | 82 |
| **Mar** | 840 | 649 | 119 | 851 | 637 | 142 | 827 | 664 | 91 |
| **Apr** | 684 | 487 | 126 | 705 | 484 | 149 | 659 | 492 | 95 |
| **May** | 550 | 353 | 125 | 581 | 359 | 149 | 513 | 345 | 95 |
| **Jun** | 662 | 478 | 113 | 693 | 488 | 136 | 622 | 465 | 87 |
| **Jul** | 855 | 657 | 125 | 891 | 668 | 149 | 812 | 643 | 95 |
| **Aug** | 833 | 635 | 125 | 869 | 646 | 149 | 790 | 622 | 95 |
| **Sep** | 490 | 307 | 113 | 521 | 315 | 136 | 452 | 296 | 87 |
| **Oct** | 554 | 355 | 125 | 578 | 355 | 149 | 526 | 357 | 95 |
| **Nov** | 783 | 606 | 108 | 795 | 597 | 129 | 768 | 617 | 82 |
| **Dec** | 1,573 | 1,381 | 119 | 1,580 | 1,365 | 142 | 1,564 | 1,401 | 91 |
| **Tot** | 11,121 | 8,841 | 1,425 | 11,372 | 8,812 | 1,701 | 10,818 | 8,876 | 1,086 |

The data in Table 5.2.1 illustrates the importance of proper implementation of T8 fixtures. The data shows that if T8 fixtures with two ballasts per fixture are installed, the energy consumption of the control classroom may actually increase. The data also denotes that more efficient lighting is not practical with electric resistance heating systems in climates dominated by heating. The best case scenario savings in Table 5.2.1 only yields a savings of $29 per year. This is true because the conversion efficiency of electrical energy to heat is 100% in both cases. Only during months with cooling loads are savings realized. The conversion to T8 fixtures will be discussed again in a later section when coupled with a heat pump.

## 5.3 IMPACT OF HIGHER EFFICIENCY HVAC SYSTEM AND CONTROLS

The performance enhanced relocatable classroom is equipped with a 3-ton, SEER 12, wall-mounted heat pump as opposed to the wall-mounted 10 kW electric furnace/air conditioning unit the control classroom utilizes. The heat pump was originally installed with 10 kW of electric resistance backup heating, but this was reduced to 5 kW before the study period began to further reduce energy consumption. It is also equipped with an energy recovery wheel designed to pre-condition ventilation air with air that is exhausted from the classroom.

The heat pump uses a demand control ventilation system that monitors indoor $CO_2$ levels. The system adjusts the speeds of the exhaust and outside air fans to control the amount of ventilation air to provide just enough ventilation for the number of current occupants. Then ventilation system does not operate the fans below about 450 ppm $CO_2$, operates them low speed between about 450 and 750 ppm, medium speed between about 750 and 1,000 ppm, and on high speed above about 1,000 ppm. A diagram of the ventilation system along with the heat recovery wheel is depicted in Figure 5.3.1. Measurements of $CO_2$ concentrations are also depicted in Figure 5.3.1.

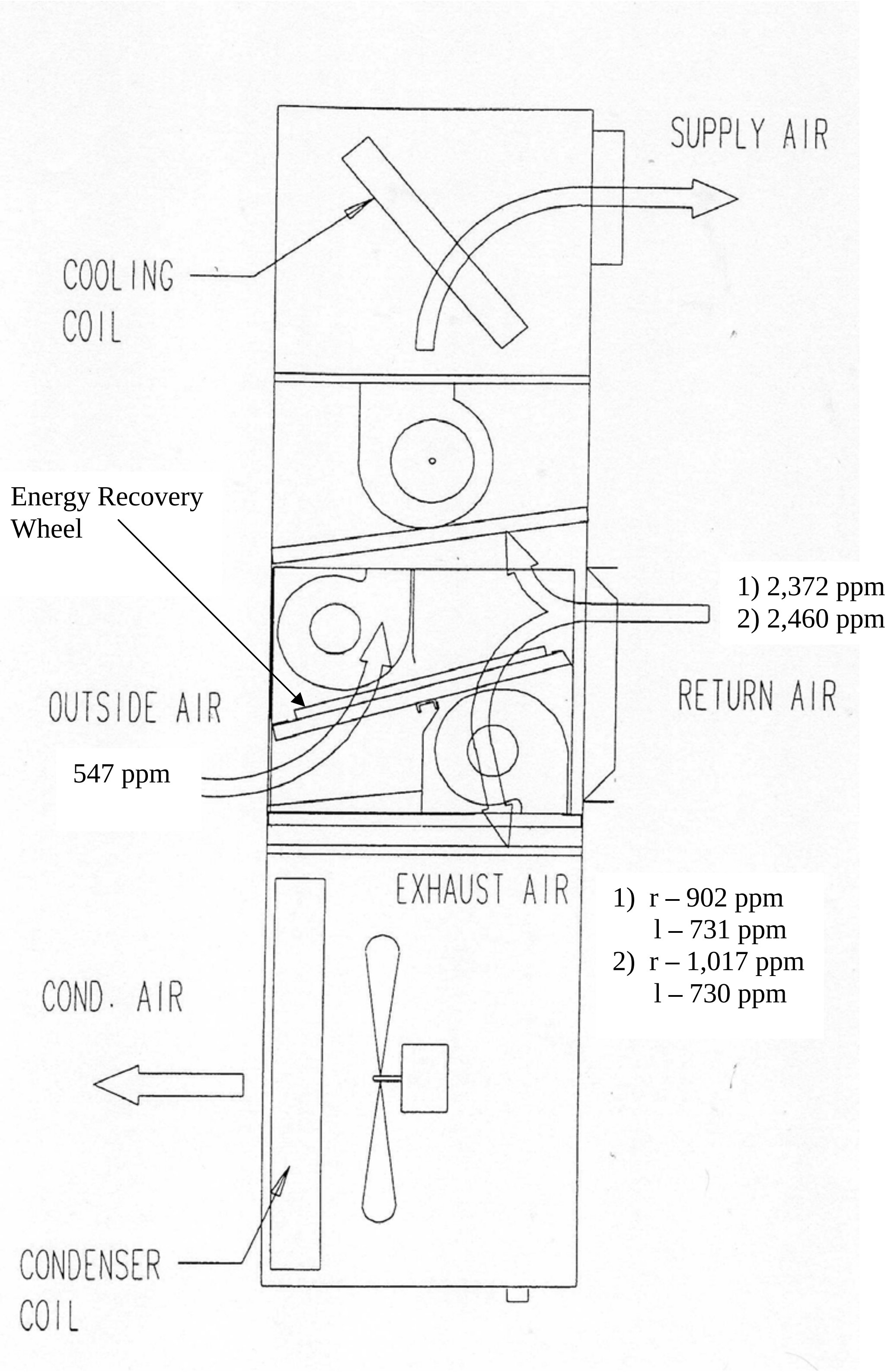

**Figure 5.3.1: Ventilation Diagram [14] With $CO_2$ Measurements**

Previous studies performed by the NCSU IAC suggest that a large portion of the outside ventilation air that enters the HVAC unit does not make its way into the classroom space, but is recirculated back out through the exhaust [9]. As depicted in Figure 5.3.1, there are no dampers in the ventilation portion of the HVAC unit to direct the flow of air. The design depends upon pressure differentials to move the air to its intended location, so, when the pressure differentials are changed, the system does not perform as designed. Figure 5.3.2 shows an air vent in the experimental classroom that has been closed. Several other vents within the classroom are also closed in an effort to help better distribute the air within the classroom. These closed vents were also documented in the control classroom, perhaps indicating an HVAC duct design flaw within both classrooms.

**Figure 5.3.2: Closed Vent in the Experimental Classroom**

Because the $CO_2$ concentration of the exhaust air is much closer to the ambient air's concentration than to the return air's concentration, it is apparent that most of the incoming ventilation air is simply exhausted and does not make its way into the classroom. This explains the higher than expected $CO_2$ concentrations found in Figure 3.1.1 for the experimental classroom.  It is speculated that the recirculation problem is caused by the altered pressure differentials due to the closed vents within the classroom.  The energy recovery wheel is probably not effective at preconditioning the outside ventilation air because of the large amount of recirculation.  Additionally, the effect of the energy recovery wheel could not be modeled using the Energy-10 software.

A Bard CS2000 unit controls the HVAC system, acting as an occupancy sensor and returning the temperature of the classroom to setback conditions when there is no movement within the classroom for a specified period of time.  The unit also handles the setback/setup temperature control for the classroom, and can learn the occupancy of the classroom eliminating the need to program the unit.  Savings from the installation of the CS2000 unit are discussed in a later section.

The Energy-10 software package is used to estimate the impact on the control classroom's energy consumption when the electric furnace/air conditioning system is replaced by a heat pump.  Table 5.3.1 illustrates the model's results for this change holding all other parameters constant.

**Table 5.3.1: Electric Furnace/Air Conditioner vs. Heat Pump**

| Month | Electric Furnace/Air Conditioner | | Heat Pump | |
|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) |
| **Jan** | 1,777 | 1,586 | 1,217 | 1,025 |
| **Feb** | 1,520 | 1,347 | 1,079 | 905 |
| **Mar** | 840 | 649 | 537 | 345 |
| **Apr** | 684 | 487 | 473 | 276 |
| **May** | 550 | 353 | 467 | 268 |
| **Jun** | 662 | 478 | 582 | 399 |
| **Jul** | 855 | 657 | 742 | 544 |
| **Aug** | 833 | 635 | 723 | 525 |
| **Sep** | 490 | 307 | 439 | 254 |
| **Oct** | 554 | 355 | 415 | 217 |
| **Nov** | 783 | 606 | 495 | 318 |
| **Dec** | 1,573 | 1,381 | 1,021 | 829 |
| **Tot** | 11,121 | 8,841 | 8,190 | 5,905 |

According to the Energy-10 model, replacing the 10 kW electric furnace/air conditioner with a 3 ton, SEER 12 heat pump reduces yearly energy consumption by approximately 26.1%. As expected, the model suggests that the greatest savings occur in the months dominated by heating. This reduction in energy consumption saves approximately $200 per year.

### 5.3.1 PROGRAMMABLE THERMOSTATS

During the first two months of the study period, the control classroom was equipped with a traditional slide-type manual thermostat. The teacher made an effort to set the temperature back nightly, however, the time the classroom took to recover to temperature each morning was too long. In the interest of comfort, the teacher stopped setting the temperature back more than a few degrees each night so the classroom would already be at conditions when she arrived. Figure 5.3.1.1 shows the temperature at the thermostat, ambient temperature, and demand curve for the HVAC system for both classrooms before the programmable thermostat was installed in the control classroom.

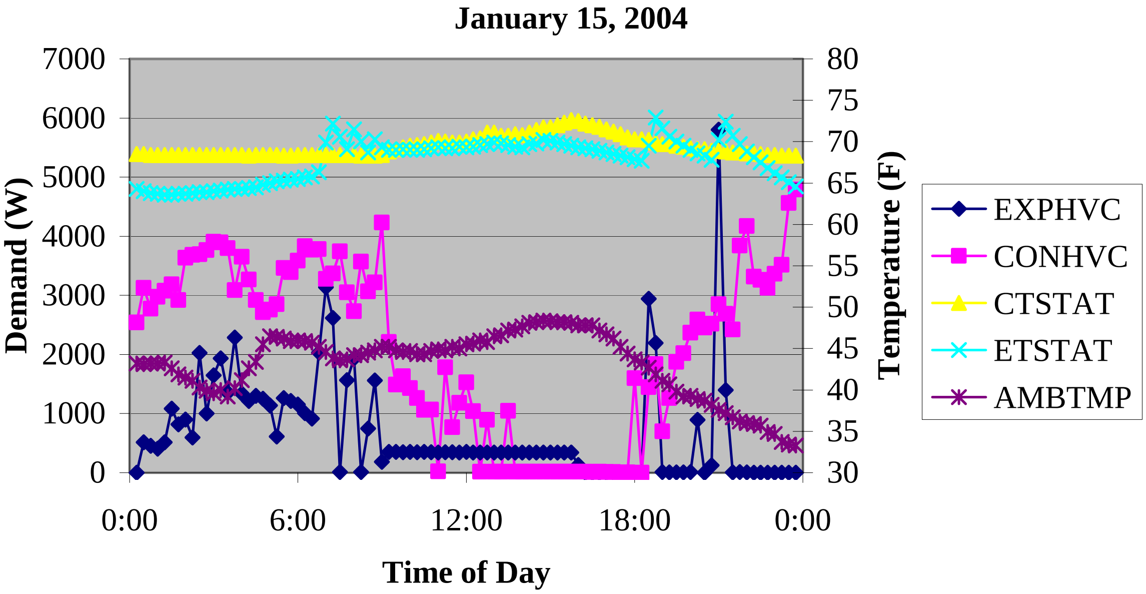

**Figure 5.3.1.1: HVAC Demand and Temperatures, Prior to Programmable Thermostat**

To compare the classrooms on a more even basis, a programmable thermostat was installed in the control classroom at the beginning of March, 2004. Figure 5.3.1.2 shows the same parameters depicted in Figure 5.3.1.1 after the installation of the programmable thermostat. Figure 5.3.1.3 is a picture of the installed programmable thermostat.

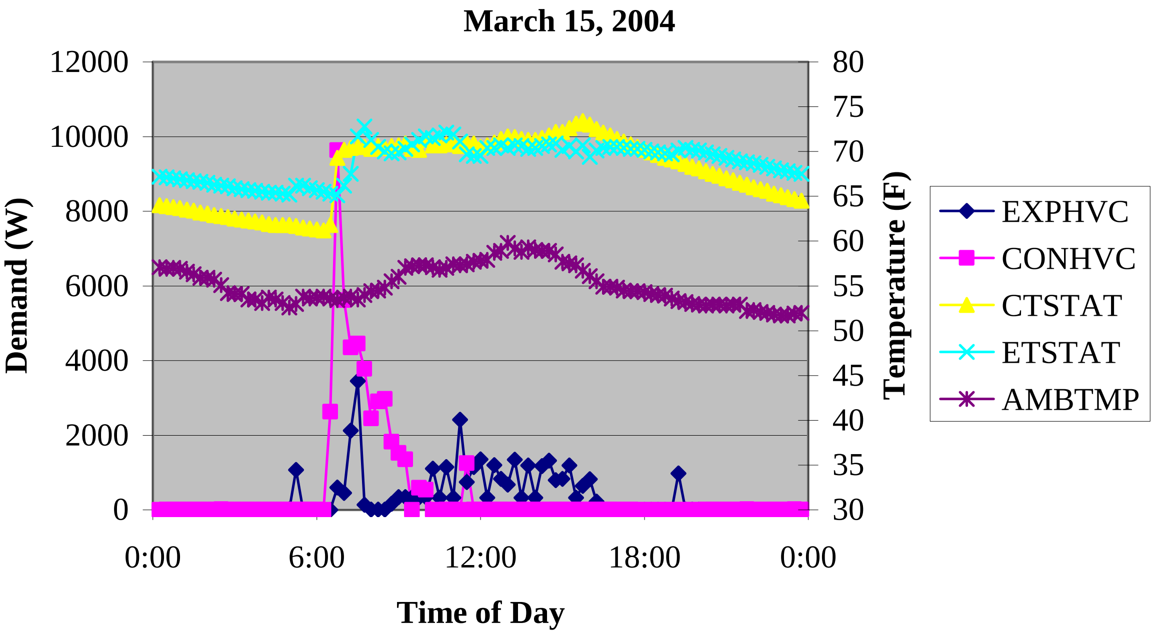

**Figure 5.3.1.2: HVAC Demand and Temperatures, After Installation of Programmable Thermostat**

**Figure 5.3.1.3: Installed Programmable Thermostat**

The programmable thermostat is programmed to hold the classroom at 68ºF in heating mode and 74ºF in cooling mode during the time between 7 AM and 4 PM Monday through Friday. The remainder of the time, the thermostat is programmed to hold the classroom at 60ºF in heating mode and 85ºF in cooling mode. The thermostat is equipped with a function that will begin to condition the classroom prior to the time it should be at the occupied temperature so that the occupants are comfortable when they arrive. This eliminated the comfort issues expressed by the teacher in the control classroom. Table 5.3.1.1 compares the estimated savings from installing a programmable thermostat versus a thermostat with no setback using the Energy-10 model. Once again, these values are for the HVAC system in the control classroom and would differ if a heat pump were utilized.

**Table 5.3.1.1: Estimated Programmable Thermostat Savings**

| Month | No Setback | | With Setback | |
|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) |
| **Jan** | 2,704 | 2,513 | 1,777 | 1,586 |
| **Feb** | 2,207 | 2,033 | 1,520 | 1,347 |
| **Mar** | 1,260 | 1,068 | 840 | 649 |
| **Apr** | 910 | 714 | 684 | 487 |
| **May** | 726 | 527 | 550 | 353 |
| **Jun** | 877 | 693 | 662 | 478 |
| **Jul** | 1,096 | 898 | 855 | 657 |
| **Aug** | 1,079 | 881 | 833 | 635 |
| **Sep** | 672 | 489 | 490 | 307 |
| **Oct** | 746 | 548 | 554 | 355 |
| **Nov** | 1,174 | 996 | 783 | 606 |
| **Dec** | 2,317 | 2,125 | 1,573 | 1,381 |
| **Tot** | 15,768 | 13,485 | 11,121 | 8,841 |

According to the Energy-10 model, a programmable thermostat could reduce the total energy consumption of the control classroom up to 29.5%. A savings of this magnitude equates to a cost savings of approximately $448.38 per year. However, this is an idealized case assuming that no setback of the manual thermostat is performed and that the set-points of the programmable thermostat are never changed. Figure 5.3.1.2 shows that the latter is not the case, and that the 68ºF set-point may not always be warm enough for the classroom’s occupants.  It is worthy to note, though, that the electric bill for the control classroom was reduced $3.47 per day when comparing the bills from January, 2004 and January, 2005, a significant cost saving.

### 5.3.2  BARD CS2000 UNIT

As described earlier, the Bard CS2000 unit acts as both an occupancy sensor as well as a programmable thermostat.  The unit has the ability to learn the occupancy of the classroom and control the internal conditions accordingly.  The CS2000 cannot be exactly modeled in Energy-10, but a close approximation is to model it as a programmable thermostat.  One of the unit's drawbacks is that it cannot be programmed to setback as far as the programmable thermostat.  The CS2000 unit is set to hold the classroom between 68ºF and 74ºF during occupied hours and setback to temperatures between approximately 63ºF and 79ºF during unoccupied hours.

The unit acts as a thermostat interrupt, so there is a thermostat located within the experimental classroom that the teacher can adjust during occupied hours.  However, during unoccupied hours, the thermostat is turned off and the CS2000 completely controls the HVAC independently.  Figure 5.3.2.1 shows a picture of the Bard CS2000 unit while Table 5.3.2.1 shows the Energy-10 data for the experimental classroom modeling the unit as a programmable thermostat as well as if no type of setback were employed.  This model is only for the heat pump application in the experimental classroom and would differ if this unit were installed in the control classroom.  The latter case's savings are discussed in the previous section.

Figure 5.3.2.1: Bard CS2000 Unit

Table 5.3.2.1: Estimated CS2000 Savings

| Month | With CS2000 Unit | | Without CS2000 Unit | |
|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) |
| **Jan** | 1,283 | 1,064 | 1,671 | 1,453 |
| **Feb** | 1,127 | 930 | 1,433 | 1,236 |
| **Mar** | 527 | 310 | 779 | 562 |
| **Apr** | 598 | 379 | 729 | 511 |
| **May** | 683 | 462 | 802 | 582 |
| **Jun** | 83 | 679 | 1,006 | 801 |
| **Jul** | 1,067 | 846 | 1,204 | 984 |
| **Aug** | 1,038 | 819 | 1,186 | 964 |
| **Sep** | 654 | 449 | 764 | 560 |
| **Oct** | 516 | 275 | 653 | 414 |
| **Nov** | 487 | 287 | 714 | 513 |
| **Dec** | 1,106 | 886 | 1,411 | 1,191 |
| **Tot** | 9,969 | 7,386 | 12,352 | 9,771 |

According to the Energy-10 model, the CS2000 unit could save up to 19.3% of the total energy consumption of the experimental classroom if no setback was previously used. This equate to a savings of $229.93 per year. Again, this is an idealized scenario as discussed with programmable thermostats. However, the CS2000 unit is not without its drawbacks. The savings in Table 12 are most likely higher than that of the actual savings. Both Figures 5.3.1.1 and 5.3.1.2 show a ‘spike’ in the demand curves for the experimental classroom late in the afternoon. It is speculated that this ‘spike’ in energy use is due to the janitor entering the classroom and the occupancy sensor of the CS2000 unit detecting his presence since a corresponding ‘spike’ is not seen in the control classroom. This ‘spike’ is also seen in the lighting demand curve, further supporting the theory of the janitor’s occupation. Figure 5.3.1.1 shows that the HVAC system utilized the electric strip backup heat during the period to return the classroom to temperature. This ‘spike’ in the late afternoon reduces the effectiveness of the CS2000 unit and causes the experimental classroom to use more energy during this period than if a simple programmable thermostat was installed.

Additionally, during several weeks of the study period, the CS2000 unit mistakenly learned that Sundays were occupied periods. Figure 5.3.2.2 shows the demand profile for the lighting and HVAC system in the experimental classroom during one of these Sundays.

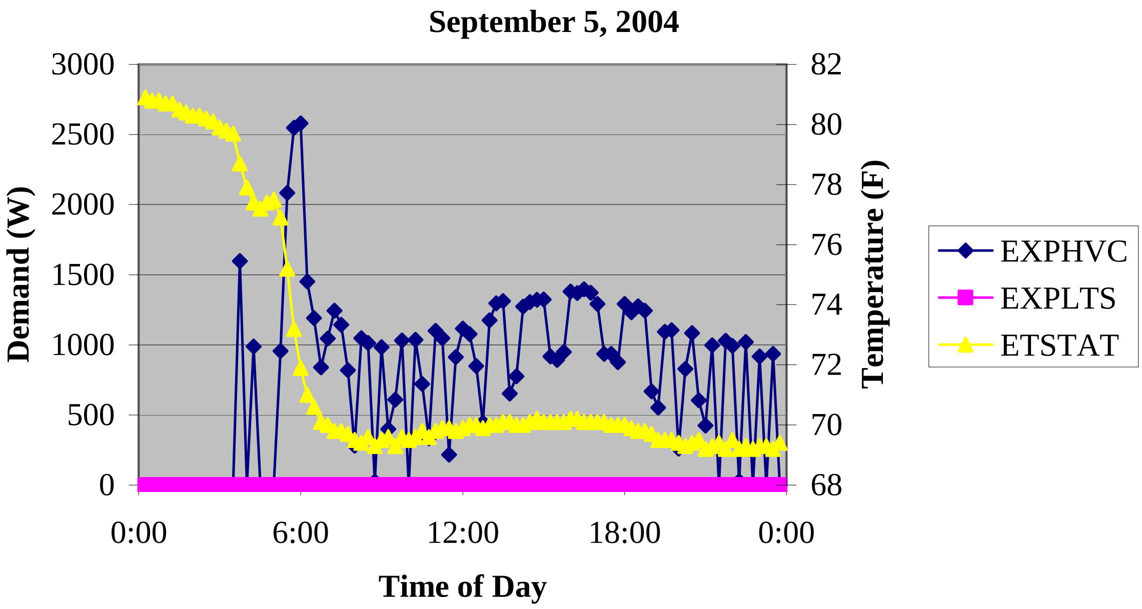

**Figure 5.3.2.2: CS2000 Holding Conditions During Unoccupied Sunday**

Figure 5.3.2.2 clearly shows that the experimental classroom is unoccupied because the lighting circuit, controlled by occupancy sensors, shows no usage. However, the CS2000 unit has mistakenly learned that Sundays are occupied and therefore conditions the interior space accordingly. This occurs during several Sundays during this time period. After consulting engineers from Bard, the CS2000 unit was reset by disconnecting its power supply for a weekend; but, had the classroom not been monitored with data-logging equipment, this mistake would not have been caught and much energy and money would have been wasted.

### 5.3.3 HEAT PUMP WITH BETTER INSULATION AND ENVELOPE SEALING

The Energy-10 software package is used to evaluate the addition of a 3 ton, SEER 12 heat pump system to the control classroom and its relationship to better insulation and envelope sealing. Table 5.3.3.1 compares the control classroom's building model modified with the addition of a heat pump and the control classroom's building model modified with both the addition of a heat pump and better insulation and envelope sealing.

**Table 5.3.3.1: Comparison of Better Insulation and Envelope Sealing with a Heat Pump**

| Month | Standard Insulation and Envelope Sealing | | Better Insulation and Envelope Sealing | |
|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) |
| **Jan** | 1,217 | 1,025 | 1,047 | 855 |
| **Feb** | 1,079 | 905 | 946 | 774 |
| **Mar** | 537 | 345 | 462 | 270 |
| **Apr** | 473 | 276 | 449 | 252 |
| **May** | 467 | 268 | 466 | 268 |
| **Jun** | 582 | 399 | 588 | 405 |
| **Jul** | 742 | 544 | 743 | 544 |
| **Aug** | 723 | 525 | 723 | 524 |
| **Sep** | 439 | 254 | 448 | 265 |
| **Oct** | 415 | 217 | 389 | 191 |
| **Nov** | 495 | 318 | 428 | 252 |
| **Dec** | 1,021 | 829 | 880 | 689 |
| **Tot** | 8,190 | 5,905 | 7,569 | 5,289 |

Estimated savings from installing better insulation and envelope sealing after a heat pump has been installed is only 7.6%. This equates to a savings of approximately $59.92 per year. The data in Table 5.3.3.1 actually estimates increased usage during the summer months, probably because the increased infiltration from the less well sealed building acts as an economizer at times during these periods.

### 5.3.4 INCREASED MINIMUM OCCUPIED OUTSIDE AIR

As stated in earlier sections, the ventilation rate in the control classroom is suspected to be below the ASHRAE minimum recommendation of 15 cfm per occupant. The Energy-10 model assumes that the classrooms are occupied by 20 persons during the occupied periods. This equates to a minimum ventilation rate, or minimum occupied outside air (MOOA) of 300 cfm. Because the performance enhanced classroom is equipped with a demand control ventilation system that actively controls the indoor $CO_2$ concentrations, the MOOA value of 300 cfm was used to calculate its energy consumption. However, measurements within the control classroom indicate that its MOOA value could be as low as 100 cfm, although probably unlikely. Therefore, the Energy-10 model estimates the energy consumption of the control classroom using an MOOA value of 200 cfm.

Although the lower value for MOOA results in decreased energy consumption, it does not meet the minimum ASHRAE requirement. Table 5.3.4.1 compares the energy consumption of the control classroom equipped with the electric furnace/air conditioner and MOOA values of 200 and 300 cfm as well as the control classroom equipped with a heat pump and MOOA values of 200 and 300 cfm.

**Table 5.3.4.1: Impact of MOOA on Energy Consumption**

| Month | Electric Furnace/Air Conditioner, MOOA = 200 cfm | | Electric Furnace/Air Conditioner, MOOA = 300 cfm | | Heat Pump, MOOA = 200 cfm | | Heat Pump, MOOA = 300 cfm | |
|---|---|---|---|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) |
| **Jan** | 1,777 | 1,586 | 2,050 | 1,858 | 1,217 | 1,025 | 1,394 | 1,202 |
| **Feb** | 1,520 | 1,347 | 1,752 | 1,579 | 1,079 | 905 | 1,248 | 1,075 |
| **Mar** | 840 | 649 | 965 | 773 | 537 | 345 | 591 | 400 |
| **Apr** | 684 | 487 | 759 | 562 | 473 | 276 | 504 | 307 |
| **May** | 550 | 353 | 574 | 376 | 467 | 268 | 474 | 275 |
| **Jun** | 662 | 478 | 684 | 500 | 582 | 399 | 597 | 414 |
| **Jul** | 855 | 657 | 894 | 696 | 742 | 544 | 767 | 569 |
| **Aug** | 833 | 635 | 874 | 676 | 723 | 525 | 751 | 553 |
| **Sep** | 490 | 307 | 496 | 313 | 439 | 254 | 440 | 258 |
| **Oct** | 554 | 355 | 606 | 408 | 415 | 217 | 427 | 228 |
| **Nov** | 783 | 606 | 884 | 707 | 495 | 318 | 544 | 368 |
| **Dec** | 1,573 | 1,381 | 1,798 | 1,607 | 1,021 | 829 | 1,169 | 978 |
| **Tot** | 11,121 | 8,841 | 12,336 | 10,055 | 8,190 | 5,905 | 8,906 | 6,627 |

As expected, the additional ventilation caused the energy consumption to increase for both cases. Also, the increase was not as drastic for the heat pump system because its efficiency is higher than the electric furnace/air conditioner system. The cost to bring the control classroom up to the ASHRAE standard with the electric furnace/air conditioner is less than $117 per year. If the control classroom were equipped with the heat pump unit of the experimental classroom, the cost to bring the classroom up to the ASHRAE standard is less than $69 per year. Both of these values are based upon the year-round operation of the classroom, and, since Chapel Hill High School is not a year-round school, the actual cost to comply with the standard would be lower than these values.

### 5.3.5 HEAT PUMP WITH T8 FIXTURES

As discussed in a previous section, the change from T12 to T8 fixtures in a classroom with electric resistance heating does not save an appreciable amount of energy. However, when the classroom is equipped with a heat pump, the conversion efficiency of the electrical energy to heat may be different enough for the T8 fixtures and the heat pump to have a larger impact on the overall energy consumption of the classroom.

As for the electric furnace/air conditioner, three situations will be modeled with the heat pump system on the control classroom's model: the current sixteen two bulb, single ballast per fixture T12 lights, the ten three bulb, two ballasts per fixture T8 lights in the experimental classroom, and the ten three bulb, single ballast per fixture T8 lights found to be more efficient in the previous example. Table 5.3.5.1 shows the Energy-10 model's comparison of these three cases.

**Table 5.3.5.1: Lighting Comparison with Heat Pump**

| Month | 16 - 2 Bulb, T12 Fixtures, No Day Lighting, Heat Pump | | | 10 - 3 Bulb, T8 Fixtures, 2 Ballasts per Fixture, No Day Lighting, Heat Pump | | | 10 - 3 Bulb, T8 Fixtures, 1 Ballast per Fixture, No Day Lighting, Heat Pump | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Lights (kWh) | Total (kWh) | HVAC (kWh) | Lights (kWh) | Total (kWh) | HVAC (kWh) | Lights (kWh) |
| **Jan** | 1,217 | 1,025 | 119 | 1,231 | 1,016 | 142 | 1,202 | 1,038 | 91 |
| **Feb** | 1,079 | 905 | 108 | 1,095 | 900 | 129 | 1,059 | 911 | 82 |
| **Mar** | 537 | 345 | 119 | 556 | 342 | 142 | 515 | 351 | 91 |
| **Apr** | 473 | 276 | 126 | 499 | 278 | 149 | 443 | 277 | 95 |
| **May** | 467 | 268 | 125 | 498 | 274 | 149 | 429 | 260 | 95 |
| **Jun** | 582 | 399 | 113 | 612 | 407 | 136 | 545 | 389 | 87 |
| **Jul** | 742 | 544 | 125 | 775 | 552 | 149 | 702 | 532 | 95 |
| **Aug** | 723 | 525 | 125 | 756 | 534 | 149 | 684 | 515 | 95 |
| **Sep** | 439 | 254 | 113 | 468 | 262 | 136 | 403 | 246 | 87 |
| **Oct** | 415 | 217 | 125 | 442 | 219 | 149 | 382 | 213 | 95 |
| **Nov** | 495 | 318 | 108 | 514 | 316 | 129 | 472 | 322 | 82 |
| **Dec** | 1,021 | 829 | 119 | 1,038 | 823 | 142 | 1,002 | 839 | 91 |
| **Tot** | 8,190 | 5,905 | 1,425 | 8,484 | 5,923 | 1,701 | 7,838 | 5,893 | 1,086 |

Table 5.3.5.1 shows that the change from T12 to T8 fixtures does not have a significant impact on the consumption of the heat pump HVAC system. It does, however, reiterate the importance of choosing the correct fixture, showing that the improper T8 fixture may actually consume more energy than its T12 counterpart. Table 5.3.5.1 also shows that the change to T8, single ballast fixtures saves only $33.96 per year without daylighting.

## 5.4 IMPACT OF SKYLIGHTS ON HVAC SYSTEMS

The performance enhanced, experimental classroom is equipped with six skylights that allow natural sunlight into the classroom during the day. The skylights are part of a day lighting system that allows the light fixtures within the classroom to dim as more light is available through the skylights, maintaining a constant light level of light at the desktops. Another consideration in the addition of the skylights was to improve the learning environment of the classroom by providing more natural light; however, this claim cannot be assessed within the scope of this thesis project.

Essentially, the skylights are windows located on the roof of the classroom. They are covered with a glazing that helps block the solar radiation, helping to reduce loads from solar gain. This glazing as well as a view of the skylights can be seen in Figure 5.4.1.

**Figure 5.4.1: Outdoor View of Skylights**

The Energy-10 model is used to estimate the impact of the addition of the skylights on the control classroom for both an electric furnace/air conditioner and a heat pump HVAC system. The model is capable of predicting the effects of the skylight addition by assessing both the solar gain and heat transfer components. The skylights are modeled as six 3040 double pane, low-e windows placed on the roof of the building. Although this is not the actual case of the experimental classroom, the results should be close enough to gain an idea of their impact. The estimated energy consumption is depicted in Table 5.4.1.

**Table 5.4.1: Estimated Impact of the Addition of Skylights**

| Month | Electric Furnace/Air Conditioner, No Skylights | | Electric Furnace/Air Conditioner, With Skylights | | Heat Pump, No Skylights | | Heat Pump, With Skylights | |
|---|---|---|---|---|---|---|---|---|
| | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) | Total (kWh) | HVAC (kWh) |
| **Jan** | 1,777 | 1,586 | 1,717 | 1,526 | 1,217 | 1,025 | 1,165 | 974 |
| **Feb** | 1,520 | 1,347 | 1,436 | 1,262 | 1,079 | 905 | 1,030 | 857 |
| **Mar** | 840 | 649 | 762 | 571 | 537 | 345 | 511 | 318 |
| **Apr** | 684 | 487 | 702 | 506 | 473 | 276 | 516 | 319 |
| **May** | 550 | 353 | 672 | 474 | 467 | 268 | 579 | 380 |
| **Jun** | 662 | 478 | 863 | 680 | 582 | 399 | 745 | 562 |
| **Jul** | 855 | 657 | 1,059 | 860 | 742 | 544 | 907 | 709 |
| **Aug** | 833 | 635 | 1,028 | 829 | 723 | 525 | 881 | 684 |
| **Sep** | 490 | 307 | 622 | 439 | 439 | 254 | 548 | 365 |
| **Oct** | 554 | 355 | 601 | 402 | 415 | 217 | 464 | 266 |
| **Nov** | 783 | 606 | 761 | 585 | 495 | 318 | 489 | 312 |
| **Dec** | 1,573 | 1,381 | 1,552 | 1,361 | 1,021 | 829 | 1,010 | 818 |
| **Tot** | 11,121 | 8,841 | 11,775 | 9,495 | 8,190 | 5,905 | 8,845 | 6,564 |

The data in Table 5.4.1 shows that the energy consumption of the modeled classrooms decrease in the heating season and increase during the cooling season with the addition of the skylights. This indicates that the solar gain component of the skylights dominates the heat transfer component. The energy consumption of the classroom with an electric furnace/air conditioner was increased approximately 5.8% with the addition of the skylights while the energy consumption of the classroom with a heat pump was increased 8.0%. The increase is a higher percentage in the latter because of its lower initial consumption.

It must be noted that the addition of the skylights was the most expensive design change to the control classroom. The total cost of the skylights, less the one time engineering cost to include them in the design, is $4,260. The benefits of the skylights with respect to day lighting savings cannot justify this expense.

## 6.0 CONCLUSIONS

Measured results show that the performance enhanced relocatable classroom saved a total of 3,518 kWh and $339.44 during the 2004 calendar year. This represents a 30.6% reduction in energy consumption compared to the control classroom. The majority of the savings were due to the decreased consumption of the performance enhanced classroom's HVAC system. Measured savings on this circuit were 3,752 kWh, more than the total savings of the performance enhanced classroom, equating to a 40.4% reduction in total HVAC energy consumption. The savings for the HVAC system are higher than the overall savings because the plug loads in performance enhanced classroom were higher than in the control classroom, reducing the total energy savings. Measured savings on the lighting circuit totaled 227 kWh, after subtracting the month of January, which was prior to the adjustment of the dimming control unit. This equates to an 18.7% reduction in lighting circuit consumption compared to the control classroom.

The majority of the measured energy savings were recorded during the months of January and February, prior to the installation of a programmable thermostat in the control classroom. The energy savings of the performance enhanced classroom compared to the control classroom totaled 2,845 kWh, 80.9% of the total measured energy savings, during these two months. During the months in which mostly cooling loads occurred, the performance enhanced classroom consumed more energy than the control classroom. This is primarily because the HVAC system in the control classroom also consumed more energy during this time period. During the remaining months in which mostly heating loads occurred, the performance enhanced classroom consumed less energy than the control classroom, both in terms of total consumption and HVAC system consumption.

It is suspected that the increased energy consumption of the performance enhanced classroom during the months with cooling loads is because the control classroom does not meet the ASHRAE standard ventilation requirement, as evidenced by its higher indoor $CO_2$ concentrations. The higher ventilation rate in the performance enhanced classroom causes its energy usage to increase in order to condition the increased ventilation air. The Energy-10 software model was used to normalize this difference. The model indicates that if the ventilation air in the control classroom were increased from 200 to 300 cfm, the yearly energy consumption of the classroom would increase approximately 10.9%.

As evidenced by the large energy savings during the months of January and February, the most effective design change for the reduction of energy use is the installation of a programmable thermostat. The Energy-10 model predicts that the programmable thermostat in the control classroom saves approximately 29.5% of the energy that would be consumed if no setback were used. The actual savings are most likely lower than this amount because the model uses an idealized case where the occupants never setback the thermostat set-point. In actuality, the manual thermostat is setback slightly during unoccupied periods by the control classroom's teacher. However, the electrical bill from January 2005 shows that the classroom is saving \$3.47 per day when compared to the electrical bill from January 2004, a savings of approximately \$107.57 for that month alone. The only difference in the classroom between these two periods is the installation of a programmable thermostat.

Likewise, the Energy-10 model was used to estimate the savings from the Bard CS2000 unit in the performance enhanced classroom. The model predicted that that the CS2000 unit reduced the classroom's electrical energy consumption 19.3% from the total consumption of the classroom if no setbacks were used. The savings from the CS2000 unit is most likely overestimated again in this case because of the same reasons as the programmable thermostat. Additionally, the CS2000 unit activates the HVAC system in the late afternoon, most likely because is senses the presence of the janitor, while the programmable thermostat in the control classroom does not. The CS2000 unit is also prone to learning that periods of the week are occupied, even when they are not. This situation occurred with the unit around September of 2004. The unit's mistake would not have been caught had the classroom not been data-logged and monitored periodically. These occurrences increased the consumption of the performance enhanced classroom. For its cost and reliability, the programmable thermostat is a better choice than the CS2000 unit.

Measurements were made to determine the effectiveness of the energy recovery wheel in the HVAC system of the performance enhanced classroom. $CO_2$ concentration measured at this time indicate that the majority of the outside ventilation air never makes its way into the inside space of the classroom; rather, it is recirculated and exhausted from the unit. This makes the energy recovery wheel mostly ineffective. Additionally, the Energy-10 software model could not estimate its effectiveness. The most obvious explanation of this is that there are no dampers in the HVAC's ventilation system to mechanically separate the air streams. The unit depends on pressure differentials created by fans to separate the air streams. Because there are several closed duct vents inside the classroom, the pressure differentials are not as designed and, therefore, outside ventilation air is not moved into the classroom but is exhausted back out of the unit.

The Energy-10 model was employed to estimate the savings from installing the heat pump system from the performance enhanced classroom in the control classroom. The model estimates that replacing the 10 kW electric furnace/air conditioner system in the control classroom with the same heat pump from the performance enhanced classroom yields a yearly energy savings of 2,931 kWh, or 26.4% of its current consumption. This equates to a yearly cost savings of approximately $200 per year.

The Energy-10 model was also used to estimate the savings from the increased insulation and better envelope sealing of the performance enhanced classroom. The model predicted a reduced energy consumption of 2,289 kWh if the control classroom were fitted with the increased insulation and better envelope sealing of the performance enhanced classroom. This is a savings of 21.4% and $220.86 per year. The majority of the savings were estimated to occur during the winter months, the months in which the classrooms are occupied by students. The model predicted a savings of only 621 kWh if the control classroom were equipped with the same heat pump as the performance enhanced classroom. This difference is due to the greater efficiency of the heat pump during the heating season than the electric furnace.

The energy consumption of the classrooms was modeled with three different lighting scenarios. The first was the sixteen two bulb, single ballast, T12 fixtures contained in the control classroom, the second was with the ten three bulb, dual ballast, T8 fixtures contained in the performance enhanced classroom, and the third was with ten three bulb, single ballast, T8 fixtures that consume less energy than their dual ballast counterparts. No day lighting was employed in the model. The dual ballast fixtures were found to consume more energy than the T12 fixtures when no dimming was utilized. The model estimated that the total consumption of the control classroom would increase 252 kWh per year if the dual ballast fixtures were installed. However, if the single ballast T8 fixtures were installed, the control classroom would consume 303 kWh less per year than with the T12 fixtures. This represents a cost savings of approximately $29 per year.

These same scenarios were modeled in the control classroom equipped with the same heat pump as the performance enhanced classroom to investigate the difference the HVAC system might have in this case. When the two ballast fixtures were compared to the T12 fixtures, the results were an increase in energy consumption of 294 kWh per year. When the single ballast T8 fixtures were compared to the T12 fixtures, the results were a decrease in the classroom’s total energy consumption of 646 kWh. This results in a savings of approximately $33.96 per year. This case does, however, illustrate the importance of selecting the proper fixture and that a change to T8 fixtures does not necessarily result in energy or cost savings.

Finally, the Energy-10 model was used to estimate the impact of the skylights on the energy consumption of the classrooms. The model predicted that the energy consumption of the control classroom would increase 654 kWh per year if skylights were installed. The skylights actually saved energy during some of the winter months, but the increase in consumption during the cooling months overshadowed these savings. The model predicted that the control classroom would consume 655 kWh more per year if the classroom utilized the heat pump system of the performance enhanced relocatable classroom. From the models predictions of the impact of skylights coupled with the measured savings from the lighting circuit, it can be deduced that the day lighting scheme most likely causes the total consumption of the performance enhanced relocatable classroom to increase.

Collection of data from both the control and the performance enhanced relocatable classroom continues. FSEC has and will continue to prepare reports outlining the performance of these classrooms in comparison to their counterparts located in Florida and New York. The NCSC will also continue to monitor the results of the classrooms and continue to evaluate their performance.

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