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DESIGN AND EVALUATION OF ENERGY EFFICIENT MODULAR CLASSROOM STRUCTURES

PHASE II
FINAL REPORT

DE-FG03 94 ER 81814

Modern Building Systems, Inc.
and
Energy Studies in Buildings Laboratory
University of Oregon

VOLUME I

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PHASE II
FINAL REPORT

Modern Building Systems, Inc.
P.O. Box 110
9493 Porter Road
Aumsville, OR 97325, U.S.A.

Energy Studies in Buildings Laboratory
Department of Architecture
University of Oregon
Eugene, OR 97403, U.S.A.

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RESEARCH TEAM

Modern Building Systems, Inc.

Energy Studies in Buildings Laboratory
University of Oregon

G.Z. Brown
Sarah Bernhard
Dana Bjornson
John Briscoe
Sean Fremouw
Jeff Kline
Pawan Kumar
Paul Larocque
Dale Northcutt
Zhunquin Wang

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1.0 EXECUTIVE SUMMARY

Introduction

We are developing innovations to enable modular builders to improve the energy performance of their classrooms with no increase in first cost. The Modern Building Systems' (MBS) classroom building conforms to the stringent Oregon energy code, and at \$18/ft^2 (\$1.67/m^2) (FOB the factory) it is at the low end of the cost range for modular classrooms. We have investigated daylighting, cross-ventilation, solar preheat of ventilation air, air-to-air heat exchanger, electric lighting controls, and down-sizing HVAC systems as strategies to improve energy performance. We were able to improve energy performance with no increase in first cost in all climates examined. Two papers and a full report on Phase I of this study are available (see References).

Background

This project was funded by the U.S. Department of Energy under its Small Business Innovation Research Program in two phases. The project team consists of Modern Building Systems, Inc. (MBS), a manufacturer of modular buildings located in Aumsville, Oregon, and the Energy Studies in Buildings Laboratory (ESBL) at the University of Oregon, in Eugene, Oregon.

The work described in this report is from the second phase of the project. In the first phase we redesigned the basic modular classroom to incorporate energy strategies including daylighting, cross-ventilation, solar preheating of ventilation air, and insulation. We also explored thermal mass but determined that it was not a cost-effective strategy in the five climates we examined. Energy savings ranged from 6% to 49% with an average of 23%. Paybacks ranged from 1.3 years to 23.8 years, an average of 12.1 years.

In Phase II the number of baseline buildings was expanded by simulating buildings that would be typical of those produced by MBS for each of the seven locations/climates. A number of parametric simulations were performed for each

energy strategy. Additionally we refined our previous algorithm for a solar ventilation air wall preheater and developed an algorithm for a roof preheater configuration. These algorithms were coded as functions in DOE 2.1E.

We were striving for occupant comfort as well as energy savings. We performed computer analyses to verify adequate illumination on vertical surfaces and acceptable glare levels when using daylighting. We also used computational fluid dynamics software to determine air distribution from cross-ventilation and used the resulting interior wind speeds to calculate occupant comfort and allowable outside air temperatures for cross-ventilation.

Research Carried Out

Base case buildings conforming to the ASHRAE 90.1 standard as well as over 1,000 building configurations with energy efficient features were modeled for a nine-month school period in seven locations/climates using the DOE 2.1E modeling software. The seven climates studied were Fairbanks, AK; Phoenix, AZ; Sacramento, CA; Miami, FL; Honolulu, HI; Astoria, OR; and Spokane, WA.

To choose the mix of energy strategies to model in the DOE2.1E runs for each climate, we developed a method to compare incremental costs versus energy savings for each energy saving strategy. The most promising energy-efficient features in each climate were integrated and further evaluated using seven different criteria: 1) the building that was the least expensive based on first cost and would save more energy than the base case building, 2) the building with the shortest simple payback period, 3) the building with the best total savings in a five-year period (based on first cost and energy savings), 4) the building with the best total savings in a ten-year period (based on first cost and energy savings), 5) the building with the best energy savings in dollars, 6) the building with the best energy savings at the site, and 7) the building with the best energy savings in dollars that was closest to no increase in first cost.

The basic Modern Building Systems unit before redesign consists of two 14'x 64' (4.3m x 19.5m) modules that are put together on site to create two 28'x32' (8.5m x

9.8m) classrooms. Wall insulation is R11 (1.9 C m^2/W), roof insulation R30 (5.3 C m^2/W), and floors R19 (3.4 C m^2/W). Each classroom has one 4'x4' (1.2m x 1.2m) window, fluorescent lighting and one 3-ton (10.5 kW) heat pump; see figure 1. We redesigned the basic classroom unit (see figures 2 and 3) to incorporate energy strategies including daylighting, cross-ventilation, solar preheating of ventilation air, and insulation.

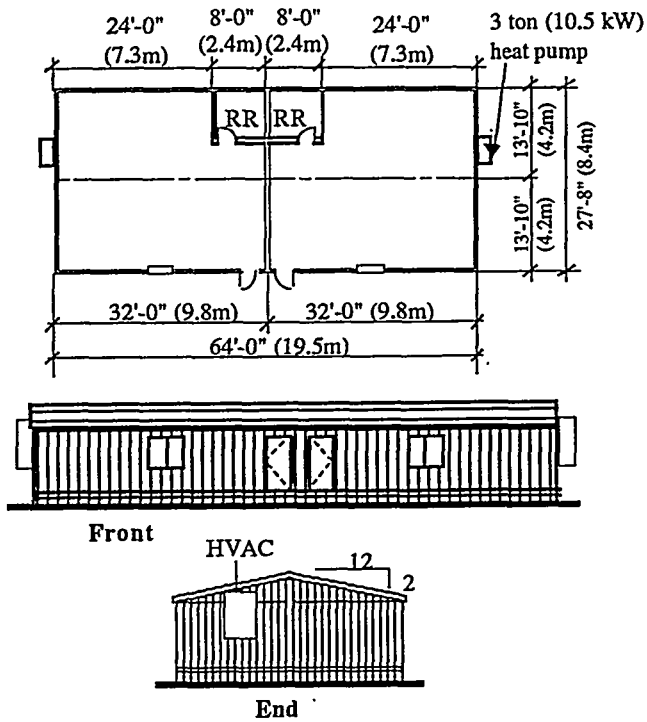


Figure 1, Base case Unit

To make the results easily comparable, we created separate base case buildings for each climate using the ASHRAE 90.1 standard. For each climate we performed over 300 parametric simulations of individual energy saving features and cost analyses using the DOE2.1E computer modeling software. The strategies explored were: 1) window size; 2) insulation R-values; 3) window overhangs; 4) a roof preheater; 5) a radiant barrier; 6) window blinds; 7) efficient lighting; 8) an econimizer; 9) a heat exchanger; and 10) a solar wall. All of the energy savings and costs were plotted together for each location.

We then used the graphs to identify the most promising combinations of

strategies and tradeoffs that would produce the best energy savings at the lowest cost. We then narrowed our explorations to a limited number of combinations to do integrated runs in order to obtain integrated performance predictions. Close to 1000 runs per location were performed.

To narrow the choices of features to be used in the prototype building in each climate, we evaluated the results of the integrated simulations using the seven criteria mentioned previously.

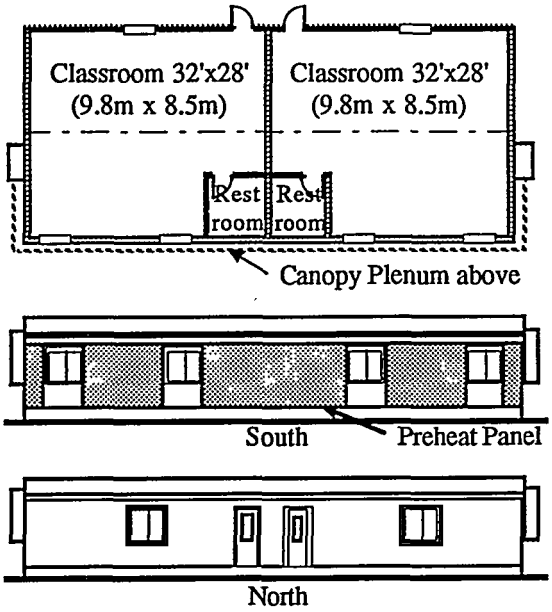


Figure 2, Classroom after Redesign

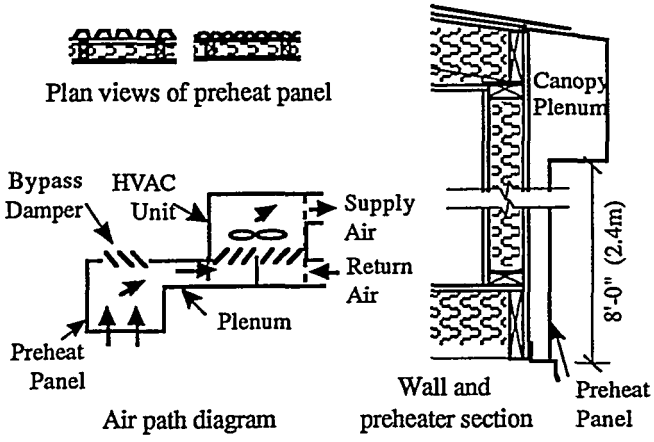


Figure 3, Preheater Details

Figure 4 combines the results of the seven criteria, seven climates, and seven

base case buildings onto one chart. Each climate does not necessarily show seven points on the graph since some building configurations met more than one criteria. The horizontal scale is incremental construction cost over the ASHRAE 90.1 base case, while the vertical axis is annual energy savings in dollars. The diagonal lines show 5 and 10 year net savings equivalency lines. All points on the same line have the same net savings over the line's specified time frame. The equivalency lines passing through the origin are simple payback lines.

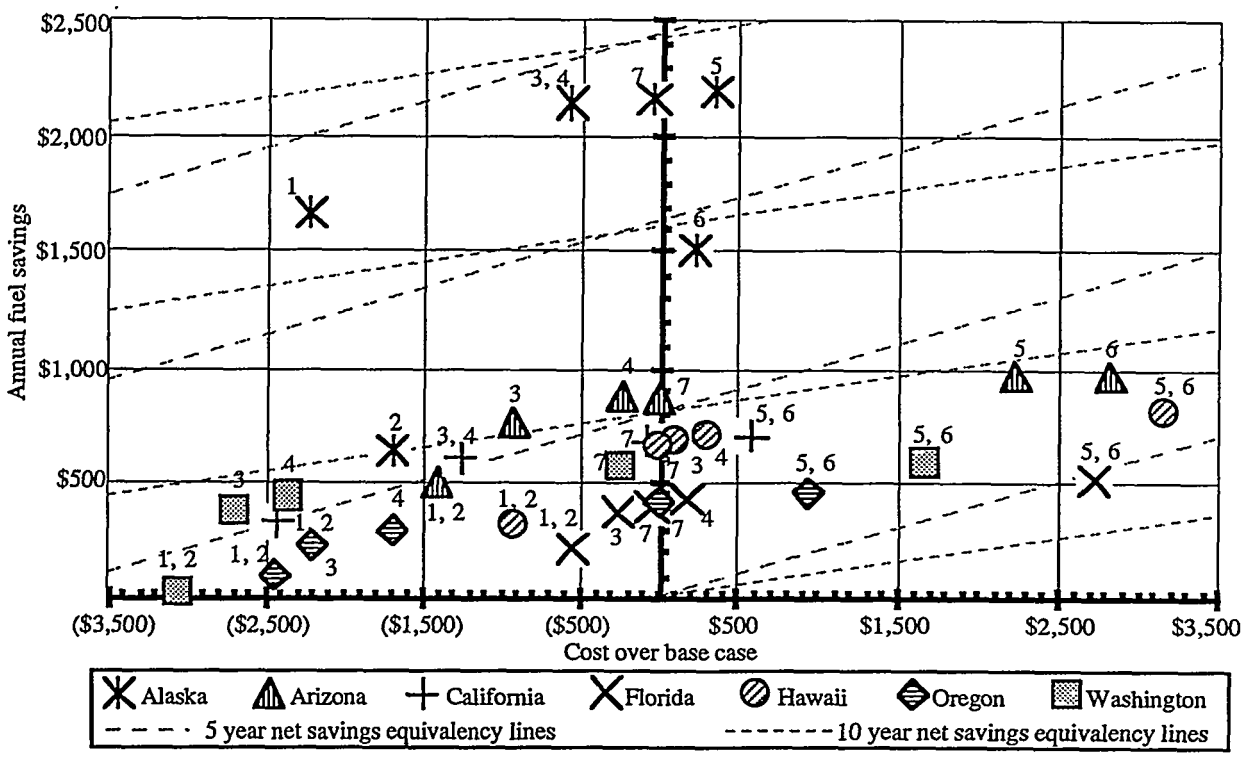


Figure 4, Summary of Seven Climate Zones

Fairbanks, Alaska

Most of the runs showed an advantage in switching from the electric heat pump in the base case model to a #2 fuel oil furnace. These models use more energy at the site but less at the source and cost less to run due to the less expensive #2 fuel oil cost. An air-to-air heat exchanger showed the most promise for energy savings but had a more expensive first cost and longer simple payback than other

options selected. Due to the large heating load, most glazing faced south unless the solar wall preheater was used, in which case the windows were oriented north (leaving the entire south wall for the preheater).

Symbol	Criteria	Building Description
Origin	Base case	Roof R38 (6.7 C m2/W), wall R30 (5.3 C m2/W) studs @ 16" (40.6 cm) OC, floor R30 (5.3 C m2/W), 9@8040 vinyl frame double pane air filled, 4 tube T12 lights always on during class time, heat pump.
Star #1	Least expensive and save energy	Roof R38 (6.7 C m2/W), wall R19 (3.4 C m2/W) studs @ 24" (61.0 cm) OC, floor R19 (3.4 C m2/W), 6@2040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, oil furnace with cross-ventilation.
Star #2	Least simple payback	Same as #1 except heat pump.
Star #3	Best 5 year total savings	Same as #1 except 6@6040 vinyl frame double pane argon filled, 60% effective heat exchanger.
Star #4	Best 10 year total savings	Same as #3.
Star #5	Best energy dollar savings	Roof R38 (6.7 C m2/W), wall R21 (3.7 C m2/W) studs @ 24" (61.0 cm) OC, floor R30 (5.3 C m2/W), 6@6040 vinyl double pane argon low-e inside pane 0.1, 3 tube T8 lights with manual off, oil furnace with cross-ventilation, 60% effective heat exchanger.
Star #6	Best energy savings	Same as #5 except 6@2040 vinyl frame double pane argon filled low-e inside pane 0.1, heat pump.
Star #7	Best energy dollar savings closest to no increase in cost	Same as #5 except wall R19 (3.4 C m2/W) studs @ 24" (61.0 cm) OC and floor R19 (3.4 C m2/W).

Figure 5, Fairbanks, AK

Phoenix, Arizona

Because of an abundance of solar radiation, a radiant barrier with reduction in envelope insulation showed much promise. Cross-ventilation was examined, but due to high outdoor temperatures it proved not very useful much of the year. Floor

insulation was eliminated for coupling with cooler crawl space air. Awnings or overhangs could potentially reduce the cooling load if the building is not using dimmable ballasts. Increasing the glazing area was an advantage whether using continuous dimming lights or manual on/off lighting.

Symbol	Criteria	Building Description
Origin	Base case	Roof R21 (3.7 C m2/W), wall R7 (1.2 C m2/W) studs @ 16" (40.6 cm) OC, floor R7 (1.2 C m2/W), 4@8040 + 1@4040 aluminum frame double pane air filled, 4 tube T12 lights always on during class time, heat pump.
Triangle #1, #2	Least expensive and save energy & Least Simple Payback	Roof R11 (1.9 C m2/W), wall R0 studs @ 24" (61.0 cm) OC, floor R0, 6@2040 aluminum frame double pane air filled, 4 tube T12 with manual off, radiant barrier in the wall, heat pump.
Triangle #3	Best 5 year total savings	Same as #1 except wall R7 (1.2 C m2/W) studs @ 24" (61.0 cm) OC, 6@6040 aluminum frame double pane air filled.
Triangle #4	Best 10 year total savings	Roof R11 (1.9 C m2/W), wall R13 (2.3 C m2/W) studs @ 24" (61.0 cm) OC, floor R0, 6@6040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, radiant barrier in the roof, heat pump with cross-ventilation.
Triangle #5	Best energy dollar savings	Same as #4 except 3 tube T8 lights continuous dimming, 40% effective heat exchanger.
Triangle #6	Best energy savings	Roof R11 (1.9 C m2/W), wall R13 (2.3 C m2/W) studs @ 24" (61.0 cm) OC, floor R0, 6@8040 vinyl frame double pane argon filled low-e outside pane 0.04, 3 tube T8 lights continuous dimming, radiant barrier in wall & roof, heat pump with cross-ventilation.
Triangle# 7	Best energy dollar savings closest to no increase in cost	Roof R11 (1.9 C m2/W), wall R13 (2.3 C m2/W) studs @ 24" (61.0 cm) OC, floor R0, 6@8040 aluminum frame double pane air filled, 3 tube T8 with manual off, radiant barrier in the wall, heat pump with cross-ventilation.

Figure 6, Phoenix, AZ

Sacramento, California

Part way through the analysis it was decided to switch the location modeled from

Bakersfield to Sacramento to better approximate Modern Building Systems' sales territory in northern California. Eliminating the economizer, while increasing the energy savings, enabled us to look at some different options due to the initial cost reduction. This climate's cooling load could not be handled completely by cross-ventilation.

Symbol	Criteria	Building Description
Origin	Basecase	Roof R15 (2.6 C m2/W), wall R7 (1.2 C m2/W) studs @ 16" (40.6 cm) OC, floor R7 (1.2 C m2/W), 8@6040 aluminum frame double pane air filled, 4 tube T12 lights always on during class
Cross #1	Least expensive and save energy	Roof R11 (1.9 C m2/W), wall R19 (3.4 C m2/W) studs @ 24" (61.0 cm) OC, floor R0, 6@2040 vinyl frame double pane argon filled, 4 tube T12 lights with manual off, heat pump.
Cross #2	Least simple payback	Same as # 1 except Roof R19 (3.4 C m2/W), 6@4040 vinyl frame double pane argon filled.
Cross #3, #4	Best 5 year total savings & Best 10 year total savings	Roof R19 (3.4 C m2/W), wall R19 (3.4 C m2/W) studs @ 24" (61.0 cm) OC, floor R11 (1.9 C m2/W), 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, heat pump with cross-ventilation.
Cross #5, #6	Best energy dollar savings & Best energy savings	Roof R38 (6.7 C m2/W), wall R21 (3.7 C m2/W) studs @ 24" (61.0 cm) OC, floor R11 (1.9 C m2/W), 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, heat pump with cross-ventilation, 60% effective heat exchanger.
Cross #7	Best energy dollar savings closest to no increase in cost	Same as #3 except wall R19 (3.4 C m2/W) studs @ 24" (61.0 cm) OC, 40% effective heat exchanger.

Figure 7, Sacramento CA

Miami, Florida

Due to a large cooling load, a radiant barrier showed an energy savings. Continuously dimming ballasts played a larger role in this climate than others. Cross-ventilation was not examined due to the high outdoor temperature and humidity much of the year. Awnings or overhangs could potentially help if lights

with dimmable ballasts are not used.

Symbol	Criteria	Building Description
Origin	Base case	Roof R11 (1.9 C m2/W), wall R0 studs @ 16" (40.6 cm) OC, floor R0, 4@8040 aluminum frame double pane air filled, 4 tube T12 lights always on
X #1, #2	Least expensive and save energy & Least simple payback	Roof R11 (1.9 C m2/W), wall R0 studs @ 24" (61.0 cm) OC, floor R0, 6@2040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, radiant barrier in the walls, heat pump.
X #3	Best 5 year total savings	Same as #1 except 6@6040 aluminum frame double pane air filled.
X #4	Best 10 year total savings	Same as #3 except 3 tube T8 lights with manual off.
X #5, #6	Best energy dollar savings & Best energy savings	Roof R11 (1.9 C m2/W), wall R11 (1.9 C m2/W) studs @ 24" (61.0 cm) OC, floor R0, 6@6040 aluminum frame double pane air filled low-e outside pane 0.1, 3 tube T8 lights with continuous dimming, radiant barrier in the walls & roof, heat pump.
X #7	Best energy dollar savings closest to no increase in cost	Roof R11 (1.9 C m2/W), wall R11 (1.9 C m2/W) studs @ 24" (61.0 cm) OC, floor R0, 6@6040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, radiant barrier in the walls, heat pump.

Figure 8, Miami, FL

Honolulu, Hawaii

Due to a large cooling load, a radiant barrier showed an advantage. The continuously dimming ballasts played a larger role in this climate than others. Due to the cooling load, no floor insulation was used for better coupling with cool crawl space air. Cross-ventilation could not handle the entire cooling load due to the high outdoor temperature and humidity much of the year. Awnings or overhangs could possibly help if lights with dimmable ballasts are not used.

Symbol	Criteria	Building Description
Origin	Base case	Roof R11 (1.9 C m2/W), wall R0 studs @ 16" (40.6 cm) OC, floor R0, 4@8040+1@4040 aluminum frame double pane air filled, 4 tube T12 lights always on during class time, heat pump.
Circle #1, #2	Least expensive and save energy & Least simple payback	Roof R0, wall R0 studs @ 24" (61.0 cm) OC, floor R0, 6@2040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, radiant barrier in the walls, heat pump.
Circle #3	Best 5 year total savings	Roof R11 (1.9 C m2/W), wall R0 studs @ 24" (61.0 cm) OC, floor R0, 6@6040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, radiant barrier in the walls, heat
Circle #4	Best 10 year total savings	Same as #3 except wall R11 (1.9 C m2/W) studs @ 24" (61.0 cm) OC.
Circle #5, #6	Best energy dollar savings & Best energy savings	Roof R11 (1.9 C m2/W), wall R11 (1.9 C m2/W) studs @ 24" (61.0 cm) OC, floor R0, 6@8040 aluminum double pane air low-e outside pane 0.04, 3 tube T8 lights with continuous dimming, radiant barrier in walls & roof, heat pump with cross-ventilation.
Circle #7	Best energy dollar savings closest to no increase in cost	Roof R0, wall R0 studs @ 24" (61.0 cm) OC, floor R0, 6@6040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, radiant barrier in the roof, heat pump with cross-ventilation.

Figure 9, Honolulu, HI

Astoria, Oregon

In this primarily heating climate, an increase in envelope insulation and decrease in the overall area of glazing proved most useful to reduce conduction losses. Switching to a three-tube T8 lighting scheme also proved worthwhile. A heat pump with a 60% effective heat exchanger saved energy but increased initial costs.

Symbol	Criteria	Building Description
Origin	Base case	Roof R13 (2.3 C m2/W), wall R15 (2.6 C m2/W) studs @ 16" (40.6 cm) OC, floor R19 (3.4 C m2/W), 11@8040+1@4040 aluminum frame double pane air filled, 4 tube T12 lights always on during class time, heat pump.
Diamond #1, #2	Least expensive and save energy & Least simple payback	Roof R30 (5.3 C m2/W), wall R11 (1.9 C m2/W) studs @ 24" (61.0 cm) OC, floor R19 (3.4 C m2/W), 6@2040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, electric furnace with cross-ventilation.
Diamond #3	Best 5 year total savings	Roof R30 (5.3 C m2/W), wall R11 (1.9 C m2/W) studs @ 24" (61.0 cm) OC, floor R11 (1.9 C m2/W), 2@2040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, heat pump.
Diamond #4	Best 10 year total savings	Same as #3 except wall R15 (2.6 C m2/W) studs @ 24" (61.0 cm) OC, 3 tube T8 lights with manual off.
Diamond #5, #6	Best energy dollar savings & Best energy savings	Roof R38 (6.7 C m2/W), wall R21 (3.7 C m2/W) studs @ 24" (61.0 cm) OC, floor R19 (3.4 C m2/W), 4@6040 aluminum double pane argon & 2@2040 aluminum double pane argon, 3 tube T8 lights with manual off, heat pump, 60% effective heat exchanger.
Diamond #7	Best energy dollar savings closest to no increase in cost	Roof R30 (5.3 C m2/W), wall R19 (3.4 C m2/W) studs @ 24" (61.0 cm) OC, floor R11 (1.9 C m2/W), 2@2040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, heat pump, 60% effective heat exchanger.

Figure 10, Astoria, OR

Spokane, Washington

The elimination of the economizer enabled us to look at some different options due to the initial cost reduction. The ability to switch to less expensive natural gas and rely solely on cross-ventilation for the cooling load (cross-ventilation handles all but 4 to 20 hours during the school year) proved very advantageous. A heat exchanger or solar air collector to temper the incoming fresh air showed promise.

Symbol	Criteria	Building Description
Origin	Base case	Roof R19 (3.4 C m2/W), wall R19 (3.4 C m2/W) studs @ 16" (40.6 cm) OC, floor R21 (3.7 C m2/W), 8@8040+1@4040 vinyl frame double pane air filled, 4 tube T12 lights always on during class time, heat pump with economizer.
Square #1, #2	Least expensive and save energy & Least simple payback	Roof R38 (6.7 C m2/W), wall R19 (3.4 C m2/W) studs @ 24" (61.0 cm) OC, floor R11 (1.9 C m2/W), 6@2040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, electric furnace with cross-ventilation.
Square #3	Best 5 year total savings	Same as #1 except natural gas furnace with cross-ventilation.
Square #4	Best 10 year total savings	Same as #3 except 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off.
Square #5, #6	Best energy dollar savings & Best energy savings	Roof R38 (6.7 C m2/W), wall R21 (3.7 C m2/W) studs @ 24" (61.0 cm) OC, floor R30 (5.3 C m2/W), 6@2040 vinyl frame double pane argon filled low-e inside pane 0.2, 3 tube T8 lights with manual off, solar wall, heat pump with cross-ventilation.
Square #7	Best energy dollar savings closest to no increase in cost	Same as #5 except 6@6040 vinyl frame double pane argon filled low-e inside pane 0.2, natural gas furnace with cross-ventilation, 60% effective heat exchanger.

Figure 11, Spokane, WA

Conclusions

While all of the buildings examined used less energy than the ASHRAE 90.1 standard, many also resulted in a decrease in first cost. Criteria #1 (least expensive first cost) and criteria #2 (shortest simple payback) produced buildings with decreased first costs in all climates. Criteria #3 (best total five-year savings) resulted in buildings with decreased first costs in all climates but Hawaii while criteria #4 (best total ten-year savings) resulted in buildings with decreased costs in all climates but Florida and Hawaii. The largest increase in first cost resulted from criteria #5 (building with best energy savings in dollars) in all climates but Arizona. In all climates but Alaska, the building with the best dollar savings

(criteria #5) and the building with the best energy savings at the site (criteria #6) were very similar. This was not the case in Alaska because the criteria #5 building used a #2 oil furnace and the criteria #6 building used a heat pump which resulted in different energy consumption at the site. Criteria #7 (best energy savings in dollars that was closest to no increase in first cost) resulted in buildings that saved more fuel than criteria #1, #2, and #3 in all climates. As a group, the building configurations examined in Alaska had approximately double the annual fuel savings than the other climates. This was primarily due to the long heating season in Alaska as compared to the other climates.

For this paper we examined the buildings resulting from criteria #1 and #4 more closely. Criteria #1 buildings showed the most dramatic reductions in first cost. The decrease in costs were achieved primarily by using the smallest window area modeled and reducing or maintaining the floor, roof, and wall insulation levels (except in California where the wall insulation increased). Because windows cost more per unit area and have a lower insulative value than walls, roofs, and floors we were able to reduce first costs while maintaining energy efficiency by decreasing the window area. Reduced daylighting did not appear to have so great an impact as to exclude this cost-saving strategy in any of the climates examined. More efficient electric lighting in the form of T8 tubes, however, were used in Alaska, Oregon, and Washington. Changing heating systems to a #2 oil furnace in Alaska and an electric furnace in Oregon and Washington also resulted from criteria #1.

As in criteria #1, all the buildings resulting from criteria #4 except Florida had reduced or equal window area compared to the ASHRAE 90.1 standard. In fact, all climates used the same window size except Oregon which used substantially less. Wall insulation levels increased or remained the same in each climate. Roof insulation levels increased or remained the same everywhere except Arizona where it was reduced and a radiant barrier added. Floor insulation appears to be the anomaly in that it was increased only in California and remained the same or decreased in all the other climates. All climates changed to 3 tube T8 light fixtures with manual controls. It is interesting to note that criteria #4 created buildings that used a heat pump either alone or in conjunction with cross

ventilation or a heat exchanger in all climates.

We have selected five prototypes with the best energy dollar savings for construction and installation at each of the school districts in the representative climates. The first of these prototypes has been installed in St. Helens, Oregon, and will be monitored for energy performance in Spring 1999.

2.0 BASIC UNIT WITH ENERGY FEATURES

The building developed in Phase I was refined due to changes in building codes, the addition of two more baselines to represent a wider climate range, an update to the cost of the building and its components, improved simulations of components of the building and integration of components in the building, and optimization of glazing size and location.

2.1 TECHNICAL OBJECTIVE #1: REFINE PHASE I DESIGN

Technical objective #1 included revision of the Phase I architectural design incorporating code restraints in the seven regions, identification of control systems, computer simulations of various building components, computer simulations of the integration of the most promising components, analysis of occupant comfort, and cost analysis of the Phase II design.

2.1.1 Architectural Design and Analysis

This task included review of UBC, CABO, ADA and transportation codes; optimization of the building insulation for cost and energy performance; and the development of various eave details to act as shading devices with consideration to both cost and energy performance in the seven regions.

2.1.1.1 Code review

Objective

The objective of this task was to determine the current building, construction and energy codes applicable in each of the climate zones in order to identify and incorporate code restraints in the seven regions.

Methodology

A systematic review of state and local codes was performed to determine the most code conforming designs possible. From this information we established a base line building design. We then insured that proposals for each new design would still meet the basic requirements for each code.

Results

The results for this task are grouped in the tables below for each climate zone identified. For exact construction techniques see the drawing specifications on Sheet 2 of the construction drawings for the seven baseline buildings located in the appendix.

Oregon

Building Codes						
Building Code	Occupancy Group	Construction Type	Allowable Area	Allowable Height	Minimum Set Backs	Occupant Load
OSSC						
UBC	E1	5-N	8000 SF	3 Stories	20 feet	89

Mechanical Codes						
Mechanical Code	Ventialtion Rate	Total OSA	Economiser Required	Heat Pump Required	Program. Stat	
OMSC						
UMC	15 cfm/per	1328 cfm	Yes	No	Yes	

Plumbing Codes						
Plumbing Code	P./Occ. Load	Number of W.C.	Number of Lav's	Number of Drink. F.	Uni-Sex Allowed	Fixtures In Adj. Bld.
OPSC						
UPC	45	2 HC	2 HC	1std/1 HC	No	Allowed

Electrical Codes						
Electrical Code	Design w/sf	Min. # Recepticals	Service Size	Service Voltage	Service Phase	
NEC	3	None	200amp	120/240	1	

Energy Codes						
Energy Code	Wall Insulation	Floor Insulation	Roof Insulation	Window U-Value	Door U-Value	Lighting w/sf
OSSC						
Chpt 13	R-11	R-11	R-19	0.50	Exempt	1.2

Figure 12, Codes – Oregon

Washington

Building Code	Occupancy Group	Construction Type	Allowable Area	Allowable Height	Minimum Set Backs	Occupant Load
WAC51-30						
UBC	E1	5-N	8000 SF	3 Stories	20 feet	89

Mechanical Codes						
Mechanical Code	Ventialtion Rate	Total OSA	Economiser Required	Heat Pump Required	Program. Stat	
WAC51-32	WAC51-04					
UMC	15 cfm/per	1328 cfm	Yes	Yes	Yes	

Plumbing Codes						
Plumbing Code	P./Occ. Load	Number of W.C.	Number of Lav's	Number of Drink. F.	Uni-Sex Allowed	Fixtures In Adj. Bld.
WAC51-26						
UPC	45	2 HC	2 HC	1std/1 HC	No	Allowed

Electrical Codes						
Electrical Code	Design w/sf	Min. # Recepticals	Service Size	Service Voltage	Service Phase	
NEC	3	None	200amp	120/240	1	

Energy Codes						
Energy Code	Wall Insulation	Floor Insulation	Roof Insulation	Window U-Value	Door U-Value	Lighting w/sf
WAC51-11						
NREC	R-11	R-19	R-19	0.90	0.6	1.2

Figure 13, Codes - Washington

California

Building Code	Occupancy Group	Construction Type	Allowable Area	Allowable Height	Minimum Set Backs	Occupant Load
Title 24						
UBC	E1	5-N	8000 SF	3 Stories	20 feet	89

Mechanical Codes						
Mechanical Code	Ventialtion Rate	Total OSA	Economiser Required	Heat Pump Required	Program. Stat	
Title 23						
UMC	05 cfm/per	443 cfm	No	No	Yes	

Plumbing Codes						
Plumbing Code	P./Occ. Load	Number of W.C.	Number of Lav's	Number of Drink. F.	Uni-Sex Allowed	Fixtures In Adj. Bld.
Title 23						
UPC	45	2 HC	2 HC	1std/1 HC	No	Allowed

Electrical Codes						
Electrical Code	Design w/sf	Min. # Recepticals	Service Size	Service Voltage	Service Phase	
NEC	3	None	200amp	120/240	1	

Energy Codes						
Energy Code	Wall Insulation	Floor Insulation	Roof Insulation	Window U-Value	Door U-Value	Lighting w/sf
Cal						
energy code	R-11	R-11	R-19	0.90	0.6	1.2

Figure 14, Codes – California

Alaska

Building Code	Occupancy Group	Construction Type	Allowable Area	Allowable Height	Minimum Set Backs	Occupant Load
UBC	E1	5-N	8000 SF	3 Stories	20 feet	89

Mechanical Codes						
Mechanical Code	Ventialtion Rate	Total OSA	Economiser Required	Heat Pump Required	Program. Stat	
UMC	05 cfm/per	443 cfm	No	No	No	

Plumbing Codes						
Plumbing Code	P./Occ. Load	Number of W.C.	Number of Lav's	Number of Drink. F.	Uni-Sex Allowed	Fixtures In Adj. Bld.
UPC	45	2 HC	2 HC	None	No	Allowed

Electrical Codes						
Electrical Code	Design w/sf	Min. # Recepticals	Service Size	Service Voltage	Service Phase	
NEC	3	None	200amp	120/240	1	

Energy Codes						
Energy Code	Wall Insulation	Floor Insulation	Roof Insulation	Window U-Value	Door U-Value	Lighting w/sf
	R-13	R-19	R-30	0.50	0.6	1.2

Figure 15, Codes – Alaska

Hawaii

Building Codes						
Building Code	Occupancy Group	Construction Type	Allowable Area	Allowable Height	Minimum Set Backs	Occupant Load
UBC	E1	5-N	8000 SF	3 Stories	20 feet	89

Mechanical Codes						
Mechanical Code	Ventialtion Rate	Total OSA	Economiser Required	Heat Pump Required	Program. Stat	
UMC	05 cfm/per	443 cfm	No	No	Yes	

Plumbing Codes						
Plumbing Code	P./Occ. Load	Number of W.C.	Number of Lav's	Number of Drink. F.	Uni-Sex Allowed	Fixtures In Adj. Bld.
UPC	45	2 HC	2 HC	1std/1 HC	No	Allowed

Electrical Codes						
Electrical Code	Design w/sf	Min. # Recepticals	Service Size	Service Voltage	Service Phase	
NEC	3	None	200amp	120/240	1	

Energy Codes						
Energy Code	Wall Insulation	Floor Insulation	Roof Insulation	Window U-Value	Door U-Value	Lighting w/sf
	R-7	R-7	R-19	None	None	1.2

Figure 16, Codes – Hawaii

Arizona

Building Codes						
Building Code	Occupancy Group	Construction Type	Allowable Area	Allowable Height	Minimum Set Backs	Occupant Load
UBC	E1	5-N	8000 SF	3 Stories	20 feet	89

Mechanical Codes						
Mechanical Code	Ventialtion Rate	Total OSA	Economiser Required	Heat Pump Required	Program. Stat	
UMC	15 cfm/per	1328 cfm	No	No	Yes	

Plumbing Codes						
Plumbing Code	P./Occ. Load	Number of W.C.	Number of Lav's	Number of Drink. F.	Uni-Sex Allowed	Fixtures In Adj. Bld.
UPC	45	2 HC	2 HC	1std/1 HC	No	Allowed

Electrical Codes						
Electrical Code	Design w/sf	Min. # Recepticals	Service Size	Service Voltage	Service Phase	
NEC	3	None	200amp	120/240	1	

Energy Codes						
Energy Code	Wall Insulation	Floor Insulation	Roof Insulation	Window U-Value	Door U-Value	Lighting w/sf
	R-11	R-11	R-19	None	None	1.2

Figure 17, Codes – Arizona

Florida

Building Code	Occupancy Group	Construction Type	Allowable Area	Allowable Height	Minimum Set Backs	Occupant Load
	E1	5-N	8000 SF	3 Stories	20 feet	89

Mechanical Codes						
Mechanical Code	Ventialtion Rate	Total OSA	Economiser Required	Heat Pump Required	Program. Stat	
	15 cfm/per	1328 cfm	Yes	No	Yes	2

Plumbing Codes						
Plumbing Code	P./Occ. Load	Number of W.C.	Number of Lav's	Number of Drink. F.	Uni-Sex Allowed	Fixtures In Adj. Bld.
	45	2 HC	2 HC	1std/1 HC	No	Allowed

Electrical Codes						
Electrical Code	Design w/sf	Min. # Recepticals	Service Size	Service Voltage	Service Phase	
	3	None	200amp	120/240	1	

Energy Codes						
Energy Code	Wall Insulation	Floor Insulation	Roof Insulation	Window U-Value	Door U-Value	Lighting w/sf
	R-7	R-7	R-11	0.90	1	1.2

Figure 18, Codes – Florida

Please note that Florida is outside of Modern Building Systems, Inc.'s normal market area and the building codes of this climate were verified by contact with local manufacturers for determination of Florida Industry Standards. The information in this table is exactly that " Industry Standard" and does not reflect a particular model code standard.

Conclusions

For the most part this type of structure is built the same way from location to location across the United States. The building codes are very similar in all seven

climate zones. Modern Building Systems, Inc.'s typical construction practices meet or exceed all of the structural, mechanical, plumbing, electrical and energy codes identified. See figure 19 below for the differences between the states identified in regard to Energy Code Envelope "minimum requirements". The values in the table were used for the base line designs in each climate zone. The "Base Line Design" values represent the typical design standard expected by the customer in each of these climate zones.

Energy Codes Summary						
Climate	Description	Wall Insulation	Floor Insulation	Roof Insulation	Window U-Value	Door U-Value
Oregon	Code Min.	R-11	R-11	R-19	0.5	EXEMPT
	Base line design	R-11	R-11	R-30	0.5	0.6
Washington	Code Min.	R-11	R-19	R-19	0.9	0.6
	Base line design	R-19	R-19	R-30	0.35	0.6
California	Code Min.	R-11	R-11	R-19	0.9	0.6
	Base line design	R-11	R-11	R-30	0.5	0.6
Alaska	Code Min.	R-13	R-19	R-30	0.5	0.6
	Base line design	R-19	R-19	R-38	0.35	0.6
Hawaii	Code Min.	R-7	R-7	R-19	None	None
	Base line design	R-11	R-11	R-19	0.5	0.6
Arizona	Code Min.	R-11	R-11	R-19	None	None
	Base line design	R-11	R-11	R-19	0.5	0.6
Florida	Code Min.	R-7	R-7	R-11	0.9	1
	Base line design	R-11	R-11	R-30	0.5	0.6

Figure 19, Energy Codes Summary

2.1.1.2 Optimize Structure for Insulation and Cost

Objective

The objective of this task is to redesign the structural and insulation components for optimum performance and to prepare a preliminary cost comparison analysis of those components.

Methodology

All reasonable alternatives for the baseline models were considered using actual data collected from computer simulations. They included items such as insulation values, window size and placement, stud spacing, and local standards. Each component was considered for cost, availability, and local usage in each climate zone.

It was determined that the stud spacing could be widened to 24" on center from Modern Building Systems, Inc.'s standard spacing of 16" on center. Insulation practices were changed to maximize performance without changing cost.

Results

Stud spacing was widened to 24" on center. Insulation was changed to match the seven climate zones. In many cases the insulation was increased while in others it was partially eliminated.

2.1.1.3 Long Roof Overhangs

Objective

To design and detail construction drawings for long roof overhangs to provide energy savings.

Methodology

Construction drawings were created using Modern Building Systems, Inc. computer aided drafting software *Arris*. Details are derived from structural analysis and cost effective construction measures. The design of the overhangs has to allow for easy construction and transportation without adding to the cost. Energy savings were evaluated for each size of overhang.

Results and Conclusions

Construction drawings were created incorporating the most energy efficient and cost effective construction techniques. The overhangs ranged in length from 2'-0" to 6'-0". Any overhang over 2'-0" in length has to be site constructed. This construction can be either panels or standard site framing. Several factors determined the cost savings. They included transportation costs, site built labor costs, and size of the overhang. Energy savings in regard to shading were found to be minimal when compared to loss of natural daylighting. More energy was used to light the room than was saved by the long roof overhangs. The 2'-0" overhang was found to be the most cost effective, although it provided only minimal energy savings. The 2'-0"overhang was primarily an architectural feature.

2.1.1.4 Schematic Toilet Rooms

Objective

To design a minimum sized restroom meeting all applicable codes.

Methodology

A review of all applicable codes to achieve a minimal sized restroom.

Results

Using Modern Building Systems, Inc.'s current standards as well as the current Uniform Building Code and Americans with Disabilities Act a minimum sized restroom was designed.

Conclusions

See attached minimum sized restroom.

2.1.2 Cost Analysis

Objective

The objective of this task was to determine the costs for all of the various baseline

alternatives in Phase II and develop a baseline building for each of the seven climate zone. We then improved cost estimates for lighting controls, eave details, preheaters, and other alternatives. Cost estimates were calculated for the revised designs for Phase II.

Methodology

All reasonable alternatives for the baseline models were analyzed using data collected from computer simulations. Alternatives included items such as insulation values, window size and placement, stud spacing, and local standards. Each component was considered for cost, availability, and local usage in each climate zone.

Results

MBS supplies

2.1.2.1 Revise Baselines

Objective

To revisit the baseline pricing established in Phase I and update and correct cost estimates to reflect our current baseline decisions.

Methodology

Using Modern Building Systems, Inc.'s estimating software and historical data estimates were prepared for each climate zone of the cost of each building. This information will be used then to compare costs of new energy features and determine cost savings or increases, if any.

Results

Results are shown in figure 20, Base Line Cost Estimates.

Baseline Cost Estimates										
Climate	Div.1	Div.6	Div. 7	Div.8	Div.9	Div. 10	Div. 15	Div.16	Total Cost	Cost / SF
Astoria, Or.	$584	$11,065	$3,497	$813	$2,703	$112	$4,773	$4,675	$28,222	$15.75
Sacremento, Ca.	$584	$11,080	$3,923	$813	$2,789	$112	$5,913	$4,765	$29,979	$16.73
Fairbanks, Ak.	$515	$11,880	$4,030	$960	$2,789	$112	$6,053	$4,265	$30,604	$17.08
Honolulu, Hi.	$515	$10,990	$3,324	$813	$2,766	$112	$5,973	$4,265	$28,758	$16.05
Miami, Fl.	$515	$11,020	$3,493	$813	$2,766	$112	$5,497	$4,052	$28,268	$15.77
Phoenix, Az.	$515	$11,020	$3,324	$813	$2,766	$112	$6,053	$4,265	$28,868	$16.11
Spokane, Wa.	$584	$11,377	$3,852	$830	$2,766	$112	$5,913	$4,765	$30,199	$16.85

Figure 20, Base Line Cost Estimates

Conclusions

The costs identified in these estimates is very typical of the average costs of similar projects currently being constructed by Modern Building Systems, Inc.

2.1.1.2 Compare Photocells and Occupancy Sensors

The objective of this task is to compare the overall cost and efficiency of photocells and occupancy sensors, analyze the results, and determine the most feasible application in each of the seven climate zones.

Methodology

We compared photocells and occupancy sensors against each other for overall performance and energy savings. We then compared total costs to determine the most feasible use in each of the seven climate zones. We then compared comfort levels of actual installations.

Results

A comparison between photocells and occupancy sensors has shown the following cost results:

Usage by customers has provided the following results. Classrooms equipped

with continuous dimming photocells were accepted readily by the occupants. However, the stepped dimming ballasts were an annoyance and several complaints were filed. Occupancy sensors were the lighting control of choice. Occupants had no complaints and praised their use.

Conclusions

Photocells with continuous dimming ballasts were used in the following climate zones: Honolulu, Hawaii; Phoenix, Arizona; and Miami, Florida; Astoria, Oregon; and Sacramento, California. Photocells with continuous stepped ballasts were not used.

Occupancy sensors were used in the following climate zones: Spokane, Washington; and Fairbanks, Alaska.

2.1.3 Control Systems

We used inputs to develop possible areas of concern. We then identified types of controls and their requirements, using applicable codes from technical objective #1 and results gained from analysis of long roof overhangs. We then consulted with a control specialist, using collected data and integrated and analyzed results to develop a system that would work with the Phase II design and establish its cost.

Objective

The objective of this task was the identification of possible control systems and their requirements for operation.

Methodology

We consulted with a building control system specialist, who then determined which controller system best met the buildings requirements.

Results

Several meetings and phone conversations were held between Industrial Controls Company and Modern Building Systems, Inc. to determine the best control

system for the building. Ron Johnson of Industrial Controls Company researched our needs and determined that the Honeywell Excel 50 control system, the newest member of the EXCEL 5000 system, would best meet our needs. This system has the ability to control one building or a complex of buildings. It is 365 day programmable and will control the mechanical system, outside air intake, and dimming lights if the building is equipped.

Conclusions

Industrial Controls Company recommends the Honeywell Excel 50 control unit. This unit provides for the wide range of components found in the seven climate zones.

2.1.3.1 Integrated 365 day control system

The objective of this task was to identify a control unit that would control all aspects of the building (i.e. mechanical unit, heater exchange fans, occupancy sensors, daylight sensors, return air sensors, and carbon dioxide sensors).

Methodology

A control expert from Industrial Control Company was consulted to determine the best system available to control the building. Industrial Control Company specializes in distributing controllers from several major manufacturers.

Results

The control system chosen was the Honeywell Excel 50. Climate zones have no effect on the performance of the unit. Programming of this unit is required. Programming is set up individually for each building. A template program can be saved and downloaded to like buildings. It is 365 day programmable and will control the mechanical system, heat exchanger fans, occupancy sensor, daylight sensors, return air sensors, and carbon dioxide sensors. The Honeywell Excel 50 has the ability to control one building or a complex of buildings. The control is very compact and is installed in a standard stud bay. The installation of the control system is required to be done by a certified professional.

Conclusions

The Honeywell Excel 50 is the control unit of choice. It is easily programmed and installed. This unit provides for easy expansion and upgrades.

2.1.4 Computer Simulations

The Phase II design was evaluated for energy performance versus cost by analyzing individual changes in: insulation levels; use of a solar air preheater on the walls; use of a solar air preheater on the roof; types of windows used in the building; types of shades used with the building; and the use of radiant barriers in the envelope. The most promising combinations in each region were integrated together and simulated to optimize the design. The building was analyzed for occupancy thermal comfort and visual comfort.

2.1.4.1 Energy costs

Objective

Compare the energy consumption of the parametric cases with base case. Also compare the cost of the parametric cases with the base case.

Methodology

The comparison of energy consumption was done by taking the total site energy result from the DOE-2.1E simulation for the base case and subtracting the paratmetric case result. This would give the energy saved over the base case. The cost of the parametric case was subtracted from the base case. This allowed a cost comparison of each of the parametric cases with their corresponding energy savings over the base case.

Conclusions

This allowed a cost comparison of each of the parametric cases with their corresponding savings over the base case.

2.1.4.2 Base case

Objective

Using DOE-2.1E run simulations of the base case of the classroom. All seven climates were analyzed: Fairbanks, Alaska; Phoenix, Arizona; Bakersfield, California; Miami, Florida; Honolulu, Hawaii; Astoria, Oregon; and Spokane, Washington.

Methodology

The energy baseline for all the climates was simulated using information gathered during the earlier part of phase one of the project. The simulations use a nine month school period. The schedules for people, lights, and equipment were based on a study of a classroom module in Warrington, Oregon. The building was a 28' x 64' with its long sides facing north and south. The south face of the building had two 4040 double pane windows (shading coefficient of 0.81 and U value of 0.48 BTU/sqft hr °F) with aluminum or vinyl frames depending on climate. Differences in energy related characteristics varying by climate are shown in figures 21 to 24. The south face also had two insulated steel doors (U values of 0.20 BTU/sqft hr °F). The wall construction was 2x4 or 2x6 studs 16" on center with insulation of R11 or R19. The roof was 2x8 joists 24" on center with insulation of R19, R30, or R38 in the main part of the roof and R11 in the first two feet of the eaves. The floor was 2x8 joists 16" on center with insulation of R11 or R 19. The lighting was by fourteen 2'x4' recessed four-tube 34W fluorescent lights with T12 magnetic ballasts for a designed output of 50 foot candles. The classroom was furnished with standard desks and chairs occupying 45% of the floor area and having a distributed weight of 2 lbs/square foot. The building had a capacity of 52 people that generated 240 BTU/hr/person of latent heat and 100 BTU/hr/person of sensible heat into the space. The building had an infiltration rate of 0.237 ACH. There were two six-gallon water heaters with 1200 W heating elements to serve the two restrooms in the building. The HVAC system consisted of two three-ton heat pumps with either 10 kW or 15 kW electrical resistance heaters and some climates had an enthalpy economizer. The heat pumps were modeled as Package Single Zoned (PSZ) systems with the heat pump as the heat source. A Bard, Wall-Mount Hi-Boy heat pump model WH361-A was used to

obtain the performance curves of the system for cooling capacity, heating capacity, and efficiency curves.

	Roof		Wall		Floor	
Climate	R-value main/eaves	joist spacing	R-value	stud spacing	R-value	joist spacing
Fairbanks, AK	38/11	2x8 24" OC	19	2x6 16" OC	19	2x8 16" OC
Phoenix, AZ	19/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Bakersfield, CA	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Miami, FL	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Honolulu, HI	19/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Astoria, OR	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Spokane, WA	30/11	2x8 24" OC	19	2x6 16" OC	19	2x8 16" OC

Figure 21, Base case insulation levels and stud/joist spacing

Climate	Window frame type
Fairbanks, AK	vinyl
Phoenix, AZ	aluminum
Bakersfield, CA	aluminum
Miami, FL	aluminum
Honolulu, HI	aluminum
Astoria, OR	aluminum
Spokane, WA	vinyl

Figure 22, Base case window frame style

Climate	Electrical resistance heater (kW)	Heating capacity (BTU/hr)	Cooling capacity (BTU/hr)	Enthalpy economizer
Fairbanks, AK	15	51,200	35,600	no
Phoenix, AZ	10	34,400	35,600	no
Bakersfield, CA	10	34,400	35,600	yes
Miami, FL	10	34,400	35,600	no
Honolulu, HI	10	34,400	35,600	no
Astoria, OR	10	34,400	35,600	no
Spokane, WA	10	34,400	35,600	yes

Figure 23, Base case HVAC system

Climate	Altitude (feet above sea level)	Average outdoor dry bulb temperature during school year (°F)
Fairbanks, AK	436	17
Phoenix, AZ	1,112	66
Bakersfield, CA	475	60
Miami, FL	7	74
Honolulu, HI	12	75
Astoria, OR	8	49
Spokane, WA	2,357	42

Figure 24, climate data

Conclusions

The results of the base case building's annual energy consumptions are shown in figure 25 for each of the climates.

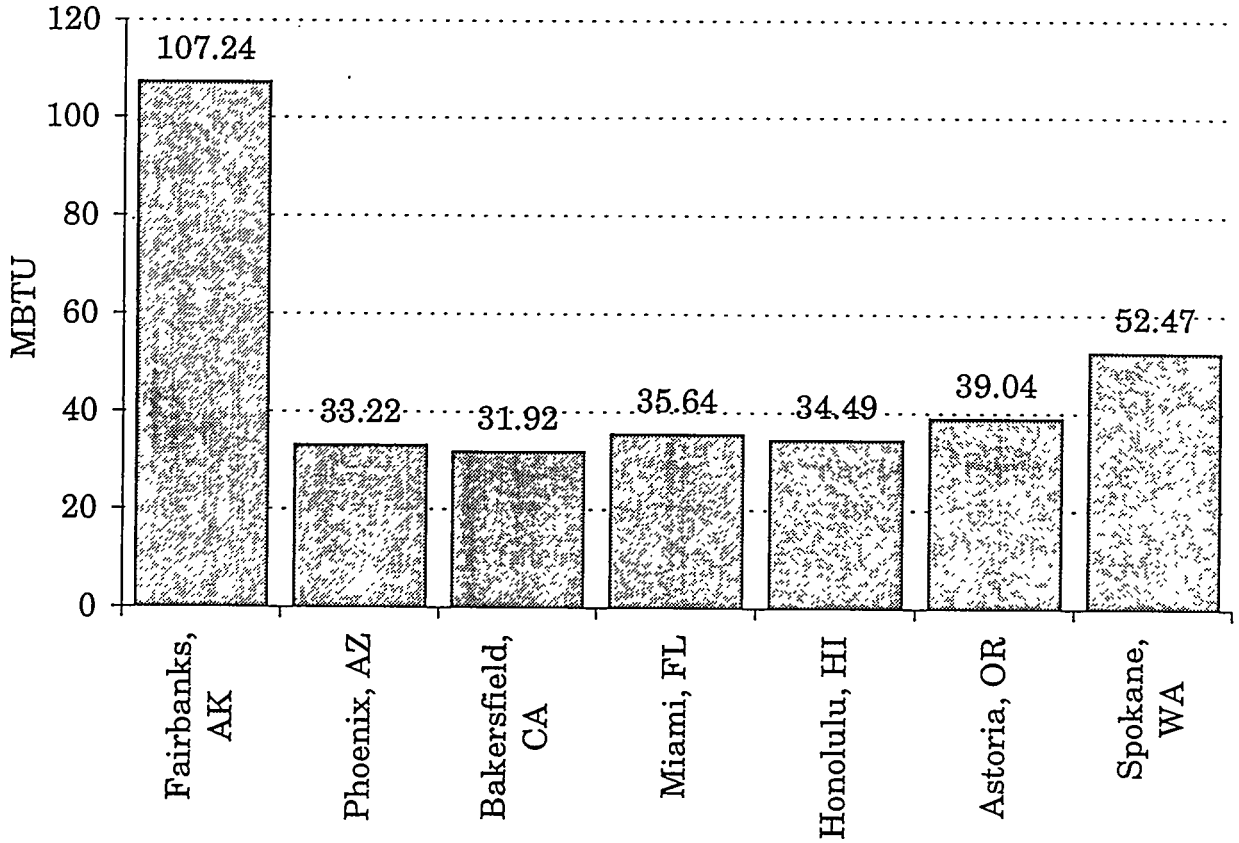


Figure 25, annual energy use of the base case

2.1.4.3 Insulation Parametrics

Objective

Using DOE-2.1E run parametric simulations of the insulation in the roof, walls, and floor of the classroom. The thickness of the insulation was varied to correspond to varying R values of insulation. All seven climates where analyzed.

Methodology

The effective R value was calculated to account for the studs and joist in parallel with the insulation. The roof is 24" OC and assumes that 6% of the roof area is joists. The walls are 16" OC and 24" OC and assumes that 20% and 15% of the wall area is studs, increased stud area is due to framing around doors, windows, and plates. The floor is 16" OC and assumes that 10% of the floor area is joists. The corresponding R value of insulation is shown in figure 1 with its effective R value and its effective thickness of fiberglass insulation. The results we used to

modify the DOE-2.1E input file for each of the climates and the results were compared to the base case. The base case is different for each climate, see figure 2. The base case also has two 4040 windows and two solid metal door on the south side of the building. The parametric cases has six 4040 windows, two on the north and four on the south, and two metal doors with 1/2 lite double pane glass on the north side. The parametric cases have continuous dimming fluorescent lights with a photo sensor set at 50 foot candles in the middle of the class room at desk height and an occupancy sensor. The base case has fluorescent lights with an occupancy sensor only. One insulation level is varied at a time for the parametric cases while the all other building functions are held at the base case level, with the exception of the lighting, windows, and doors as mentioned above. The difference of the parametric buildings annual kWh energy use minus the base case building's annual kWh energy use is the annual kWh saving as shown in figures 28 through 34.

Air R value from ASHRAE 1989 Fundementals pg. 22.2 Table 2 (50° mean 10° difference) E=.82

thickness	vertical	horizontal roof (up)	45° roof (up)	horizontal floor (down)
0.5	0.91	0.84	0.9	0.92
0.75	1.01	0.87	0.94	1.02
1.5	1.02	0.89	0.94	1.15
3.5 +	1.01	0.93	0.96	1.24

Soft wood conductance 0.8
Fiberglass conductivity 0.025

Vertical Walls

inch OC	stud	stud thickness (inches)	stud R	insulation R	insulation thickness (inches)	air thickness (inches)	air R	U stud	U gap	Uave	Rave	Fiberglass thickness (ft)
16	2x4	3.5	4.375	0	0	3.5	1.010	0.229	0.990	0.838	1.194	0.030
16	2x4	3.5	4.375	7	2	1.5	1.020	0.229	0.125	0.145	6.875	0.172
16	2x4	3.5	4.375	11	3.5	0	0.000	0.229	0.091	0.118	8.443	0.211
16	2x4	3.5	4.375	13	3.5	0	0.000	0.229	0.077	0.107	9.324	0.233
16	2x4	3.5	4.375	15	3.5	0	0.000	0.229	0.067	0.099	10.096	0.252
16	2x6	5.5	6.875	19	5.5	0	0.000	0.145	0.053	0.071	14.046	0.351
16	2x6	5.5	6.875	21	5.5	0	0.000	0.145	0.048	0.067	14.884	0.372
16	2x10	9.5	11.875	30	9	0.5	0.910	0.084	0.032	0.043	23.406	0.585
16	2x12	11.5	14.375	38	10	1.5	1.020	0.070	0.026	0.034	29.057	0.726
24	2x4	3.5	4.375	0	0	3.5	1.010	0.229	0.990	0.876	1.142	0.029
24	2x4	3.5	4.375	7	2	1.5	1.020	0.229	0.125	0.140	7.129	0.178
24	2x4	3.5	4.375	11	3.5	0	0.000	0.229	0.091	0.112	8.964	0.224
24	2x4	3.5	4.375	13	3.5	0	0.000	0.229	0.077	0.100	10.033	0.251
24	2x4	3.5	4.375	15	3.5	0	0.000	0.229	0.067	0.091	10.995	0.275
24	2x6	5.5	6.875	19	5.5	0	0.000	0.145	0.053	0.067	15.025	0.376
24	2x6	5.5	6.875	21	5.5	0	0.000	0.145	0.048	0.062	16.053	0.401
24	2x10	9.5	11.875	30	9	0.5	0.910	0.084	0.032	0.040	24.919	0.623
24	2x12	11.5	14.375	38	10	1.5	1.020	0.070	0.026	0.032	31.038	0.776

2/12 roof assume horizontal and no trapped air portion for calculations (MAIN portion of roof) air layer is added in DC

inch OC	joist	joist thickness (inches)	joist R	insulation R	insulation thickness (inches)	air thickness	air R	U joist	U gap	Uave	Rave	Fiberglass thickness (ft)
24	2x8	7.5	9.375	0	0	7.5	0.930	0.107	1.075	1.017	0.983	0.025
24	2x8	7.5	9.375	7	2	0	0.000	0.107	0.143	0.141	7.108	0.178
24	2x8	7.5	9.375	11	3.5	0	0.000	0.107	0.091	0.092	10.887	0.272
24	2x8	7.5	9.375	13	3.5	0	0.000	0.107	0.077	0.079	12.705	0.318
24	2x8	7.5	9.375	15	3.5	0	0.000	0.107	0.067	0.069	14.479	0.362
24	2x8	7.5	9.375	19	5.5	0	0.000	0.107	0.053	0.056	17.898	0.447
24	2x8	7.5	9.375	21	5.5	0	0.000	0.107	0.048	0.051	19.546	0.489
24	2x8	7.5	9.375	30	9	0	0.000	0.107	0.033	0.038	26.502	0.663
24	2x8	7.5	9.375	38	10	0	0.000	0.107	0.026	0.031	32.116	0.803

Floor insulation includes incapsulated air layer

inch OC	joist	joist thickness (inches)	joist R	insulation R	insulation thickness (inches)	air thickness	air R	U joist	U gap	Uave	Rave	Fiberglass thickness (ft)
16	2x8	7.5	9.375	0	0	7.5	1.240	0.107	0.806	0.736	1.358	0.034
16	2x8	7.5	9.375	7	2	5.5	1.240	0.107	0.121	0.120	8.341	0.209
16	2x8	7.5	9.375	11	3.5	4	1.240	0.107	0.082	0.084	11.877	0.297
16	2x8	7.5	9.375	13	3.5	4	1.240	0.107	0.070	0.074	13.537	0.338
16	2x8	7.5	9.375	15	3.5	4	1.240	0.107	0.062	0.066	15.132	0.378
16	2x8	7.5	9.375	19	5.5	2	1.240	0.107	0.049	0.055	18.138	0.453
16	2x8	7.5	9.375	21	5.5	2	1.240	0.107	0.045	0.051	19.556	0.489

Figure 26, Equivalent R-values of roof, walls, and floor

	Roof		Wall		Floor	
Climate	R-value	spacing	R-value	spacing	R-value	spacing
Fairbanks, AK	38/11	2x8 24" OC	19	2x6 16" OC	19	2x8 16" OC
Phoenix, AZ	19/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Bakersfield, CA	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Miami, FL	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Honolulu, HI	19/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Astoria, OR	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Spokane, WA	30/11	2x8 24" OC	19	2x6 16" OC	19	2x8 16" OC

Figure 27, Base case insulation levels and stud/joist spacing.

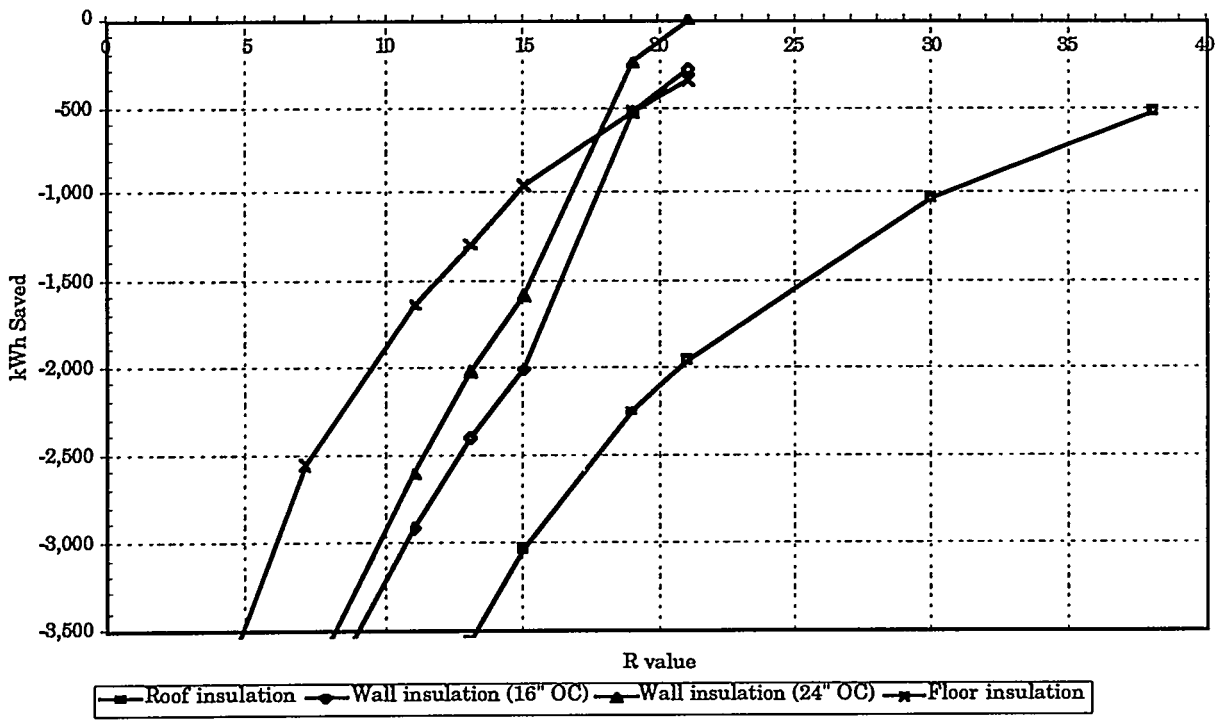


Figure 28, Fairbanks, AK insulation level and kWh saved over base case

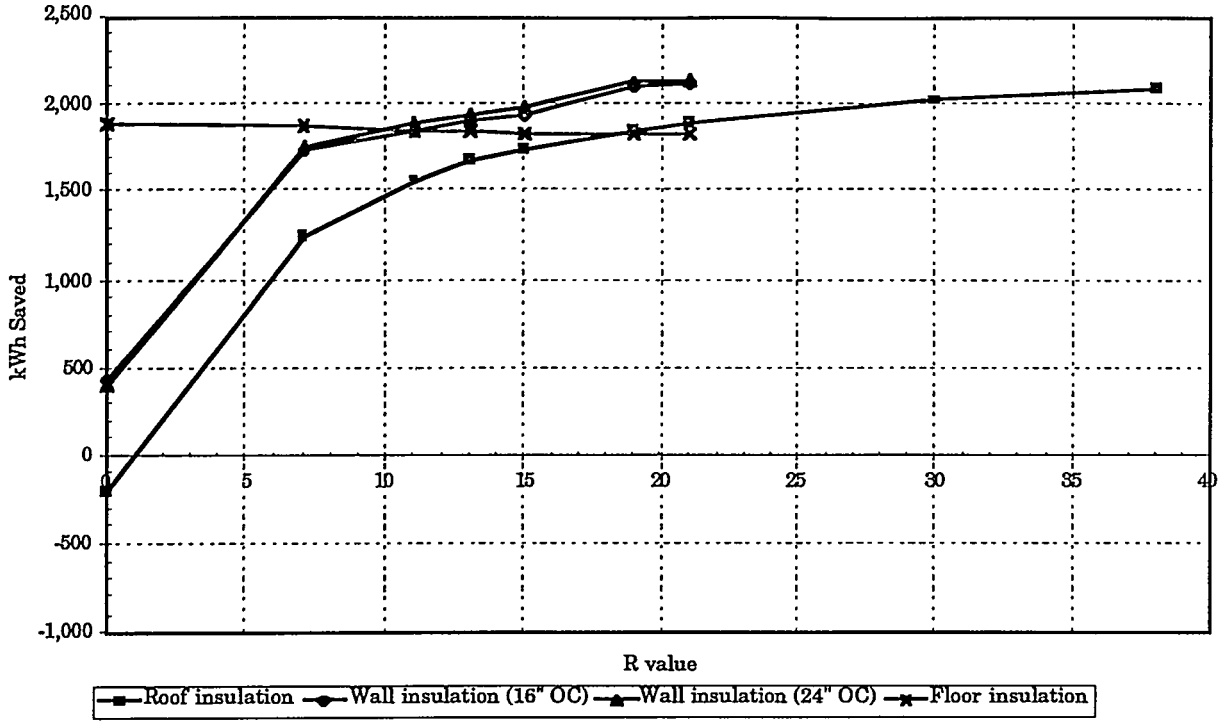


Figure 29, Phoenix, AZ insulation level and kWh saved over base case

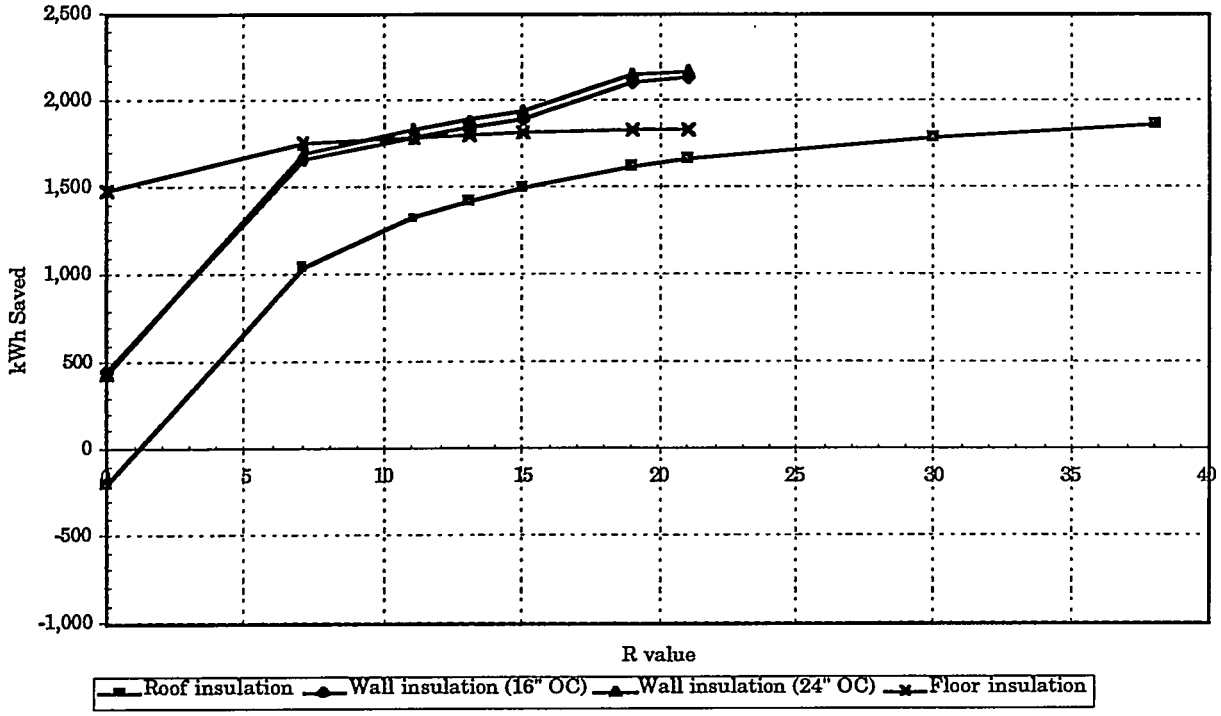


Figure 30, Bakersfield, CA insulation level and kWh saved over base case

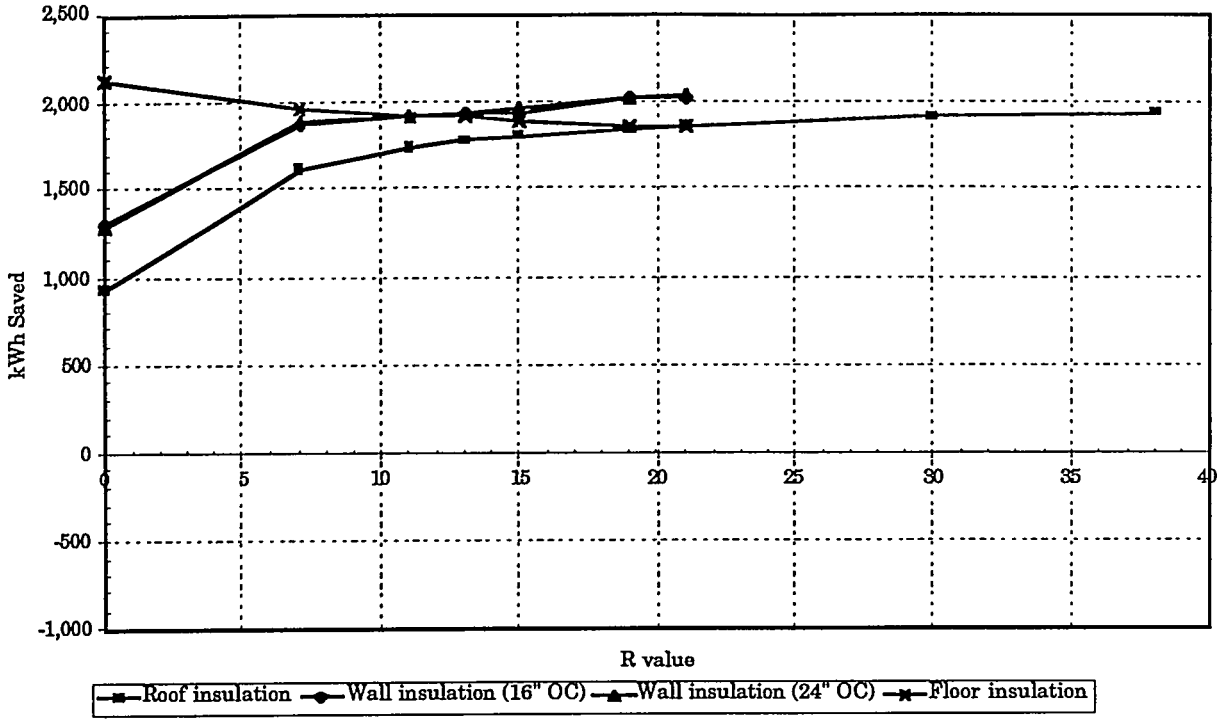


Figure 31, Miami, FL insulation level and kWh saved over base case

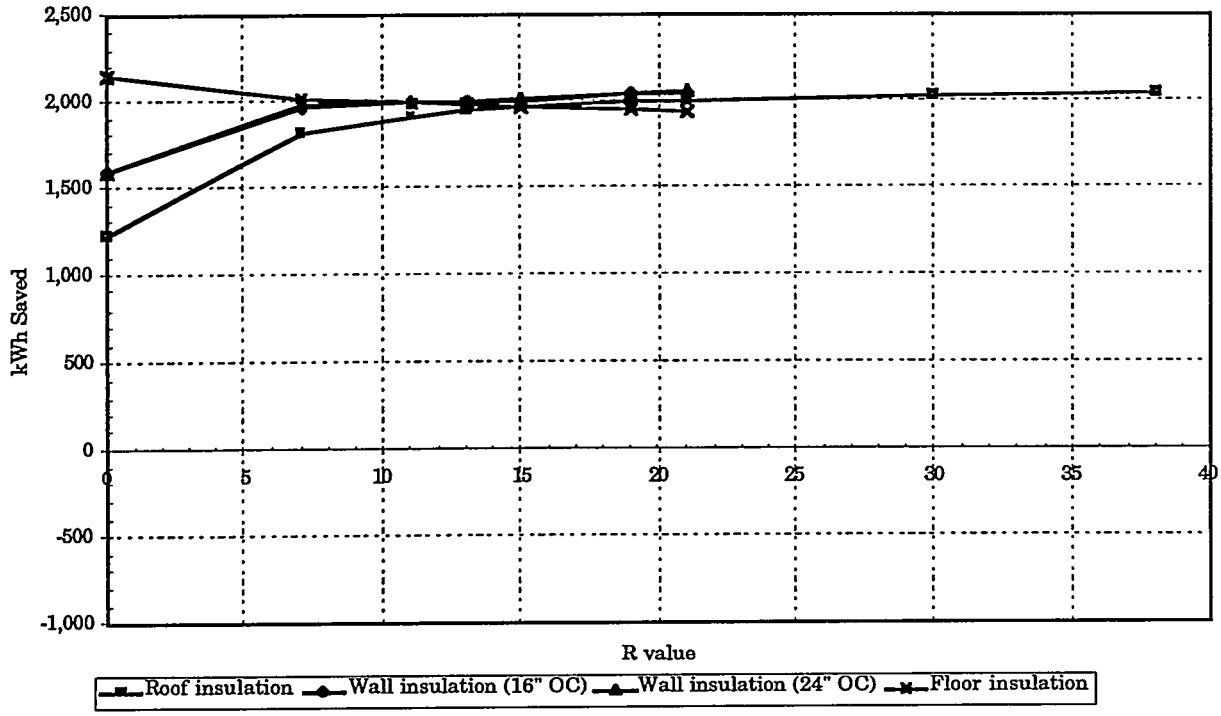


Figure 32 , Honolulu, HI insulation level and kWh saved over base case

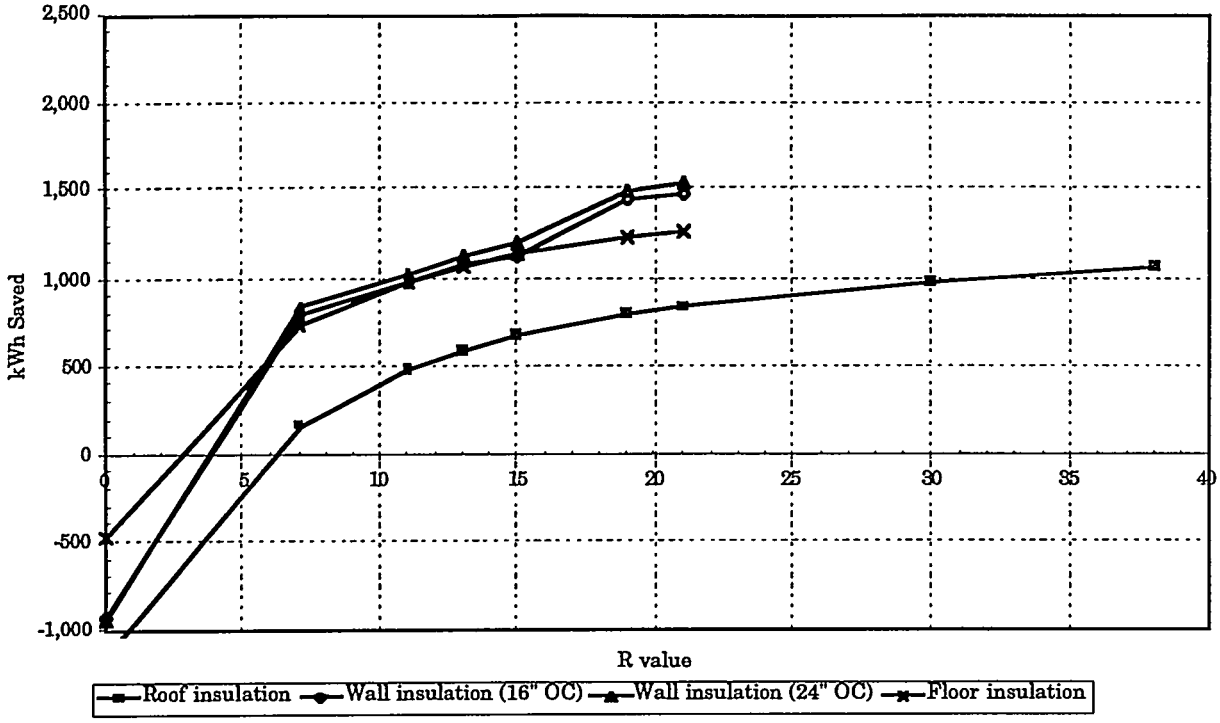


Figure 33, Astoria, OR insulation level and kWh saved over base case

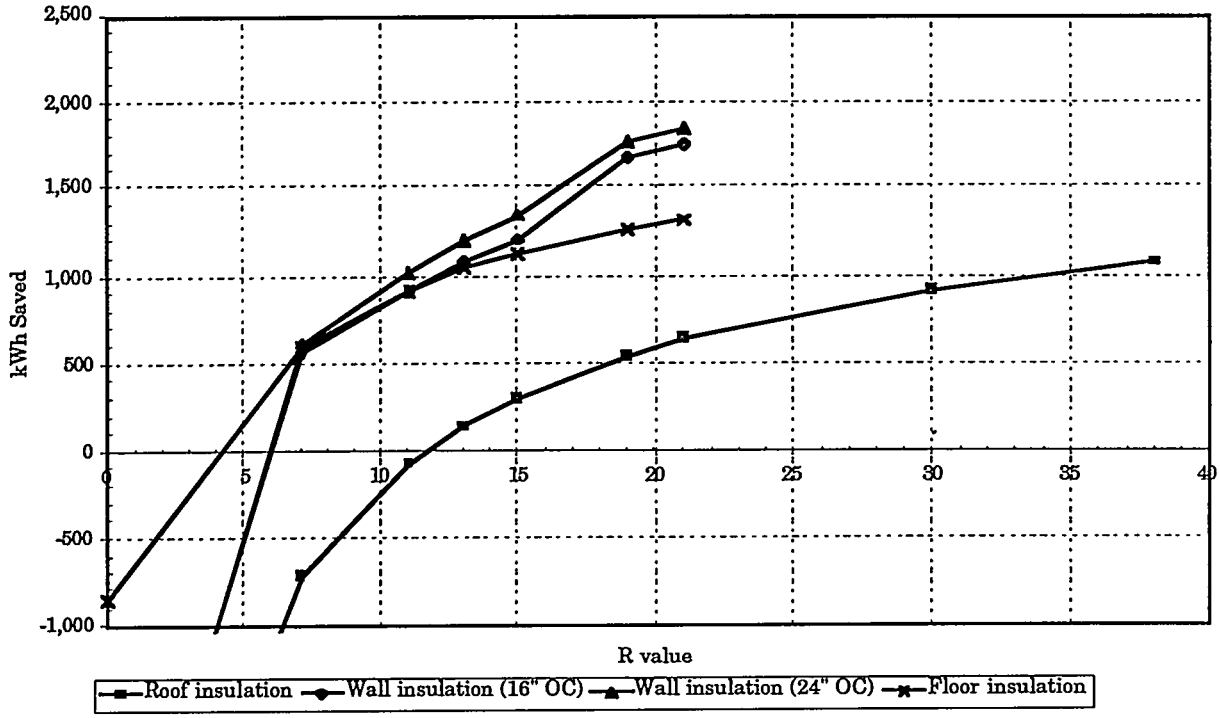


Figure 34, Spokane, WA insulation level and kWh saved over base case

Conclusions

In Fairbanks, Alaska, increasing of the insulation level of any component is a savings in this heavily heating dominated climate. The addition of more double pane window area in this climate causes the heating load to increase over the solar gain. Increasing the insulation level starts to bring it back to the base case's energy consumption.

In Phoenix, Arizona, increasing the roof and wall insulation causes increased savings. Decreasing the floor insulation also causes increased savings by ground coupled cooling through the floor.

In Bakersfield, California, the greatest gains in savings is from increasing the wall and roof insulation. The floor insulation savings is relatively flat as long as there is any insulation but a drop in savings if the floor is left uninsulated.

In Honolulu, Hawaii, and Miami, Florida, there is an increase savings as the wall and roof insulation is increased, but the savings is slight as the insulation level is increased. Decreasing the floor insulation also causes increased savings by ground coupled cooling through the floor.

In Astoria, Oregon, and Spokane, Washington, increasing of the insulation level of any component is a savings. The greatest benefits tend to be increasing the wall insulation levels.

2.1.4.4 Refine Preheater Code

Objective

Refine the preheater module code for DOE 2.1E to include the effect on south wall R-value of the heated air behind the transpired collector surface against the face of the south wall.

Methodology

During the operating hours of the preheater all the conduction loss occurring through the area of the south wall behind the preheater is captured by the incoming air. In order to perform the simulation, a revised heat transfer algorithm was developed using convective and radiative properties developed by Kutscher, Christensen, and Barker (1993). The solar insolation on the south wall calculated by the loads program is stored as a variable in the preheater FORTRAN code and read back during the System calculations when the main preheater algorithm is executed.

Results

The revised R value of the portion of the wall with the preheater is,

$$R_{equivalent} = \frac{1}{\frac{1}{\frac{1}{h_1} + \frac{1}{h_2}} + h_{r1-2}} + \frac{1}{h_{convection} + h_{radiation}}$$

This accounts for the convective and radiative properties of the air around the preheater and in the preheater cavity (see figure 1). Details of the equation in the appendix.

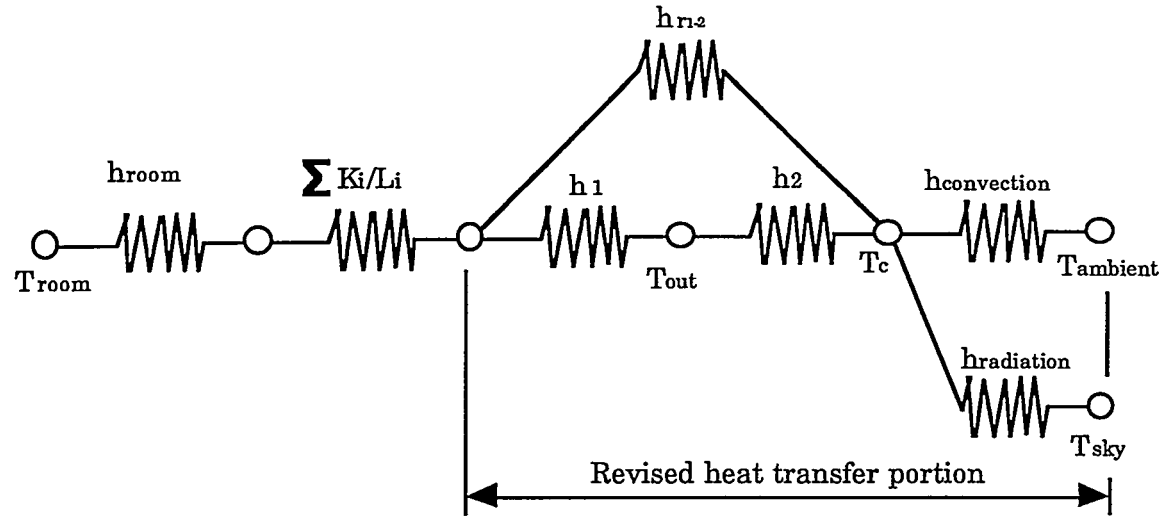


Figure 35, Thermal resistance of the wall preheater

Conclusions

The equivalent R value varies with the environment the building is in, the flow through the preheater, and the size of the preheater. The ranges of the equivalent R value is from 0.270 to .634 (m^2°K)/W. This is a small value when compared to the overall resistance of the wall with insulation.

2.1.4.5 Solarwall

Objective

Develop a DOE2.1E function which simulates the performance of a Solarwall™ preheater located on the south side of the classroom and use this function to estimate the annual energy savings with the Solarwall.

Methodology

Actual performance data was used from the General Motors plant in Oshawa, Ontario, Canada. The following equation was derived from regression analysis on the data.

temperature increase = a*I + b

where

$$a = 0.39157 + 0.03038*flow - 0.19575*flow^{1/2}$$

$$b = 6.62503 + 0.27785*flow - 0.75707*flow^{1/2}$$

flow = air flow through the preheater in cfm/sqft

I = solar radiance in BTU/hr/ft^2

The solar radiance for each hour of simulation is stored in the loads program. This information is then recalled in the systems program and used for the calculations. The DOE2.1E function calculates a new drybulb temperature based on the above equations and the solar radiance data. The revised temperature is then used as the outdoor drybulb temperature for that hour. The systems program performs its normal calculations and modifies the loads for the next hour.

The function accuracy was monitored by means of displaying the inputs and outputs of the formula in the simulation output file. These results were examined to ensure that proper temperature increases were being calculated and that the information was being transferred to the systems program correctly.

Results

It was necessary to revise the solarwall algorithm after certain discoveries. In all climates there was a period for which the preheated air was being overheated and contributing to the cooling load. This was overcome by adding the equivalent of a bypass damper. These are currently in use on Solarwall components for the summer months. The bypass damper was modeled as a set temperature. If the air was heated past this temperature, it would be reset to the set temperature. In reality this would be achieved using a thermostat control which would mix an optimum amount of outside and preheated air. After running several trial runs with different set temperatures and different climates it was found that a set temperature of 65 was ideal.

With this temperature control, the optimum performance of the Solarwall was at minimum flow possible. This allows maximum preheating of the air with any

overheating being compensated for by the bypass damper. The minimum flow corresponds to the ventilation requirement of 15 cfm per person. The solarwall flow was adjusted to this for each of the simulated areas (ventilation cfm/preheater area). A variable speed fan is another approach that was tested, but the results were similar to a single speed fan due to the damper. If a damper is not available, a variable speed fan is recommended.

The maximum benefit was achieved using the largest solarwall area available. It was found however that the benefit did not decrease substantial with smaller areas. Additional areas were simulated which correspond to the maximum area available for windows sizes of 6040 and 8040. The windows were not added, only the area was modified to reflect the performance of the solarwall with reduced areas. (see results below)

The outside film U value of the wall was set to 1 for the times that the solarwall was expected to be on using a schedule. A schedule was approximated based on a previous solarwall run. The times when the solarwall was on did not change after the simulation was run with the film U schedule so the schedules were not modified. It was found however that the difference of total building energy use between filmU = 1, filmU unchanged, and filmU based on the schedule, was negligible.

The change in R-value of the wall was investigated and determined to be small. It was never incorporated into the simulations.

The final results for the five simulated climates were as follows:

	no solarwall	no solarwall	solarwall	solarwall	solarwall
	base	base parametric	4040 window area	6040 window area	8040 window area
Fairbanks, AK	107.2	109.0	98.0	98.3	98.9
Phoenix, AZ	33.2	26.9	26.6	26.6	26.6
Bakersfield, CA	31.9	25.8	24.4	24.4	24.4
Astoria, OR	39.0	35.7	31.5	31.6	31.6
Spokane, WA	52.5	49.3	39.8	39.9	40.1

Figure 36, Total building energy with different solarwall areas

Conclusions

The solarwall preheater performed as expected based on Phase 1 estimates. Fairbanks, AK, and Spokane, WA, are the best candidates for a Solarwall. Astoria, OR showed a potential savings but cost may be an overriding factor. Phoenix, AZ, and Bakersfield, CA, produced only small energy savings. This was found to be caused by the relatively high morning heating loads for the two climates. During these times the solar radiance was either non-existent or too small to make an impact.

2.1.4.6 Fangers Comfort Criteria

Objective

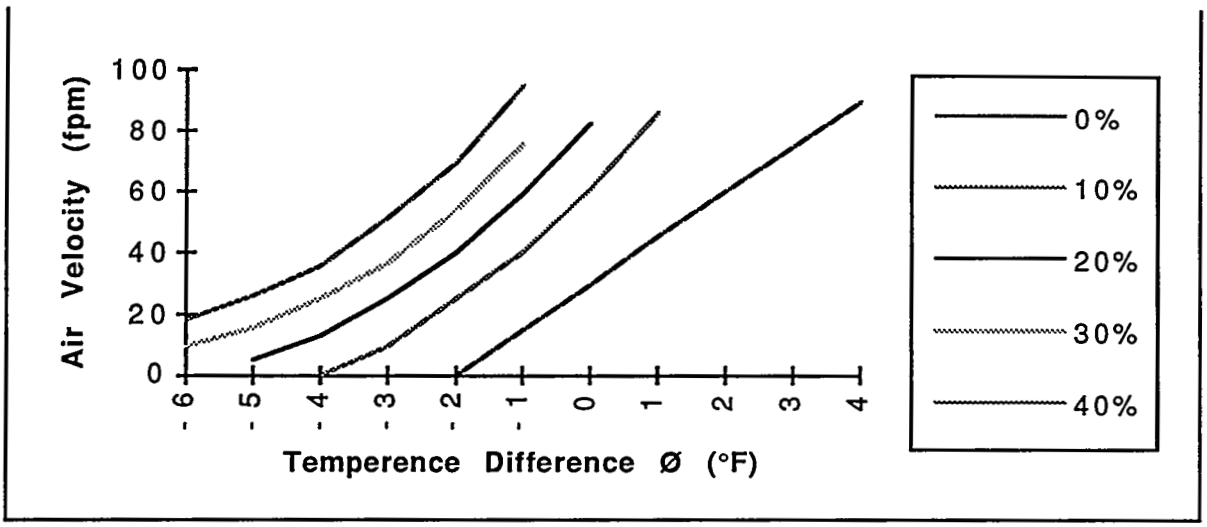
The objectives of this task were: 1) to find the optimum window locations from the standpoint of ventilation and occupant comport; 2) to determine minimum outside air temperatures for given air changes per hour (ACH) to be used in DOE2 modeling; 3) to determine if the outside temperature was adequate to allow for cross-ventilation in the MBS climates which had a small cooling component. Cross-ventilation could eliminate the need for an air conditioning unit. The three climates investigated were Fairbanks, AK, Astoria, OR, and Spokane, WA.

Methodology

To find optimum window locations, Quick 'n' Simple (a fluid dynamics simulation program) was used to find air speeds at a distance of 5' from the windows for a given ACH. This was done for the suggested window locations

from Task Illuminance on Vertical Surfaces. If any layout for a particular window size had significantly lower air speeds, it would have been chosen as the optimum strategy.

To determine minimum outside temperatures for a given ACH, the following graph and equation from the ASHRAE Handbook of Fundamentals were used:



$Ø = (tx - tc) - 0.07(Vx - 30)$ where Ø = effective draft temp difference
tx = local airstream dry-bulb temp, °F
tc = average room dry-bulb temp, °F
Vx = local airstream velocity, fpm

Figure 37, Percent People Feeling Discomfort in neck Region

At 1 ACH intervals, Ø was read from the 30% uncomfortable curve and an outside temperature computed. This was done for each of the suggested window layouts given in Task Illuminance on Vertical Surfaces. The local airstream velocity used for this calculation was the highest found at 5' from windows for each set of runs.

The maximum outside temperatures for cross ventilation curves generated in the first part of this task were reviewed. Equations were derived from these curves for each window size using the polynomial curve fit feature in Excel. Each hour of cooling was then evaluated in DOE2.1E using data from the weather files and the Excel equations:

for 2040 windows

$$\text{minimum outside temp} = -0.0637*ACH^2 + 2.1063*ACH + 61.139$$

for 4040 windows

$$\text{minimum outside temp} = -0.0246*ACH^2 + 1.2623*ACH + 60.516$$

for 6040 windows

$$\text{minimum outside temp} = -0.0155*ACH^2 + 0.9853*ACH + 60.392$$

for 8040 windows

$$\text{minimum outside temp} = -0.0128*ACH^2 + 0.8426*ACH + 59.894$$

Air changes per hour (ACH) were calculated based on wind speed, wind direction, and maximum open window area, using the following:

$$ACH = \frac{\text{speed} * 0.2967169 * 4 * 1/2 * \text{window area} * 3600}{2 * \text{volume}}$$

where

speed = | windspeed * cos(direction) | (knots)

0.2967169 = conversion from knots to ft/s

window area = area of one window in ft^2

volume = total interior volume in ft^3

3600 = conversion from per second to per hour

Only 4040 windows were simulated but the remaining equations were input into the function to allow further studies using different window sizes.

The resulting minimum temperature was compared to the actual outdoor temperature. If the actual temperature was equal to or less than the required minimum temperature, cooling by natural ventilation was deemed possible. It

was assumed that if the temperature was cooler than the minimum the windows would only be partially open, reducing the ACH, and still allowing for a comfortable natural cooling.

Results

For the three climates investigated, cooling by natural ventilation was not possible for all cooling hours. The outside temperature was adequate to allow cooling by natural ventilation for the following percentages:

Fairbanks, AK	61.2% of the time	(30 out of 49 cooling hours)
Astoria, OR	79.8%	(83 out of 104 cooling hours)
Spokane, WA	41.3%	(88 out of 213 cooling hours)

At 5' from the window, air speed did not vary with window location. Of more critical importance was window size. The smaller the window, the lower the air speed a 5' from the window.

The minimum outside air temperatures for the four window sizes are given in the graph below:

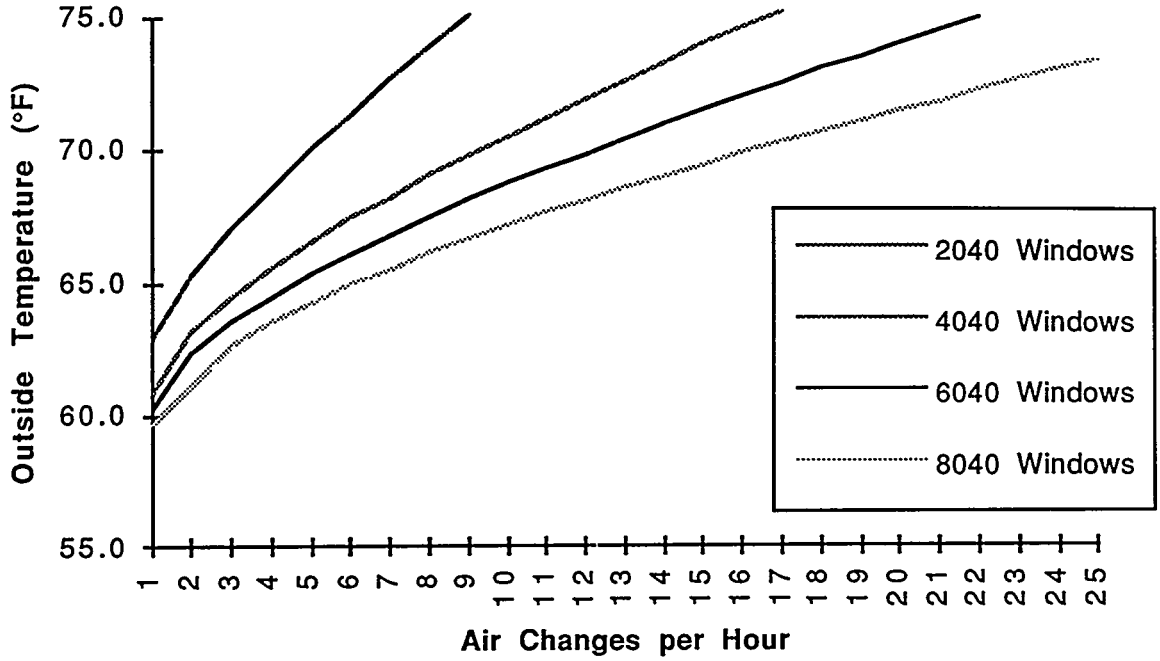


Figure 38, Minimum Outside Temperature for Cross Ventilation

Conclusions

In general, larger windows provide for greater air changes per hour for a given air speed through the windows. This allows for greater occupant comfort when ventilating with cool outside air (for low outside air speeds).

The minimum outside air temperatures with which the classrooms can be comfortably vented are somewhat higher than those assumed in Phase I. The minimum temperatures given here will be used in any subsequent DOE2 simulations.

For the three climates investigated, cooling by natural ventilation was not possible for all cooling hours. The outside temperature was adequate to allow cooling by natural ventilation for the following percentages:

Fairbanks, AK	61.2% of the time	(30 out of 49 cooling hours)
Astoria, OR	79.8%	(83 out of 104 cooling hours)
Spokane, WA	41.3%	(88 out of 213 cooling hours)

Natural ventilation is a possible strategy for reducing the cooling load in all climates but alone it would not handle the entire cooling load. Another possible alternative to air conditioning is to employ a fan which could reduce the outside air temperatures by 6 to 8 degrees F, allowing for natural ventilation when it would not otherwise be possible. It is estimated that the fan could improve the percentages for AK, OR, and WA to 80.4%, 94.1%, and 67.2% respectively.

This analysis also does not include the hotter summer months of July and August when the school is not being used. If the building were to be used during these months, an air conditioner or similar device is recommended for all climate.

2.1.4.7 Evaluate visual comfort

Objective

The objective of this task was to develop a strategy for window placement and shading that best provides for occupant visual comfort.

Methodology

Radiance (a Unix based ray-tracing software package from Lawrence Berkeley Laboratory) was used as the primary glare evaluation tool. Glare output consisted of a polar plot of the CIE glare index for 3 potential student viewpoints for each situation tested. An example of this output and a diagram of the student locations is given below:

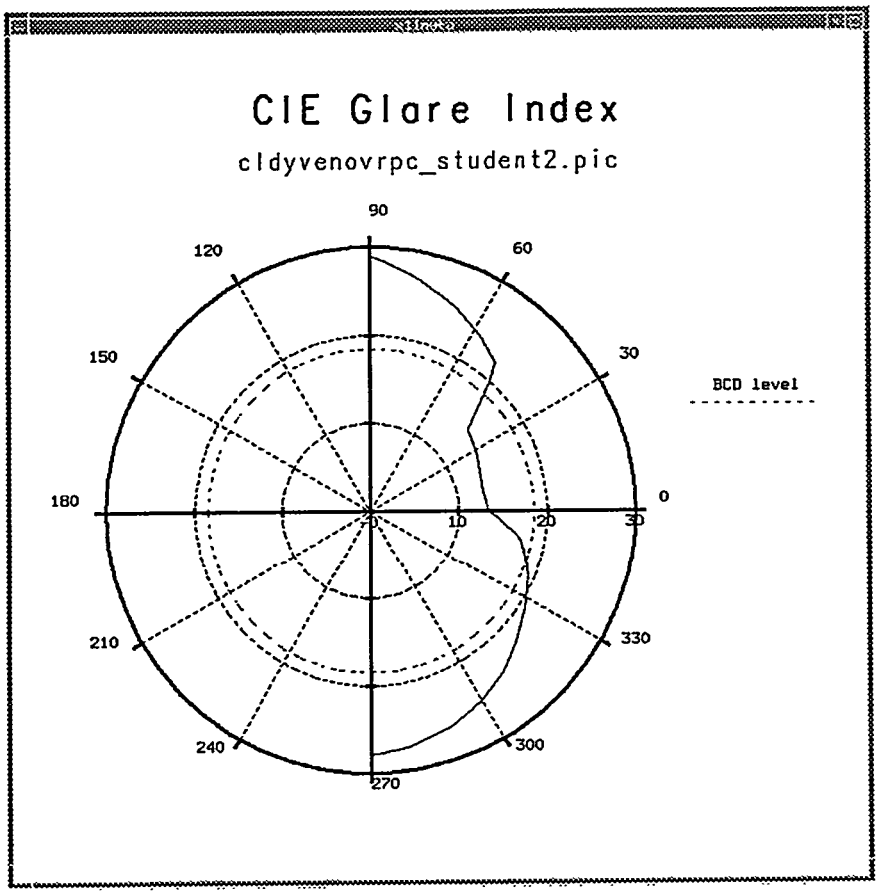


Figure 39, Glare Index

Zero degrees corresponds to looking toward the west wall of a west classroom. Turning one's head south is represented by angles 0° - 90°, while turning to the north corresponds to angles 360° - 270°. Glare values increase radially from the center. The BCD level indicated corresponds to a 50% visual comfort probability.

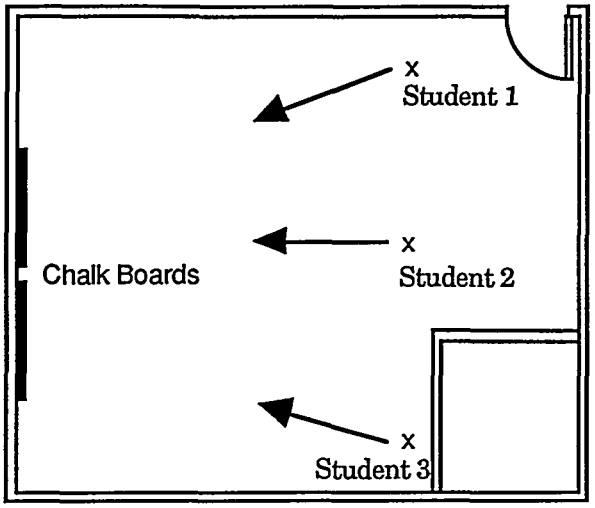


Figure 40, Student Locations and View Directions

The Illuminating Engineering Society's recommendation for a classroom glare index of 16 or lower was set as a design goal (Hopkinson, 103). Using an initial window layout for 6' by 4' windows (6040) as described in the Phase I Final Report, four shading strategies were tested for the worst case condition of a cloudy June day at 44° N latitude. The strategies tested were: venetian blinds (reflectance = 60%), vertical blinds (ref. = 60%), exterior roll-down shades (transmittance = 25%) and no shades. These same strategies were used in task: Illuminance on Vertical Surfaces. With consideration of the recommendation from that task, the best strategy was chosen and tested under both sunny and cloudy conditions with and without overhangs to determine if overhangs were necessary. The east/west placement of the south windows was also varied to determine the impact of window placement on glare. From the results of these runs, a recommendation was made.

While the Phase I Final Report recommended the same window sizes and layouts for all the non-Alaska units, it recommended smaller windows for the Fairbanks unit. Thus, another complete set of runs was done for the smaller windows (2040) and at Fairbank's latitude. These runs followed the same procedure given above.

Results

The initial 6040 cloudy runs and subsequent sunny runs resulted in the following

"straight-ahead" CIE glare index numbers ("straight-ahead" refers to 0° on the polar plots and corresponds to looking toward the end wall away from the restroom):

Shading Strategy	Student 1	Student 2	Student 3
None	25.6	24.4	22.7
Exterior Rolldown	15.3	13.9	13.8
Vertical Blinds	20.5	21.1	22.0
Venetian Blinds	14.2	11.4	16.1
Ven. Blinds w/ Overhangs	14.7	13.4	16.9
Ven. Blinds & Ovr. in Sun	17.0	14.8	15.4
Venetian Blinds in Sun	19.1	14.5	14.3

Figure 41, "Straight Ahead" Glare Index Values for 6040 Windows

The Alaska runs (2040) produced these glare index values:

Shading Strategy	Student 1	Student 2	Student 3
None	23.4	23.0	21.9
Exterior Rolldown	14.2	11.7	3.2
Vertical Blinds	20.1	23.0	16.1
Venetian Blinds	14.5	7.9	4.7
Ven. Blinds & Ovr. in Sun	20.0	13.1	6.3
Venetian Blinds in Sun	20.0	15.3	6.5

Figure 42, "Straight Ahead" Glare Index Values for 2040 Windows

While these "straight ahead" glare values are of utmost importance and offer a quick gauge of a strategy's effectiveness, the entire polar plot was considered in determining the best strategy. (See appendix for plot printouts)

Conclusions

Venetian blinds with overhangs offer the best strategy for limiting glare. Small east-west displacements of the windows do not significantly alter the glare index of the viewpoints tested. This fact allows for more freedom of window placement in Task: Illuminance on Vertical Surfaces. While overhangs reduced glare for sunny days, the impact was of less significance than venetian blinds. If overhangs are prohibitive to other design goals such as solar heating, they may be

eliminated without much effect on visual comfort. Lengths required to shade entire windows at solar noon on the 21st of various months are shown below:

	June	May-July	Apr-Aug	Mar-Sept	Feb-Oct	Jan-Nov	Dec
Astoria	2.06	2.49	3.40	4.84	6.72	9.17	10.15
Bakersfield	1.33	1.64	2.49	3.89	5.46	7.13	8.06
Fairbanks	4.42	4.99	6.33	9.17	13.23	22.08	28.29
Honolulu	0.00	0.41	1.13	2.27	3.40	4.70	5.14
Miami	0.41	0.72	1.44	2.60	3.76	5.14	5.62
Phoenix	0.93	1.23	2.06	3.40	4.84	6.33	6.92
Spokane	2.60	2.93	3.89	5.62	7.82	10.51	12.21

Figure 43, Required Overhang Lengths to Shade at Solar Noon on the 21st of the Months Shown (Dimensions in Feet)

2.1.4.8 Roof Preheater

Objective

Develop a computer simulation using DOE 2.1E to predict and optimize the performance of a preheater installed on the roof. The roof preheater is a corrugated roof with air pulled between the corrugated metal and the roof sheathing, from the eaves up to the ridge and then distributed into the air heating system.

Methodology

The algorithm for the heat transfer from the classroom through the preheater to the ambient was developed taking into consideration the conductive, convective and radiative properties of the building and ambient environment (see figure 2). Using the equation derived in Duffie and Beckman (1991) for air heaters the useful energy gain of the preheater was determined. This refined preheater algorithms is used to simulate the performance of the roof preheater.

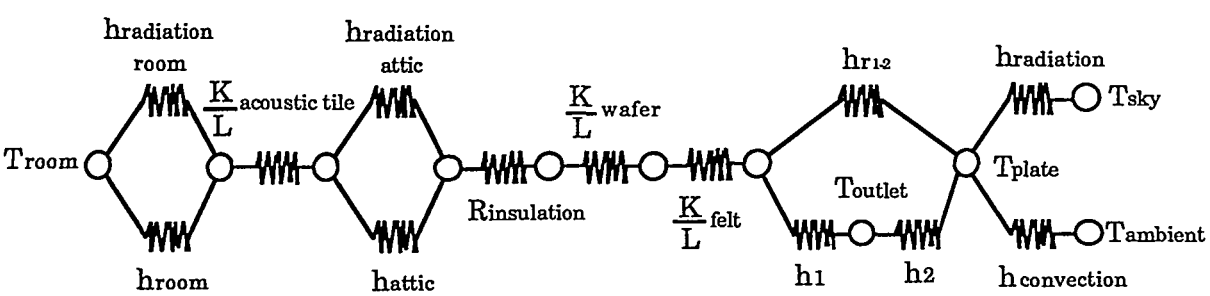


Figure 44, Thermal resistance of the roof with a roof preheater.

All pertinent equations were set up in an Excel spreadsheet, which performed the iterations automatically. This spreadsheet was used to calculate the theoretical temperature increase using a range of solar radiances, outside temperatures, and indoor temperatures. The results were graphed and the linear curve fit feature of Excel was used to analize the data. It was not possible to fit one equation to the entire data set. It was found that a better fit was possible by separating the results according to the solar radiance. All equations predict the temperature increase within 0.5 degrees Kelvin. It was deteremined that indoor temperature had a negligible effect (less than 0.0001 degree Kelvin). For each range of solar radiance an equation was developed to predict the temperature increase:

Solar radiance(W/m^2)	Temperature increase (degrees Kelvin)
<80	temp increase = 0
80-90	temp increase = 0.5
90-100	temp increase = 1.0
101-200	temp increase = -1.81757 + 0.028324*solar - 0.00086*dbt
201-300	temp increase = -2.23581 + 0.028261*solar - 0.00073*dbt
301-400	temp increase = -2.60991 + 0.028157*solar - 0.00226*dbt
401-500	temp increase = -2.94928 + 0.028041*solar - 0.00373*dbt
501-600	temp increase = -3.25666 + 0.027918*solar - 0.00513*dbt
601-700	temp increase = -3.53292 + 0.027790*solar - 0.00646*dbt
>700	temp increase = -3.77906 + 0.027659*solar - 0.00775*dbt

These equations were incorporated into the DOE2.1E simulations using a function similar to that used for the solarwall. The function stores the solar radiance in the loads program and the information is recalled in the systems program where the increase in drybulb temperature is calculated.

The roof preheater is assumed to be on the south roof only.

Results

The useful energy gain of the preheater is a function of the collector size, heat removal factor, and losses, the solar gain and the temperature of the air.

$$Q_u = A_c \bullet FR \bullet (S - U_L \bullet (T_{inlet} - T_{ambient}))$$

It can be an iterative process to find Qu since the properties of the air are temperature dependent and the preheater warms the air. A check of the properties of the air used to arrive at Qu and the temperature of the air as a result of Qu should be done to confirm that the results are consistent. Details of the equations are in the appendix.

The same five climates (Fairbanks, AK, Phoenix, AZ, Bakersfield, CA, Astoria, OR, and Spokane, WA) that were considered for the Solarwall were also simulated using the roof preheater. Assuming metal roofing with a one inch profile the following results were achieved:

Location	base parametric (MBTU)	with roof preheater (MBTU)	savings (MBTU)
Fairbanks, AK	109.0	101.6	7.4
Phoenix, AZ	26.9	26.8	0.1
Bakersfeild, CA	25.8	24.7	1.1
Astoria, OR	35.7	33.3	2.4
Spokane, WA	49.3	44.1	5.2

Figure 45, Roof preheater savings

Conclusions

With initial guesses of a mean film temperature in the preheater of 10°K above the ambient air temperature and a mean plate temperature of 30°K above the ambient air temperature usually only one or two iterations are necessary for this model to come up with consistent numbers.

Based on theoretical analysis the roof preheater is not expected to perform as well as the Solarwall. The cost of the roof preheater, however, is much less compared to the $2,000 estimated cost of the Solarwall. It may be a cost-effective strategy in Fairbanks and Spokane with the current results, but the theoretical formulae do not account for any snow cover that may reduce the efficiency of the roof preheater in colder climates. Astoria may also be a candidate for a roof preheater since the additional cost is minimal.

2.1.4.9 Integrated performance.

Objective

Using DOE-2.1E to predict the performance of the whole building, define a prototype building for each of the 7 climates.

Methodology

This is a nine month school year from September through mid June, with no use in the summer. The building has a relatively high internal load, due to the 52 people in the building, and a high air exchange rate, required by the minimum fresh air of 15 cfm per person. To narrow down the choices for the prototype buildings in each of the climates, we looked at evaluating the results based on seven filters: 1) the building that was the least expensive based on first cost and would save more energy than the base case building, 2) the building with the least simple payback, 3) the building with the best total savings in a five year period (based on first cost and energy savings), 4) the building with the best total savings in a ten year period (based on first cost and energy savings), 5) the building with the best energy savings in dollars, 6) the building with the best energy savings at the site, and 7) the building with the best energy savings in dollars that was closest to no increase in first cost.

Some general comments from an energy stand point: if you are not using photo-controlled lighting then decrease the size of the windows to increase the resistance of the walls, if you are using photo-controlled then increase the size of the windows to take advantage of the lighting reduction, switch the walls from 16 inch on center studs to 24 inch on center, 3 tube T8 ballasts are a savings over the 4 tube T12 ballasts and still give the required 50 foot candles of lighting level at the desks, an occupancy sensor for the lighting controls, blinds are planned to be installed and used for glare and media on all windows and doors, it was decided to use 1/2 lit doors in all climates, and adjusting the thermometer set back points farther could gain further energy savings but might compromise comfort to plants and animals in the classroom. Additional benefits could be realized due to the demand load if the buildings are part of a larger energy rate schedule. However due to the variety of choices school districts could face through out the

country we choose to simulate all of them as stand alone small businesses to choose the rate structure. The following is a summary of over 5,000 parametric DOE-2.1E simulation runs for the integrated models and over 2,000 parametric DOE-2.1E simulation runs for the parametric models.

Results

General

Figures 46 -69, show the results of the integrated performance. The x-axis is the increase or decrease in the first cost of the building as compared with the base case building and the y-axis is the annual savings (positive) or increase (negative) in the fuel bill from energy savings options of the integrated buildings. The base case building is represented as the origin, the zero first cost and zero savings. Each pattern on the chart represents a particular building. Within a given pattern some things are held constant while other components are varied. For example, for Fairbanks, Alaska, figure 46, the triangle shapes that are brown on the border and blue in the center are all buildings (cost of 200 to 800 dollars over the base case and savings of 1,400 to 1,500 dollars per year) with the following similar components: lighting style and controls (3 tube T8 lights where the occupants turn off the lights when the center of the room can sustain 50 foot candles due to daylighting), size and number of windows (there are six 2'x4' windows in the building), type of doors (two _ light insulated metal doors), type of HVAC system (two oil furnaces, and the classroom is cross ventilated through the doors and windows for cooling); and the amount of insulation in the envelope, the type of glazing in the windows and the type of window frame varied. In other climates the location and type of radiant barrier was also varied. The blue dashed lines are 5 year lines, when the line goes through the origin it is the simple pay back line and anything that lies on the line saves as much in energy in five years as its increase in first cost from the base case. The blue lines above this are similar in that all the points on the same line have the same net savings after five years just that for the blue lines farther up the y-axis the net result after five years will be positive, more will be saved than the increase in first cost. Likewise the blue lines below the dashed blue line that goes through the origin will have the same net savings after five years just that for the blue lines farther down the y-axis the net result after five years will be negative, less will be saved than the

increase in first cost. The dashed red lines are the same thing just that the time frame is now ten years instead of 5 years as in the blue lines. The specific data for each of the building configurations is presented in a table in the appendix.

Fairbanks, Alaska

Most of the runs showed an advantage by switching from the electric heat pump in the basecase model to a #2 fuel oil furnace, see figures 46 - 47. These models uses more energy at the site but less at the source and costs less to run due to the less expensive #2 fuel oil as the heating source. An air to air heat exchanger showed the most promise for energy savings but had a more expensive first cost and longer simple payback than other options selected. Due to the large heating load the side with the most glazing faced South, unless the solar wall preheater is used then the windows oriented north leaving the whole south wall for the preheater. There is still some questions in my mind about the use of this in such a cold climate with the air freezing in the holes and plugging up the system (I don't think snow drifts will be a factor in this location but that is another consideration). The summary based on the 7 filters is shown in the figure 48.

Phoenix, Arizona

Due to the larger cooling load the radiant barrier with reduction in envelope insulation showed a repeated advantage, see figures 49-50. Due to the cooling load the floor insulation was removed for ground coupling. Cross ventilation was looked at but due to the high outdoor temperature most of the year it could handle the comfort on its own. Awnings or overhangs could possible help if the building is not using dimmable ballasts but the radiant barrier may be doing most of the work already. Increasing the glazing area was an advantage whether using continuous dimming lights or photo-controlled manual off lighting. The summary based on the 7 filters is shown in the figure 51.

Sacramento, California

Part way through the analysis it was decided to switch from Bakersfield to Sacramento to get to a climate closer to Modern Building System's sales territory of northern California. The elimination of the economizer, while increasing the energy savings, enable us to look at some different options due to the cost

reduction of the economizer, see figures 52 - 53. This climates cooling load could not be handled completely by cross ventilation alone and still keep the classroom comfortable. The summary based on the 7 filters is shown in figure 54.

Miami, Florida

Due to the larger cooling load the radiant barrier with reduction in envelope insulation showed a repeated advantage, see figures 55-56. The continuously dimming ballasts played a larger role in this climate. Due to the cooling load the floor insulation was eliminated for ground. Cross ventilation was not looked at due to the high outdoor temperature and humidity most of the year. Awnings or overhangs could possible help if you aren't using dimmable ballasts but the radiant barrier may be doing most of the work already. The summary based on the 7 filters is shown in the figure 57.

Honolulu, Hawaii

Due to the larger cooling load the radiant barrier with reduction in envelope insulation showed a repeated advantage, see figures 58-59. The continuously dimming ballasts played a larger role in this climate. Due to the cooling load the floor insulation was eliminated for ground. Cross ventilation was not looked at due to the high outdoor temperature and humidity most of the year. Awnings or overhangs could possible help if you aren't using dimmable ballasts but the radiant barrier may be doing most of the work already. The summary based on the 7 filters is shown in the figure 60.

Astoria, Oregon

Due to the moderate climate, low energy rates, and a building that is pretty well optimized for this climate, it was more difficult to come up with cost effective efficiency measures, see figures 61-62. Most of the load is heating so a better envelope was more cost effective than other options. The base case design of 2 windows, no lit in the door, and windows oriented south, was better in this respect. The summary based on the 7 filters is shown in the figure 63.

Spokane, Washington

The elimination of the economizer enable us to look at some different options due

to the cost reduction of the economizer (see figures 64-65). The ability to switch to a less expensive heating fuel of Natural gas and being able to switch to a furnace only and rely on cross ventilation for the cooling load (cross ventilation handles all but 4 to 20 hours during the school year). A heat exchanger or solar air collector to temper the incoming fresh air showed promise. The summary based on the 7 filters is shown in the figure 66.

Since every climate did not have the same strategies applied to the building figures 68-69 show a summary of the chart legends including the row numbers of the tables in the appendix that went into that collection for that category.

Column 1 – Description of the pattern used in the chart describing the pattern's shape, the color of its border, and the color that fills in the border.
Column 2 – A reprint of the pattern used in the chart.
Column 3 – A description of the common features of the classrooms for comparison between results. It tells the type of lighting and controls, the number of windows, the size of the windows, the type of HVAC system used, whether cross ventilation by the operable windows and doors where used for cooling purposes, whether extra HVAC related equipment was used such as an economizer, a solar wall air preheater, or a heat exchanger. Things that varied within the category is the insulation level of the roof, wall, and floor, the spacing of the studs in the walls, the type of window frame, the type of glazing, and whether a radiant barrier was used and where.
Column 4 through 10 – The row numbers for each of the climates where this category applies.

Conclusions

Figure 67 combines the results of the seven filters, seven climates, and seven base case buildings onto one chart. Every climate does not have seven patterns since some of the same building configurations come out under different filters.
We have chosen to purse five prototypes having the best energy dollar savings for the construction and installation at each of the school districts in the representative climates(Fairbanks, Alaska; Sacramento, California; Honolulu, Hawaii; Astoria, Oregon and Spokane, Washington).

Fairbank

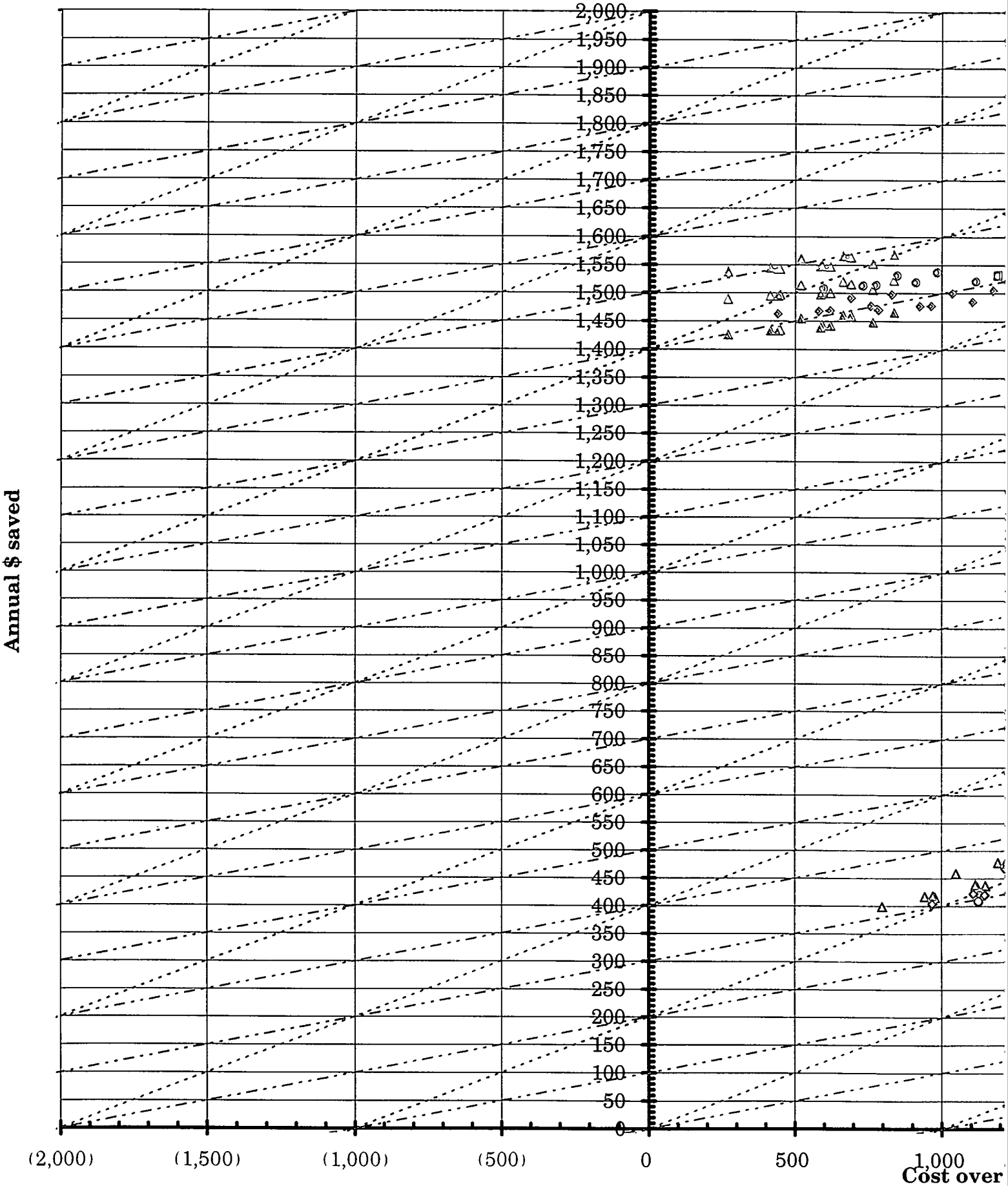


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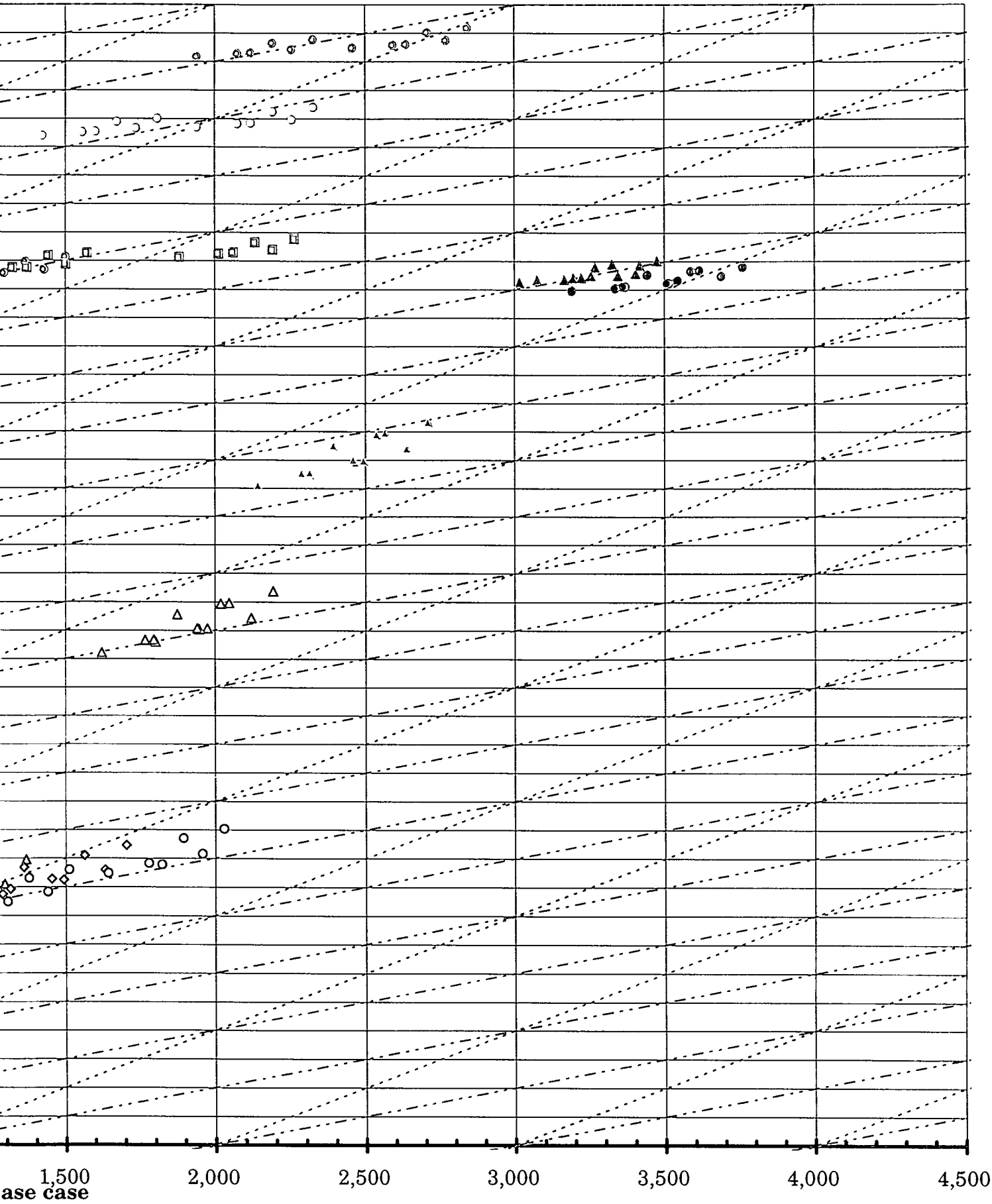
Figure 46, Fairb



ase case

- ▲ 3 tube T8 lights with manual off, 6-2040 win
- ◆ 3 tube T8 lights with manual off, 6-4040 win
- ● 3 tube T8 lights with manual off, 6-6040 win
- ○ 3 tube T8 lights with manual off, 6-6040 win
- ● 3 tube T8 lights with manual off, 6-6040 win
- ■ 3 tube T8 lights with manual off, 6-8040 win
- ▲ 3 tube T8 lights with manual off, 6-2040 win
- △ 3 tube T8 lights with manual off, 6-2040 win
- △ 3 tube T8 lights with manual off, 6-2040 win
- ◇ 3 tube T8 lights with manual off, 6-4040 win
- ○ 3 tube T8 lights with manual off, 6-6040 win
- △ 3 tube T8 lights with manual off, 6-2040 win
- △ 3 tube T8 lights with manual off, 6-2040 win
- ▲ 3 tube T8 lights with manual off, 6-2040 win
- ● 3 tube T8 lights with manual off, 6-6040 win

------ 5 year payback lines

–·–· 10 year payback lines

ws, oil furn. with cross ventilation

ws, oil furn. with cross ventilation

ws, oil furn. 60% HX

ws, oil furn. 40% HX

ws, oil furn. with cross ventilation

ws, oil furn. with cross ventilation

ws, HP 60% HX

ws, HP with cross ventilation 40% HX

ws, HP with cross ventilation

ws, HP with cross ventilation

ws, HP with cross ventilation

ws, oil furn. with cross ventilation 50setback

ws, oil furn. with cross ventilation 45setback

ws, oil furn. with cross ventilation Solarwall

ws, oil furn. with cross ventilation Solarwall

Fairbanks, Alaska		Electric		#2 Fuel Oil		Total
Filter	Building Description	kWh	$	gallons	$	kWh
Base case	Roof R38, Wall R19 studs @ 16" OC, Floor R19, 2@4040 vinyl frame double pane air filled, 4 tube T12 lights always on during class time, HP,	36,945	$4,004	0	$0	36,945
Least expensive and save energy	Roof R38, Wall R19 studs @ 24" OC, Floor R19, 6@2040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Oil furnace with cross ventilation,	5,184	$901	1,519	$1,677	66,930
Least simple payback	Roof R38, Wall R19 studs @ 24" OC, Floor R19, 6@2040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Oil furnace with cross ventilation,	5,184	$901	1,519	$1,677	66,930
Best 5 year total savings	Roof R38, Wall R19 studs @ 24" OC, Floor R19, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Oil furnace with cross ventilation, 60%HX,	4,574	$832	1,116	$1,264	49,938
Best 10 year total savings	Roof R38, Wall R19 studs @ 24" OC, Floor R19, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Oil furnace with cross ventilation, 60%HX,	4,574	$832	1,116	$1,264	49,938
Best energy dollar savings	Roof R38, Wall R21 studs @ 24" OC, Floor R30, 6@6040 vinyl frame double pane argon filled low e inside pane 0.1, 3 tube T8 lights with manual off, Oil furnace with cross ventilation, 60%HX,	4,603	$836	1,063	$1,209	47,813
Best energy savings	Roof R38, Wall R21 studs @ 24" OC, Floor R30, 6@2040 vinyl frame double pane argon filled low e inside pane 0.1, 3 tube T8 lights with manual off, HP, 60%HX,	25,068	$2,737	0	$0	25,068
Best energy dollar savings closest to no increase in cost	Roof R38, Wall R19 studs @ 24" OC, Floor R19, 6@2040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Oil furnace with cross ventilation,	5,184	$901	1,519	$1,677	66,930

Figure 48, Fairban

;)	Savings over base case				Simple payback	Net cost	Total (source)	5 year total savings	10 year total savings
$	kWh	% reduction	$	% reduction	years	$	kWh	$	$
004	0	0%	$0	0%	0.0	$0	110,835	$0	$0
578	-29,985	-81%	$1,426	36%	0.2	$268	77,298	$6,862	$13,992
578	-29,985	-81%	$1,426	36%	0.2	$268	77,298	$6,862	$13,992
,096	-12,993	-35%	$1,908	48%	1.0	$1,938	59,086	$7,602	$17,142
,096	-12,993	-35%	$1,908	48%	1.0	$1,938	59,086	$7,602	$17,142
,045	-10,868	-29%	$1,959	49%	1.5	$2,842	57,019	$6,953	$16,748
,737	11,877	32%	$1,267	32%	2.1	$2,710	75,204	$3,625	$9,960
,578	-29,985	-81%	$1,426	36%	0.2	$268	77,298	$6,862	$13,992

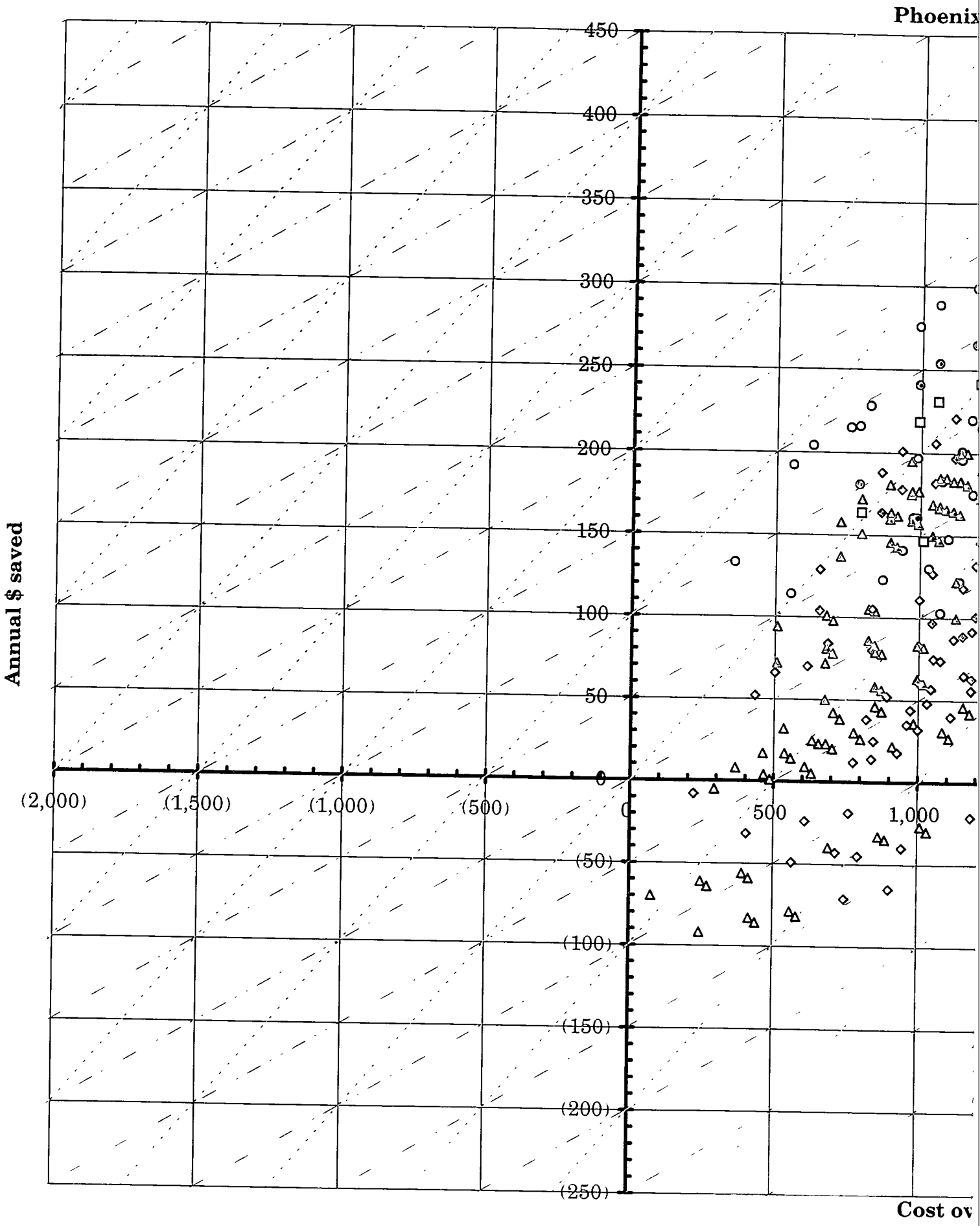
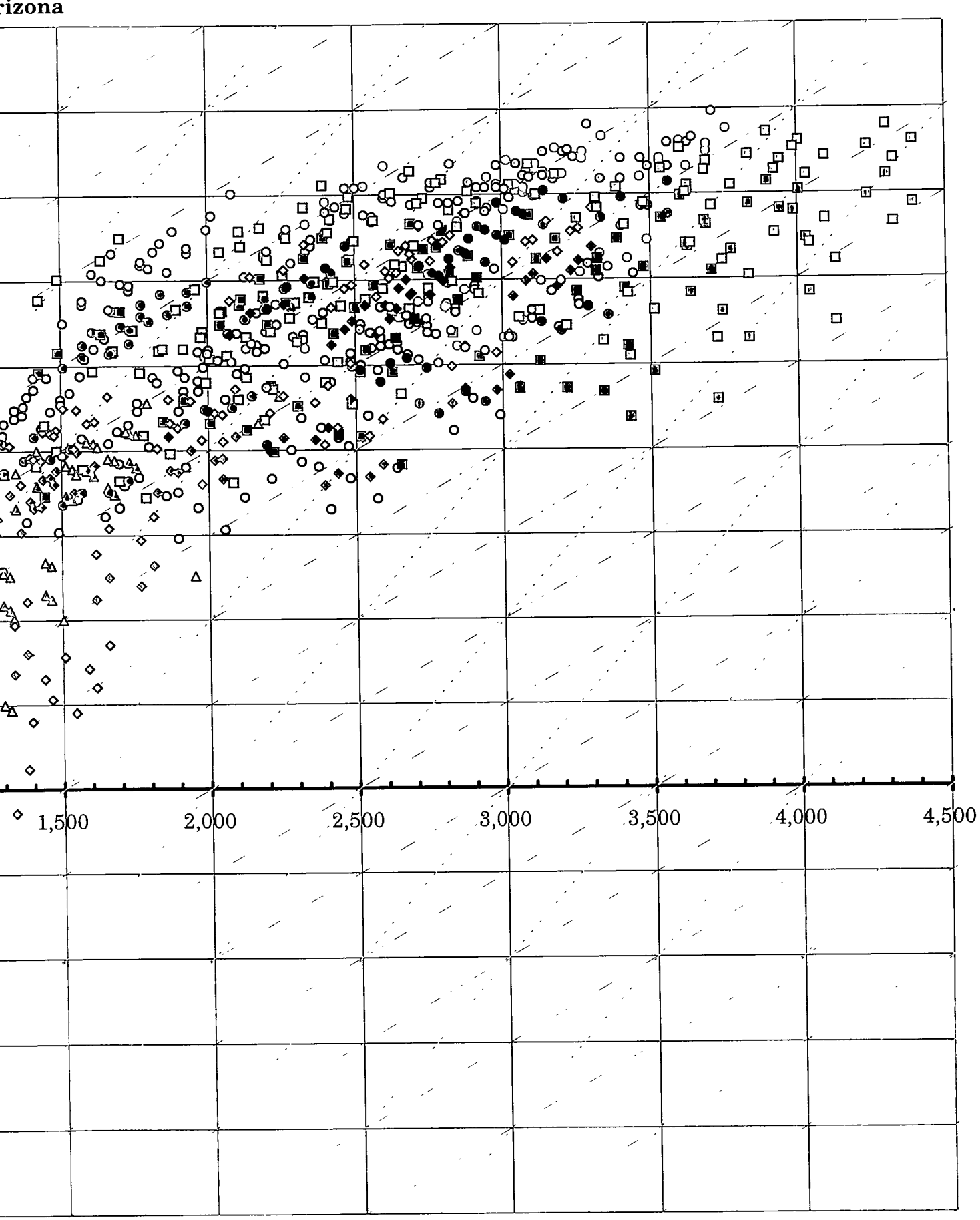


Figure 49, Phoe

rizona



er base case

ix, Arizona - graph

- ○ 4 tube T12 lights with manual c
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- ○ 3 tube T8 lights with manual of
- ○ 3 tube T8 lights with manual of
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- △ 3 tube T8 lights with manual of
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- ◆ 3 tube T8 lights with cont. dimr
- ● 3 tube T8 lights with cont. dimr
- ■ 3 tube T8 lights with cont. dimr
- ◇ 3 tube T8 lights with cont. dimr
- ○ 3 tube T8 lights with cont. dimr
- ○ 3 tube T8 lights with cont. dimr
- □ 3 tube T8 lights with cont. dimr
- · · · 5 year payback lines
- — 10 year payback lines

Figure 50, Pho

f, 6-6040 windows, HP 60% HX

f, 6-6040 windows, HP 40% HX

6-6040 windows, HP with cross ventilation 60% HX

6-6040 windows, HP with cross ventilation 40% HX

f, 6-2040 windows, HP

f, 6-4040 windows, HP

f, 6-6040 windows, HP

f, 6-8040 windows, HP

6-2040 windows, HP

6-4040 windows, HP

6-6040 windows, HP

6-8040 windows, HP

6-2040 windows, HP with cross ventilation

6-2040 windows, HP with cross ventilation 40% HX

6-4040 windows, HP with cross ventilation

6-6040 windows, HP with cross ventilation

6-8040 windows, HP with cross ventilation

ing, 6-4040 windows, HP

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ing, 6-8040 windows, HP

ing, 6-4040 windows, HP with cross ventilation

ing, 6-6040 windows, HP with cross ventilation

ing, 6-6040 windows, HP with cross ventilation 40% HX

ing, 6-8040 windows, HP with cross ventilation

Phoenix, Arizona		Electric		Auxiliary fuel		Total
Filter	Building Description	kWh	$	gallons	$	kWh
Base case	Roof R19, Wall R11 studs @ 16" OC, Floor R11, 2@4040 aluminum frame double pane air filled, 4 tube T12 lights always on during class time, HP,	9,946	$1,263	0	$0	9,946
Least expensive and save energy	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 440MD, Radiant barrier in the wall, HP,	8,639	$1,130	0	$0	8,639
Least simple payback	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 440MD, Radiant barrier in the wall, HP,	8,639	$1,130	0	$0	8,639
Best 5 year total savings	Roof R11, Wall R7 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 440MD, Radiant barrier in the wall, HP,	8,135	$1,071	0	$0	8,135
Best 10 year total savings	Roof R11, Wall R13 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, Radiant barrier in the roof, HP with cross ventilation,	7,083	$950	0	$0	7,083
Best energy dollar savings	Roof R11, Wall R13 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 332dim, Radiant barrier in the wall & roof, HP with cross ventilation 40HX,	6,493	$865	0	$0	6,493
Best energy savings	Roof R11, Wall R13 studs @ 24" OC, Floor R0, 6@8040 vinyl frame double pane argon filled low e outside pane 0.04, 332dim, Radiant barrier in the wall & roof, HP with cross ventilation,	6,446	$873	0	$0	6,446
Best energy dollar savings closest to no increase in cost	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 440MD, Radiant barrier in the wall, HP,	8,639	$1,130	0	$0	8,639

Figure 51, Ph

e)	Savings over base case				Simple payback	Net cost	Total (source)	5 year total savings	10 year total savings
$	kWh	% reduction	$	% reduction	years	$	kWh	$	$
263	0	0%	$0	0%	0.0	$0	29,838	$0	$0
,130	1,307	13%	$133	11%	2.7	$356	25,917	$309	$974
,130	1,307	13%	$133	11%	2.7	$356	25,917	$309	$974
,071	1,811	18%	$192	15%	2.9	$558	24,405	$402	$1,362
950	2,863	29%	$313	25%	4.0	$1,259	21,249	$306	$1,871
365	3,453	35%	$398	32%	9.3	$3,713	19,479	-$1,723	$267
873	3,500	35%	$390	31%	11.0	$4,302	19,338	-$2,352	-$402
,130	1,307	13%	$133	11%	2.7	$356	25,917	$309	$974

enix, Arizona - table

7/21/98

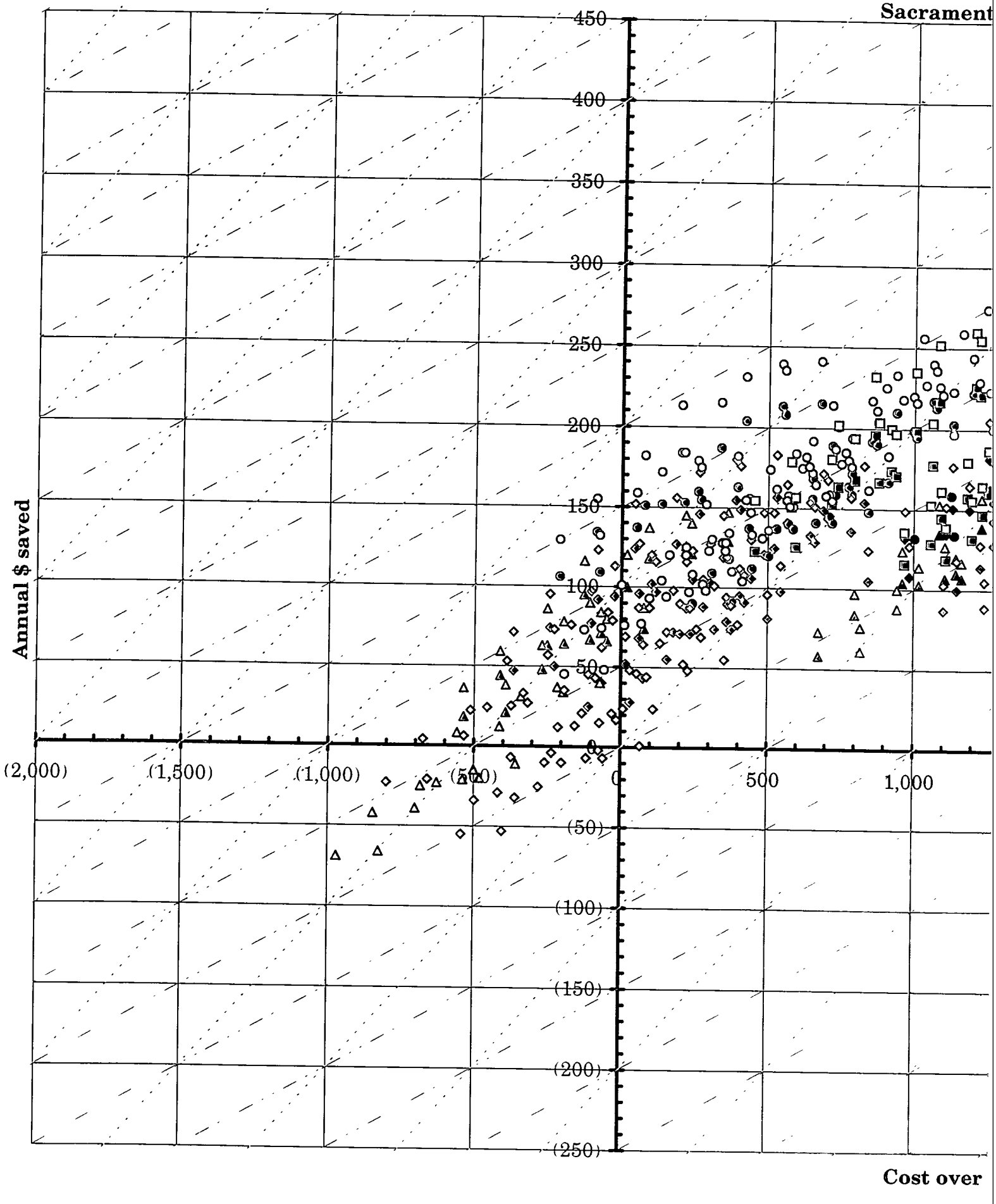

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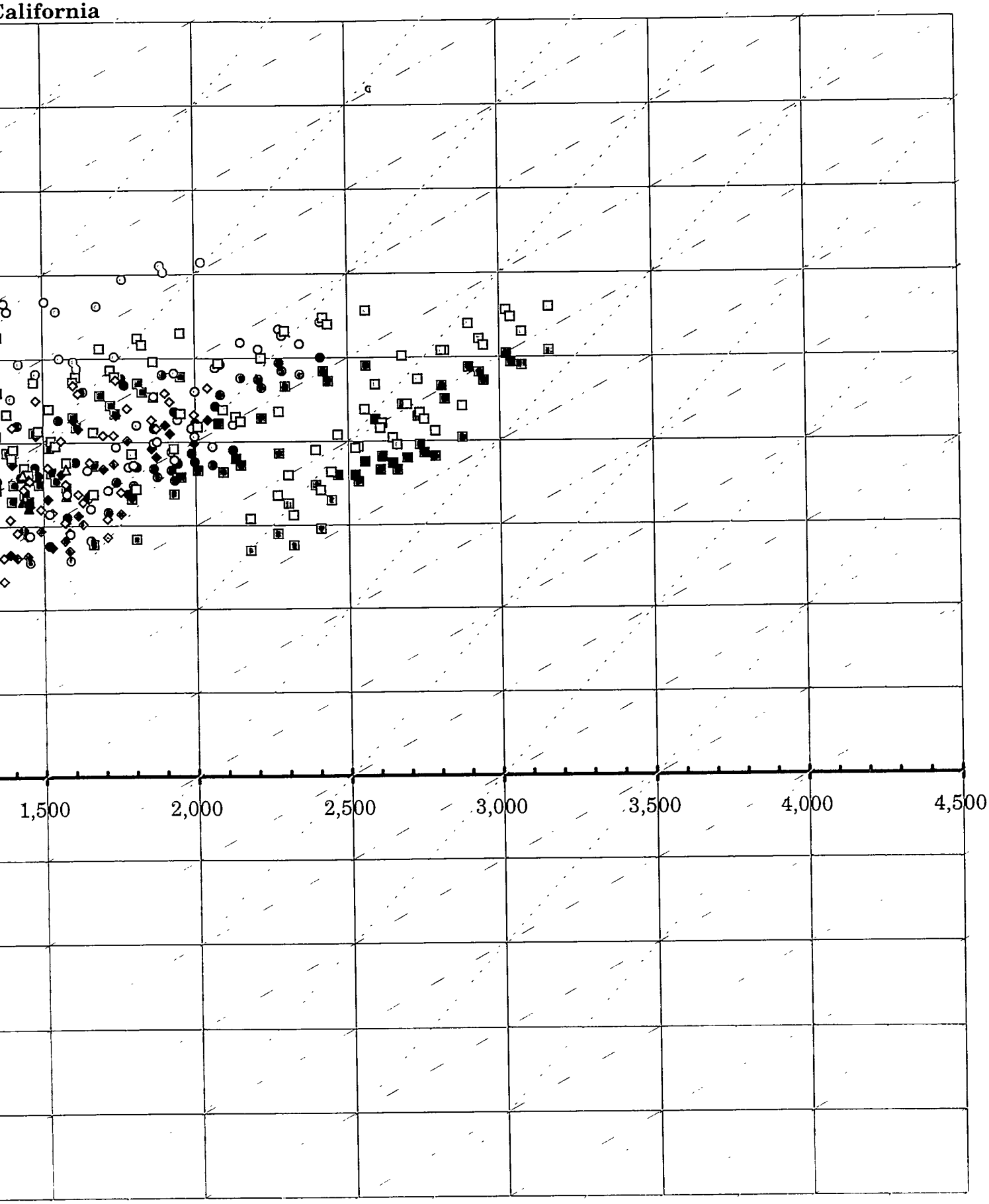
Figure 52, Sacramento,

California



ase case

California - graph

▲ 3 tube T8 lights with manual off, 6-2040 windows, HP

● 3 tube T8 lights with manual off, 6-6040 windows, HP

▲ 3 tube T8 lights with cont. dimming, 6-2040 windows, HP

● 3 tube T8 lights with cont. dimming, 6-6040 windows, HP

△ 3 tube T8 lights with manual off, 6-2040 windows, HP with cross ventilation

○ 3 tube T8 lights with manual off, 6-6040 windows, HP with cross ventilation

○ 3 tube T8 lights with manual off, 6-6040 windows, HP with cross ventilation 60% HX

△ 3 tube T8 lights with cont. dimming, 6-2040 windows, HP with cross ventilation

○ 3 tube T8 lights with cont. dimming, 6-6040 windows, HP with cross ventilation

△ 4 tube T12 lights with manual off, 6-2040 windows, HP

○ 4 tube T12 lights with manual off, 6-6040 windows, HP

— 10 year payback lines

Figure 53, Sacramento,

California

- 3 tube T8 lights with manual off, 6-4040 windows, HP
- 3 tube T8 lights with manual off, 6-8040 windows, HP
- 3 tube T8 lights with cont. dimming, 6-4040 windows, HP
- 3 tube T8 lights with cont. dimming, 6-8040 windows, HP
- 3 tube T8 lights with manual off, 6-4040 windows, HP with cross ventilation
- 3 tube T8 lights with manual off, 6-6040 windows, HP with cross ventilation 40% HX
- 3 tube T8 lights with manual off, 6-8040 windows, HP with cross ventilation
- 3 tube T8 lights with cont. dimming, 6-4040 windows, HP with cross ventilation
- 3 tube T8 lights with cont. dimming, 6-8040 windows, HP with cross ventilation
- 4 tube T12 lights with manual off, 6-4040 windows, HP

5 year payback lines

California - legend

Sacramento, California		Electric		Auxiliary fuel		Total
Filter	Building Description	kWh	$	gallons	$	kWh
Basecase	Roof R30, Wall R11 studs @ 16" OC, Floor R11, 2@4040 aluminum frame double pane air filled, 4 tube T12 lights always on during class time, HP with economizer	10,931	$896	0	$0	10,931
Least expensive and save energy	Roof R19, Wall R19 studs @ 24" OC, Floor R11, 6@2040 vinyl frame double pane argon filled, 4 tube T12 lights with manual off, HP,	10,830	$888	0	$0	10,830
Least simple payback	Roof R19, Wall R19 studs @ 24" OC, Floor R0, 6@4040 vinyl frame double pane argon filled, 4 tube T12 lights with manual off, HP,	10,882	$892	0	$0	10,882
Best 5 year total savings	Roof R19, Wall R19 studs @ 24" OC, Floor R11, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, HP with cross ventilation,	8,334	$683	0	$0	8,334
Best 10 year total savings	Roof R19, Wall R19 studs @ 24" OC, Floor R11, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, HP with cross ventilation,	8,334	$683	0	$0	8,334
Best energy dollar savings	Roof R38, Wall R21 studs @ 24" OC, Floor R11, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, HP with cross ventilation, 60% HX,	7,188	$589	0	$0	7,188
Best energy savings	Roof R38, Wall R21 studs @ 24" OC, Floor R11, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, HP with cross ventilation, 60% HX,	7,188	$589	0	$0	7,188
Best energy dollar savings closest to no increase in cost	Roof R19, Wall R19 studs @ 24" OC, Floor R0, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, HP with cross ventilation,	9,039	$741	0	$0	9,039

Figure 54, Sacramento

e)	Savings over base case				Simple payback	Net cost	Total (source)	5 year total savings	10 year total savings
$	kWh	% reduction	$	% reduction	years	$	kWh	$	$
396	0	0%	$0	0%	0.0	$0	32,793	$0	$0
388	101	1%	$8	1%	-69.8	-$558	32,490	$598	$638
392	49	0%	$4	0%	-168.6	-$675	32,646	$695	$715
583	2,597	24%	$213	24%	1.0	$204	25,002	$861	$1,926
583	2,597	24%	$213	24%	1.0	$204	25,002	$861	$1,926
589	3,743	34%	$307	34%	6.6	$2,024	21,564	-$489	$1,046
589	3,743	34%	$307	34%	6.6	$2,024	21,564	-$489	$1,046
741	1,892	17%	$155	17%	-0.5	-$83	27,117	$858	$1,633

California - table

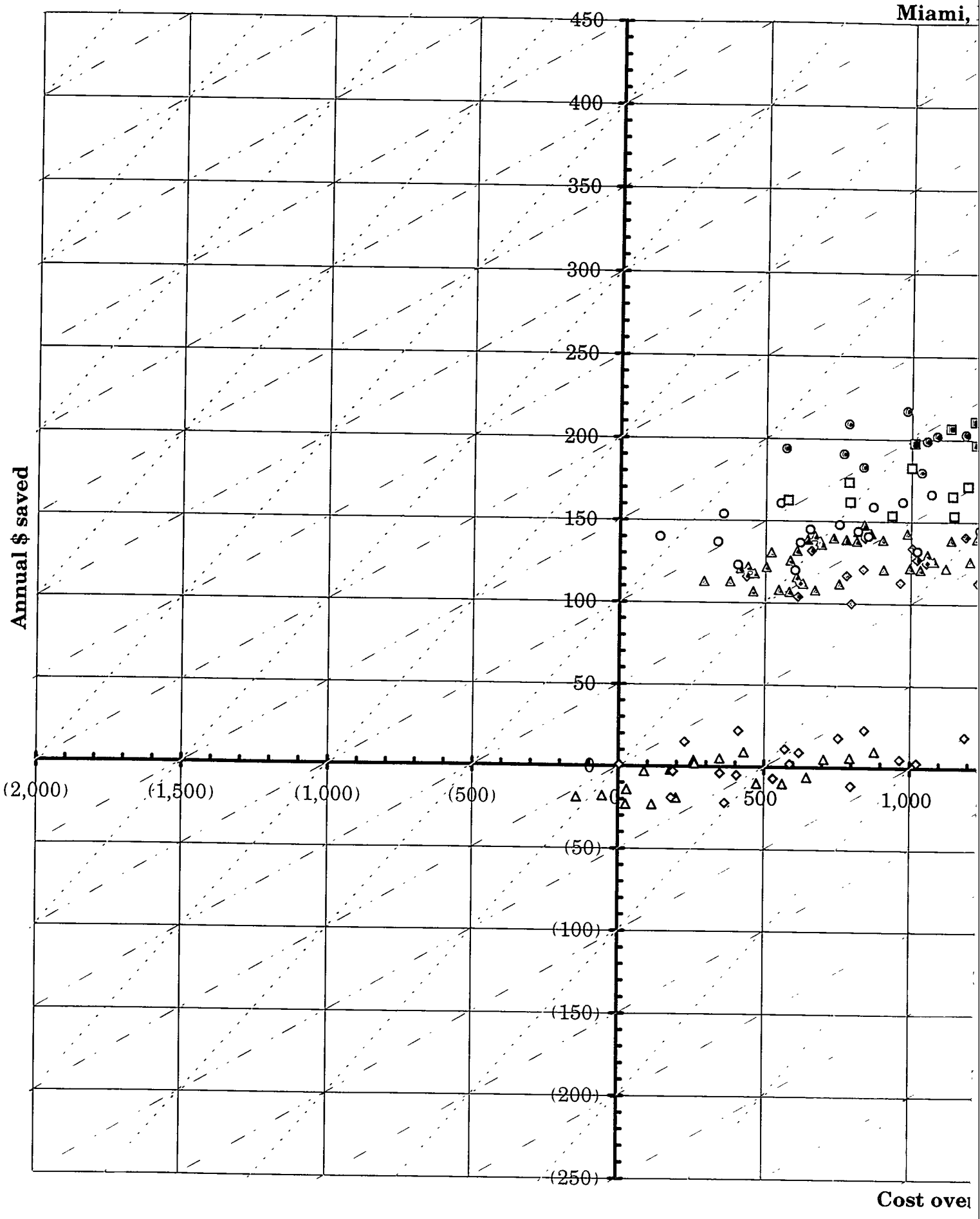


Figure 55, Miam

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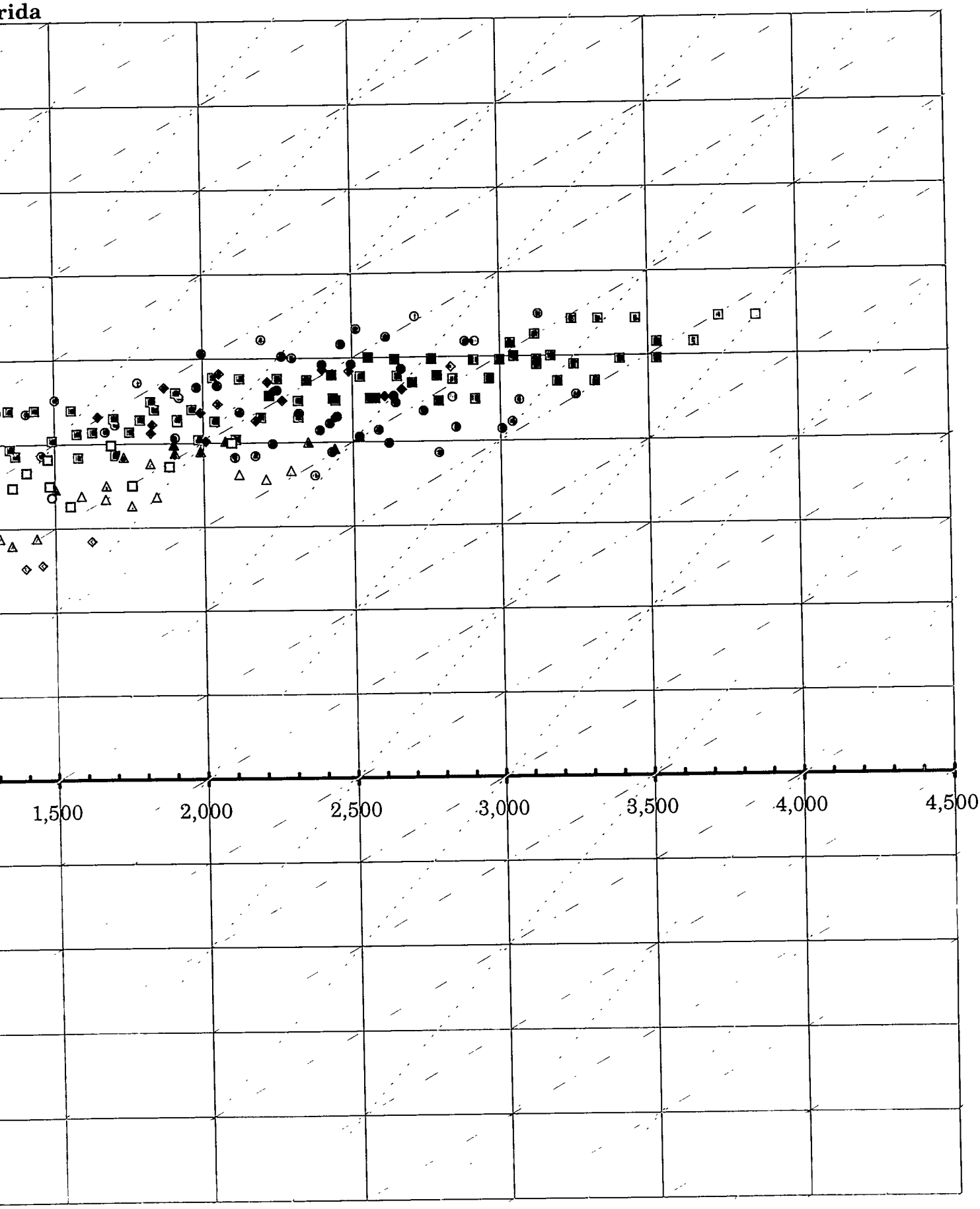


base case

, Florida - graph

▲ 3 tube T8 lights with manual off, 6-2040 windows, HP

◉ 3 tube T8 lights with manual off, 6-6040 windows, HP

▲ 3 tube T8 lights with cont. dimming, 6-2040 windows, HP

● 3 tube T8 lights with cont. dimming, 6-6040 windows, HP

△ 4 tube T12 lights with manual off, 6-2040 windows, HP

○ 4 tube T12 lights with manual off, 6-6040 windows, HP

- - - - - 5 year payback lines

Figure 56, Miam

- 3 tube T8 lights with manual off, 6-4040 windows, HP
- 3 tube T8 lights with manual off, 6-8040 windows, HP
- 3 tube T8 lights with cont. dimming, 6-4040 windows, HP
- 3 tube T8 lights with cont. dimming, 6-8040 windows, HP
- 4 tube T12 lights with manual off, 6-4040 windows, HP
- 4 tube T12 lights with manual off, 6-8040 windows, HP

10 year payback lines

Miami, Florida		Electric		Auxiliary fuel		Total
Filter	Building Description	kWh	$	gallons	$	kWh
Base case	Roof R30, Wall R11 studs @ 16" OC, Floor R11, 2@4040 aluminum frame double pane air filled, 4 tube T12 lights always on during class time, HP	10,260	$1,019	0	$0	10,260
Least expensive and save energy	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@4040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, Radiant barrier in the walls, HP,	10,117	$1,018	0	$0	10,117
Least simple payback	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, Radiant barrier in the walls, HP,	8,572	$879	0	$0	8,572
Best 5 year total savings	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, Radiant barrier in the walls, HP,	8,572	$879	0	$0	8,572
Best 10 year total savings	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, Radiant barrier in the walls, HP,	7,971	$825	0	$0	7,971
Best energy dollar savings	Roof R11, Wall R11 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled low e outside pane 0.1, 3 tube T8 lights with continuous dimming, Radiant barrier in the walls & radiant barrier in the roof, HP,	7,065	$744	0	$0	7,065
Best energy savings	Roof R11, Wall R11 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled low e outside pane 0.1, 3 tube T8 lights with continuous dimming, Radiant barrier in the walls & radiant barrier in the roof, HP,	7,065	$744	0	$0	7,065
Best energy dollar savings closest to no increase in cost	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, Radiant barrier in the walls, HP,	8,572	$879	0	$0	8,572

Figure 57, Mi

e)	Savings over base case				Simple payback	Net cost	Total (source)	5 year total savings	10 year total savings
$	kWh	% reduction	$	% reduction	years	$	kWh	$	$
019	0	0%	$0	0%	0.0	$0	30,780	$0	$0
,018	143	1%	$1	0%	2.6	$3	30,351	$2	$7
379	1,688	16%	$140	14%	1.0	$137	25,716	$563	$1,263
379	1,688	16%	$140	14%	1.0	$137	25,716	$563	$1,263
325	2,289	22%	$194	19%	2.9	$571	23,913	$399	$1,369
744	3,195	31%	$275	27%	11.4	$3,133	21,195	-$1,758	-$383
744	3,195	31%	$275	27%	11.4	$3,133	21,195	-$1,758	-$383
879	1,688	16%	$140	14%	1.0	$137	25,716	$563	$1,263

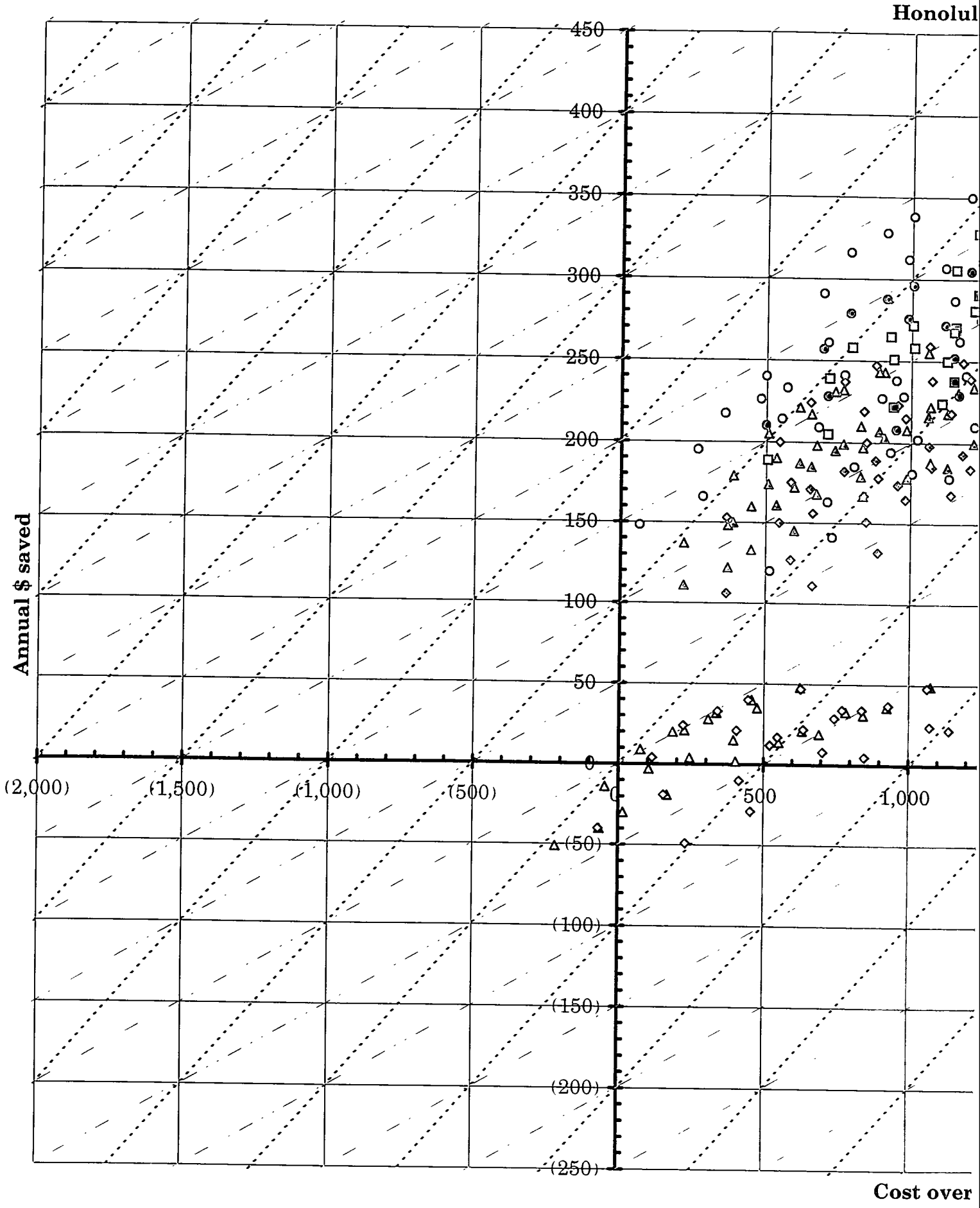
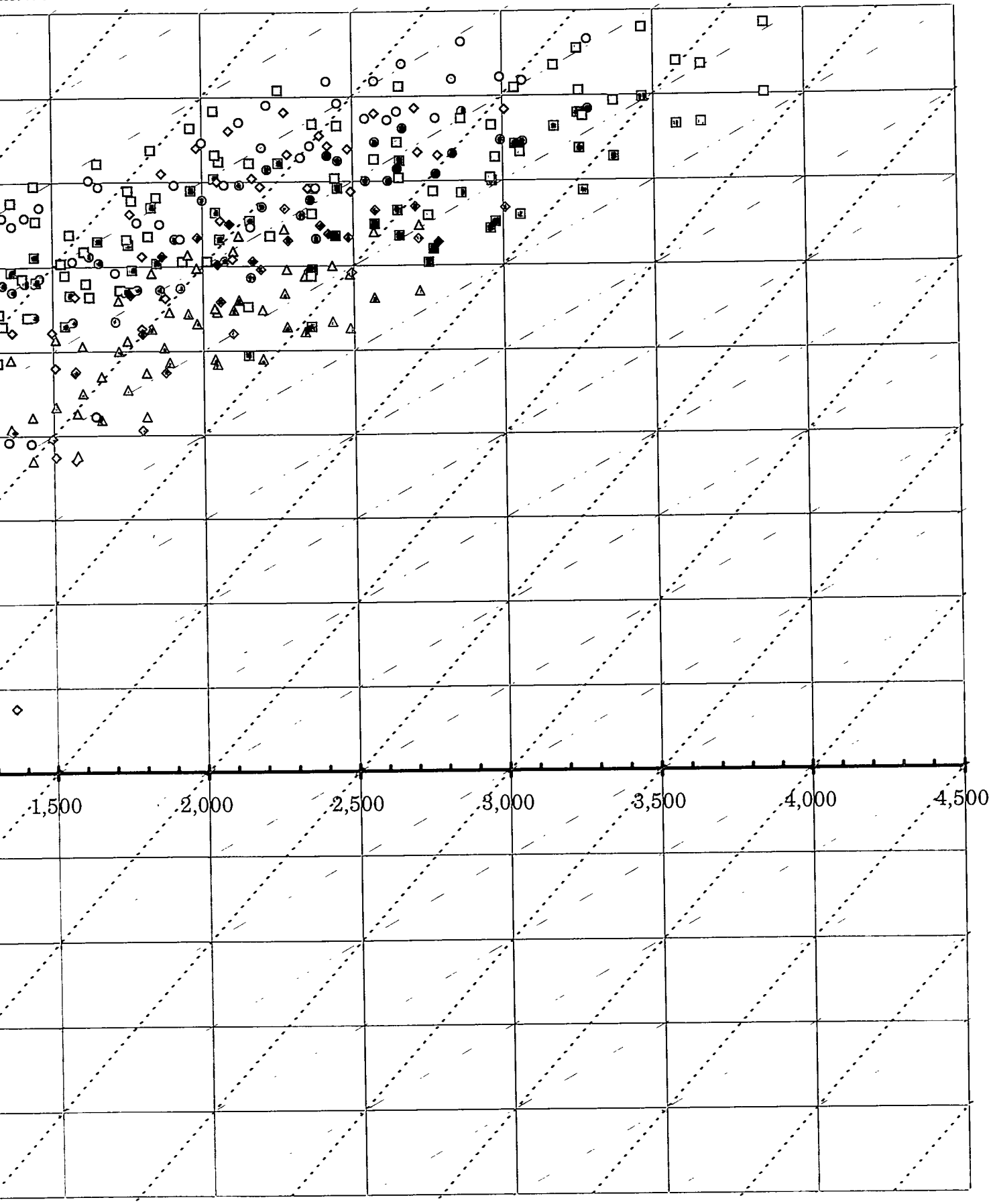


Figure 58, Honolul

Hawaii



base case

- △ 4 tube T12 lights with manual off, 6-
- ◇ 4 tube T12 lights with manual off, 6-
- ○ 4 tube T12 lights with manual off, 6-
- ◫ 4 tube T12 lights with manual off, 6-
- ▲ 3 tube T8 lights with manual off, 6-2
- △ 3 tube T8 lights with manual off, 6-2
- ◆ 3 tube T8 lights with manual off, 6-4
- ◇ 3 tube T8 lights with manual off, 6-4
- ◐ 3 tube T8 lights with manual off, 6-6
- ○ 3 tube T8 lights with manual off, 6-6
- ◩ 3 tube T8 lights with manual off, 6-8
- □ 3 tube T8 lights with manual off, 6-8
- ▲ 3 tube T8 lights with cont. dimming,
- △ 3 tube T8 lights with cont. dimming,
- ◆ 3 tube T8 lights with cont. dimming,
- ◇ 3 tube T8 lights with cont. dimming,
- ◐ 3 tube T8 lights with cont. dimming,
- ○ 3 tube T8 lights with cont. dimming,
- ◩ 3 tube T8 lights with cont. dimming,
- □ 3 tube T8 lights with cont. dimming,
- ------ 5 year payback lines
- — 10 year payback lines

Figure 59, Honolulu,

Hawaii

:0 windows, HP

:0 windows, HP

:0 windows, HP

:0 windows, HP

) windows, HP

) windows, HP with cross ventilation

) windows, HP

) windows, HP with cross ventilation

) windows, HP

) windows, HP with cross ventilation

) windows, HP

) windows, HP with cross ventilation

2040 windows, HP

2040 windows, HP with cross ventilation

4040 windows, HP

4040 windows, HP with cross ventilation

6040 windows, HP

6040 windows, HP with cross ventilation

8040 windows, HP

8040 windows, HP with cross ventilation

Iawaii - legend

Honolulu, Hawaii		Electric		Auxiliary fuel		Total
Filter	Building Description	kWh	$	gallons	$	kWh
Base case	Roof R19, Wall R11 studs @ 16" OC, Floor R11, 2@4040 aluminum frame double pane air filled, 4 tube T12 lights always on during class time, HP	10,473	$1,710	0	$0	10,473
Least expensive and save energy	Roof R0, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, Radiant barrier in the walls, HP,	9,148	$1,562	0	$0	9,148
Least simple payback	Roof R0, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, Radiant barrier in the walls, HP,	9,148	$1,562	0	$0	9,148
Best 5 year total savings	Roof R11, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, Radiant barrier in the walls, HP with cross ventilation,	7,643	$1,394	0	$0	7,643
Best 10 year total savings	Roof R11, Wall R11 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, Radiant barrier in the walls, HP with cross ventilation,	7,446	$1,372	0	$0	7,446
Best energy dollar savings	Roof R11, Wall R11 studs @ 24" OC, Floor R0, 6@8040 aluminum frame double pane air filled low e outside pane 0.04, 3 tube T8 lights with continuous dimming, Radiant barrier in the walls & radiant barrier in the roof, HP with cross ventilation,	6,519	$1,268	0	$0	6,519
Best energy savings	Roof R11, Wall R11 studs @ 24" OC, Floor R0, 6@8040 aluminum frame double pane air filled low e outside pane 0.04, 3 tube T8 lights with continuous dimming, Radiant barrier in the walls & radiant barrier in the roof, HP with cross ventilation,	6,519	$1,268	0	$0	6,519
Best energy dollar savings closest to no increase in cost	Roof R0, Wall R0 studs @ 24" OC, Floor R0, 6@6040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, Radiant barrier in the walls, HP,	9,148	$1,562	0	$0	9,148

Figure 60, Honolul

e)	Savings over base case				Simple payback	Net cost	Total (source)	5 year total savings	10 year total savings
$	kWh	% reduction	$	% reduction	years	$	kWh	$	$
,710	0	0%	$0	0%	0.0	$0	31,419	$0	$0
,562	1,325	13%	$148	9%	0.4	$65	27,444	$675	$1,415
,562	1,325	13%	$148	9%	0.4	$65	27,444	$675	$1,415
,394	2,830	27%	$316	18%	2.5	$790	22,929	$790	$2,370
,372	3,027	29%	$338	20%	3.0	$1,006	22,338	$684	$2,374
,268	3,954	38%	$442	26%	8.7	$3,867	19,557	-$1,657	$553
,268	3,954	38%	$442	26%	8.7	$3,867	19,557	-$1,657	$553
,562	1,325	13%	$148	9%	0.4	$65	27,444	$675	$1,415

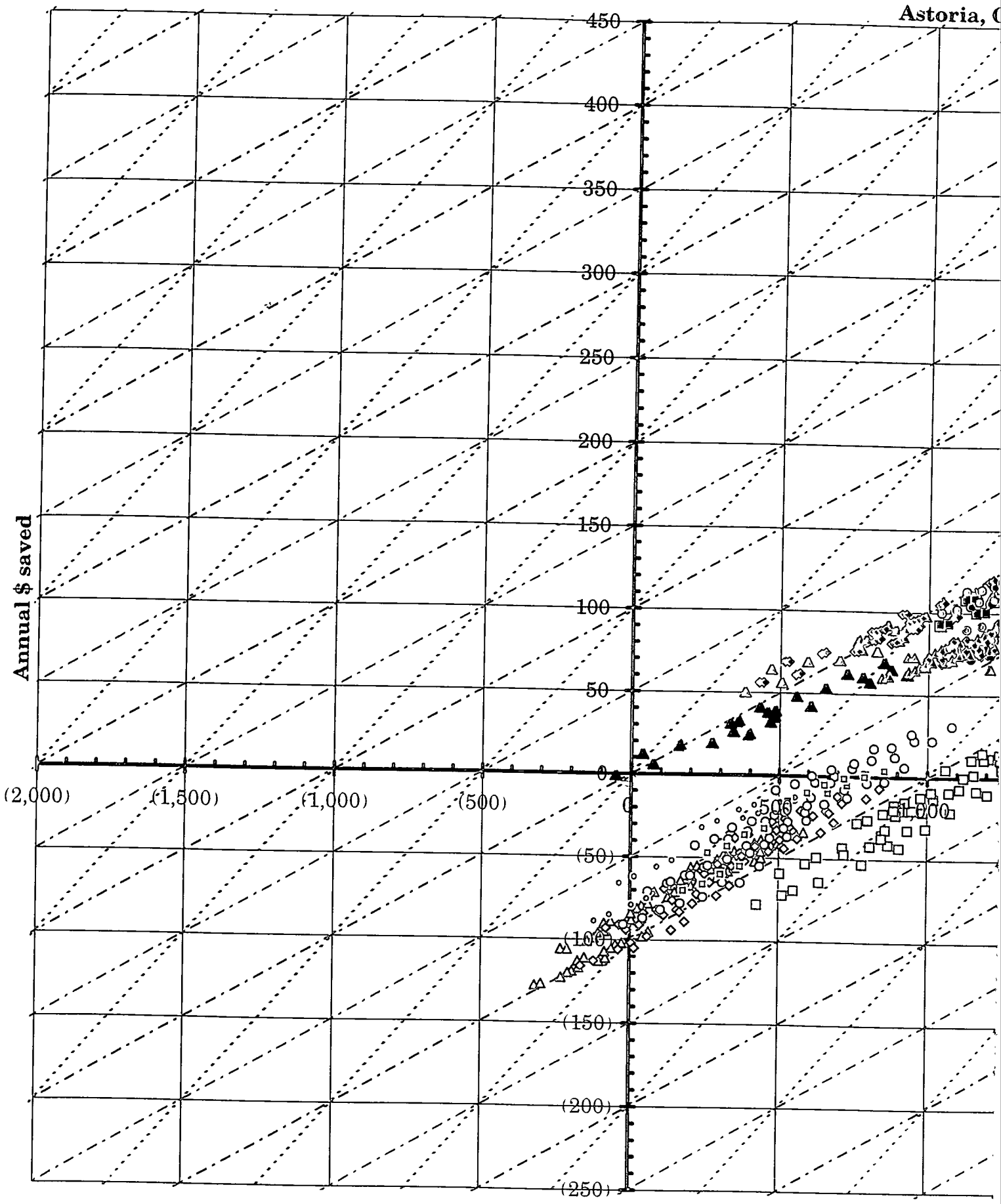
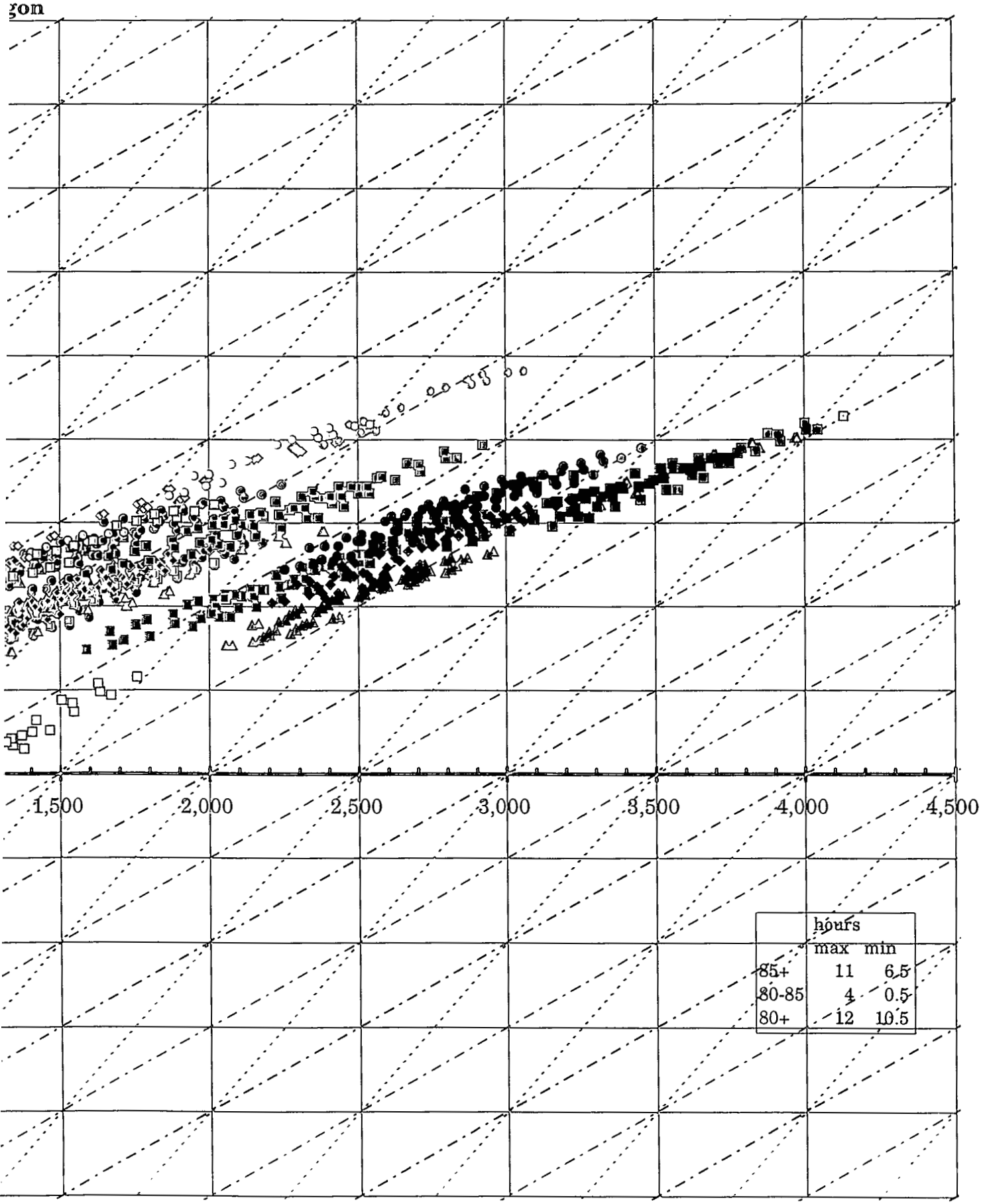


Figure 61, Astor


1,500
2,000
2,500
3,000
3,500
4,000
4,500
hours
max min
85+ 11 6.5
80-85 4 0.5
80+ 12 10.5

- 3 tube T8 lights with occupancy sensor only, 6-2
- 3 tube T8 lights with occupancy sensor only, 6-4
- 3 tube T8 lights with occupancy sensor only, 6-6
- 3 tube T8 lights with occupancy sensor only, 4-6
- 3 tube T8 lights with occupancy sensor only, 6-8
- 3 tube T8 lights with occupancy sensor only, 6-8
- 4 tube T12 lights with manual off, 2-2040 windo
- 3 tube T8 lights with manual off, 2-2040 window
- 3 tube T8 lights with manual off, 2-4040 window
- 3 tube T8 lights with manual off, 2-8040 window
- 3 tube T8 lights with manual off, 6-2040 window
- 3 tube T8 lights with manual off, 6-4040 window
- 3 tube T8 lights with manual off, 6-6040 window
- 3 tube T8 lights with manual off, 4-6040 window
- 3 tube T8 lights with manual off, 2-2040 window
- 3 tube T8 lights with manual off, 2-4040 window
- 3 tube T8 lights with manual off, 2-4040 window
- 3 tube T8 lights with manual off, 2-2040 window
- 3 tube T8 lights with manual off, 2-2040 window
- 3 tube T8 lights with manual off, 4-6040/2-2040 w
- 3 tube T8 lights with manual off, 4-6040 windows
- 3 tube T8 lights with manual off, 4-8040 windows
- 3 tube T8 lights with cont. dimming, 6-6040 wind
- 3 tube T8 lights with cont. dimming, 4-8040 wind
- 3 tube T8 lights with cont. dimming, 4-6040 wind
- 3 tube T8 lights with cont. dimming, 6-2040 wind
- 3 tube T8 lights with cont. dimming, 6-4040 wind
- 3 tube T8 lights with manual off, 6-8040 windows
- 3 tube T8 lights with cont. dimming, 6-8040 wind
- 3 tube T8 lights with manual off, 6-2040 windows
- 3 tube T8 lights with manual off, 6-4040 windows
- 3 tube T8 lights with manual off, 6-6040 windows
- 3 tube T8 lights with manual off, 4-6040 windows
- 3 tube T8 lights with manual off, 6-8040 windows
- 3 tube T8 lights with manual off, 4-8040 windows
- 5 year payback lines
- 10 year payback lines

Figure 62, Astoria,

on

windows, HP
windows, HP
windows, HP
windows/2-2040 windows, HP
windows, HP
windows/2-2040 windows, HP
HP
IP
IP
IP
IP
IP
IP
2040 windows, HP
IP Solarwall
IP 60% HX
IP 40% HX
IP 60% HX
IP 40% HX
dows, HP 60% HX
-2040 windows, HP 40% HX
-2040 windows, HP
vs, HP
vs/2-2040 windows, HP
vs/2-2040 windows, HP
vs, HP
vs, HP
HP
vs, HP
electric furn. with cross ventilation
electric furn. with cross ventilation
electric furn. with cross ventilation
2-2040 windows, electric furn. with cross ventilation
electric furn. with cross ventilation
2-2040 windows, electric furn. with cross ventilation

Astoria, Oregon		Electric		Natural Gas		Total
Filter	Building Description	kWh	$	Therms	$	kWh
Base case	Roof R30, Wall R11 studs @ 16" OC, Floor R11, 2@4040 aluminum frame double pane air filled, 4 tube T12 lights always on during class time, HP	13,830	$1,013	0	$0	13,830
Least expensive and save energy	Roof R30, Wall R15 studs @ 24" OC, Floor R11, 2@2040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, HP,	13,623	$1,001	0	$0	13,623
Least simple payback	Roof R30, Wall R15 studs @ 24" OC, Floor R11, 2@2040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, HP,	13,623	$1,001	0	$0	13,623
Best 5 year total savings	Roof R30, Wall R11 studs @ 24" OC, Floor R11, 2@2040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, HP,	13,843	$1,014	0	$0	13,843
Best 10 year total savings	Roof R30, Wall R15 studs @ 24" OC, Floor R11, 2@2040 aluminum frame double pane air filled, 3 tube T8 lights with manual off, HP,	12,762	$949	0	$0	12,762
Best energy dollar savings	Roof R38, Wall R21 studs @ 24" OC, Floor R19, 4@6040 aluminum frame double pane argon filled & 2@2040 aluminum frame double pane argon filled, 3 tube T8 lights with manual off, HP 60% HX,	9,817	$772	0	$0	9,817
Best energy savings	Roof R38, Wall R21 studs @ 24" OC, Floor R19, 4@6040 aluminum frame double pane argon filled & 2@2040 aluminum frame double pane argon filled, 3 tube T8 lights with manual off, HP 60% HX,	9,817	$772	0	$0	9,817
Best energy dollar savings closest to no increase in cost	Roof R30, Wall R15 studs @ 24" OC, Floor R11, 2@2040 aluminum frame double pane air filled, 4 tube T12 lights with manual off, HP,	13,623	$1,001	0	$0	13,623

Figure 63, Astoria, O

e)	Savings over base case				Simple payback	Net cost	Total (source)	5 year total savings	10 year total savings
$	kWh	% reduction	$	% reduction	years	$	kWh	$	$
,013	0	0%	$0	0%	0.0	$0	41,490	$0	$0
,001	207	1%	$12	1%	2.8	$34	40,869	$26	$86
,001	207	1%	$12	1%	2.8	$34	40,869	$26	$86
,014	-13	0%	($1)	0%	LOSS	-$55	41,529	$50	$45
949	1,068	8%	$64	6%	7.3	$468	38,286	-$148	$172
772	4,013	29%	$241	24%	12.7	$3,059	29,451	-$1,854	-$649
772	4,013	29%	$241	24%	12.7	$3,059	29,451	-$1,854	-$649
1,001	207	1%	$12	1%	2.8	$34	40,869	$26	$86

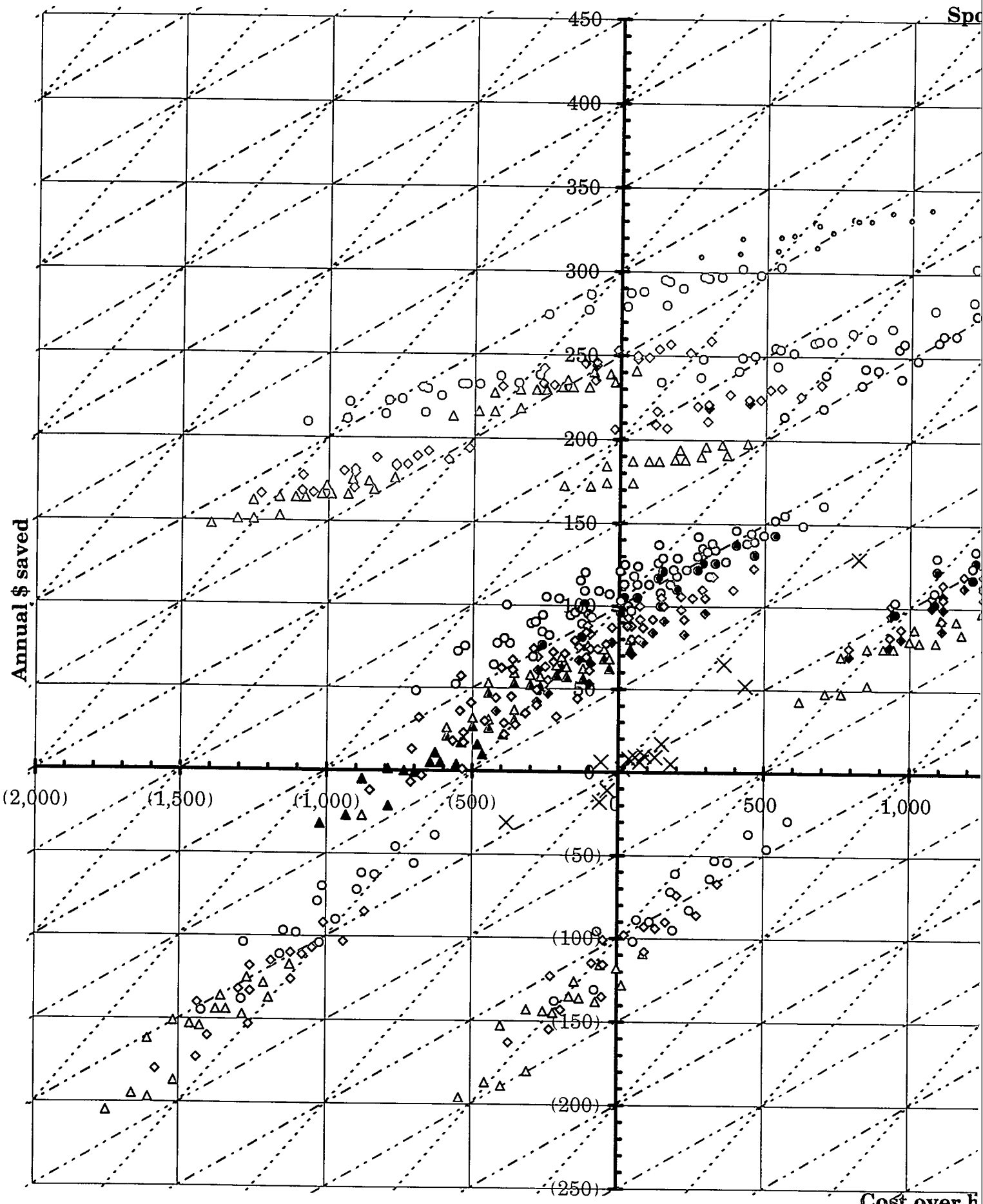
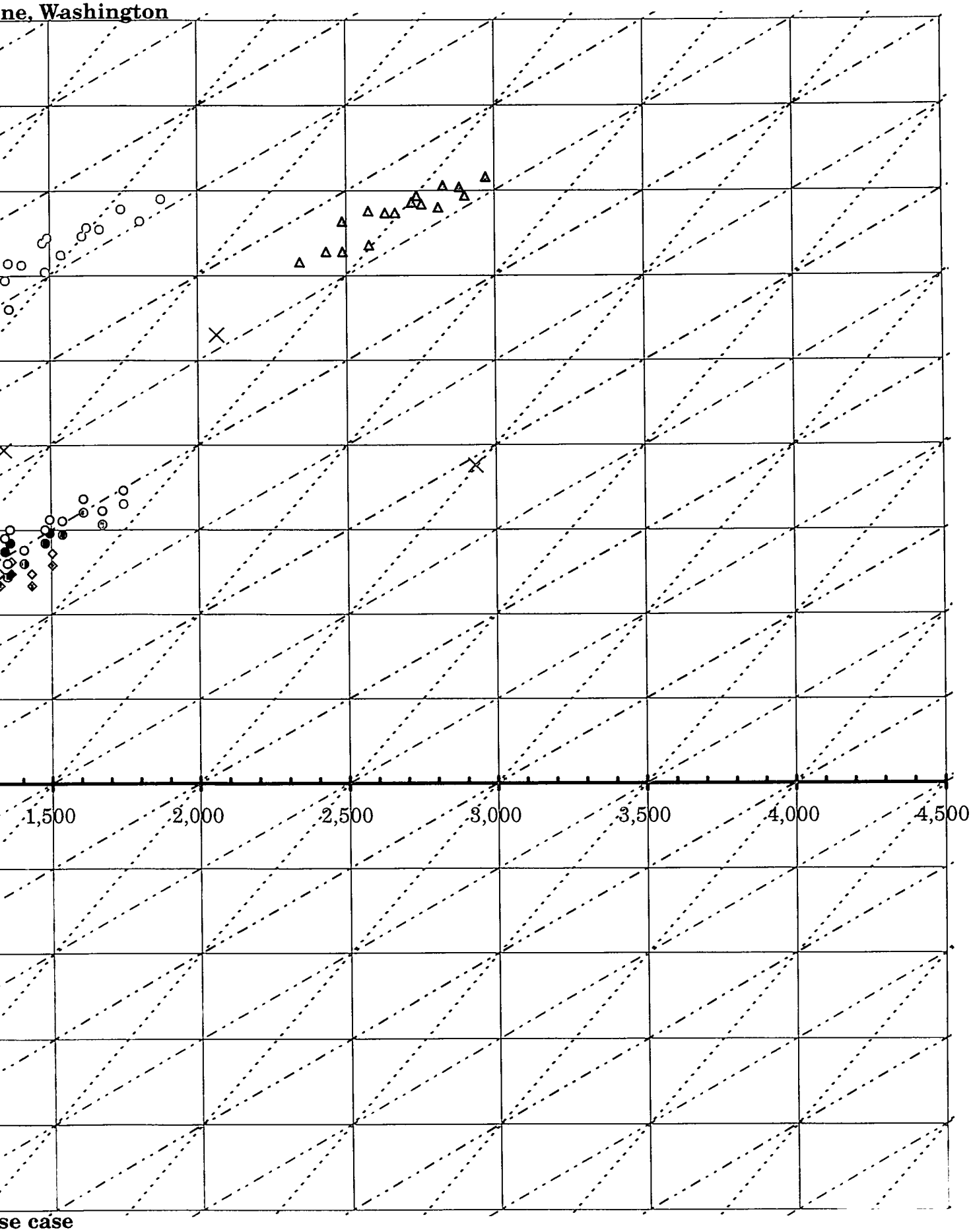


Figure 64, Spokane, Washi

ne, Washington



se case

gton - graph

- ▲ 3 tube T8 lights with manual off, 6-2040 win
- ◆ 3 tube T8 lights with manual off, 6-4040 win
- ● 3 tube T8 lights with manual off, 6-6040 win
- △ 3 tube T8 lights with manual off, 6-2040 win
- ◇ 3 tube T8 lights with manual off, 6-4040 win
- ○ 3 tube T8 lights with manual off, 6-6040 win
- △ 3 tube T8 lights with manual off, 6-2040 win
- ◇ 3 tube T8 lights with manual off, 6-4040 win
- ○ 3 tube T8 lights with manual off, 6-6040 win
- △ 3 tube T8 lights with manual off, 6-2040 win
- ◇ 3 tube T8 lights with manual off, 6-4040 win
- ▲ 3 tube T8 lights with manual off, 2-2040 win
- ○ 3 tube T8 lights with manual off, 6-6040 win
- ○ 3 tube T8 lights with manual off, 6-6040 win
- ○ 3 tube T8 lights with manual off, 6-6040 win
- ∘ 3 tube T8 lights with manual off, 6-6040 win
- △ 3 tube T8 lights with manual off, 6-2040 win
- ◇ 3 tube T8 lights with manual off, 6-4040 win
- ○ 3 tube T8 lights with manual off, 6-6040 win
- ▲ 4 tube T12 lights with manual off, 6-2040 wir
- ◇ 4 tube T12 lights with manual off, 6-4040 wir
- ○ 4 tube T12 lights with manual off, 6-6040 wir
- ◇ 3 tube T8 lights with 3 step control 6-4040 wi
- ○ 3 tube T8 lights with 3 step control 6-6040 wi
- ◇ 4 tube T12 lights with 3 step control 6-4040 v
- ○ 4 tube T12 lights with 3 step control 6-6040 v
- ◆ 3 tube T8 lights with cont. dimming, 6-4040 v
- ● 3 tube T8 lights with cont. dimming, 6-6040 v
- △ 3 tube T8 lights with cont. dimming, 6-2040 v
- ◇ 3 tube T8 lights with cont. dimming, 6-4040 v
- ○ 3 tube T8 lights with cont. dimming, 6-6040 v
- △ 3 tube T8 lights with cont. dimming, 6-2040 v
- ◇ 3 tube T8 lights with cont. dimming, 6-4040 v
- ○ 3 tube T8 lights with cont. dimming, 6-6040 v
- △ 3 tube T8 lights with cont. dimming, 6-2040 v
- ◇ 3 tube T8 lights with cont. dimming, 6-4040 v
- ○ 3 tube T8 lights with cont. dimming, 6-6040 v
- × Parametric
- ------ 5 year payback lines
- – · · – 10 year payback lines

Figure 65, Spol

ne, Washington

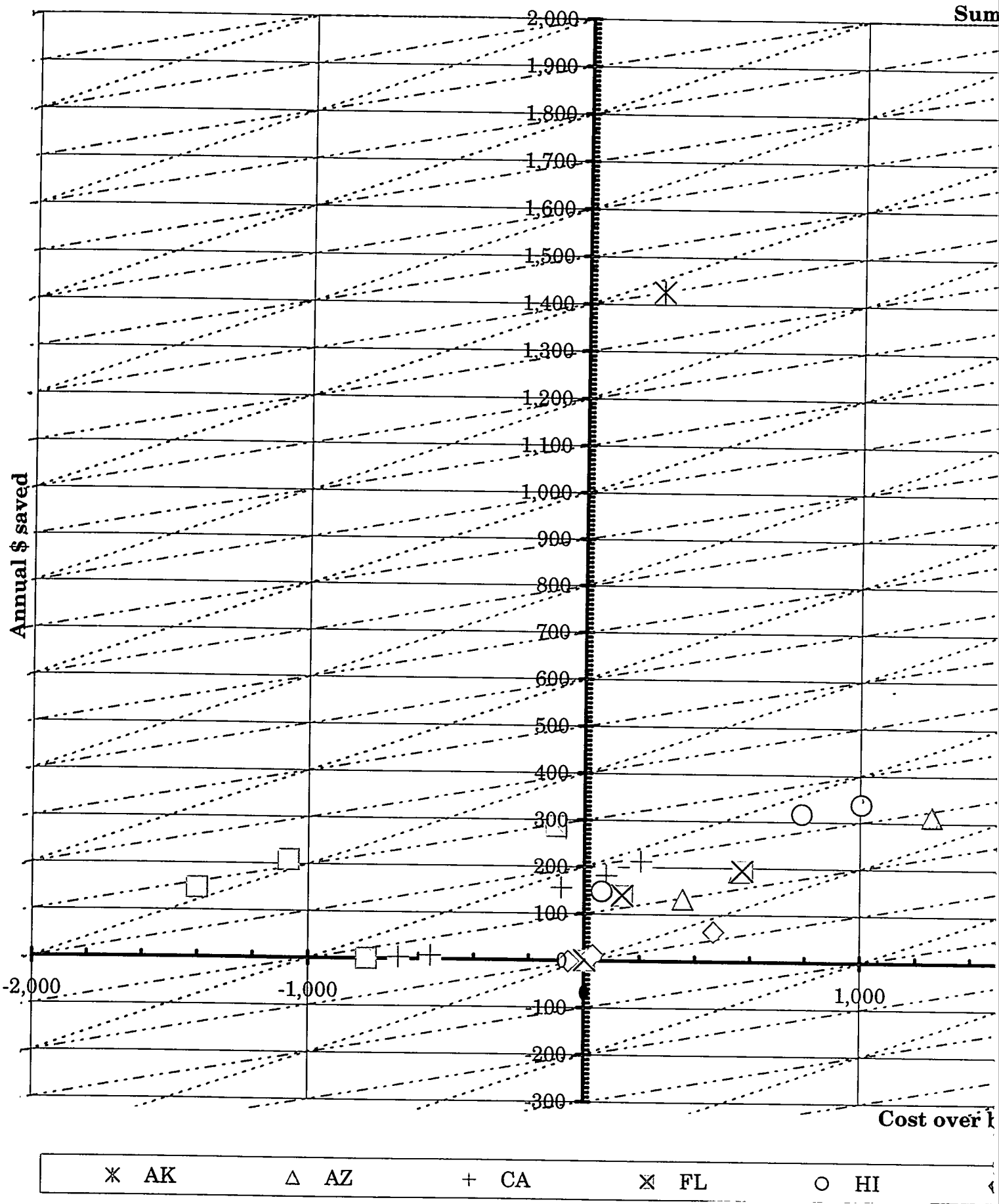
s, HP
s, HP
s, HP
s, HP with cross ventilation
s, HP with cross ventilation
s, HP with cross ventilation
s, nat. gas furn. with cross ventilation
s, nat. gas furn. with cross ventilation
s, nat. gas furn. with cross ventilation
s, nat. gas furn. with cross ventilation 40% HX
s, nat. gas furn. with cross ventilation 40% HX
s, HP Solarwall
s, HP with cross ventilation 60% HX
s, HP with cross ventilation 40% HX
s, nat. gas furn. with cross ventilation 40% HX
s, nat. gas furn. with cross ventilation 40% HX
s, electric furn. with cross ventilation
s, electric furn. with cross ventilation
s, electric furn. with cross ventilation
ows, HP
ows, HP
ows, HP
dows, HP
dows, HP
ndows, HP
ndows, HP
ndows, HP
ndows, HP
ndows, HP with cross ventilation
ndows, HP with cross ventilation
ndows, HP with cross ventilation
ndows, nat. gas furn. with cross ventilation
indows, nat. gas furn. with cross ventilation
indows, nat. gas furn. with cross ventilation
indows, electric furn. with cross ventilation
indows, electric furn. with cross ventilation
indows, electric furn. with cross ventilation

ane, Washington - legend

Spokane, Washington		Electric		Natural Gas		Tota
Filter	Building Description	kWh	$	Therms	$	kWh
Base case	Roof R30, Wall R19 studs @ 16" OC, Floor R19, 2@4040 vinyl frame double pane air filled, 4 tube T12 lights always on during class time, HP with economizer	17,055	$1,142	0	$0	17,055
Least expensive and save energy	Roof R38, Wall R19 studs @ 24" OC, Floor R11, 6@2040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Natural gas furnace with cross ventilation,	4,992	$364	1,593	$630	51,678
Least simple payback	Roof R38, Wall R19 studs @ 24" OC, Floor R19, 6@2040 vinyl frame double pane argon filled low e inside pane 0.2, 4 tube T12 lights with manual off, HP,	17,042	$1,141	0	$0	17,042
Best 5 year total savings	Roof R38, Wall R19 studs @ 24" OC, Floor R11, 6@2040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Natural gas furnace with cross ventilation,	4,992	$364	1,593	$630	51,678
Best 10 year total savings	Roof R38, Wall R19 studs @ 24" OC, Floor R11, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Natural gas furnace with cross ventilation,	4,185	$312	1,568	$621	50,138
Best energy dollar savings	Roof R38, Wall R21 studs @ 24" OC, Floor R30, 6@2040 vinyl frame double pane argon filled low e inside pane 0.2, 3 tube T8 lights with manual off, solar wall, HP with cross ventilation,	11,521	$784	0	$0	11,521
Best energy savings	Roof R38, Wall R21 studs @ 24" OC, Floor R30, 6@2040 vinyl frame double pane argon filled low e inside pane 0.2, 3 tube T8 lights with manual off, solar wall, HP with cross ventilation,	11,521	$784	0	$0	11,521
Best energy dollar savings closest to no increase in cost	Roof R38, Wall R19 studs @ 24" OC, Floor R19, 6@6040 vinyl frame double pane argon filled, 3 tube T8 lights with manual off, Natural gas furnace with cross ventilation & 40%HX,	4,178	$312	1,362	$544	44,094

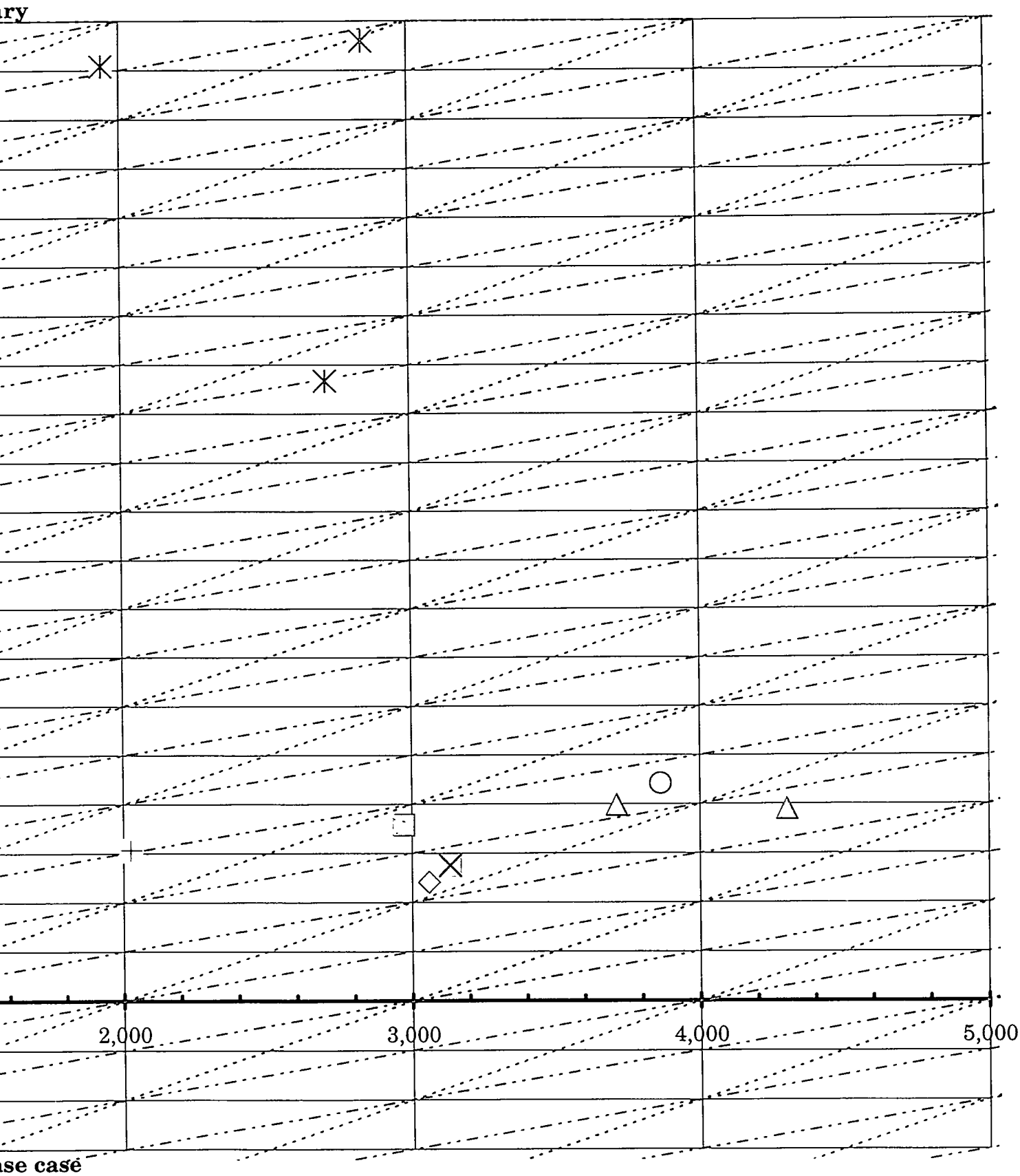
Figure 66, Spokane, Was

e)	Savings over base case				Simple payback	Net cost	Total (source)	5 year total savings	10 year total savings
$	kWh	% reduction	$	% reduction	years	$	kWh	$	$
,142	0	0%	$0	0%	0.0	$0	51,165	$0	$0
994	-34,623	-203%	$148	13%	-9.5	-$1,400	61,662	$2,140	$2,880
,141	13	0%	$1	0%	-790.4	-$790	51,126	$795	$800
994	-34,623	-203%	$148	13%	-9.5	-$1,400	61,662	$2,140	$2,880
933	-33,083	-194%	$209	18%	-5.1	-$1,072	58,508	$2,117	$3,162
784	5,534	32%	$358	31%	8.3	$2,971	34,563	-$1,181	$609
784	5,534	32%	$358	31%	8.3	$2,971	34,563	-$1,181	$609
856	-27,039	-159%	$286	25%	-0.4	-$103	52,450	$1,533	$2,963



11940/Zip99-2:tb

Figure 67, Graph



OR WA ····· 5 year payback lines — · · — 10 year payback lines

pattern shape, border color, fill color	pattern	Category description
triangle, red, pink	▲	3 tube T8 lights with cont. dimming, 6-2040 windows, HP
triangle, red, yellow	△	3 tube T8 lights with cont. dimming, 6-2040 windows, electric furn. with cross ventilation
triangle, red, purple	△	3 tube T8 lights with cont. dimming, 6-2040 windows, HP with cross ventilation
triangle, red, green	△	3 tube T8 lights with cont. dimming, 6-2040 windows, nat. gas furn. with cross ventilation
diamond, red, pink	◆	3 tube T8 lights with cont. dimming, 6-4040 windows, HP
diamond, red, yellow	◇	3 tube T8 lights with cont. dimming, 6-4040 windows, electric furn. with cross ventilation
diamond, red, purple	◇	3 tube T8 lights with cont. dimming, 6-4040 windows, HP with cross ventilation
diamond, red, green	◇	3 tube T8 lights with cont. dimming, 6-4040 windows, nat. gas furn. with cross ventilation
circle, red, pink	●	3 tube T8 lights with cont. dimming, 6-6040 windows, HP
circle, red, yellow	○	3 tube T8 lights with cont. dimming, 6-6040 windows, electric furn. with cross ventilation
circle, red, purple	○	3 tube T8 lights with cont. dimming, 6-6040 windows, HP with cross ventilation
circle, red, lt. green	○	3 tube T8 lights with cont. dimming, 6-6040 windows, HP with cross ventilation 40% HX
circle, red, green	○	3 tube T8 lights with cont. dimming, 6-6040 windows, nat. gas furn. with cross ventilation
square, red, pink	■	3 tube T8 lights with cont. dimming, 6-8040 windows, HP
square, red, purple	□	3 tube T8 lights with cont. dimming, 6-8040 windows, HP with cross ventilation
square, red, mauve	□	3 tube T8 lights with cont. dimming, 6-8040 windows,/6-2040 windows, HP
triangle, blue, pink	▲	3 tube T8 lights with manual off, 6-2040 windows, HP
triangle, blue, black	▲	3 tube T8 lights with manual off, 2-2040 windows, HP
triangle, blue, yellow	△	3 tube T8 lights with manual off, 6-2040 windows, electric furn. with cross ventilation
triangle, blue, purple	△	3 tube T8 lights with manual off, 6-2040 windows, HP with cross ventilation
triangle, blue, lt. green	△	3 tube T8 lights with manual off, 6-2040 windows, HP with cross ventilation 40% HX
triangle, blue, green	△	3 tube T8 lights with manual off, 6-2040 windows, nat. gas furn. with cross ventilation
triangle, blue, violet	△	3 tube T8 lights with manual off, 6-2040 windows, nat. gas furn. with cross ventilation 40% HX
diamond, blue, pink	◆	3 tube T8 lights with manual off, 6-4040 windows, HP
diamond, blue, black	◆	3 tube T8 lights with manual off, 2-4040 windows, HP
diamond, blue, yellow	◇	3 tube T8 lights with manual off, 6-4040 windows, electric furn. with cross ventilation
diamond, blue, purple	◇	3 tube T8 lights with manual off, 6-4040 windows, HP with cross ventilation
diamond, blue, lt. green	◇	3 tube T8 lights with manual off, 6-4040 windows, HP with cross ventilation 40% HX
diamond, blue, green	◇	3 tube T8 lights with manual off, 6-4040 windows, nat. gas furn. with cross ventilation
diamond, blue, violet	◇	3 tube T8 lights with manual off, 6-4040 windows, nat. gas furn. with cross ventilation 40% HX
circle, blue, pink	●	3 tube T8 lights with manual off, 6-6040 windows, HP
circle, blue, black	●	3 tube T8 lights with manual off, 2-6040 windows, HP
circle, blue, yellow	○	3 tube T8 lights with manual off, 6-6040 windows, electric furn. with cross ventilation
circle, blue, purple	○	3 tube T8 lights with manual off, 6-6040 windows, HP with cross ventilation
circle, blue, lt. green	○	3 tube T8 lights with manual off, 6-6040 windows, HP with cross ventilation 40% HX
circle, blue, green	○	3 tube T8 lights with manual off, 6-6040 windows, nat. gas furn. with cross ventilation
circle, blue, violet	○	3 tube T8 lights with manual off, 6-6040 windows, nat. gas furn. with cross ventilation 40% HX
square, blue, pink	■	3 tube T8 lights with manual off, 6-8040 windows, HP
square, blue, black	■	3 tube T8 lights with manual off, 2-8040 windows, HP
square, blue, yellow	□	3 tube T8 lights with manual off, 6-8040 windows, electric furn. with cross ventilation
square, blue, purple	□	3 tube T8 lights with manual off, 6-8040 windows, HP with cross ventilation
square, blue, lt. green	□	3 tube T8 lights with manual off, 6-8040 windows, HP with cross ventilation 40% HX
square, blue, green	□	3 tube T8 lights with manual off, 6-8040 windows, nat. gas furn. with cross ventilation
square, blue, violet	□	3 tube T8 lights with manual off, 6-8040 windows, nat. gas furn. with cross ventilation 40% HX
traingle, black, mauve	△	4 tube T12 lights with manual off, 6-2040 windows, HP
diamond, black, mauve	◇	4 tube T12 lights with manual off, 6-4040 windows, HP
circle, black, mauve	○	4 tube T12 lights with manual off, 6-6040 windows, HP
square, black, mauve	□	4 tube T12 lights with manual off, 6-8040 windows, HP
circle, black, lt. green	○	dud
circle, purple, lt. green	○	3 tube T8 lights with manual off, 6-6040 windows, HP 40% HX
triangle, blue, tan	△	3 tube T8 lights with 3 step control 6-2040 windows, HP
diamond, blue, tan	◇	3 tube T8 lights with 3 step control 6-4040 windows, HP
circle, blue, tan	○	3 tube T8 lights with 3 step control 6-6040 windows, HP
circle, blue, blue	○	3 tube T8 lights with 3 step control 4-6040 windows/2-2040 windows, HP
triangle, blue, brick	◔	3 tube T8 lights with 3 step control 4-6040 windows/2-2040 windows, 40% HX

Figure 68, Legend S

legend

Row numbers where these catagories apply						
Fairbanks, AK	Phoenix, AZ	Sacramento, CA	Miami, FL	Honolulu, HI	Astoria, OR	Spokane, WA
		185 to 200	63 to 80	81 to 104	425 to 488	
						377 to 392
		665 to 680		297 to 320		473 to 488
						281 to 296
	99 to 143	105 to 152	81 to 98	105 to 128	297 to 360	73 to 88
						329 to 344
	414 to 458	585 to 632		321 to 344		425 to 440
						233 to 248
	144 to 188	153 to 184 & 697 to 712	99 to 116 & 177 to 182 & 201 to 218	129 to 152	361 to 424	89 to 104
						345 to 360
	459 to 503	633 to 664		345 to 368		441 to 456
	639 to 647					
						249 to 264
	234 to 278	345 to 392	255 to 290	441 to 464	489 to 552	
	549 to 593	441 to 488		393 to 416		
	189 to 233	89 to 104	9 to 26 & 171 to 176 & 183 to 200	9 to 32	137 to 200	169 to 184
					937 to 984	
					713 to 776	361 to 376
93 to 104	504 to 548	569 to 584		225 to 248		457 to 472
165 to 176	648 to 656					
						265 to 280
						489 to 504
	9 to 53	9 to 56	27 to 44	33 to 56	9 to 72	9 to 24
					873 to 920	
					585 to 648	297 to 312
105 to 116	324 to 368	489 to 536		249 to 272		393 to 408
						201 to 216
						505 to 520
	54 to 98	57 to 88 & 681 to 696	45 to 62	57 to 80	73 to 136	25 to 40
					649 to 712	313 to 328
117 to 128	369 to 413	537 to 568 & 713 to 728		273 to 296		409 to 424
	927 to 971	729 to 744				571 to 586
						217 to 232
						521 to 536
	279 to 323	297 to 344	219 to 254	417 to 440	201 to 264	
					921 to 936	
					777 to 840	
	594 to 638	393 to 440		369 to 392		
	657 to 701	281 to 296	117 to 134	153 to 176		185 to 200
	702 to 746	201 to 248	135 to 152	177 to 200		105 to 120
	747 to 791	249 to 280	153 to 170	201 to 224		121 to 136
	792 to 836		291 to 308	465 to 488		
						41 to 56
						57 to 72

pattern shape, border color, fill color	pattern	Category description
traingle, black, tan	△	4 tube T12 lights with 3 step control 6-2040 windows, HP
diamond, black, tan	◇	4 tube T12 lights with 3 step control 6-4040 windows, HP
circle, black, tan	○	4 tube T12 lights with 3 step control 6-6040 windows, HP
square, black, tan	□	4 tube T12 lights with 3 step control 6-8040 windows, HP
X, red, none	X	Parametric
traingle, tan, blue	▲	3 tube T8 lights with manual off, 6-2040 windows, oil furn. with cross ventilation
diamond, tan, blue	◆	3 tube T8 lights with manual off, 6-4040 windows, oil furn. with cross ventilation
circle, tan, blue	●	3 tube T8 lights with manual off, 6-6040 windows, oil furn. with cross ventilation
square, tan, blue	■	3 tube T8 lights with manual off, 6-8040 windows, oil furn. with cross ventilation
traingle, tan, tan	△	3 tube T8 lights with manual off, 6-2040 windows, oil furn. with cross ventilation 45setback
traingle, tan, none	△	3 tube T8 lights with manual off, 6-2040 windows, oil furn. with cross ventilation 50setback
traingle, tan, red	▲	3 tube T8 lights with manual off, 6-2040 windows, oil furn. with cross ventilation Solarwall
circle, tan, red	●	3 tube T8 lights with manual off, 6-6040 windows, oil furn. with cross ventilation Solarwall
circle, pink, blue	●	3 tube T8 lights with manual off, 4-6040 windows/2-2040 windows, HP
square, pink, blue	■	3 tube T8 lights with manual off, 4-8040 windows/2-2040 windows, HP
circle, pink, red	●	3 tube T8 lights with cont. dimming, 4-6040 windows/2-2040 windows, HP
square, pink, red	■	3 tube T8 lights with cont. dimming, 4-8040 windows/2-2040 windows, HP
circle, yellow, blue	●	3 tube T8 lights with manual off, 4-6040 windows/2-2040 windows, electric furn. with cross ventilatic
square, yellow, blue	■	3 tube T8 lights with manual off, 4-8040 windows/2-2040 windows, electric furn. with cross ventilatic
triangle, black, black	▲	4 tube T12 lights with manual off, 2-2040 windows, HP
traingle, mauve, black	▲	3 tube T8 lights with occupancy sensor only, 6-2040 windows, HP
diamond, mauve, black	◆	3 tube T8 lights with occupancy sensor only, 6-4040 windows, HP
circle, mauve, black	●	3 tube T8 lights with occupancy sensor only, 6-6040 windows, HP
square, mauve, black	■	3 tube T8 lights with occupancy sensor only, 6-8040 windows, HP
circle, mauve, blue	●	3 tube T8 lights with occupancy sensor only, 4-6040 windows/2-2040 windows, HP
square, mauve, blue	■	3 tube T8 lights with occupancy sensor only, 6-8040 windows/2-2040 windows, HP
circle, violet, lt. green	○	3 tube T8 lights with manual off, 4-6040 windows/2-2040 windows, HP 40% HX
circle, blue, mauve	○	3 tube T8 lights with manual off, 6-6040 windows, HP with cross ventilation 60% HX
circle, black, lt. green	○	4 tube T12 lights with manual off, 6-6040 windows, HP 40% HX
circle, black, yellow	○	4 tube T12 lights with manual off, 6-6040 windows, HP 60% HX
circle, tan, lt. green	○	3 tube T8 lights with manual off, 6-6040 windows, oil furn. 40% HX
line, blue, short dash	——	5 year payback lines
line, red, 2 short dash 1 long dash	-··-·-	10 year payback lines
triangle, mauve, mauve	△	3 tube T8 lights with manual off, 2-2040 windows, HP 60% HX
diamond, mauve, lt. green	◇	3 tube T8 lights with manual off, 2-4040 windows, HP 40% HX
diamond, mauve, mauve	◇	3 tube T8 lights with manual off, 2-4040 windows, HP 60% HX
triangle, black, yellow	△	3 tube T8 lights with manual off, 2-2040 windows, HP Solarwall
circle, violet, mauve	○	3 tube T8 lights with manual off, 4-6040/2-2040 windows, HP 60% HX
triangle, mauve, lt. green	△	3 tube T8 lights with manual off, 2-2040 windows, HP 40% HX
circle, yellow, violet	○	3 tube T8 lights with manual off, 6-6040 windows, nat. gas furn. with cross ventilation 40% HX
triangle, black, violet	▲	3 tube T8 lights with manual off, 2-2040 windows, HP Solarwall
triangle, purple, mauve	△	3 tube T8 lights with manual off, 6-2040 windows, HP 60% HX
circle, tan, mauve	○	3 tube T8 lights with manual off, 6-6040 windows, oil furn. 60% HX

Figure 69, Legend Sumn

legend

Row numbers where these catagories apply						
Fairbanks, AK	Phoenix, AZ	Sacramento, CA	Miami, FL	Honolulu, HI	Astoria, OR	Spokane, WA
						137 to 152
						153 to 168
						537 to 554
9 to 20						
21 to 32						
33 to 44						
129 to 140						
57 to 68						
45 to 56						
69 to 80						
81 to 92						
					265 to 280	
					281 to 296	
					553 to 568	
					569 to 584	
					841 to 856	
					857 to 872	
					985 to 1032	
					1161 to 1224	
					1033 to 1096	
					1097 to 1160	
					1225 to 1288	
					1289 to 1304	
					1305 to 1320	
					1321 to 1336	
	972 to 1016	745 to 760				587 to 602
	837 to 881					
	882 to 926					
141 to 152						
					1369 to 1384	
					1385 to 1400	
					1401 to 1416	
					1417 to 1432	
					1337 to 1352	
					1353 to 1368	
						555 to 570
						603 to 618
177 to 188						
153 to 164						

ary (continued)

DE-FG03 94ER 81814
MODERN BUILDING SYSTEMS

2.1.4.10 Shade parametrics

Objective

To determine the optimum overhang, awning, and blind design for each of the seven climate.

Methodology

Each parametric was simulated independently in DOE2.1E for each climate. Overhang was simulated as a building shade extending past the eaves. Overhang lengths of 1, 2, 4, and 8 feet were evaluated. Awnings were not simulated due to the poor performance of the overhangs in the warmer climates. This is further discussed in the results section. Various glazing types were tested as a portion of the window parametrics. This was done in conjunction with window size and is discussed in section 2.1.4.11.

Venetian blinds were simulated using the window shading command in DOE2.1E. This command allows the user to specify a shading coefficient and visual transmittance for the blinds. Because of the impact of light angle on venetian blinds, DOE2.1E only simulates them approximately. The blinds can be set based on maximum glare or maximum solar heat gain. Both of these approaches were used. Maximum glare closes the blinds one at a time until the glare is acceptable. Maximum solar heat gain closes all the blinds if the heat gain limit is reached.

These two controls can be overridden using a shading schedule and setting the shading coefficient to 1 if open. The normal shading coefficient was set to 0.58 for venetian blinds closed at 45 degrees and 0.35 for blinds closed at 90 degrees. These values were taken from ASHRAE Fundamentals, 1993, 27.36 Table 29. Visual transmittance was set to 1 when the blinds were assumed to be open (shading schedule equal to 1), 0.35 when closed at 45 degrees, and 0.23 when closed at 90 degrees. These values were taken from DOE2.1E Supplemental, Table 2.8.

When the first series of simulations were run, no energy savings could be achieved. For this reason, additional simulations were run with a larger window

and using maximum solar heat gain.

Blinds were tested for each climate for several conditions:

max glare = 16

This is the maximum glare value for classrooms recommended in

---

max glare = 20

This is the maximum glare value for classrooms recommended by the DOE2.1E supplemental (table 2.7) and ASHRAE.

max solar heat gain = 169 BTU/hr and 4040 windows

Balance point with 4040 windows.

max solar heat gain = 84.7 BTU/hr and 8040 windows

Balance point with 8040 windows.

max solar heat gain = 50.0 BTU/hr and 8040 windows

Additional simulation to explore the effect of changing the max solar with larger windows.

max solar heat gain = 20.0 BTU/hr and 8040 windows

Additional simulation to explore the effect of changing the max solar with larger windows.

shading schedule based on solar radiance and system mode

The maximum solar heat gain was adjusted to reflect the season (heating vs. cooling). This was only applicable to the three climates which have distinct seasons, Fairbanks, Astoria, and Spokane. The remaining four climates are in cooling mode the majority of the time.

Results

Overhangs can be used to improve the energy use in some of the climates. The simulation results, total building energy in MBTUs per year, for each length tested are shown below:

Location	no overhang	1 foot overhang	2 foot overhang	4 foot overhang	8 foot overhang
Fairbanks, AK	109.02	109.16	109.53	110.85	113.00
Phoenix, AZ	26.92	26.69	26.48	27.26	29.26
Bakersfield, CA	25.79	25.72	25.85	27.28	29.45
Miami, FL	28.52	28.25	27.94	28.31	30.26
Honolulu, HI	27.67	27.49	27.54	28.46	30.22
Astoria, OR	35.69	35.84	36.21	37.36	39.10
Spokane, WA	48.32	49.49	49.93	51.51	53.80

Figure 70, Overhang simulation results

The following is a table showing the blind simulation results in all climates for each condition tested, all values are total building energy in MBTU/year:

Location	base no blinds	max glare 16	max glare 20	max solar 169	schedule & max solar 169
Fairbanks, AK	109.02	110.75	109.47	109.02	109.02
Phoenix, AZ	26.92	28.19	27.22	26.92	NA
Bakersfield, CA	25.79	27.19	26.06	25.79	NA
Miami, FL	28.52	30.16	28.94	28.52	NA
Honolulu, HI	27.67	29.58	27.95	27.67	NA
Astoria, OR	35.69	36.92	35.87	35.69	35.69
Spokane, WA	49.32	50.85	49.53	49.32	49.32

Figure 71, Blind simulation results - 4040 window

Location	8040 window no blinds	max solar 84.7	max solar 50	max solar 20	schedule & max solar 84.7
Fairbanks, AK	112.27	113.57	112.58	112.76	112.40
Phoenix, AZ	28.33	27.37	26.97	26.87	NA
Bakersfield, CA	26.20	26.11	25.88	25.93	NA
Miami, FL	30.04	29.15	28.48	27.94	NA
Honolulu, HI	28.70	28.16	27.55	27.05	NA
Astoria, OR	34.42	34.71	34.49	34.70	34.42
Spokane, WA	48.63	49.66	48.90	49.12	48.67

Figure 72, Blind simulation results - 8040 window

Blinds in the majority of cases are a detriment. This is due to the large impact daylighting has on total energy. When blinds are deployed, the daylighting is cut down and the lights are turned on. This causes an increase in heat gain and, therefore, an increase in the cooling load. When in the heating mode the solar gain should be maximized. The balance point is calculated below. For smaller windows this balance point is relatively high and is not reached as often as the balance point for larger windows.

Solar gain from windows (no blinds) = heat gain from lights + solar gain from windows (blinds down)

S*wtrans*area =

4040 window:

8040 window:

Using blinds with the larger window size begins to show some improvements in total annual energy requirements.

Conclusions

Overhangs can be employed to produce some energy benefits, but there is a large increase in cost associated with an overhang.

Blinds are likely to be used in all classrooms. They are a necessary feature for controlling the glare and lighting levels of the classroom. This study has determined that it is very difficult to operate blinds on the current base window size (4040) to create a positive effect on energy use. In reality the blinds would be operated based on max glare and the energy use would be between the results of max glare of 16 and 20. It may be worthwhile to investigate blind operation using Energy Scheming and translate the results to a more optimum shading schedule to use in the DOE2.1E simulations.

2.1.4.11 Window parametrics

Objective

Using DOE-2.1E run parametric simulations of the window size, glazing types, and frame types of the classroom. All seven climates where analyzed.

Methodology

The base case is different for each climate, see figure 73. The base case also has two double pane 4040 windows and two solid metal door on the south side of the building. The parametric cases has six windows, two on the north and four on the south, and two metal doors with 1/2 lite double pane glass on the north side. The parametric cases have continuous dimming fluorescent lights with a photo sensor set at 50 foot candles in the middle of the class room at desk height and an occupancy sensor. The base case has the same fluorescent lights with an occupancy sensor only. The parametric consists of either having the six windows vary in: size, glazing type, or frame type, while all the other building functions are held at the base case level. The exception is the lighting, windows, and doors as mentioned above. The six windows in the parametric case where varied in size from 2040, 4040, 6040, 8040, and 8050; varied in frame style from a 2" aluminum frame to a 2" vinyl frame; or varied between 24 different glazing types. The difference of the parametric buildings annual kWh energy use minus the base case building's annual kWh energy use is the annual kWh saving as shown in figures 73 through 87 and in the data tables.

	Roof		Wall		Floor	
Climate	R-value	spacing	R-value	spacing	R-value	spacing
Fairbanks, AK	38/11	2x8 24" OC	19	2x6 16" OC	19	2x8 16" OC
Phoenix, AZ	19/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Bakersfield, CA	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Miami, FL	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Honolulu, HI	19/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Astoria, OR	30/11	2x8 24" OC	11	2x4 16" OC	11	2x8 16" OC
Spokane, WA	30/11	2x8 24" OC	19	2x6 16" OC	19	2x8 16" OC

Figure 73, Base case

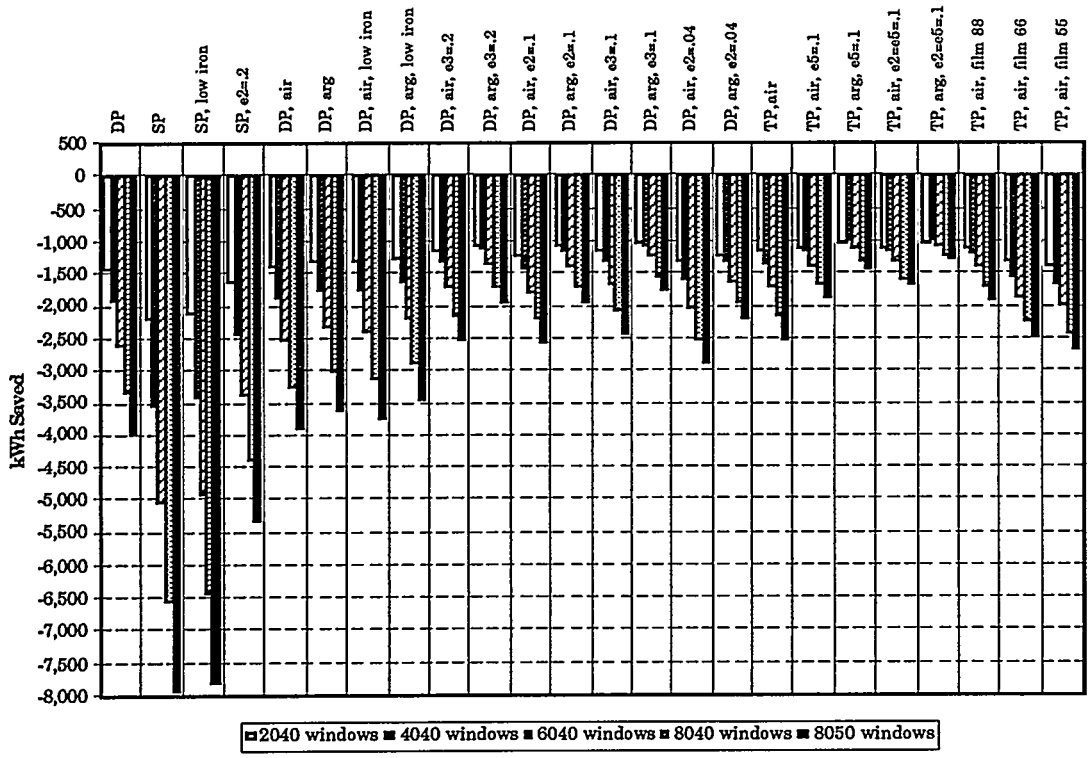


Figure 74, Fairbanks, AK Aluminum frame windows and kWh saved over base case

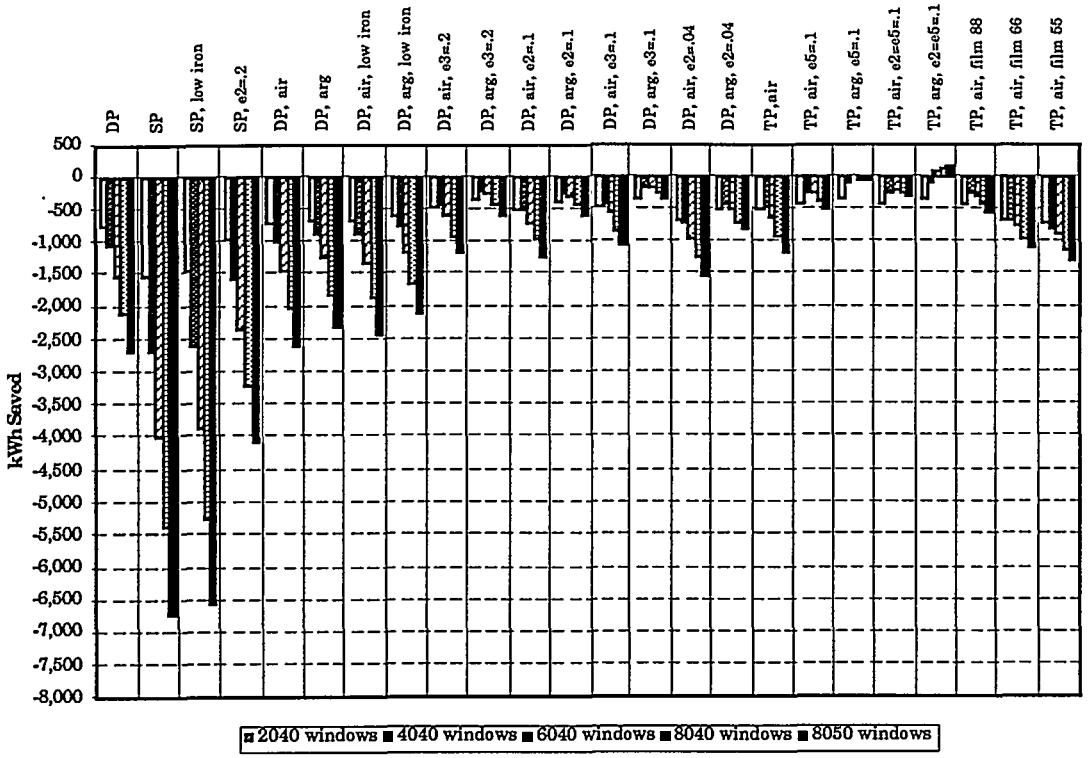


Figure 75, Fairbanks, AK Vinyl frame windows and kWh saved over base case

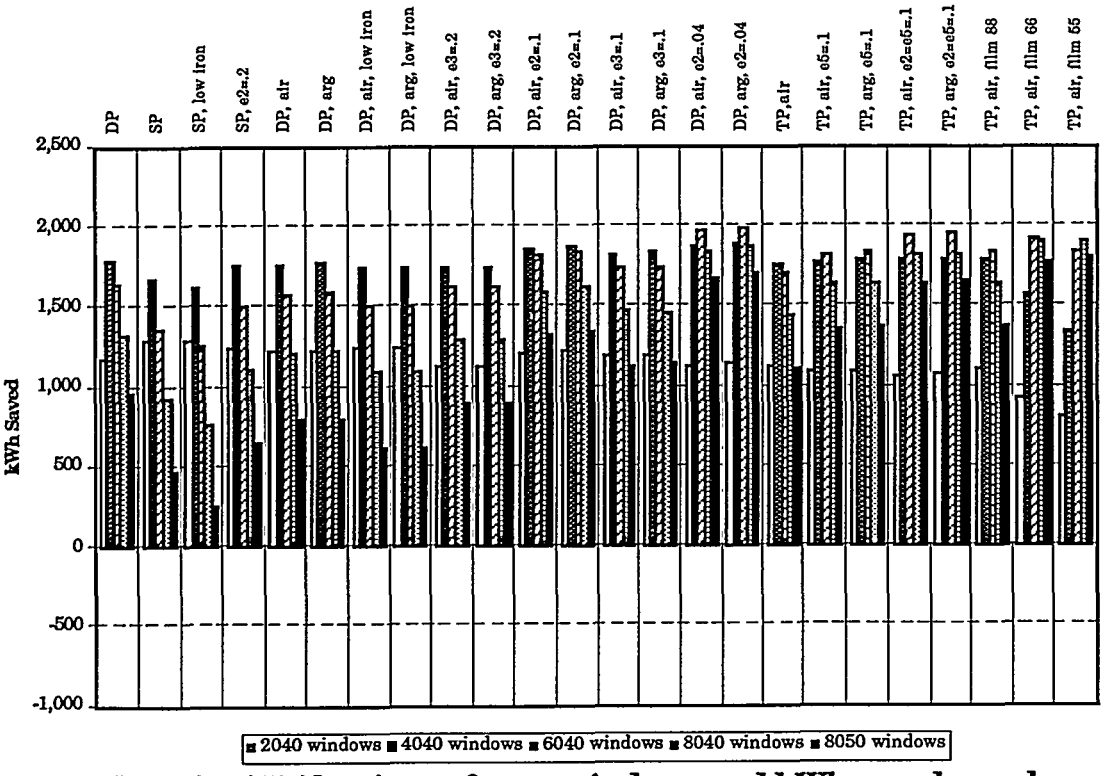


Figure 76, Phoenix, AZ Aluminum frame windows and kWh saved over base case

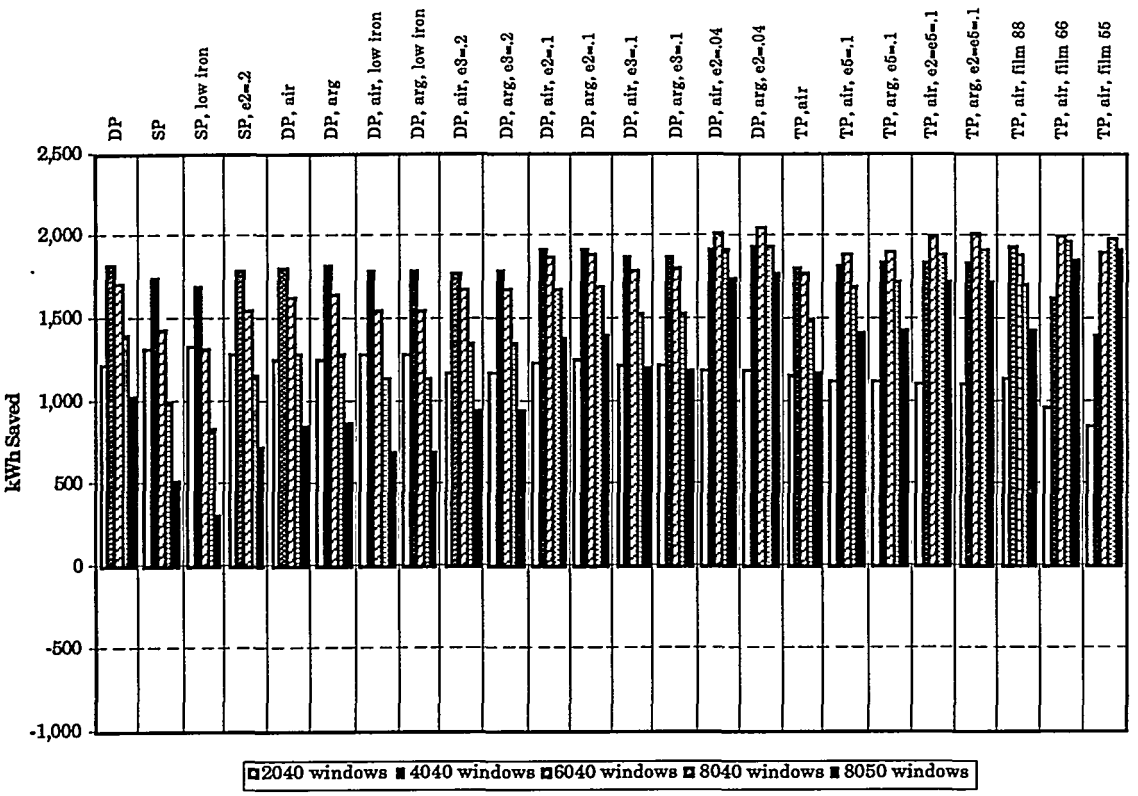


Figure 77, Phoenix, AZ Vinyl frame windows and kWh saved over base case

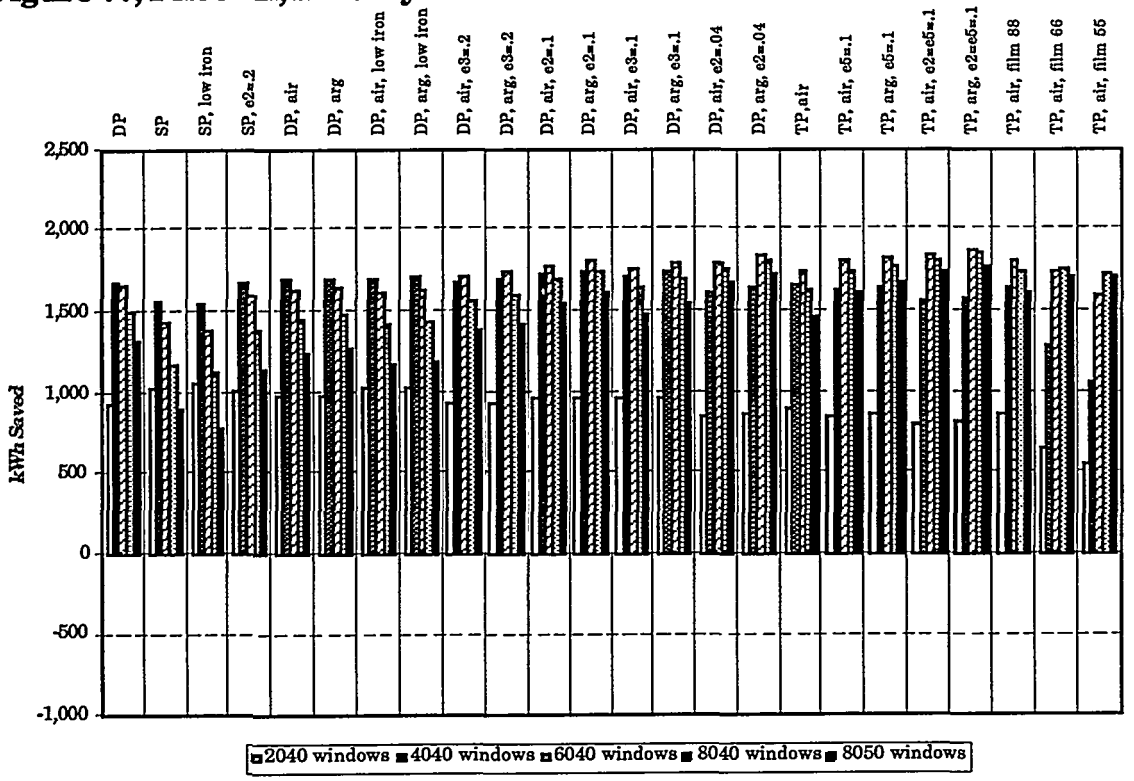


Figure 78, Bakersfield, CA Aluminum frame and kWh saved over base case

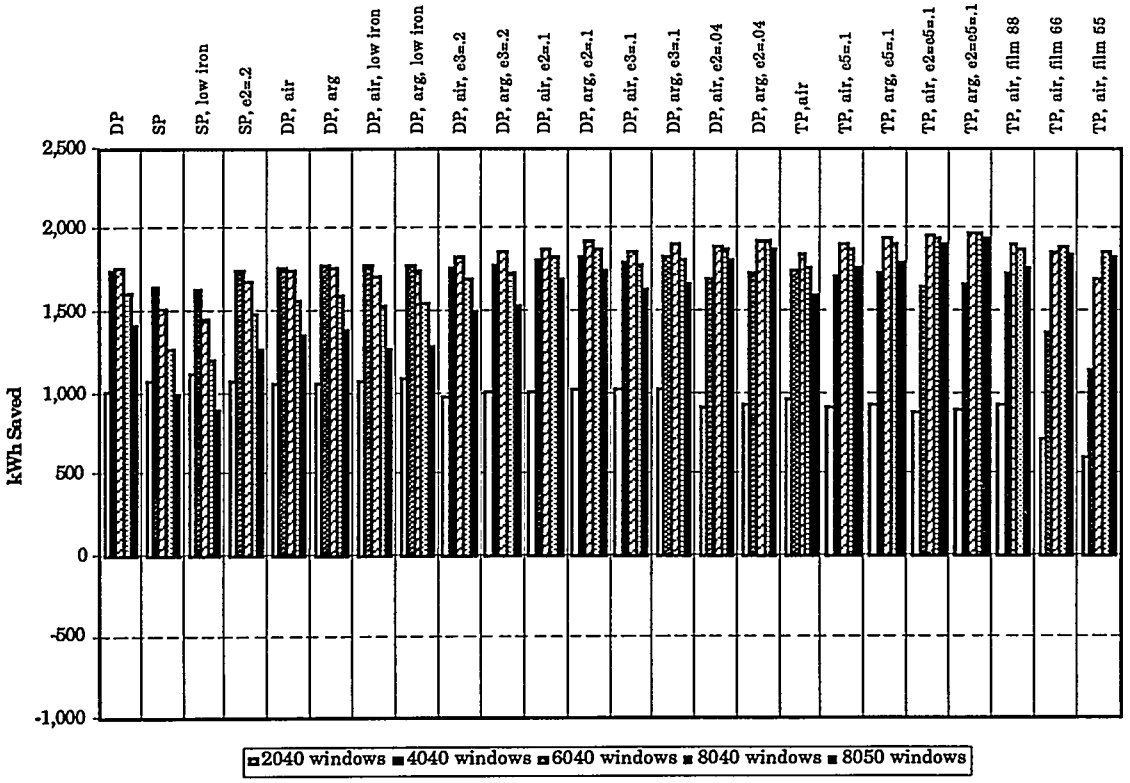


Figure 79, Bakersfield, CA Vinyl frame windows and kWh saved over base case

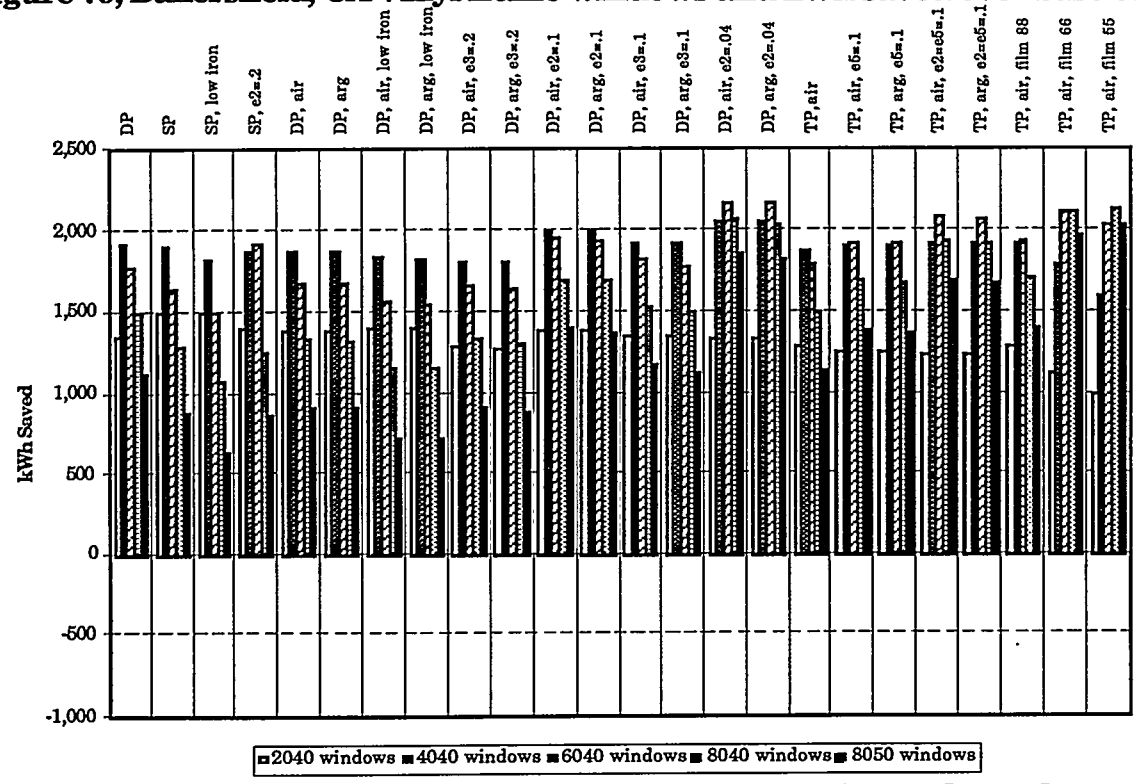


Figure 80, Miami, FL Aluminum frame windows and kWh saved over base case

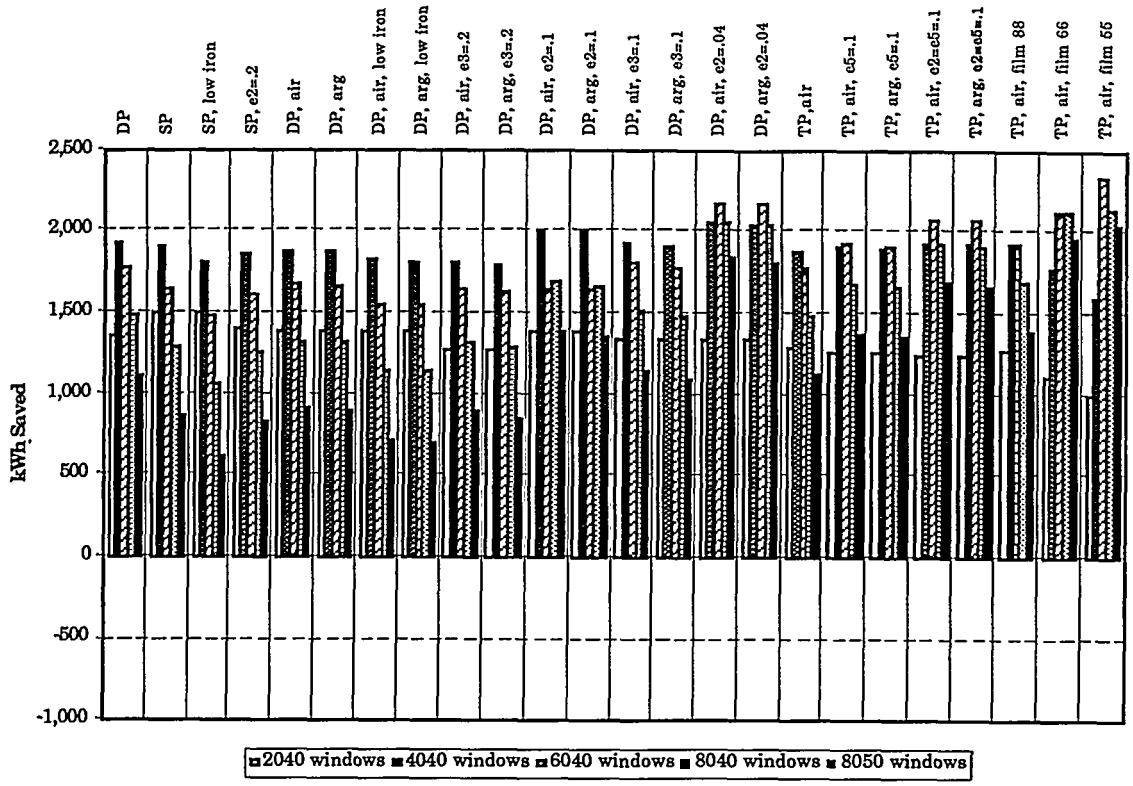


Figure 81, Miami, FL Vinyl frame windows and kWh saved over base case

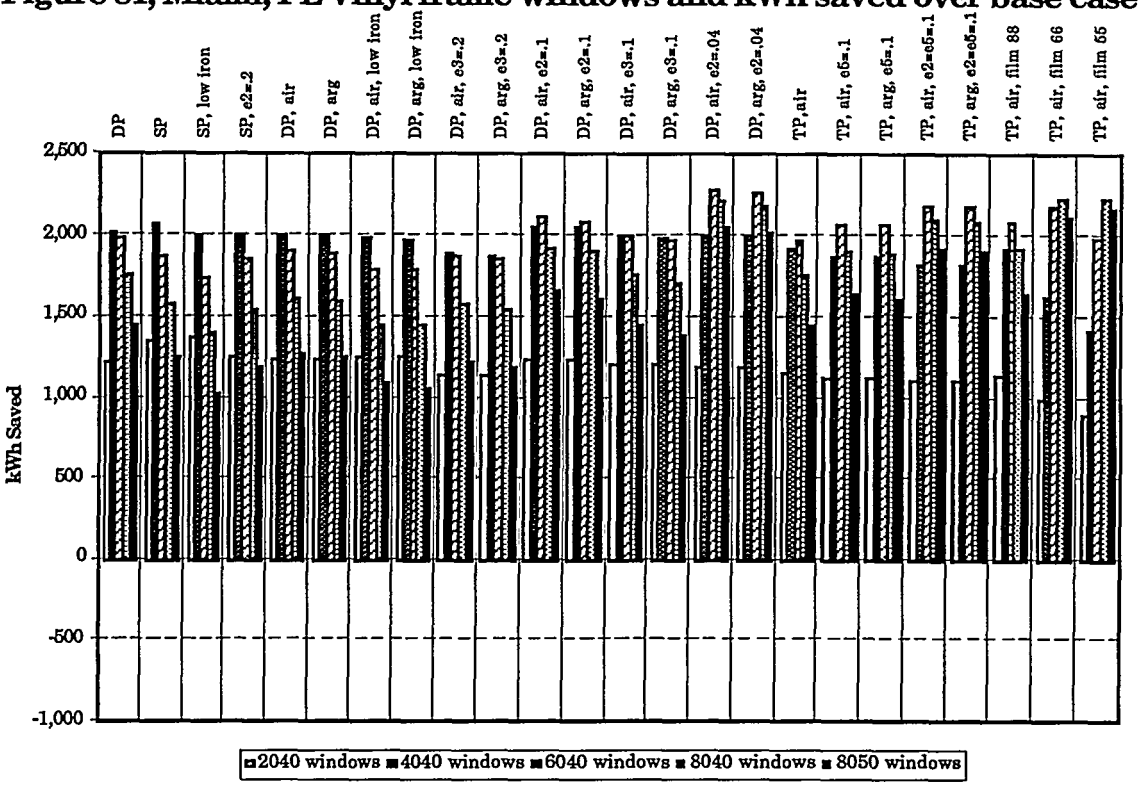


Figure 82, Honolulu, HI Aluminum frame and kWh saved over base case

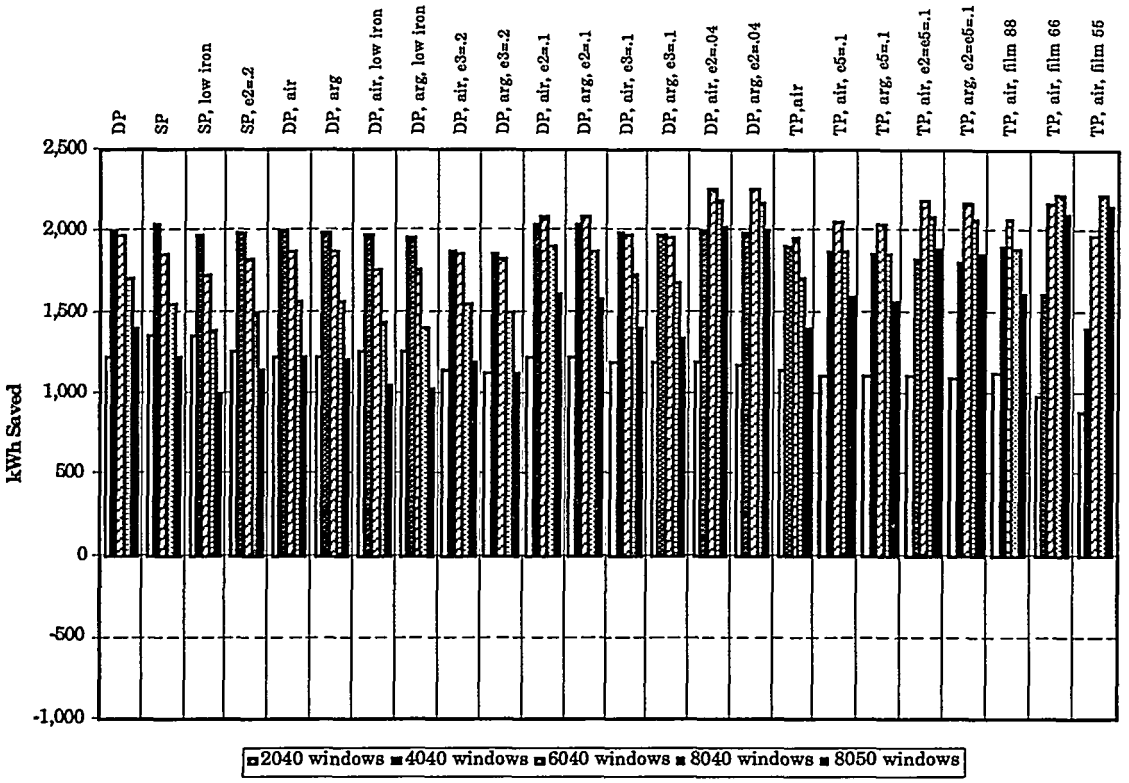


Figure 83, Honolulu, HI Vinyl frame windows and kWh saved over base case

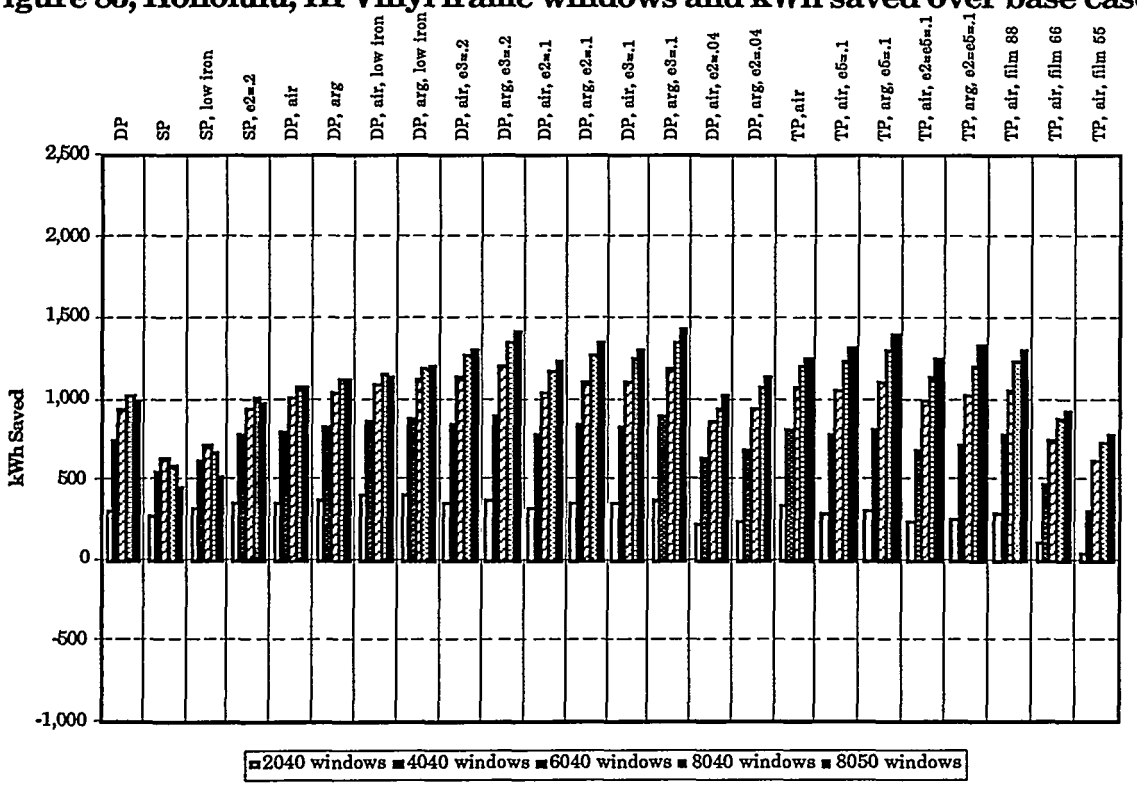


Figure 84, Astoria, OR Aluminum frame windows and kWh saved over base case

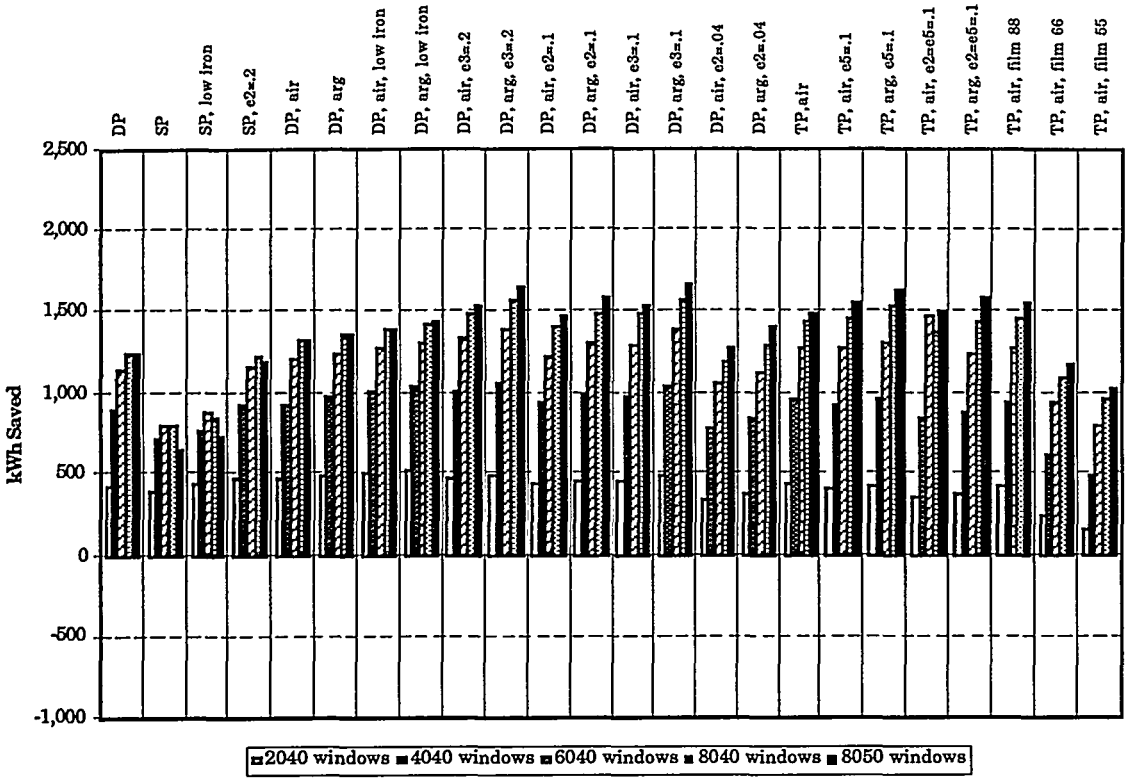


Figure 85, Astoria, OR Vinyl frame windows and kWh saved over base case

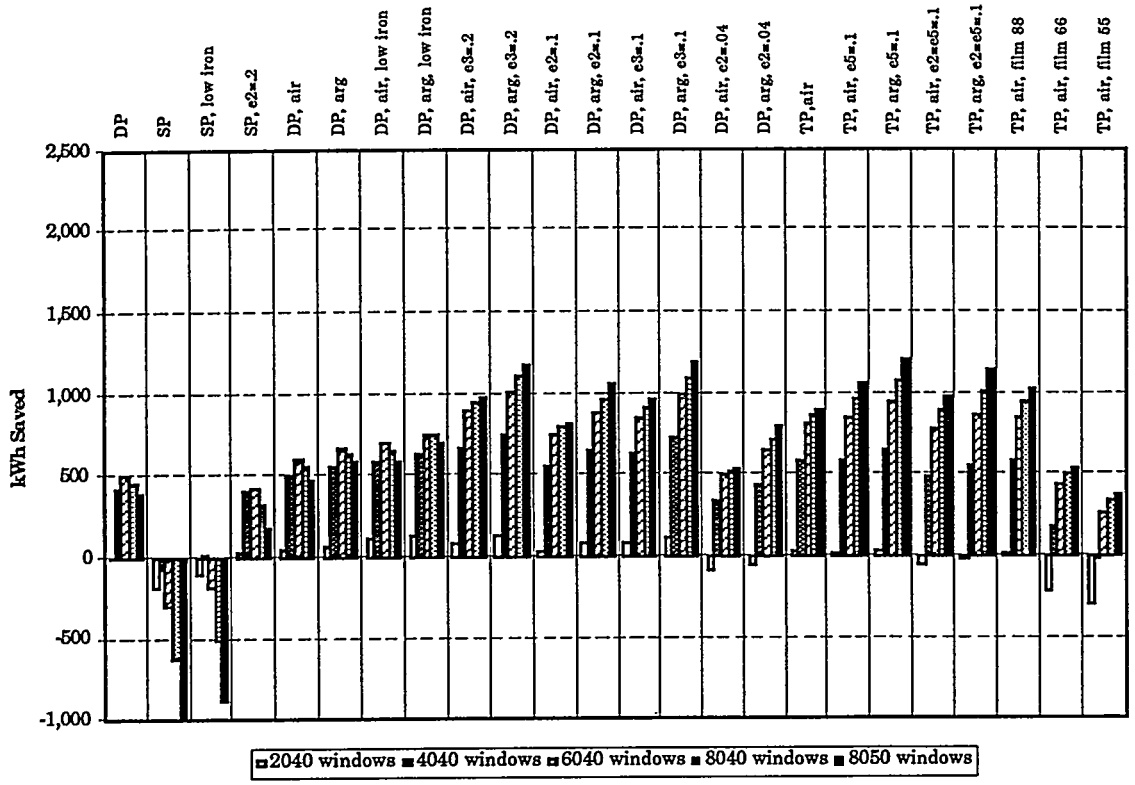


Figure 86, Spokane, WA Aluminum frame windows and kWh saved over base case

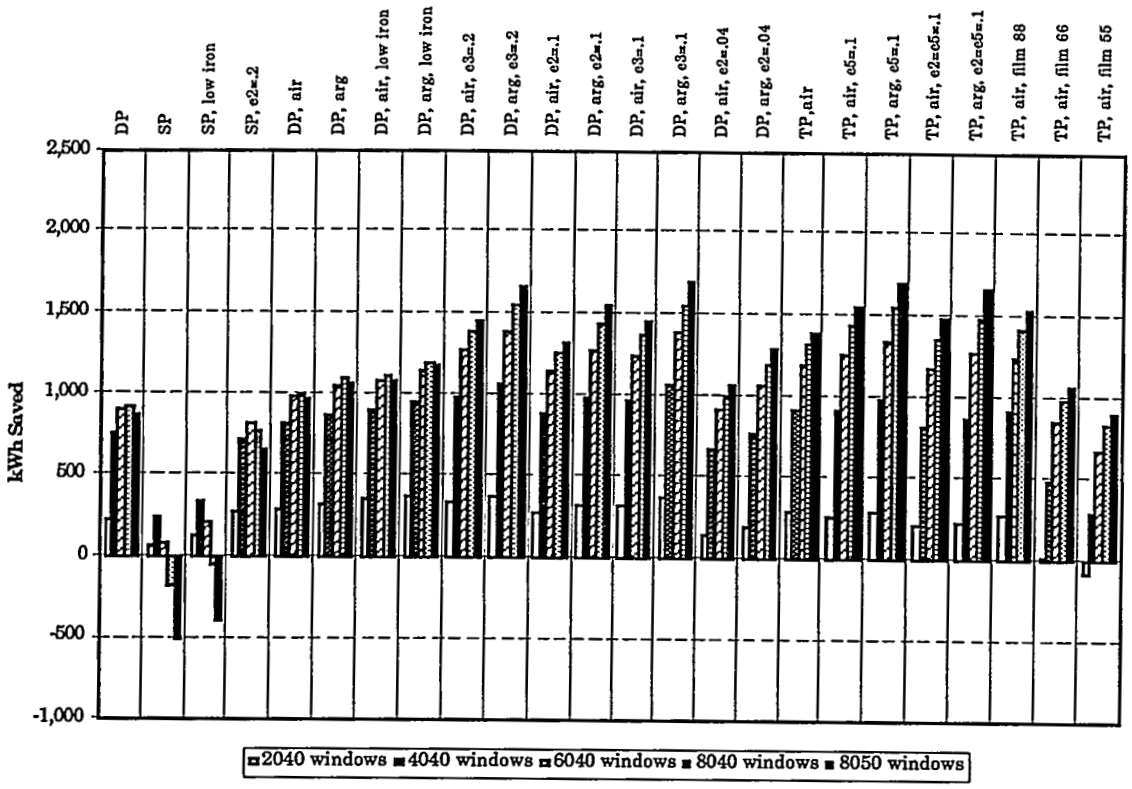


Figure 87, Spokane, WA Vinyl frame windows and kWh saved over base case

Conclusions

In Fairbanks, Alaska the high heating load of the building over compensates for the more day lighting and solar gain from windows as they get larger. Generally there is an increase in energy consumption as the window area is increased. Some exceptions are for low e, argon filled, vinyl windows where it can be seen that increasing the size does not increase the energy consumption. The only windows that cause the parametric to consume less energy than the base case is the triple pane 6040 (or larger) vinyl framed argon filled window with double low e coatings. The best performing window that cause the parametric to consume less energy than the base case is the triple pane 8050 vinyl framed argon filled window with double low e coatings of 0.1. It has a 158 kWh annual savings over the base case.

In Phoenix Arizona increasing the window area over the base case is a benefit. Depending on the window glazing type the optimum size is either a 4040, 6040 or 8040. Generally vinyl frame windows have a better performance than aluminum frame windows and argon filled windows have a better performance than air

filled windows. The best performing window that cause the parametric to consume less energy than the base case is the double pane 6040 vinyl framed argon filled window with low e coating of 0.04. It has a 2,046 kWh annual savings over the base case.

In Bakersfield, California, increasing the window area over the base case is a benefit. Depending on the window glazing type the optimum size is either a 4040, 6040 or 8040. Generally vinyl frame windows have a better performance than aluminum frame windows and argon filled windows have a better performance than air filled windows. The best performing window that cause the parametric to consume less energy than the base case is the triple pane 8040 vinyl framed argon filled window with double low e coatings of 0.1. It has a 1,978 kWh annual savings over the base case.

In Miami, Florida, increasing the window area over the base case is a benefit. Depending on the window glazing type the optimum size is either a 4040, 6040 or 8040. The optimum frame type for a given window size and glazing type varies. In some cases the aluminum frame causes less energy consumption of the building and in other cases the vinyl frame does. Generally air filled windows have a little better performance than argon filled windows. The best performing window that cause the parametric to consume less energy than the base case is the triple pane 6040 vinyl framed air filled window with film 55 in the center. It has a 2,336 kWh annual savings over the base case.

In Honolulu, Hawaii, increasing the window area over the base case is a benefit. Depending on the window glazing type the optimum size is either a 4040, 6040 or 8040. The optimum frame type for a given window size and glazing type varies. In some cases the aluminum frame causes less energy consumption of the building and in other cases the vinyl frame does. Generally air filled windows have a little better performance than argon filled windows. The best performing window that cause the parametric to consume less energy than the base case is the double pane 6040 aluminum framed air filled window with low e coating of 0.04. It has a 2,268 kWh annual savings over the base case.

In Astoria, Oregon, increasing the window area over the base case is a benefit. Depending on the window glazing type the optimum size is either a 6040, 8040 or 8050. Generally vinyl frame windows have a better performance than aluminum frame windows and argon filled windows have a better performance than air filled windows. The best performing window that cause the parametric to consume less energy than the base case is the double pane 8050 vinyl framed argon filled window with low e coating of 0.1. It has a1,659 kWh annual savings over the base case.

In Spokane, Washington, generally increasing the window area over the base case is a benefit, except for some single pane windows and small low e windows. Depending on the window glazing type the optimum size is either a 4040, 6040, 8040, or 8050. Generally vinyl frame windows have a better performance than aluminum frame windows and argon filled windows have a better performance than air filled windows. The best performing window that cause the parametric to consume less energy than the base case is the triple pane 8050 vinyl framed argon filled window with low e coating of 0.1. It has a 1,703 kWh annual savings over the base case.

2.1.4.12 Radiant barrier modeling in DOE 2.1E

Radiant barrier was previously modeled by adjusting the absorptance of the exterior surface for which the radiant barrier was applied. The absorptances used were .8 for a wall without a radiant barrier and .05 for a wall with a 5% reflective radiant barrier such as KOOL-PLY. The absorptances used were .82 for a roof without a radiant barrier and .05 for a wall with a 5% reflective radiant barrier such as KOOL-PLY.

After talking to Danny Parker he suggested instead to adjust the inside film R-value like in ASHRAE 1989 Fundamentals, page 22.2, Table 1, but you must interpolate for slopes different than 45 degrees and you must judge which one to use for the heat flow consideration (heat flow up or down), since only one value is used year round.

What I choose to do was a combination of both. I changed the absorptance of the wall from .8 to be a color halfway between white (.25) and black (.9) which is .57. For hot climates the buildings would probably tend to be light in color but over time the absorptance would change as the color changes and dirt builds up on the surface, so halfway between seems reasonable for a conservative guess of a light colored surface. I changed the absorptance of the roof from .82 to be .65 (uncolored concrete) a little more than the halfway point (.57) since I would expect a more horizontal surface to get dirtier. Picking a point halfway between seems to be a common practice for estimating long-term energy performance, per my conversation with Danny Parker, it is true that new clean surfaces will perform better.

Next to address the radiant barrier I looked at adjusting the inside film coefficient. Rather than changing the inside film coefficient I chose to adjust the R-value of the insulation based on the effects of the radiant barrier. Again some assumptions had to be made about the heat flow direction, the mean temperature, and the temperature difference. For the case when insulation filled the cavity and a radiant barrier was added such as R11 in a 2x4 wall I added the difference between the 0.05 emittance R-value for the wall (1.70) and the nonreflective, 0.90 emittance, R-value for the wall (.68), thus I added 1.02 to the R-value of the wall (data from ASHRAE Fundamentals 1997 page 24.2, Table 1). For the case where there was an air cavity in the wall I used the data from ASHRAE Fundamentals 1997 page 24.3, Table 3, with the assumption that the mean temperature was 50°F and the temperature difference was 30°F to add R2.46 to the R7 wall cavity and R2.55 to the no insulation in the cavity insulation values. For the roof insulation I used the same table and temperature assumptions but assumed a downward heat flow and that the roof is basically horizontal. Thus I added R8.17 to each of the roof cavity insulation values up to R21 insulated roofs.
Table from DOE Manual

Material	Absorptance	Paint	Absorptance
Aluminum, polished reflector sheet	0.12	Aluminum paint	0.40
Asphalt pavement, weathered	0.82	Black, flat	0.95
Brick, buff, light	0.55	Black, lacquer	0.92
Brick, red	0.88	Black, oil	0.90
Brick, Stafford blue	0.89	Black, optical flat	0.98
Brick, white glazed	0.25	Blue, azure lacquer	0.88
Cement, uncolored asbestos	0.75	Blue, dark	0.91
Cement, white asbestos	0.61	Blue, medium	0.51
Concrete, black	0.91	Blue-gray, dark	0.88
Concrete, brown	0.85	Brown, dark brown	0.88
Concrete, uncolored	0.65	Brown lacquer	0.79
Film, Mylar aluminized	0.10	Brown, medium	0.84
Felt, bituminous	0.88	Brown, medium light	0.80
Felt, bituminous, aluminized	0.40	Gray, dark	0.91
Gravel	0.29	Gray, light oil	0.75
Iron, white-on-galvanized	0.26	Green, lacquer	0.79
Lab vapor deposited coatings	0.02	Green, lacquer, dark	0.88
Marble, white	0.58	Green, light	0.47
Roof, white built-up	0.50	Green, medium dull	0.59
Roofing, green	0.86	Green, medium Kelly	0.51
Slate, blue-gray	0.87	Olive, dark drab	0.89
Tin surface	0.05	Orange, medium	0.58
Wood, smooth	0.78	Red, oil	0.74
		Rust, medium	0.78
		Silver	0.25
		White, gloss	0.25
		White, lacquer	0.21
		White, semi-gloss	0.30
		Yellow	0.57

Figure 88, Solar Absorptance for Various Exterior Surfaces (Clean)

Site source conversion

"Where should such a comparison be made – at the building site or at some point beyond? The difficulty occurs because different energy forms, in their paths of

distribution and conversion from energy resources in the earth to their actual forms of end use in the building, suffer their major burdens of conversional inefficiency at different points along those paths."

"For instance, natural gas is delivered to the site in virtually the same form as when taken out of the ground, suffering only minor burdens en-route, but in its conversion to a thermal form of energy (hot water or steam) normally distributed in a building for heating purposes, the inefficiency of conversion occurs within the building – on site. Electricity, on the other hand, is used within a building as delivered tot he site, and since there is no conversion involved, it is virtually 100% efficient – on site. The inefficiency of electricity proper – occurs at a power generating station – off site. Therefore, if overall building energy uses are compared on site, electricity is favored because it is 100% efficient, while fossil fuels must carry their onsite burden on conversion. Thus, the need arose for accounting for what happens beyond the siteline."

"An alternative point of comparison was therefore suggested as being at a resource's point of extraction (i.e., mine-mouth, wellhead). However, it was pointed out that even this would not be strictly correct, particularly if all resources were described in equivalent energy units, because each resource has characteristics that impart to it advantages or drawback, even though equivalent amounts of energy are being generated."

"For instance, a given quantity of electricity could be generated by domestic oil, by imported oil, by coal, or by nuclear fuel (uranium). The characteristics of the electricity generated by any resource would be identical; yet, should the value or worth of the energy resource used in each case be considered identical as well? Should imported oil be regarded as equivalent to domestic ail? should coal and nuclear fuel be regarded equally desirable as energy sources?"

"It is obvious that, because of certain differing societal characteristics (availability, environmental concerns, national interest implications, and so forth), these resources cannot be considered identical. It is also obvious that these issues are of an intangible and subjective -- even political – nature. It can be

argued, however, that a true and valid comparison between energy sources should take these broader societal issues into account in some way. Though not easily quantifiable, they are real issuers just the same."

We used DOE 2.1E's default values of 33.33, 100, and 100 percent for its source site efficiency values for electricity, natural gas, and fuel oil.

2.1.5 Model Tests

The window location and size in the building was evaluated for cross ventilation using the program Quick and Simple. The illumination on vertical surfaces such as chalk boards and tack boards in the classrooms were evaluated using the program Radiance.

2.1.5.1 Classroom Air Distribution

Objective

The objective of this task was to determine if there will be adequate air distribution from cross-ventilation to supply fresh air and remove heat.

Methodology

Quick 'n' Simple (a fluid dynamics simulation program) was used as the primary air distribution evaluation tool. Output consisted of velocity vector and velocity contour diagrams such as those shown below:

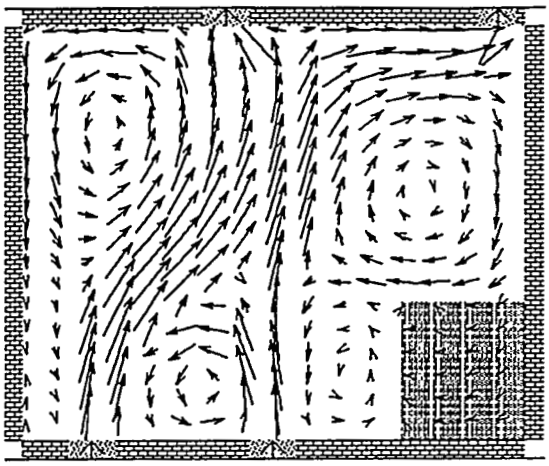


Figure 89, Velocity Vectors
(Length of arrow indicates relative air velocity.

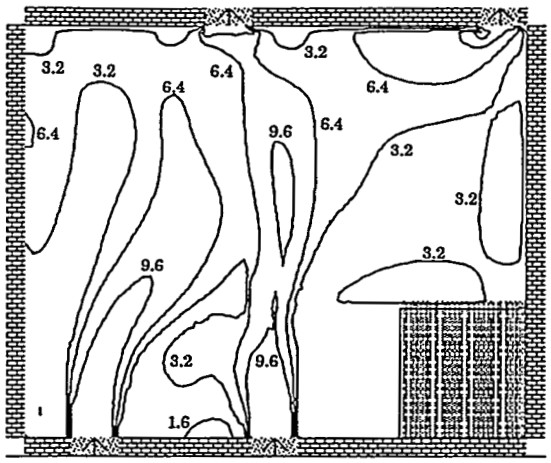


Figure 90, Equal Velocity Contours

Diagrams of this type were first produced for two 6' by 4' window (6040) layout possibilities as determined in Task: Illuminance on Vertical Surfaces: 1) South windows 2' from end wall and bathroom wall and one north window 8' from end wall 2) South windows 2' from end wall and bathroom wall and two north windows (3' by 4') located 4'and 16' from end wall. These two window location possibilities were simulated with NW, N, NE, SE, S, and SW winds each run with the door open and closed.

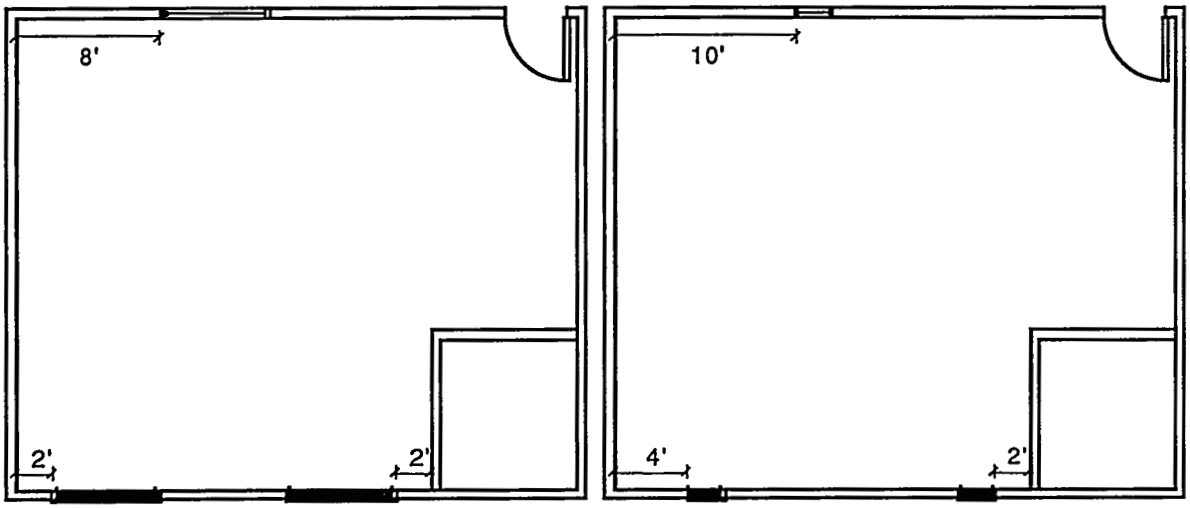


Figure 91, The Two Initial Window Layouts Considered

Runs were then done for the 2' by 4' (2040), 4' by 4' (4040), and 8' by 4' (8040) window layouts determined in Task: Illuminance on Vertical Surfaces for

SW, S, and SE winds with door open. These runs were used to determine if the mixing profiles changed significantly with different window sizes.

Results

In the initial 6040 runs, one north window always produced contour lines that indicated air speeds in all spaces within the classroom of at least 7% of the speed through the windows. With two north windows and the door closed, air movement in the area between the door and bathroom sometimes appeared stagnant with air speeds below 5% of window air speeds. The air movement was improved in this area when the door was also utilized.

The 2040, 4040, and 8040 runs showed that the mixing profiles do not change much with window size. While the numbers vary (smaller windows reduce the air speed throughout the room) the mixing patterns are very similar and no stagnant areas are produced with the door open.

Conclusions

Using one north window produces better air distribution for both door situations and is therefore the preferred window layout from this task's point of view. Using two smaller windows is less desirable, but is acceptable if the door is also used for ventilation purposes.

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Open
South Wind, 180 fpm Through Windows

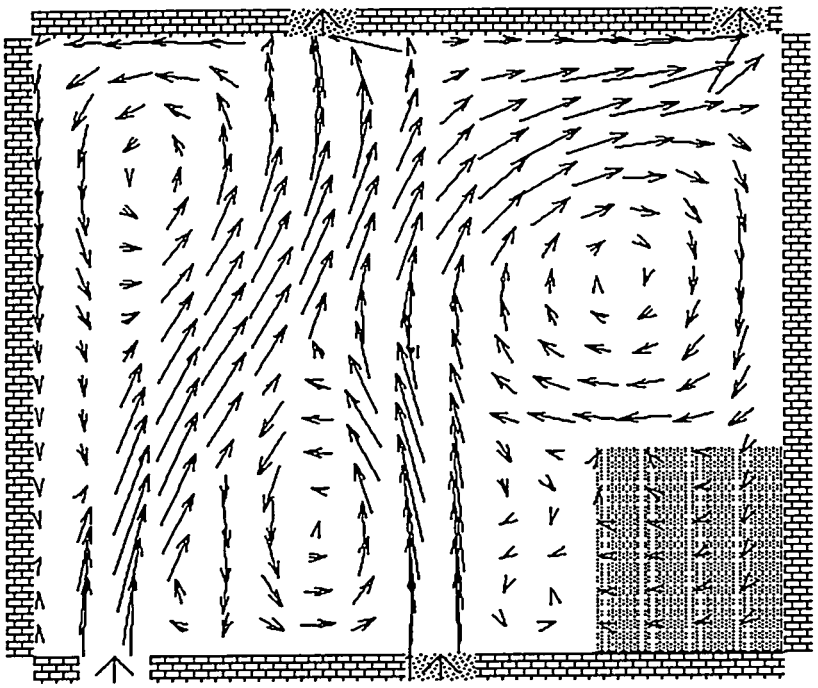


Figure 92, Velocity Vectors
(Length of arrow indicates relative air speed)

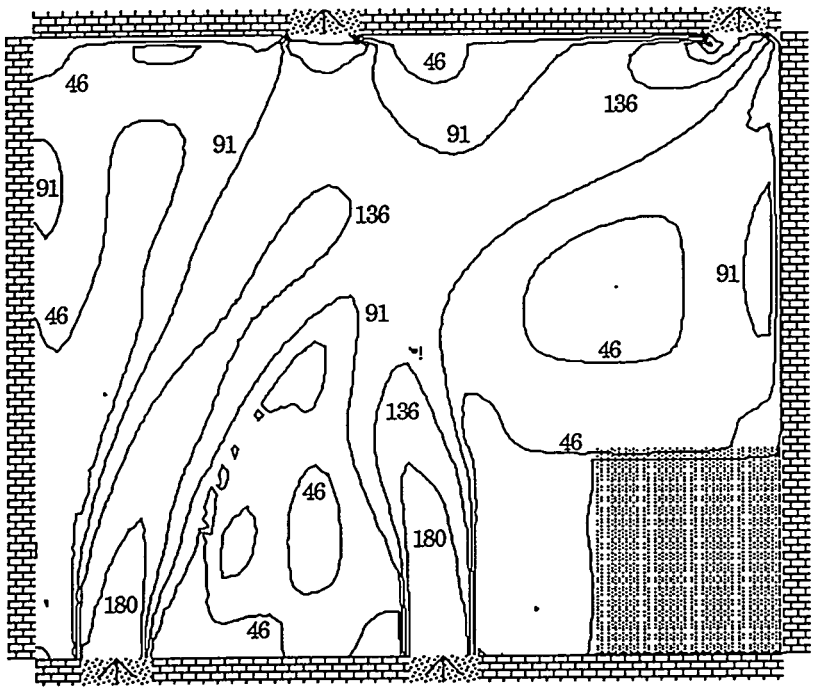


Figure 93, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Open
Southeast Wind, 180 fpm Through Windows

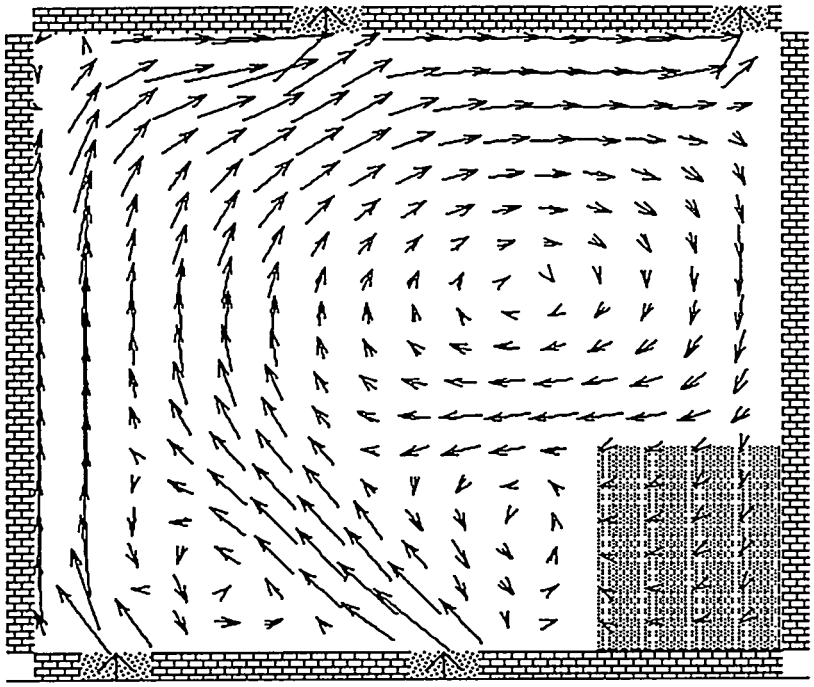


Figure 94, Velocity Vectors
(Length of arrow indicates relative air speed)

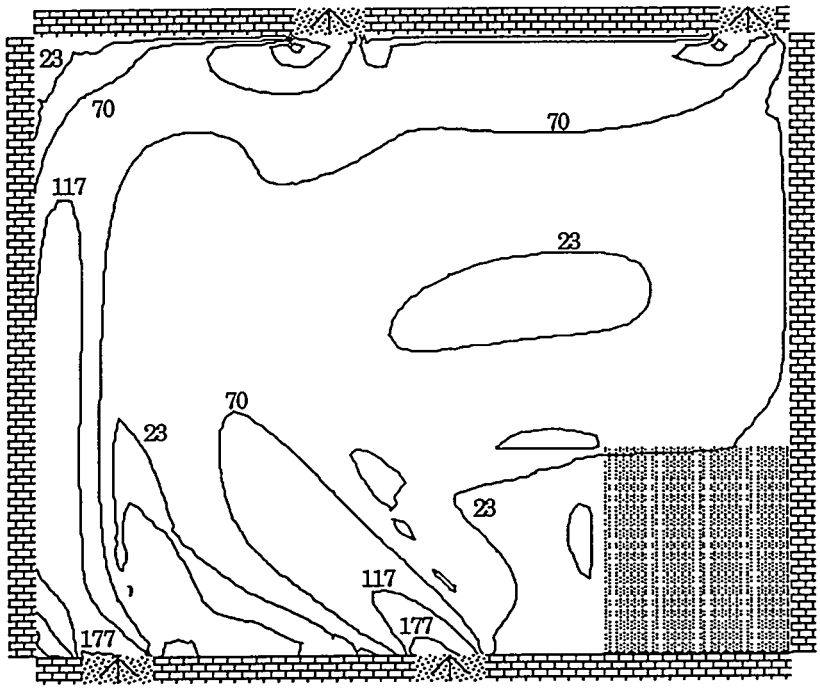


Figure 95, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Open
Northeast Wind, 180 fpm Through Windows

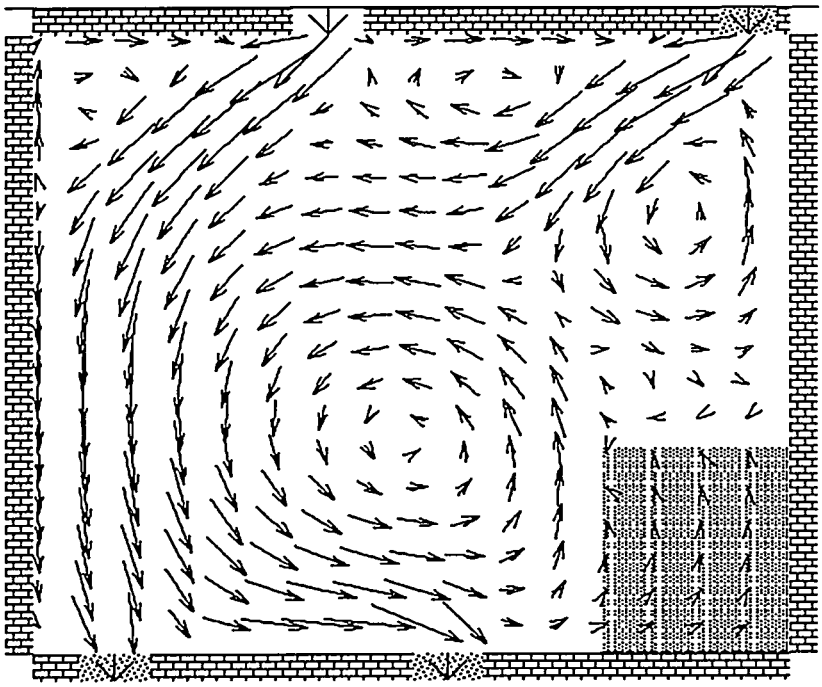


Figure 96, Velocity Vectors
(Length of arrow indicates relative air speed)

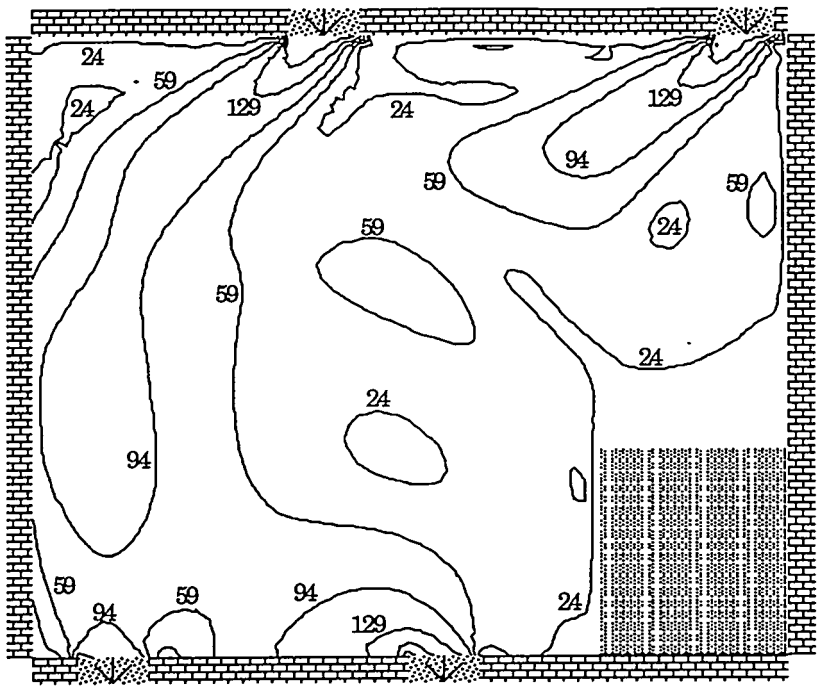


Figure 97, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Open
North Wind, 180 fpm Through Windows

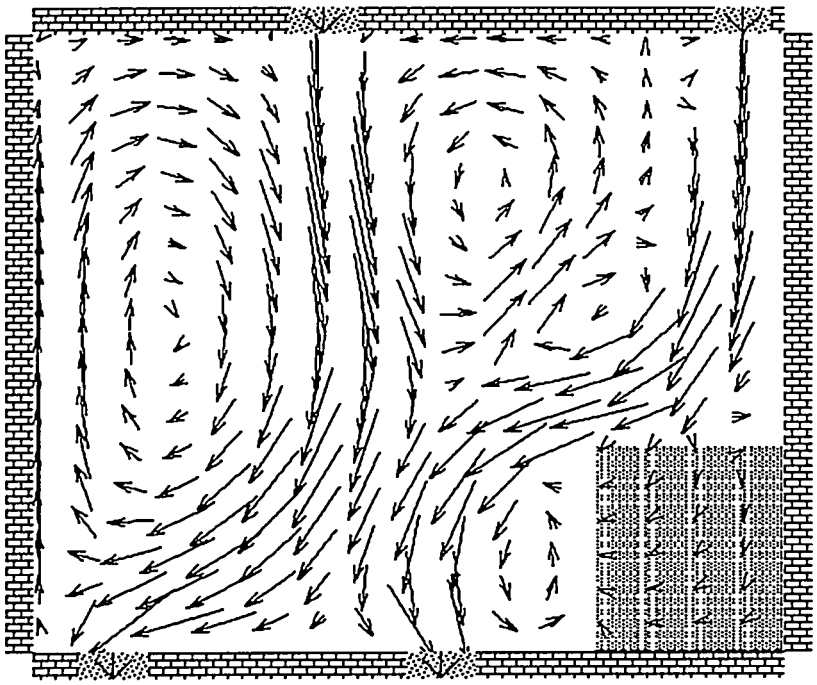


Figure 98, Velocity Vectors
(Length of arrow indicates relative air speed)

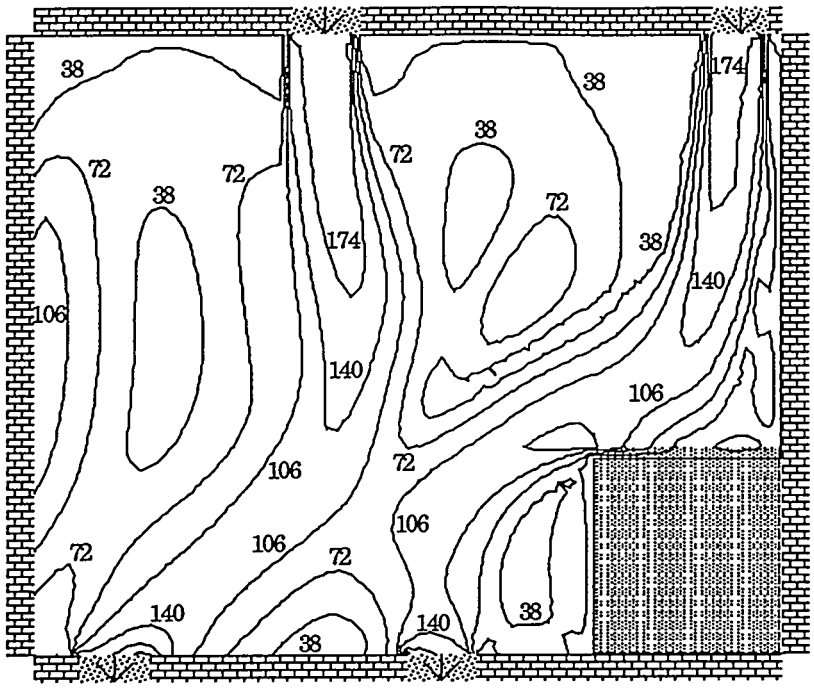


Figure 99, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Open
Northwest Wind, 180 fpm Through Windows

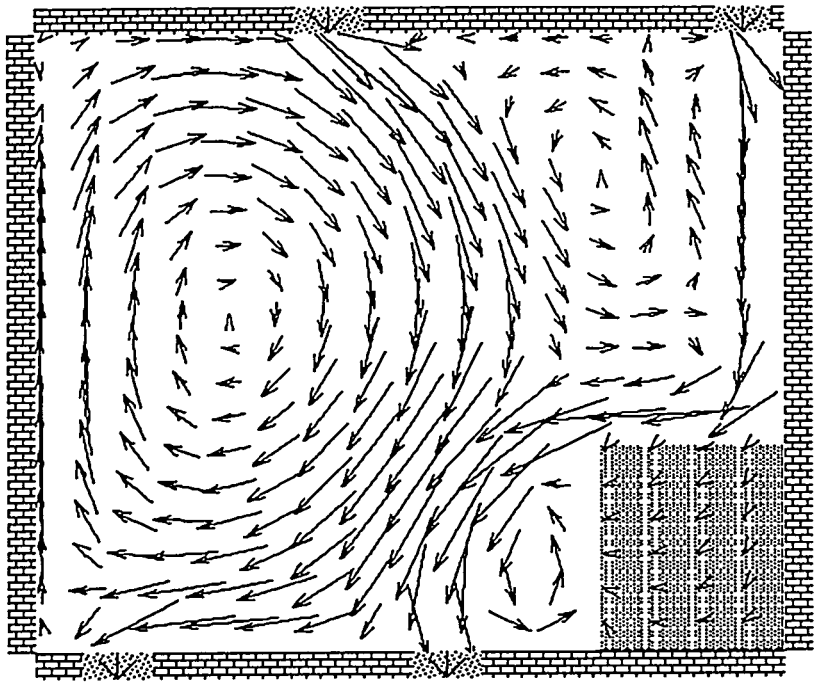


Figure 100, Velocity Vectors
(Length of arrow indicates relative air speed)

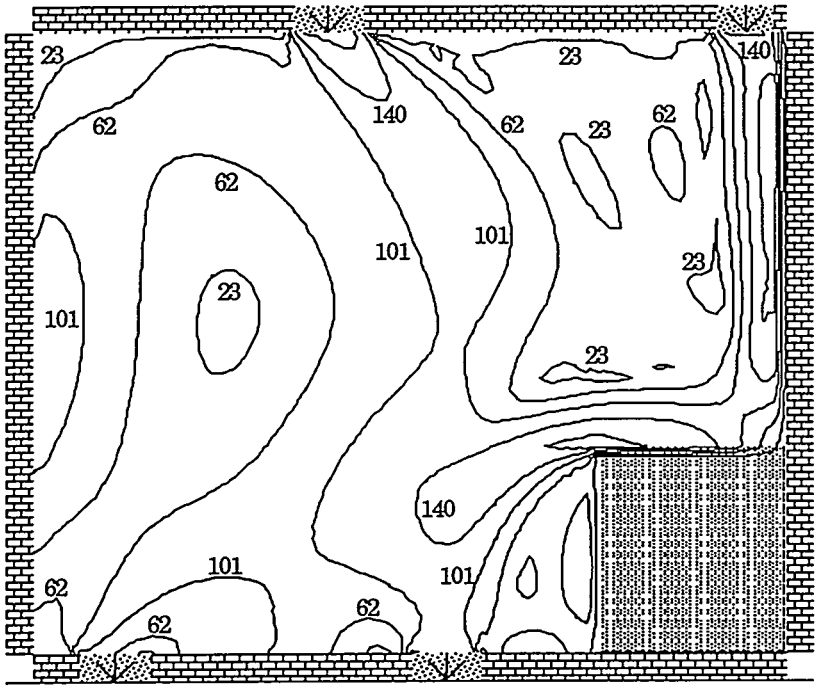


Figure 101, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Open
Southwest Wind, 180 fpm Through Windows

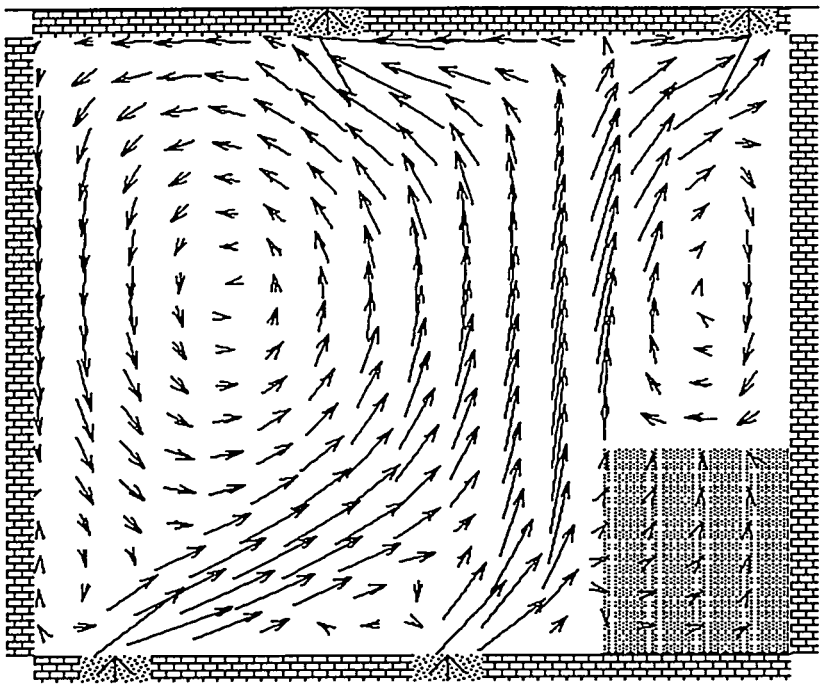


Figure 102, Velocity Vectors
(Length of arrow indicates relative air speed)

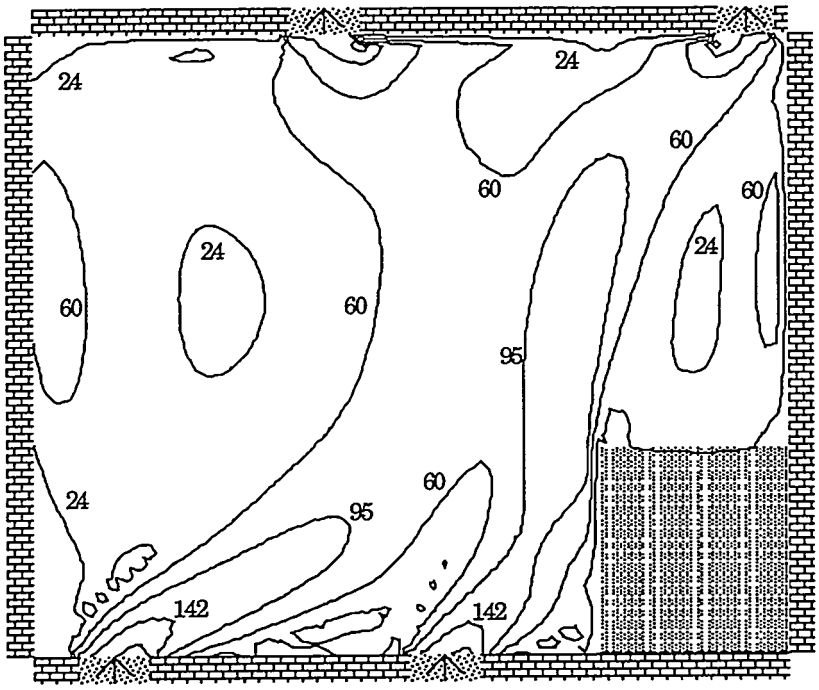


Figure 103, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Closed
South Wind, 180 fpm Through Windows

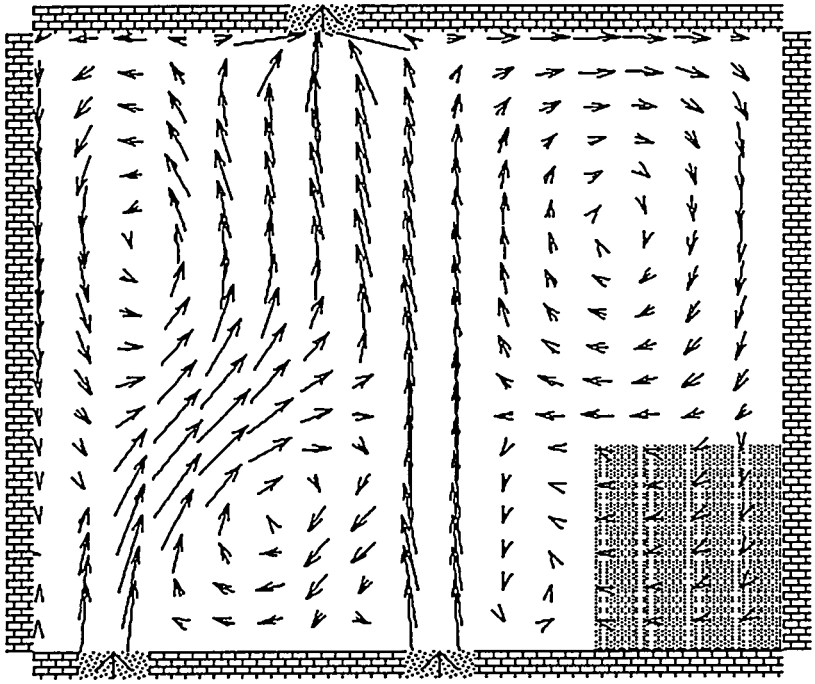


Figure 104, Velocity Vectors
(Length of arrow indicates relative air speed)

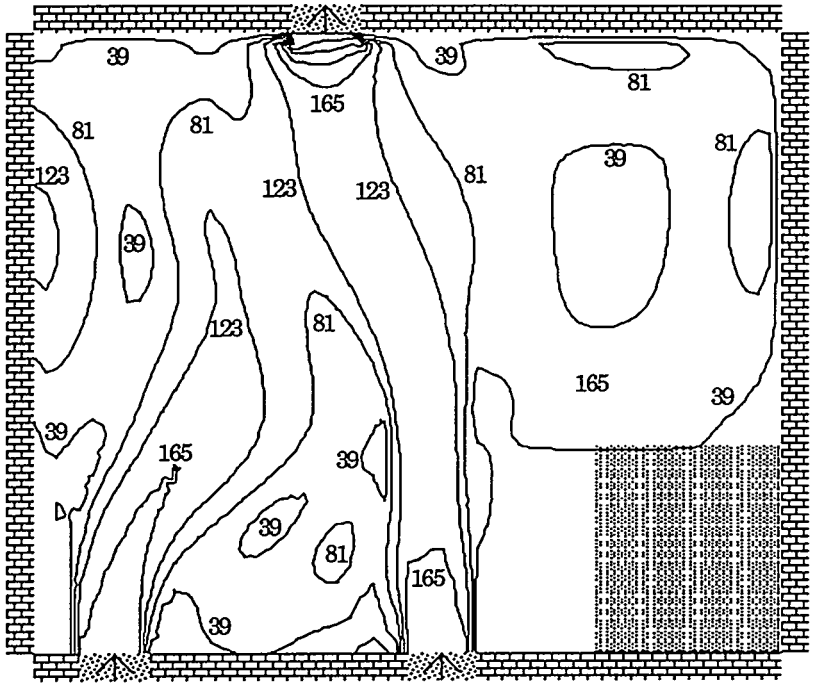


Figure 105, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Closed
South Wind, 180 fpm Through Windows

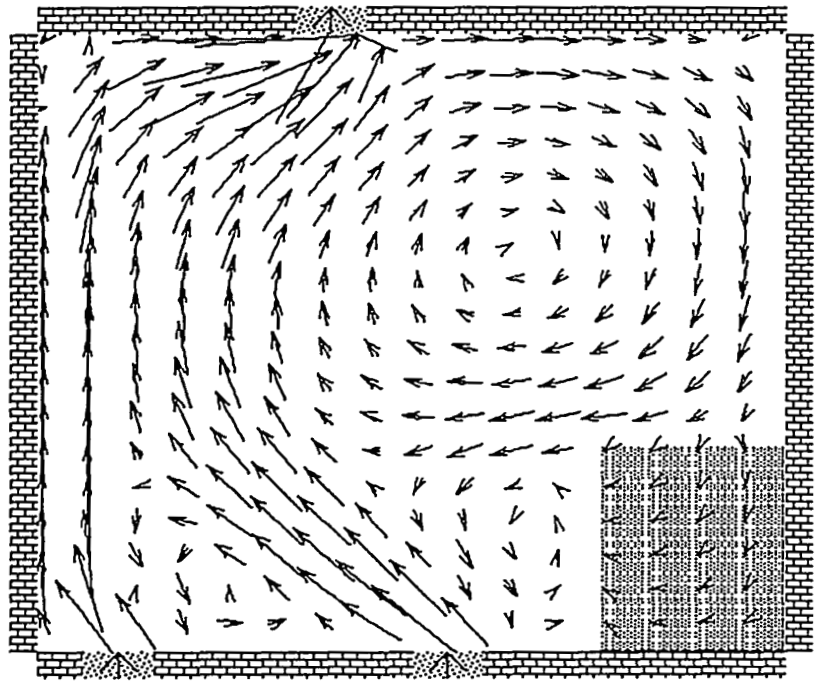


Figure 106, Velocity Vectors
(Length of arrow indicates relative air speed)

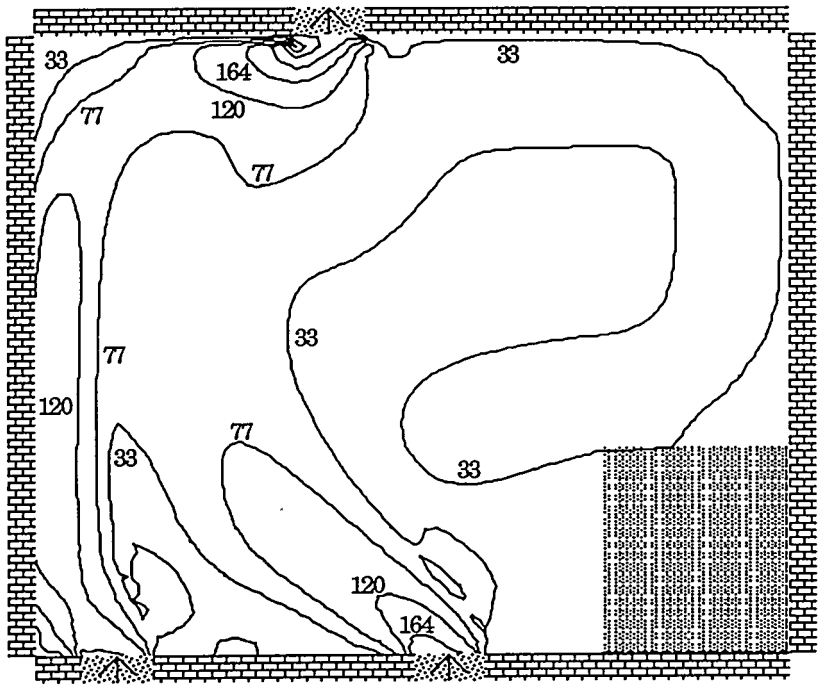


Figure 107, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Closed
Northeast Wind, 180 fpm Through Windows

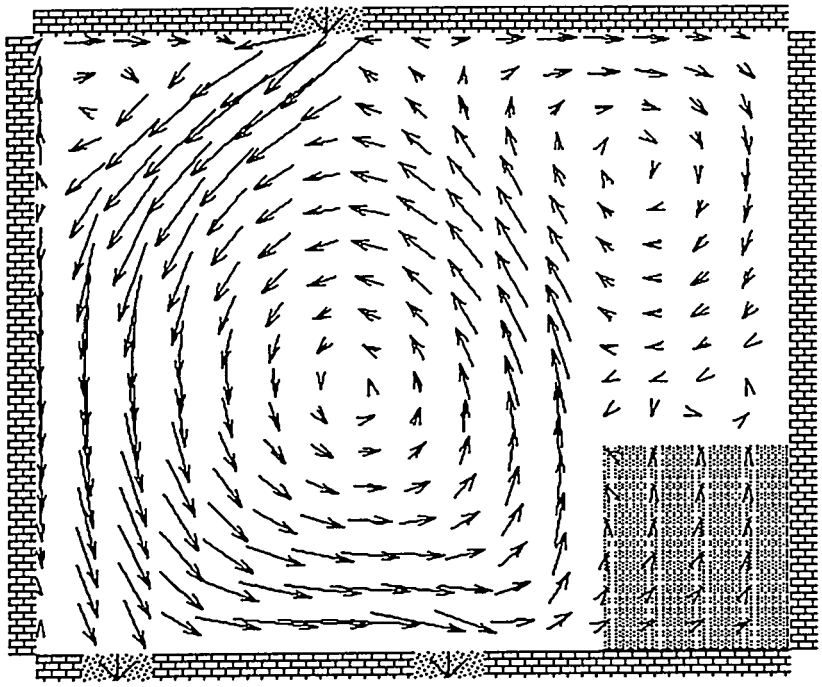


Figure 108, Velocity Vectors
(Length of arrow indicates relative air speed)

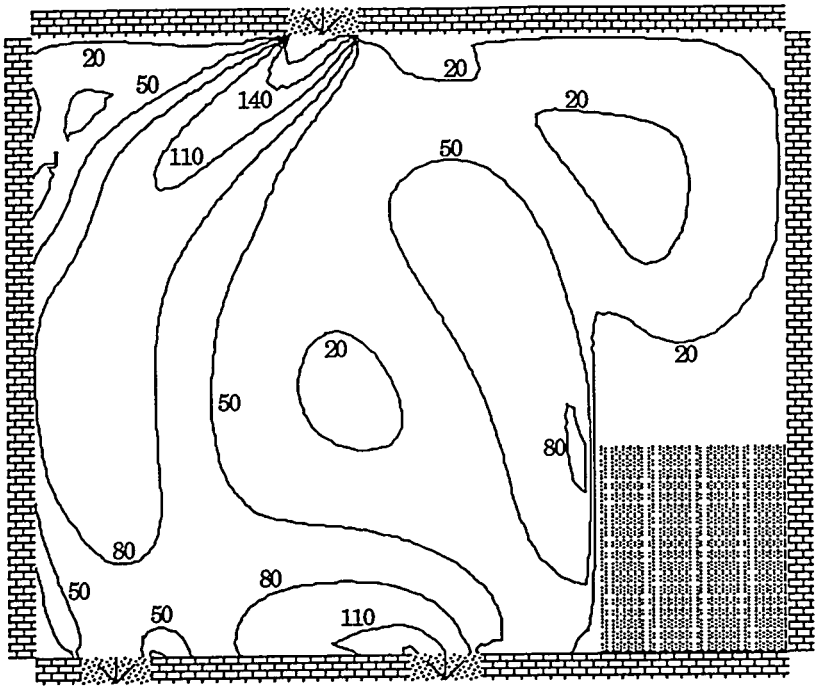


Figure 109, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Closed
North Wind, 180 fpm Through Windows

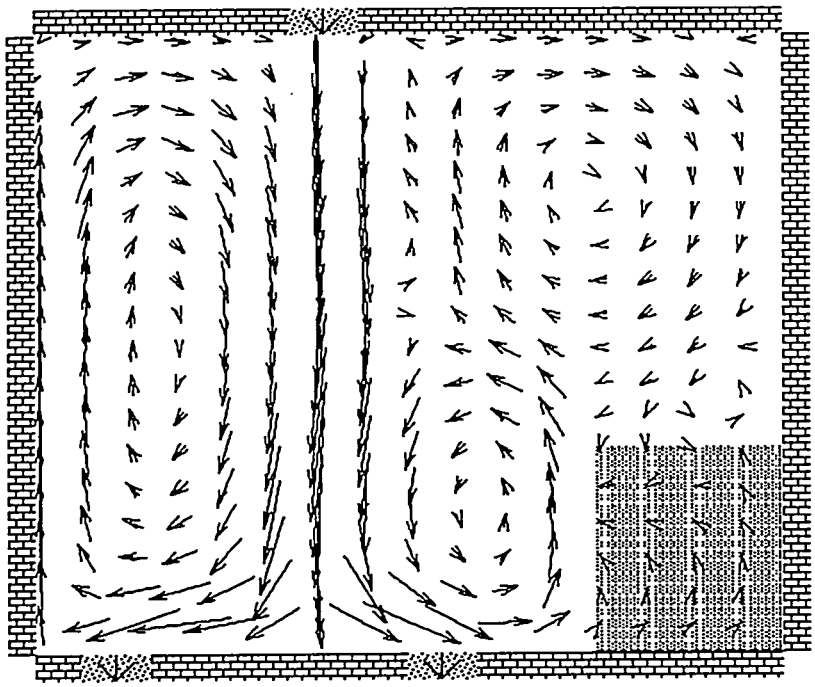


Figure 110, Velocity Vectors
(Length of arrow indicates relative air speed)

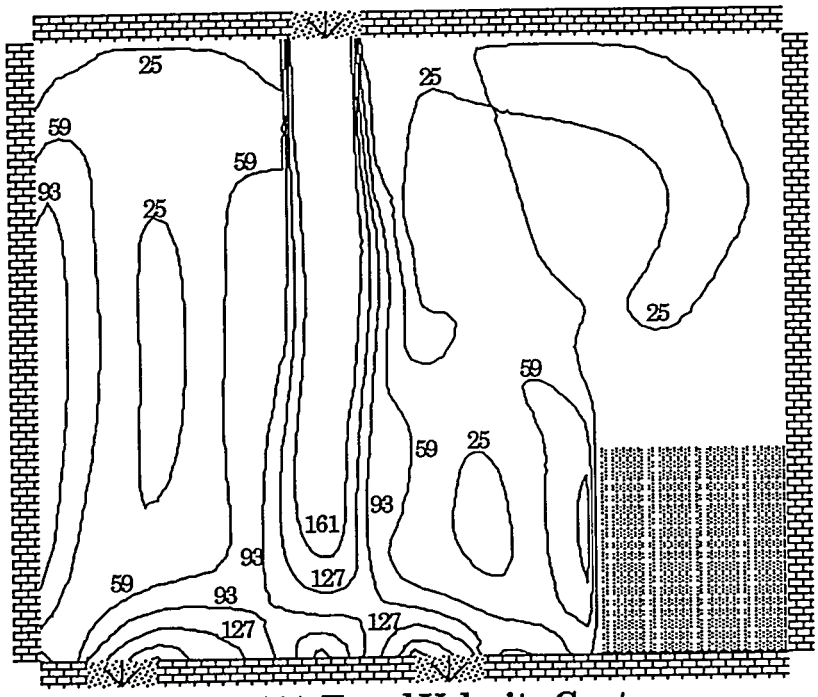


Figure 111, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Closed
Northwest Wind, 180 fpm Through Windows

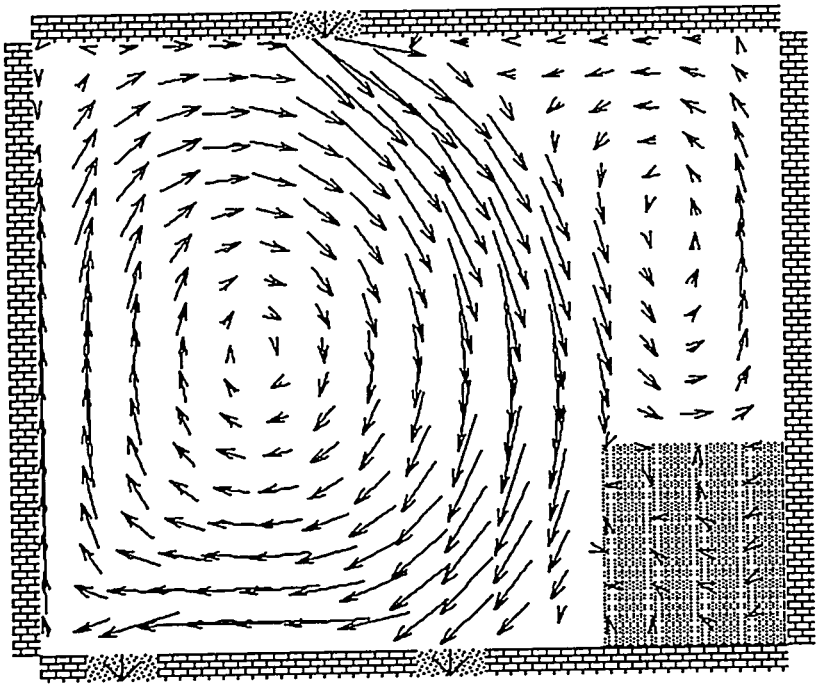


Figure 112, Velocity Vectors
(Length of arrow indicates relative air speed)

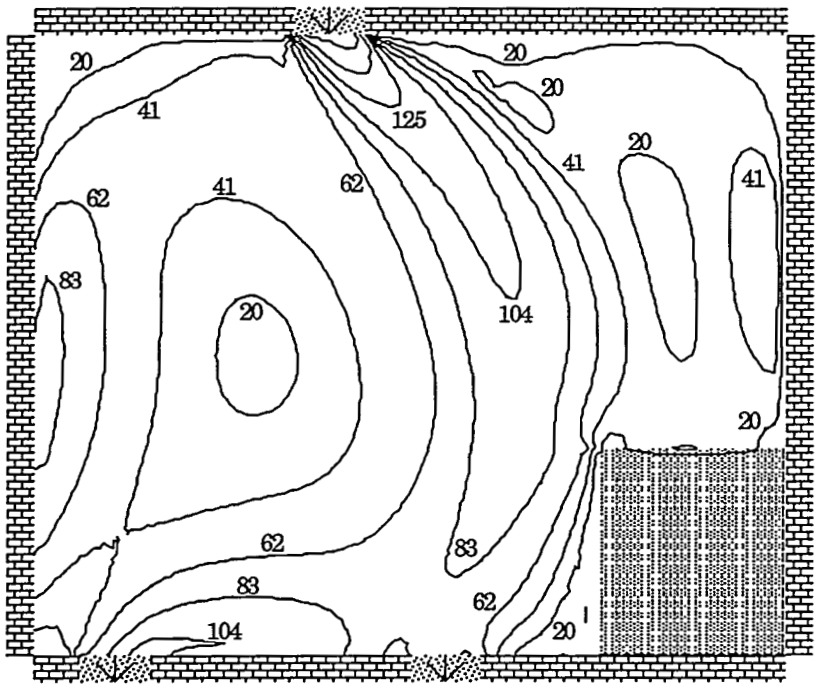


Figure 113, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
One North Window, South Windows 2' from Walls, Door Closed
Southwest Wind, 180 fpm Through Windows

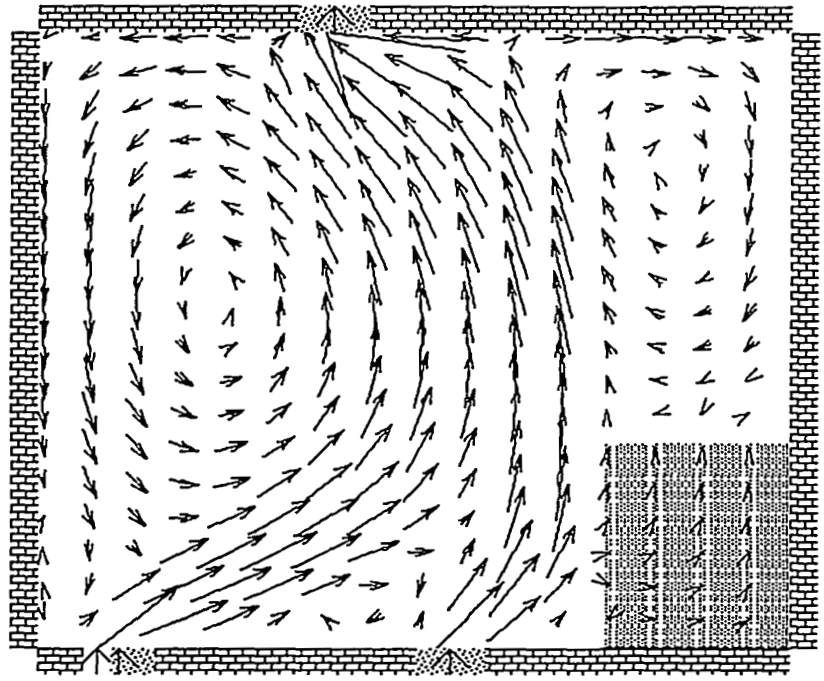


Figure 114, Velocity Vectors
(Length of arrow indicates relative air speed)

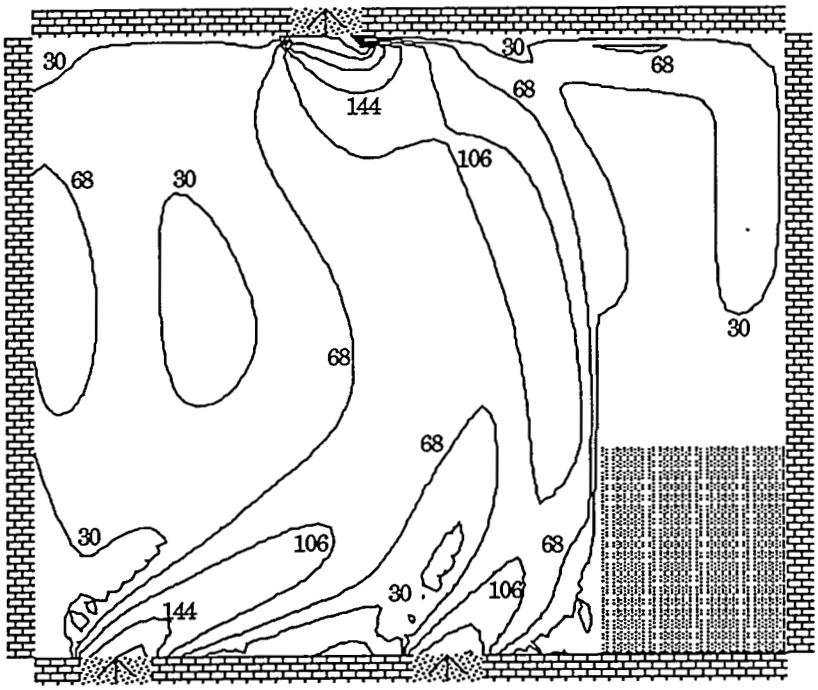


Figure 115, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Closed
South Wind, 180 fpm Through Windows

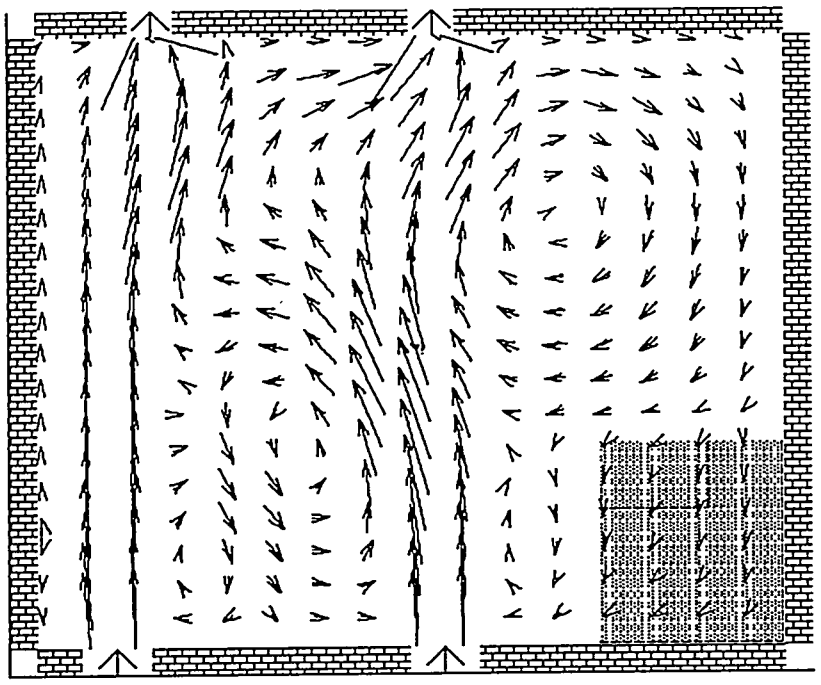


Figure 116, Velocity Vectors
(Length of arrow indicates relative air speed)

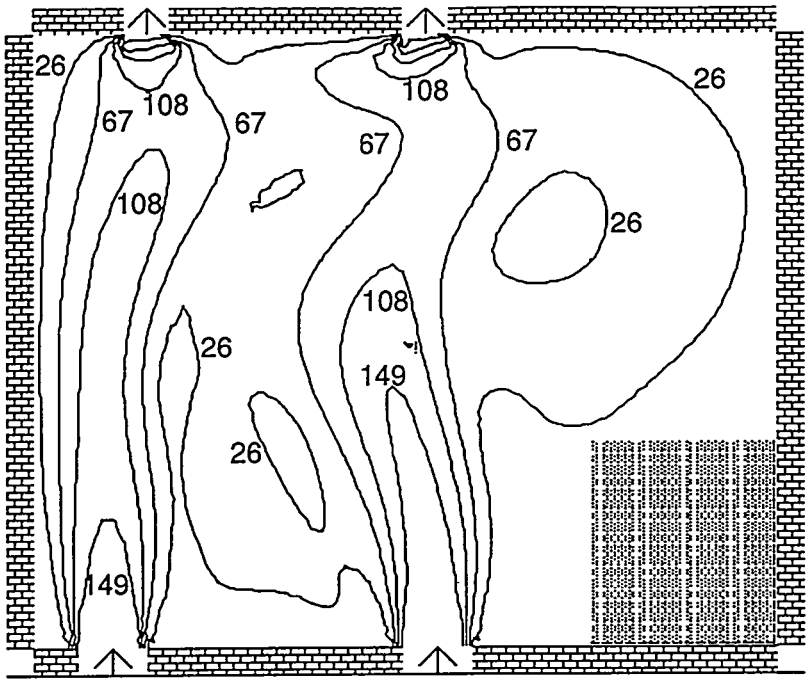


Figure 117, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Closed
Southeast Wind, 180 fpm Through Windows

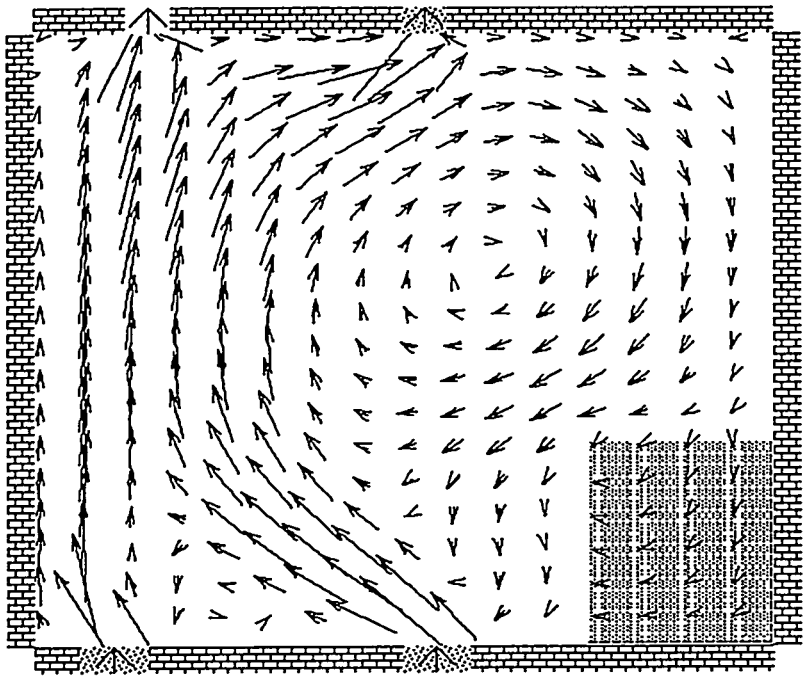


Figure 118, Velocity Vectors
(Length of arrow indicates relative air speed)

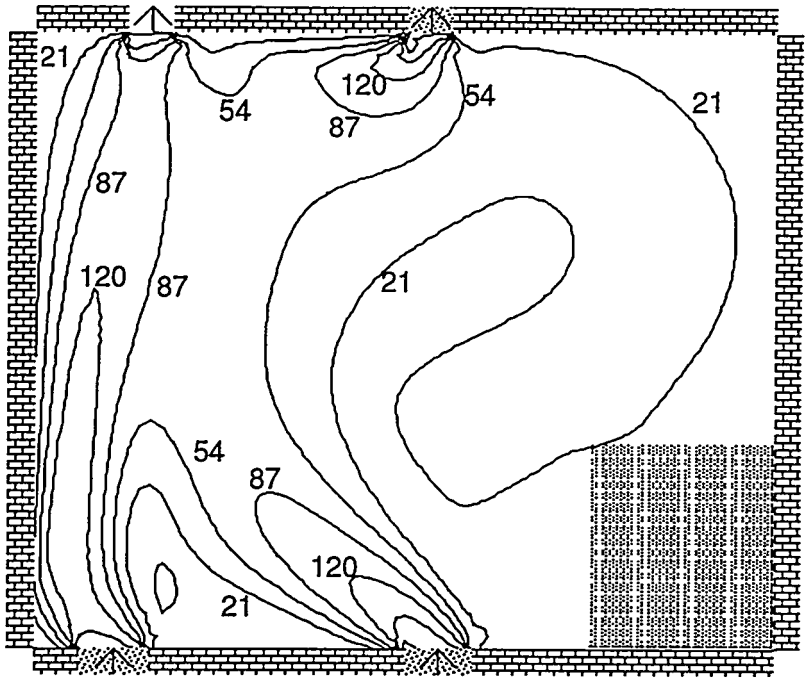


Figure 119, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Closed
Northwest Wind, 270 fpm Through Windows

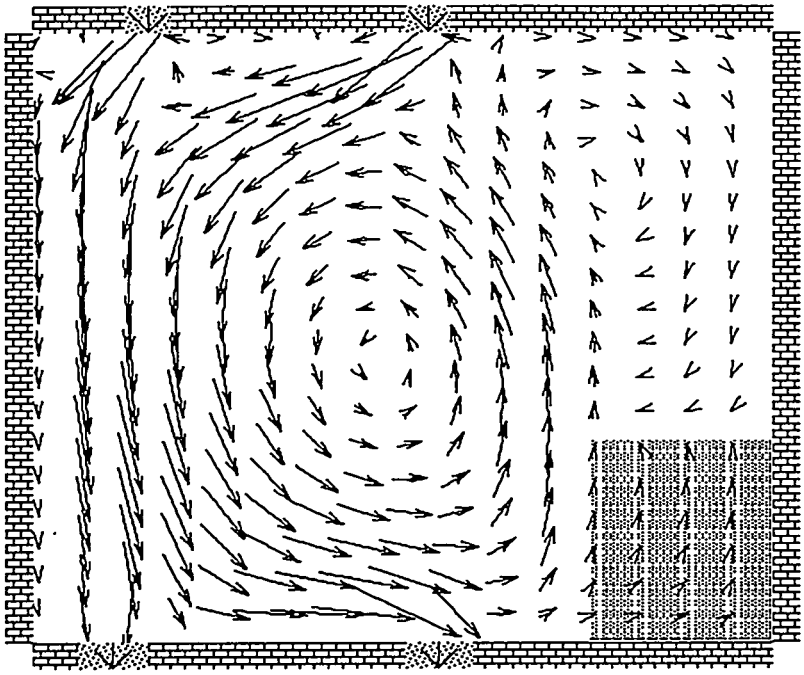


Figure 120,Velocity Vectors
(Length of arrow indicates relative air speed)

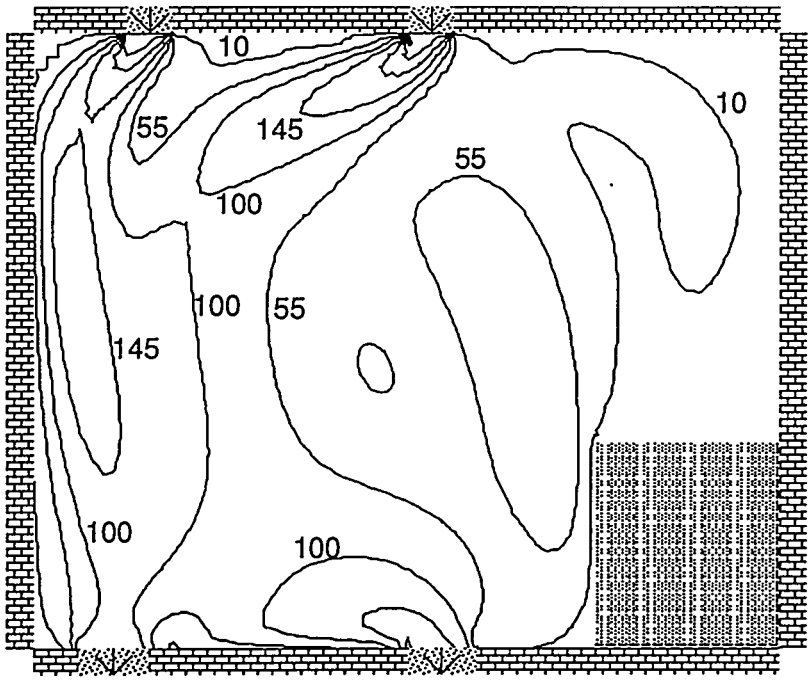


Figure 121, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Closed
North Wind, 270 fpm Through Windows

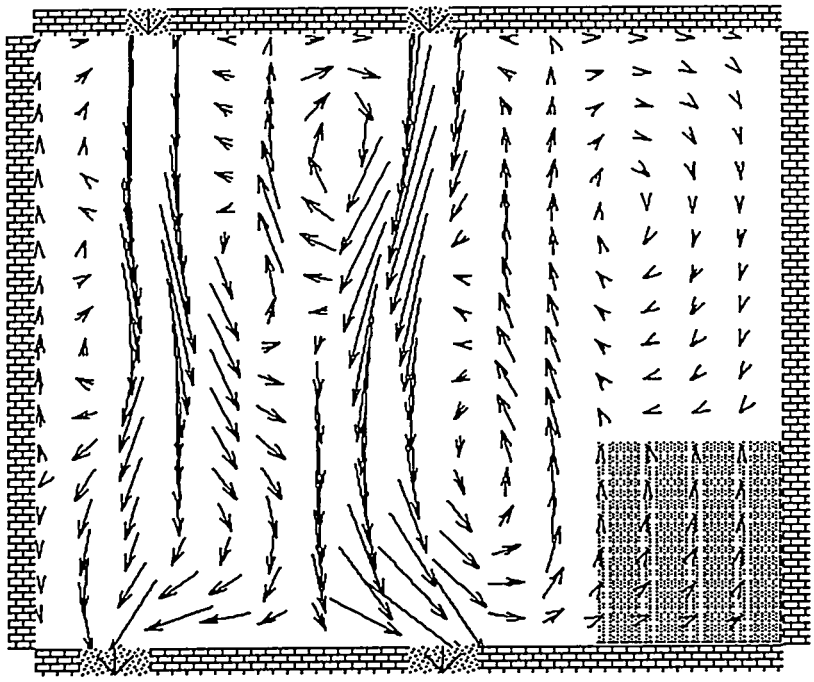


Figure 122,Velocity Vectors
(Length of arrow indicates relative air speed)

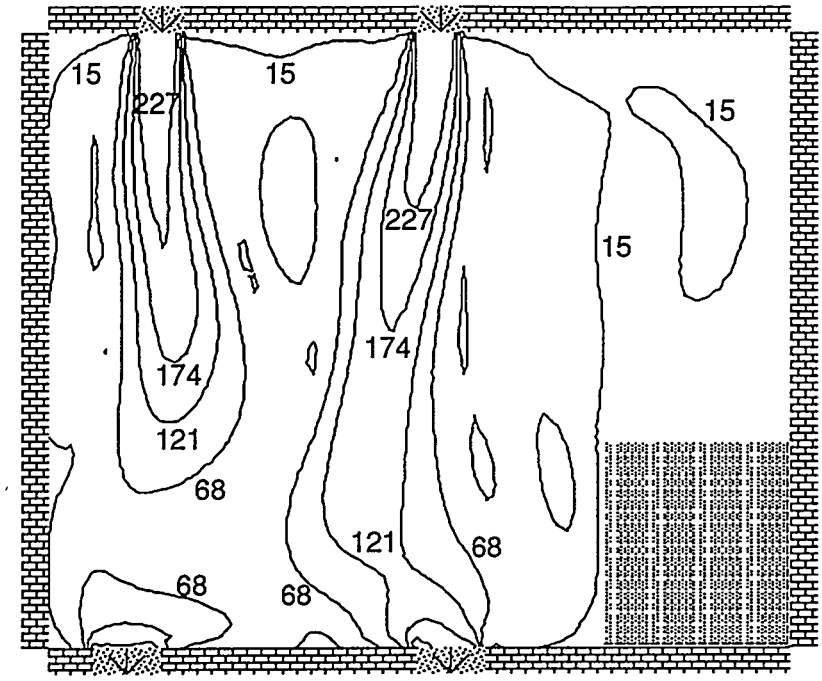


Figure 123, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Closed
Northwest Wind, 270 fpm Through Windows

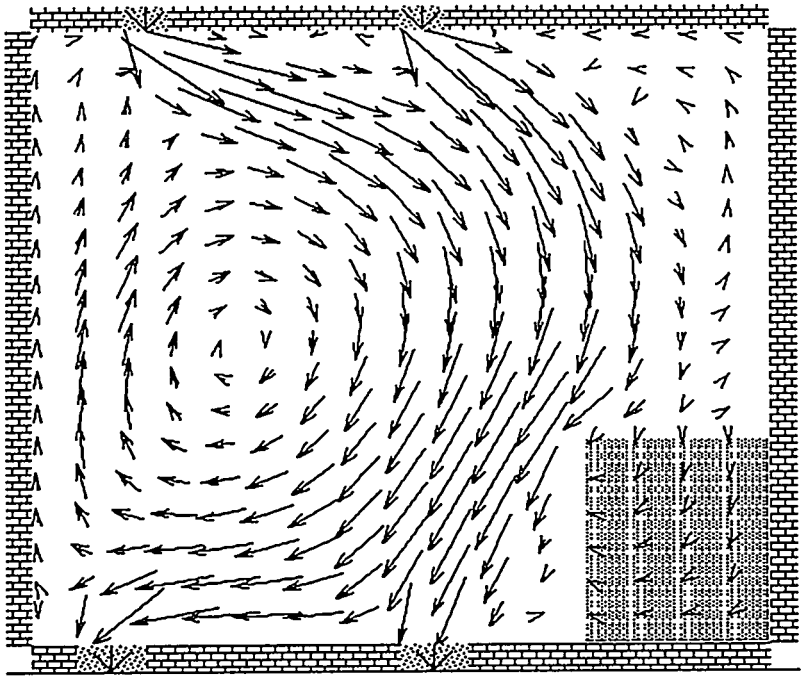


Figure 124, Velocity Vectors
(Length of arrow indicates relative air speed)

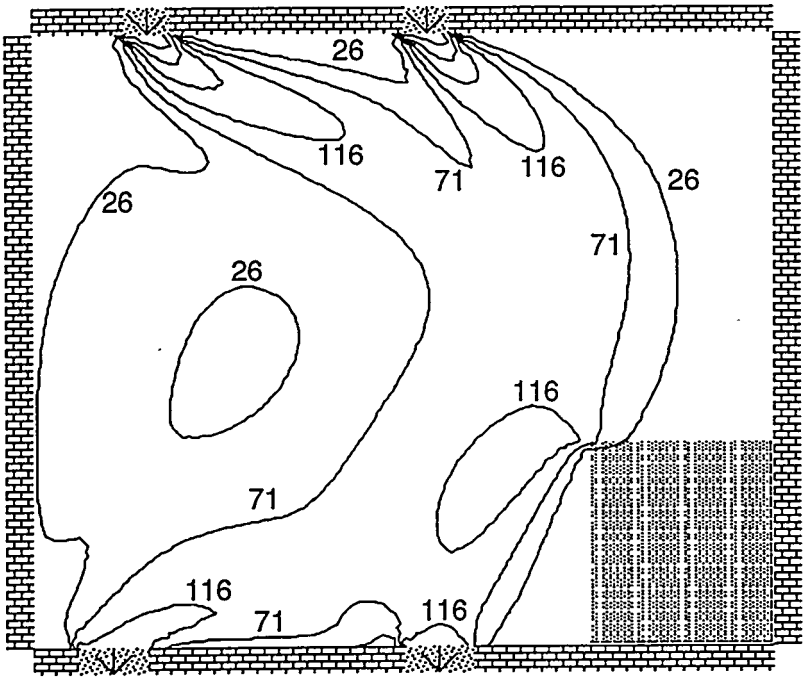


Figure 125, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Closed
Southwest Wind, 180 fpm Through Windows

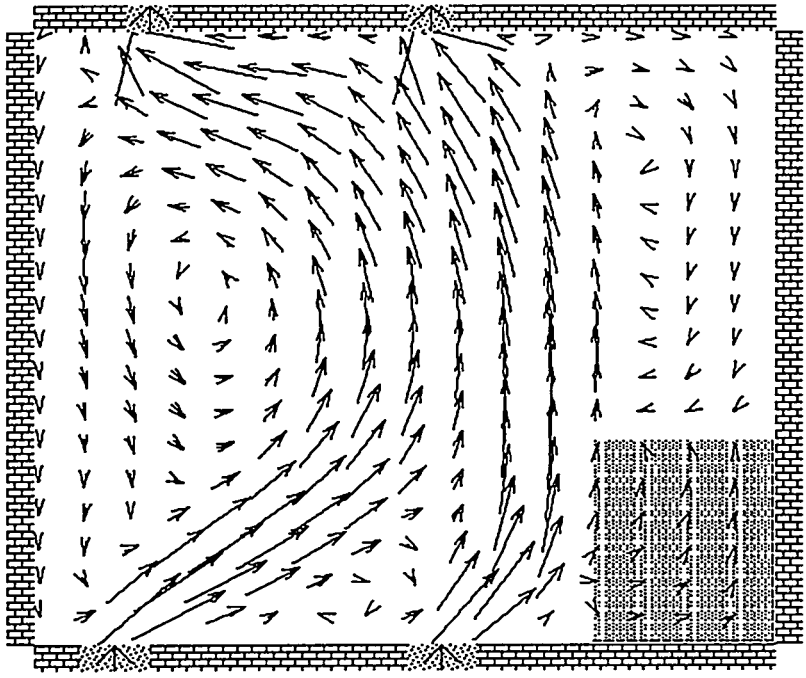


Figure 126, Velocity Vectors
(Length of arrow indicates relative air speed)

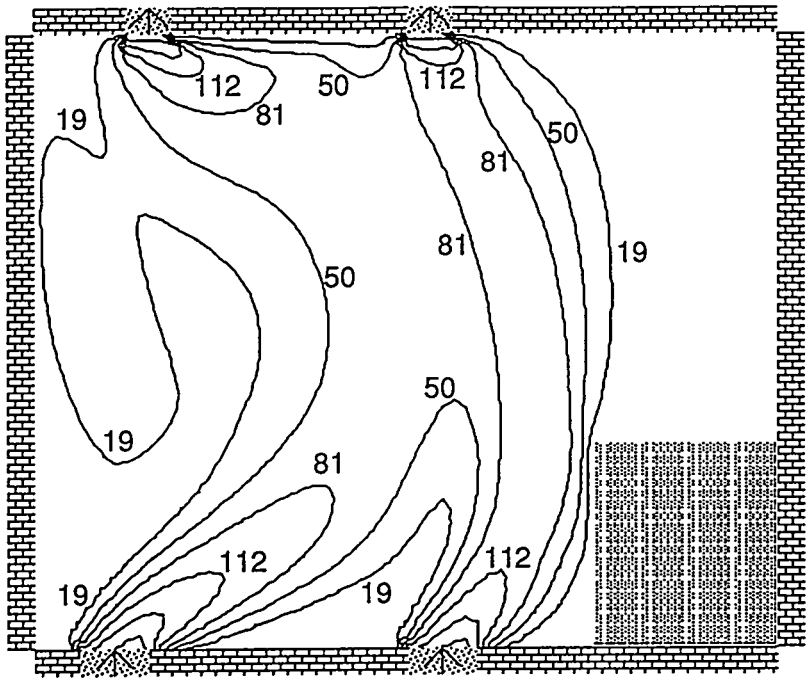


Figure 127, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Open
South Wind, 180 fpm Through Windows

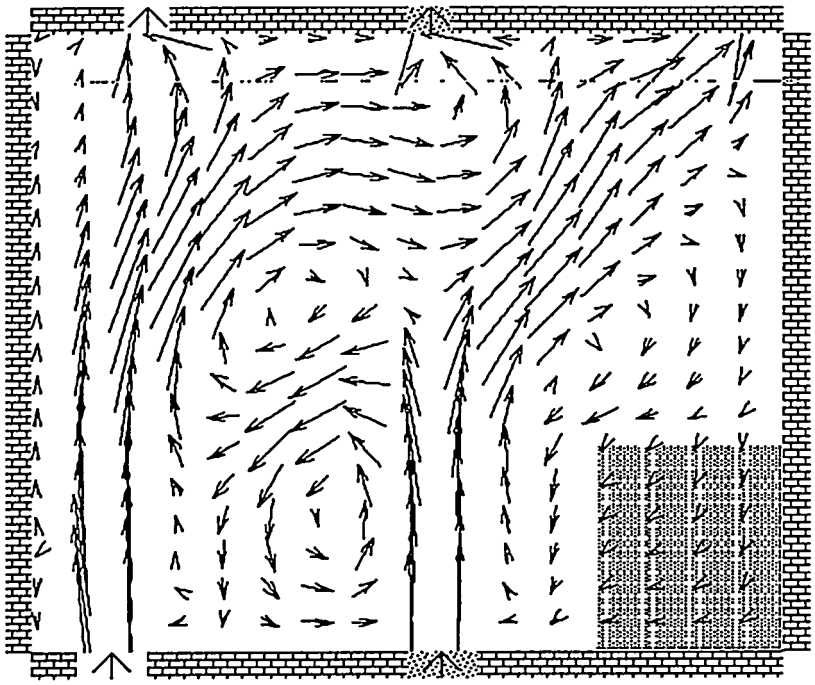


Figure 128, Velocity Vectors
(Length of arrow indicates relative air speed)

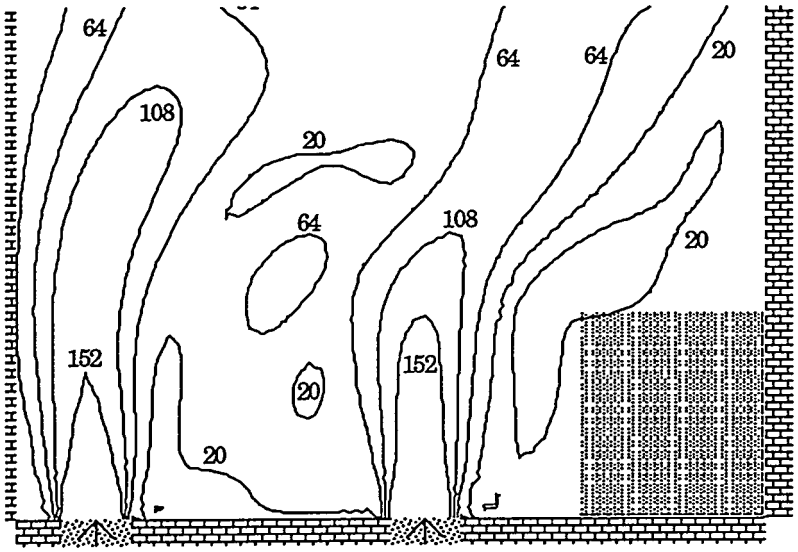


Figure 129, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Open
Southeast Wind, 180 fpm Through Windows

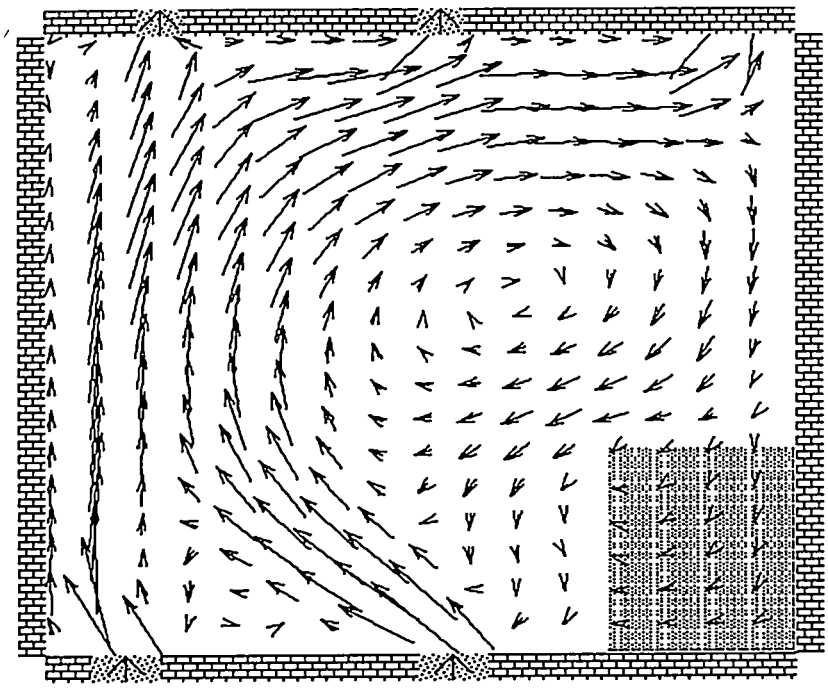


Figure 130, Velocity Vectors
(Length of arrow indicates relative air speed)

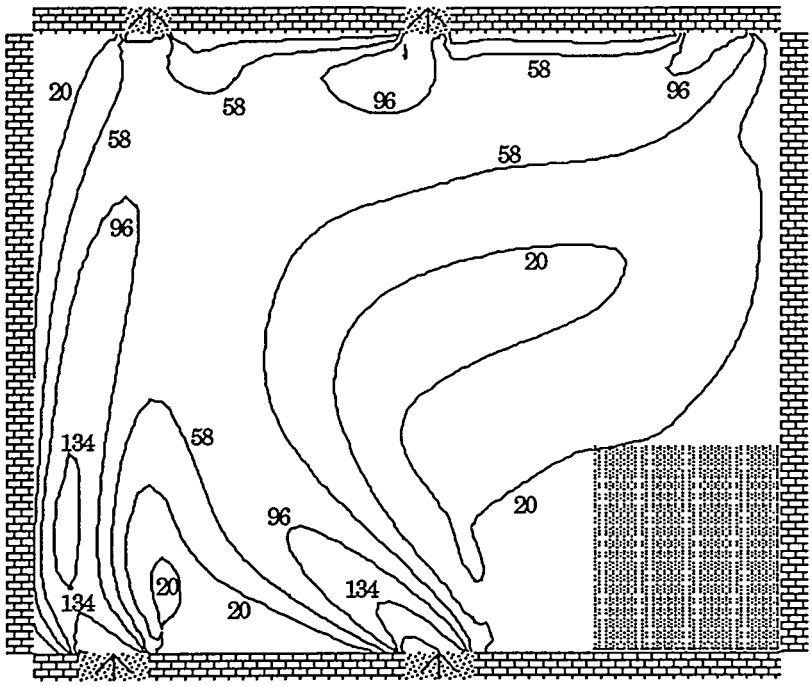


Figure 131, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Closed
Northeast Wind, 117 fpm Through Windows

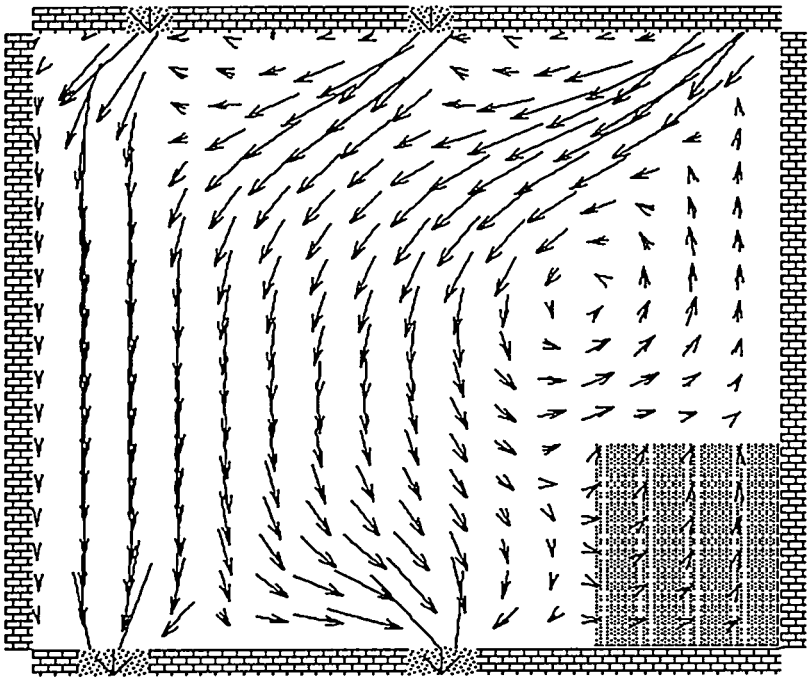


Figure 132, Velocity Vectors
(Length of arrow indicates relative air speed)

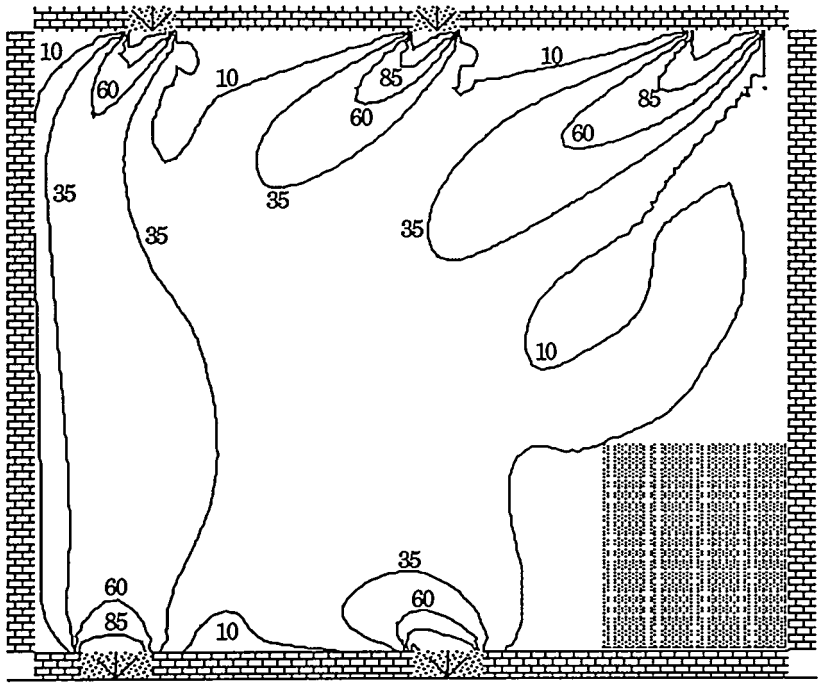


Figure 133, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Open
North Wind, 117 fpm Through Windows

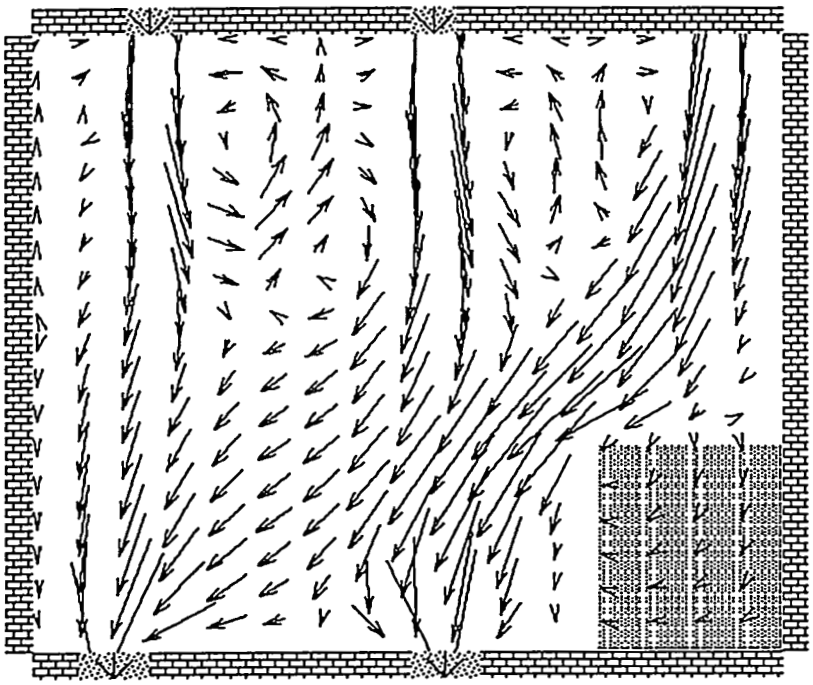


Figure 134, Velocity Vectors
(Length of arrow indicates relative air speed)

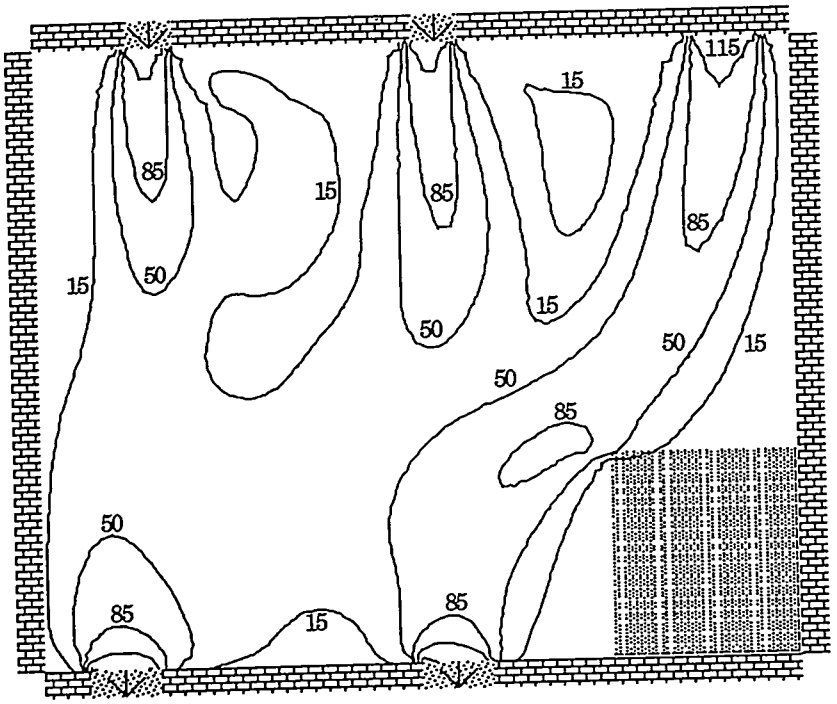


Figure 135, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Open
Northwest Wind, 117 fpm Through Windows

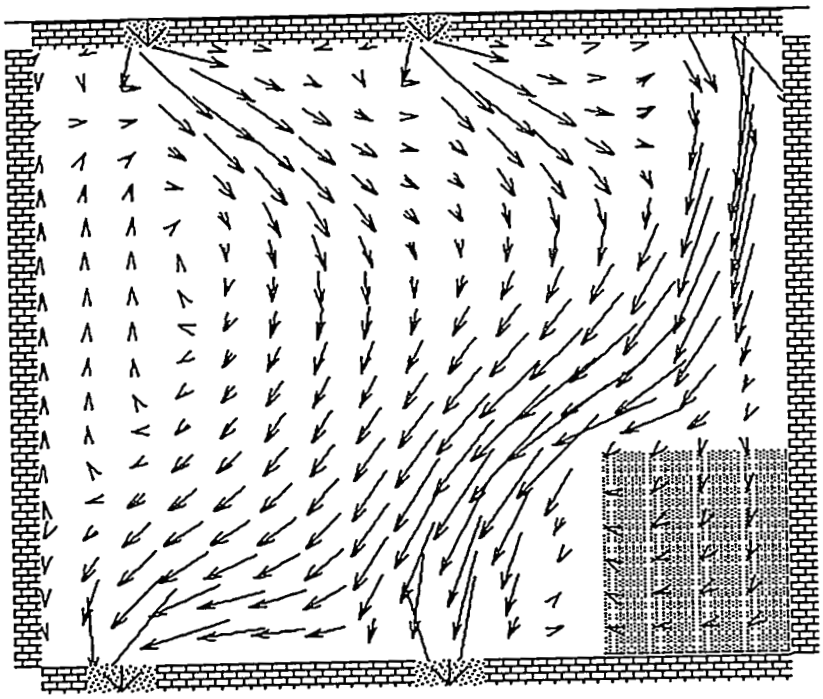


Figure 136, Velocity Vectors
(Length of arrow indicates relative air speed)

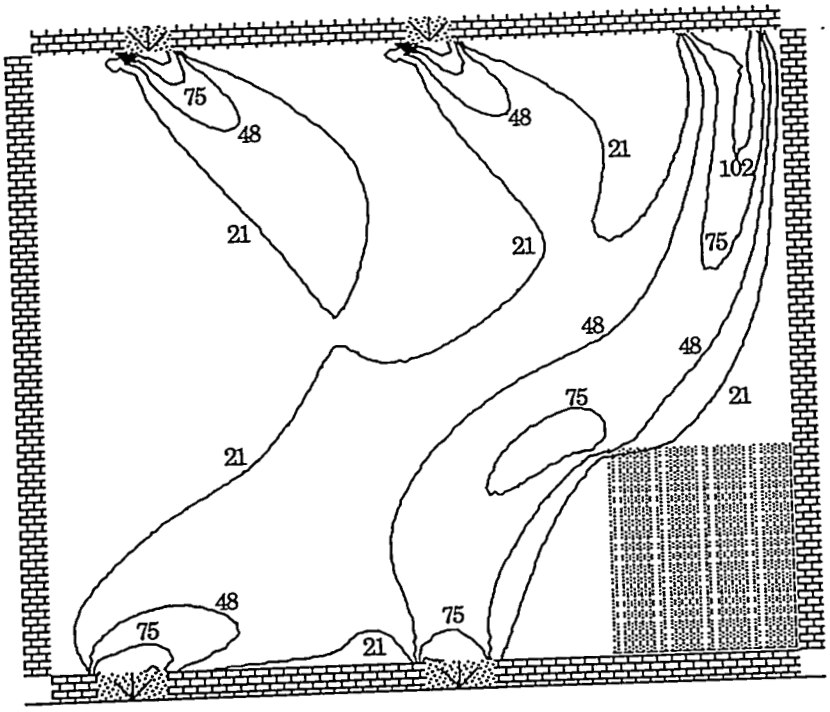


Figure 137, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 6040 Units
Two North Windows, South Windows 2' from Walls, Door Open
Southwest Wind, 180 fpm Through Windows

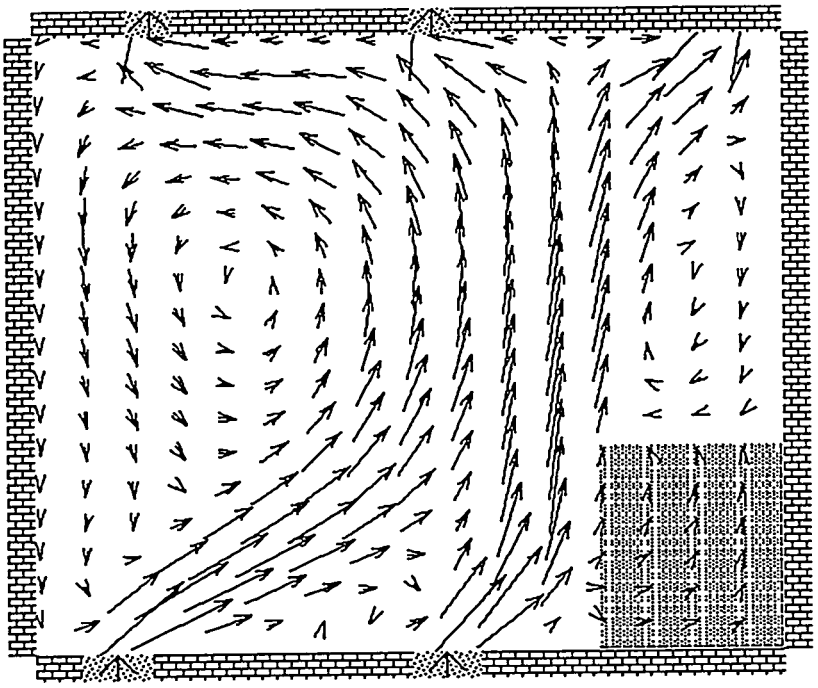


Figure 138, Velocity Vectors
(Length of arrow indicates relative air speed)

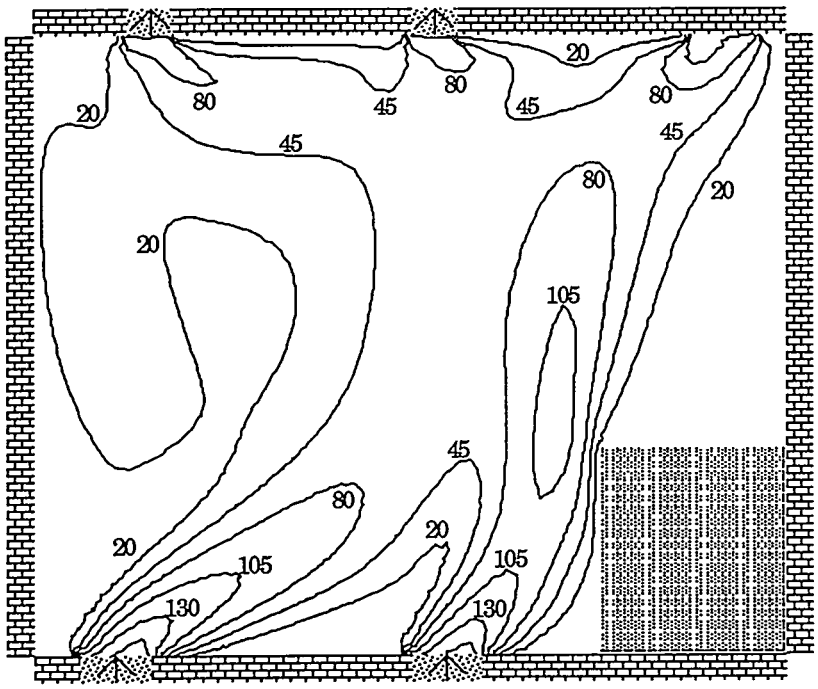


Figure 139, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 2040 Units
One North Windows, South Windows 2' from Walls, Door Open
Southeast Wind, 180 fpm Through Windows

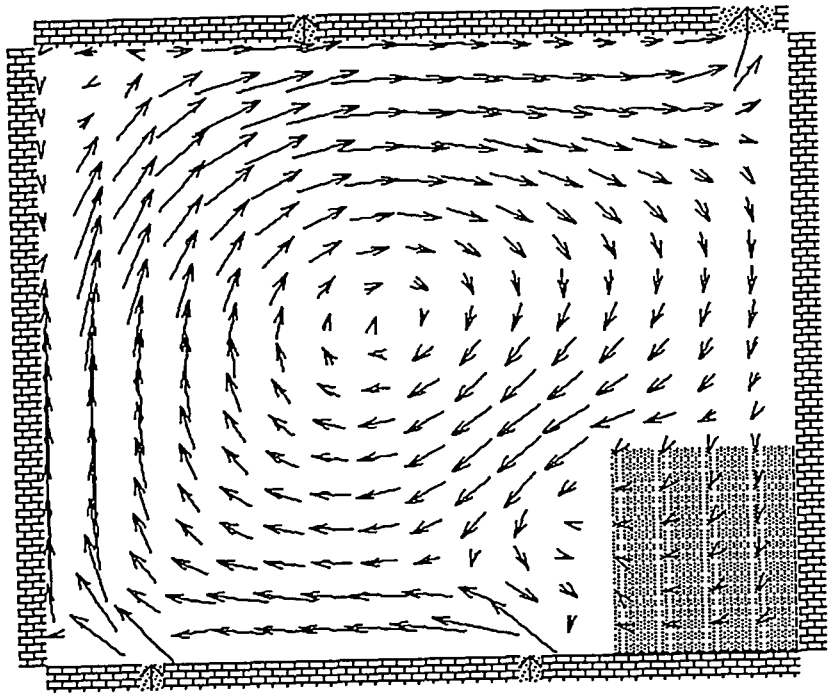


Figure 140, Velocity Vectors
(Length of arrow indicates relative air speed)

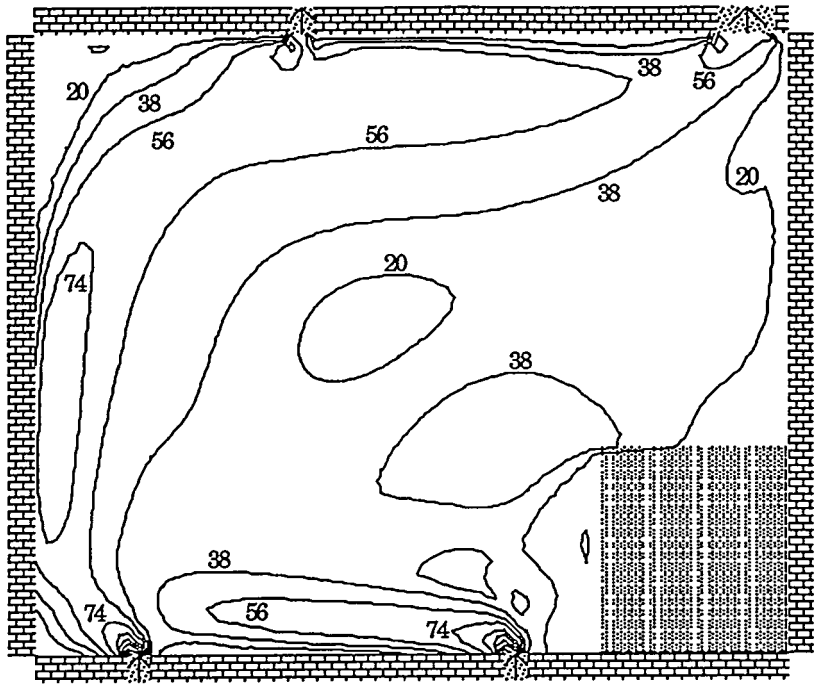


Figure 141, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 2040 Units
One North Windows, South Windows 2' from Walls, Door Open
South Wind, 180 fpm Through Windows

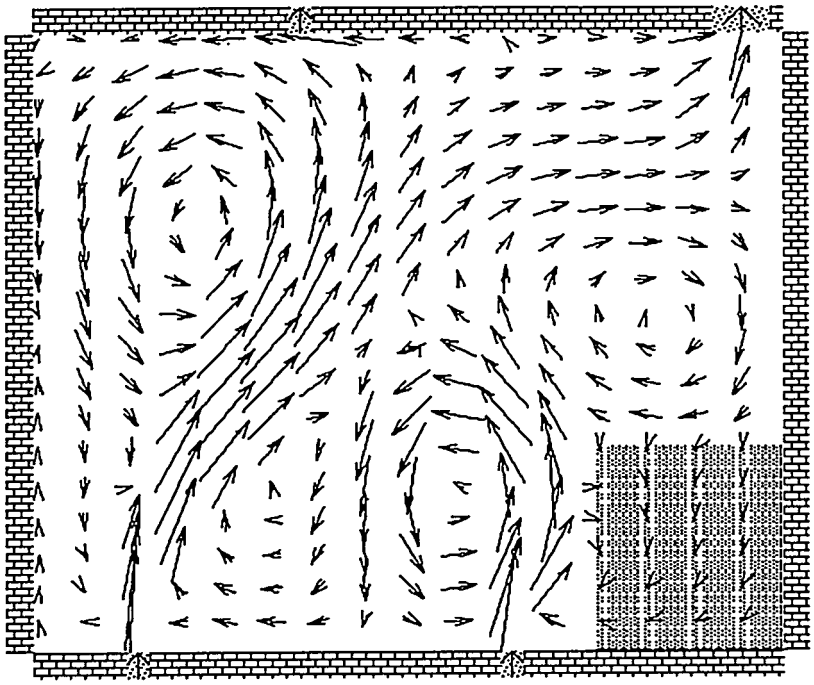


Figure 142, Velocity Vectors
(Length of arrow indicates relative air speed)

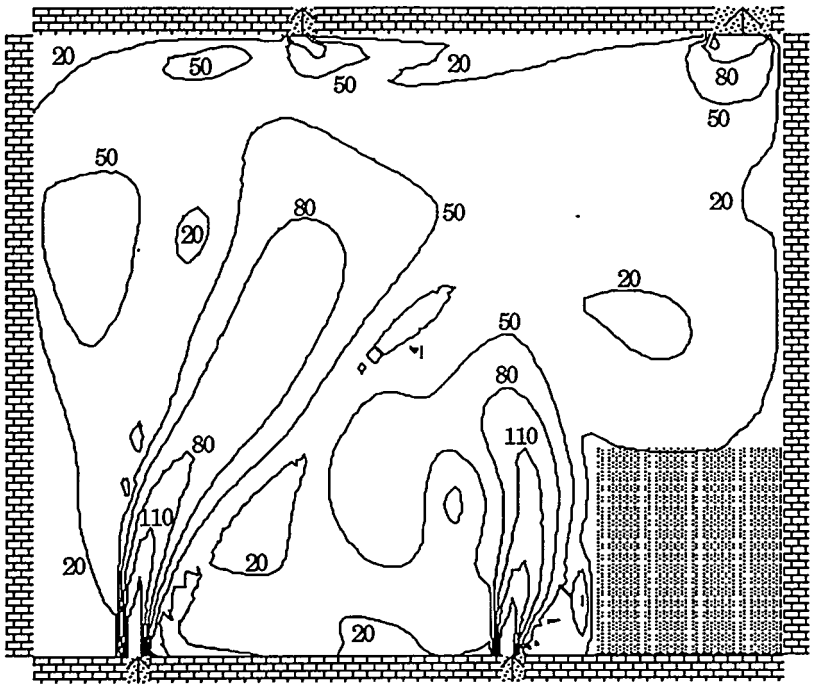


Figure 143, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 2040 Units
One North Windows, South Windows 2' from Walls, Door Open
Southwest Wind, 180 fpm Through Windows

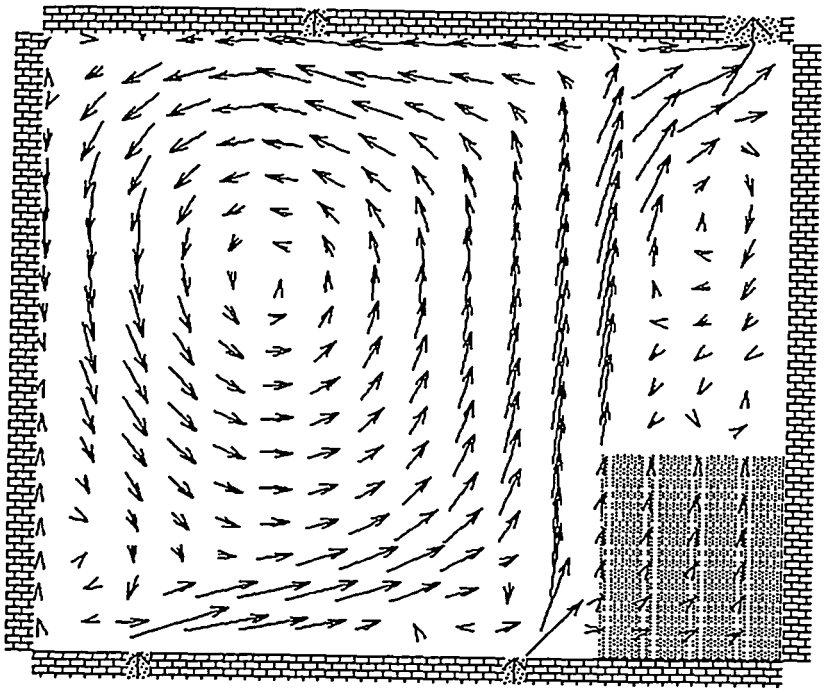


Figure 144, Velocity Vectors
(Length of arrow indicates relative air speed)

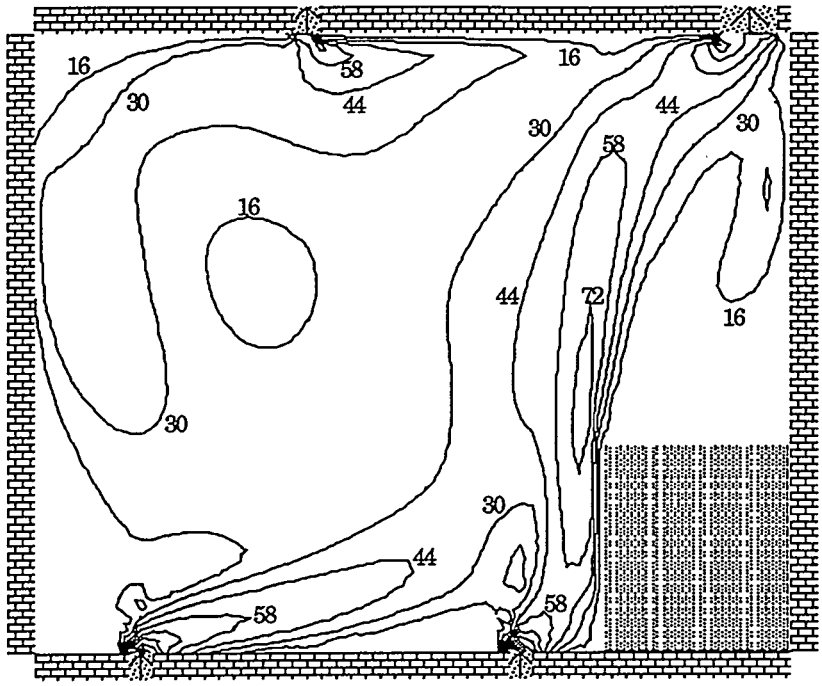


Figure 145, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 4040 Units
One North Windows, South Windows 2' from Walls, Door Open
Southeast Wind, 180 fpm Through Windows

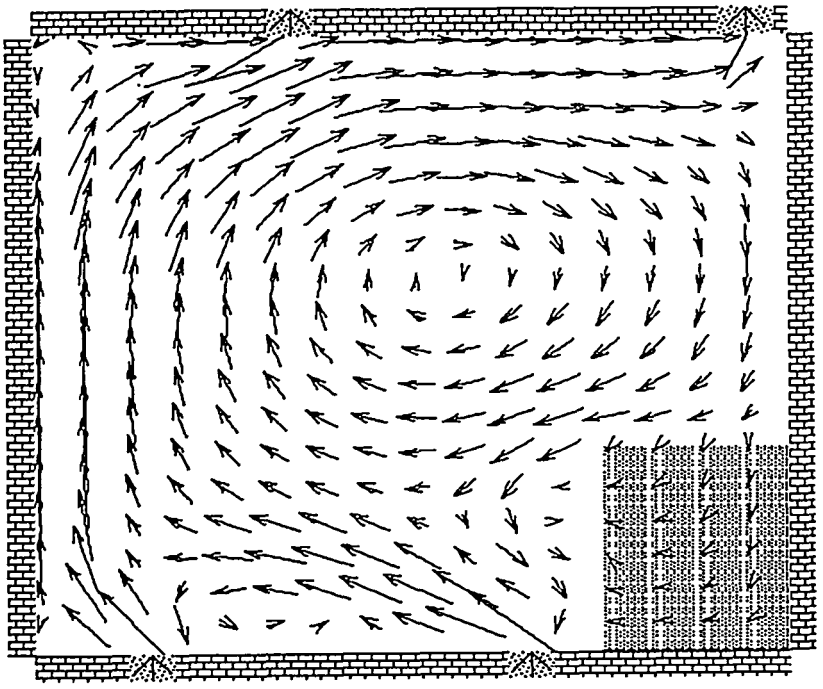


Figure 146, Velocity Vectors
(Length of arrow indicates relative air speed)

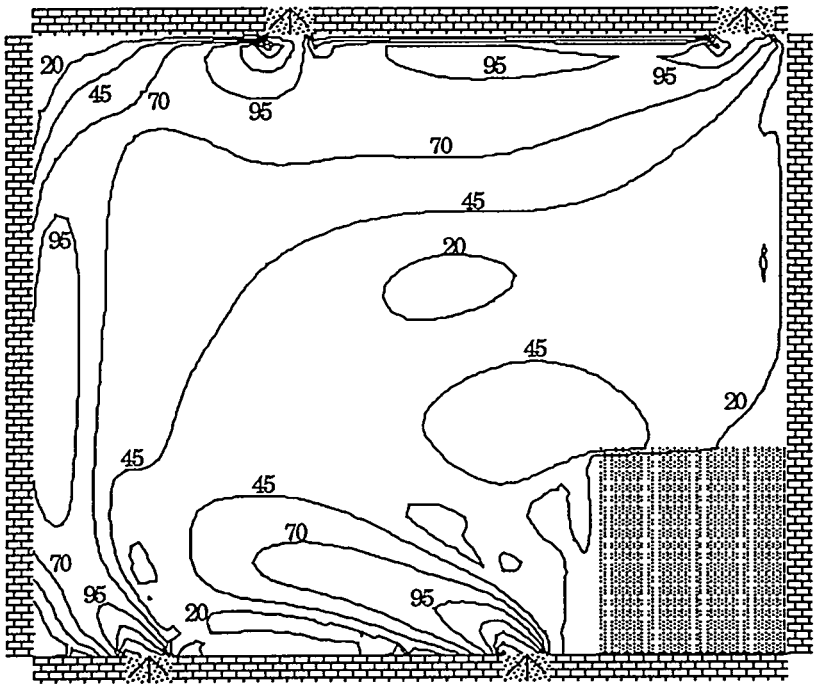


Figure 147, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 4040 Units
One North Windows, South Windows 2' from Walls, Door Open
South Wind, 180 fpm Through Windows

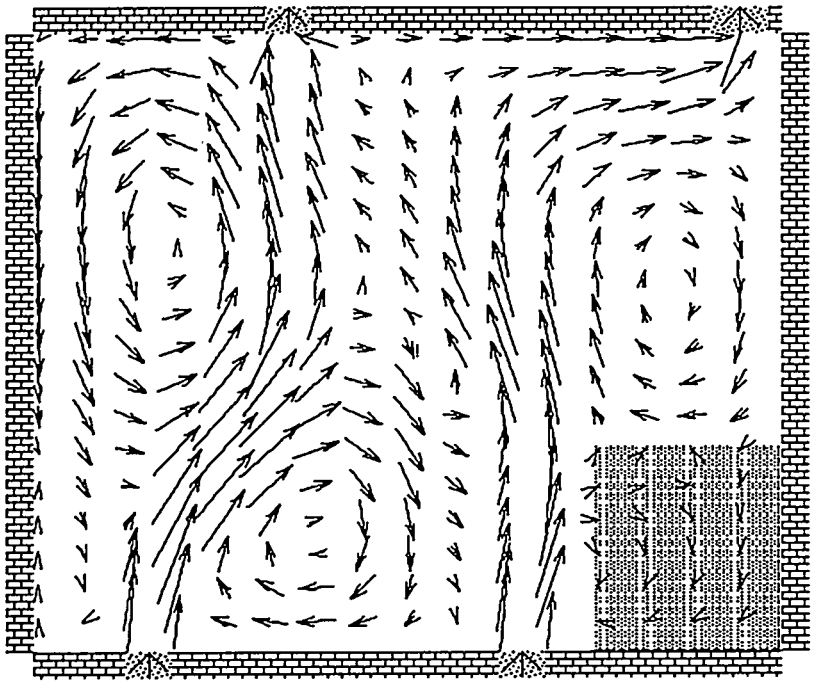


Figure 148, Velocity Vectors
(Length of arrow indicates relative air speed)

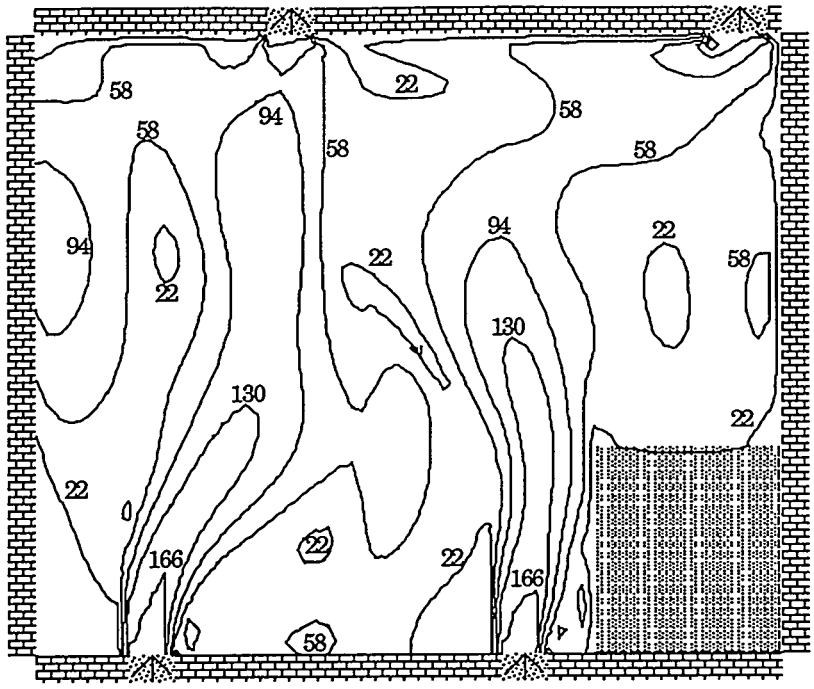


Figure 149, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 4040 Units
One North Windows, South Windows 2' from Walls, Door Open
Southwest Wind, 180 fpm Through Windows

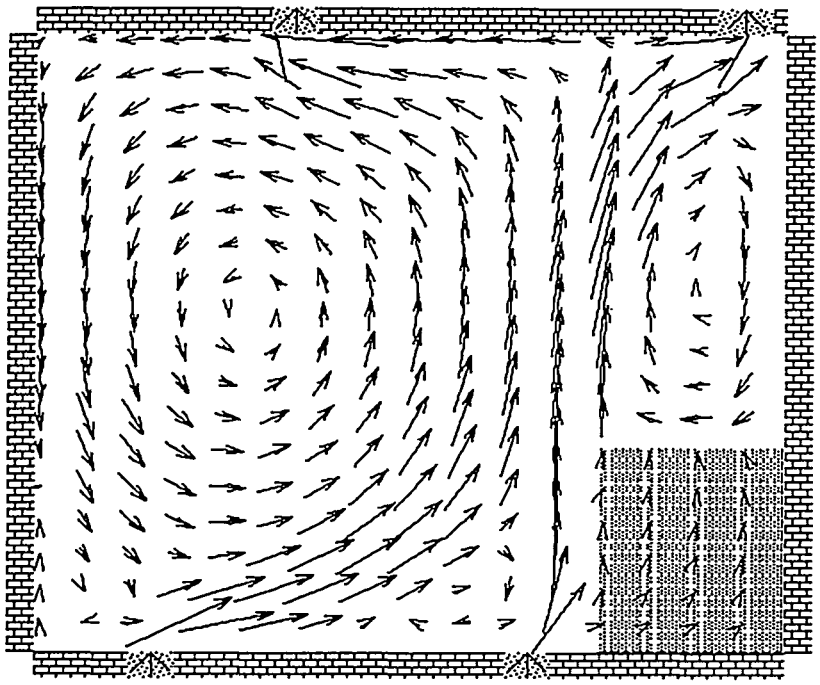


Figure 150, Velocity Vectors
(Length of arrow indicates relative air speed)

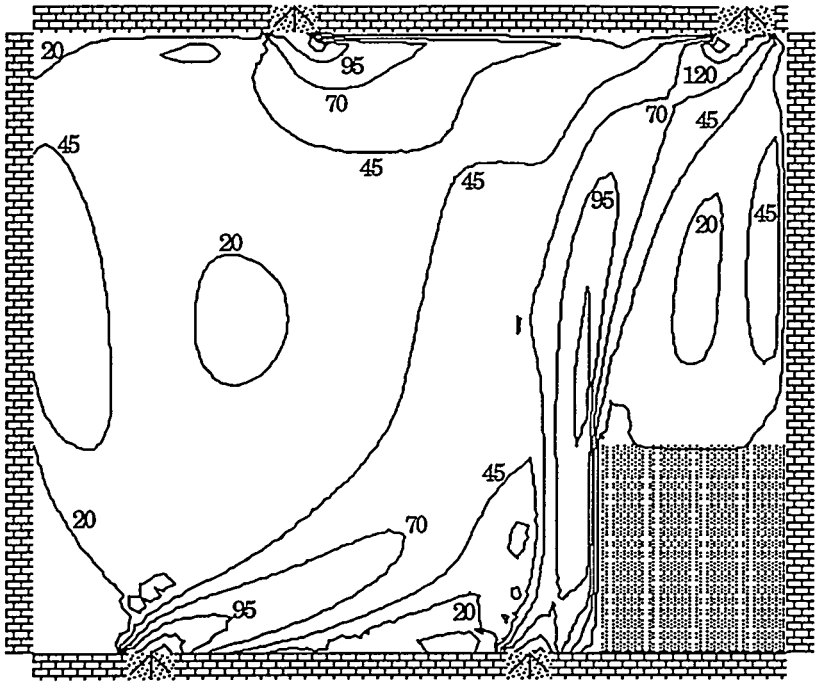


Figure 151, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 8040 Units
One North Windows, South Windows 2' from Walls, Door Open
Southeast Wind, 180 fpm Through Windows

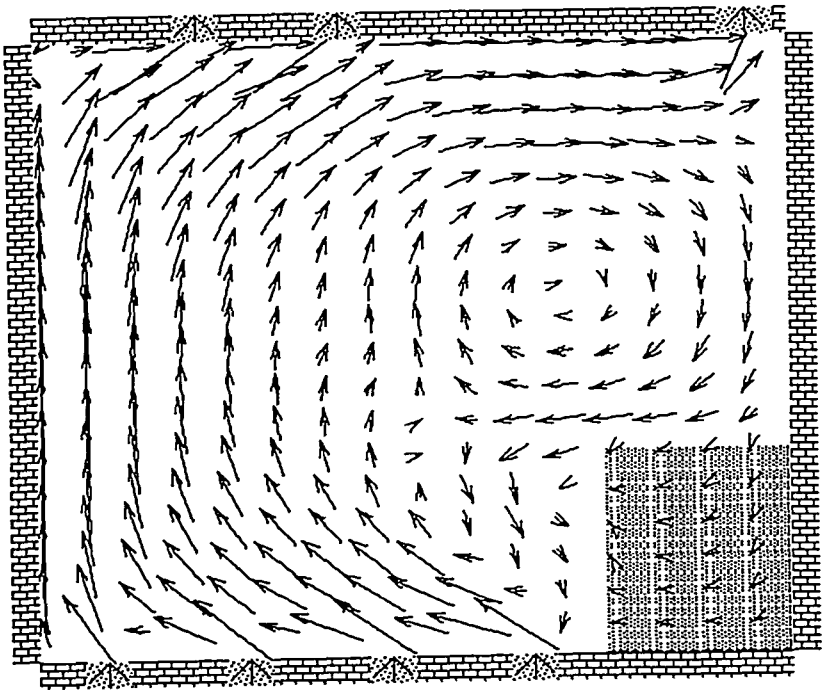


Figure 152, Velocity Vectors
(Length of arrow indicates relative air speed)

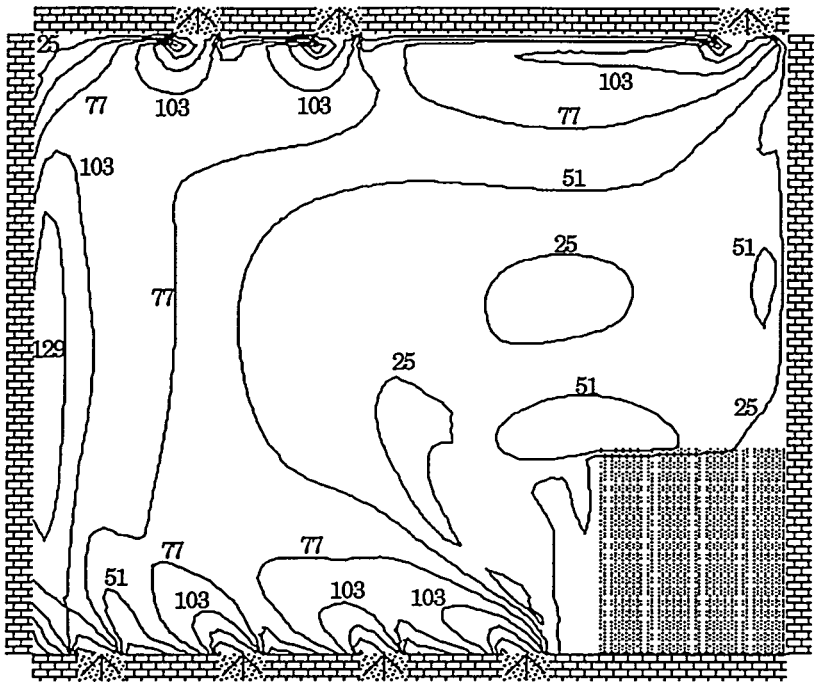


Figure 153, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 8040 Units
One North Window, South Windows 2' from Walls, Door Open
South Wind, 180 fpm Through Windows

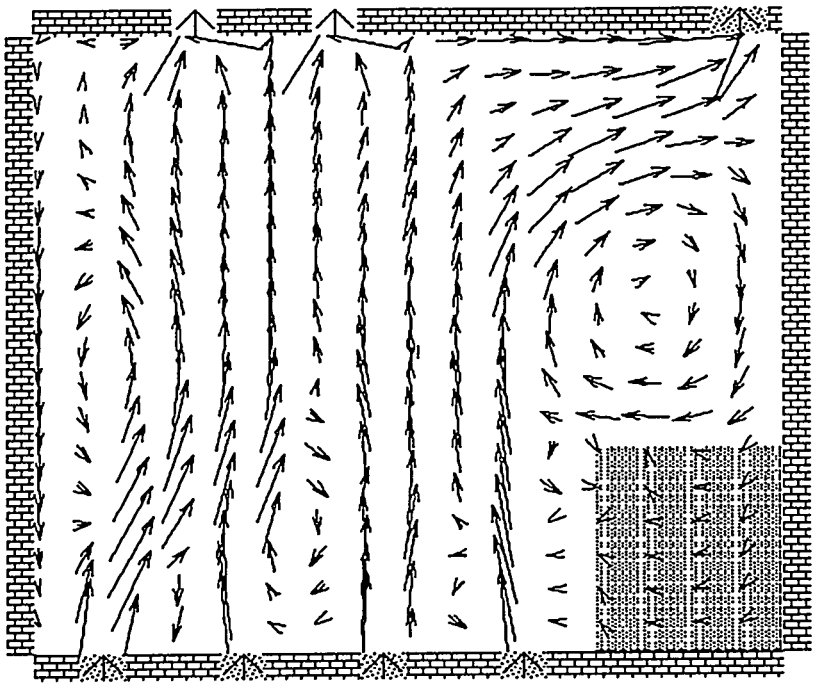


Figure 154, Velocity Vectors
(Length of arrow indicates relative air speed)

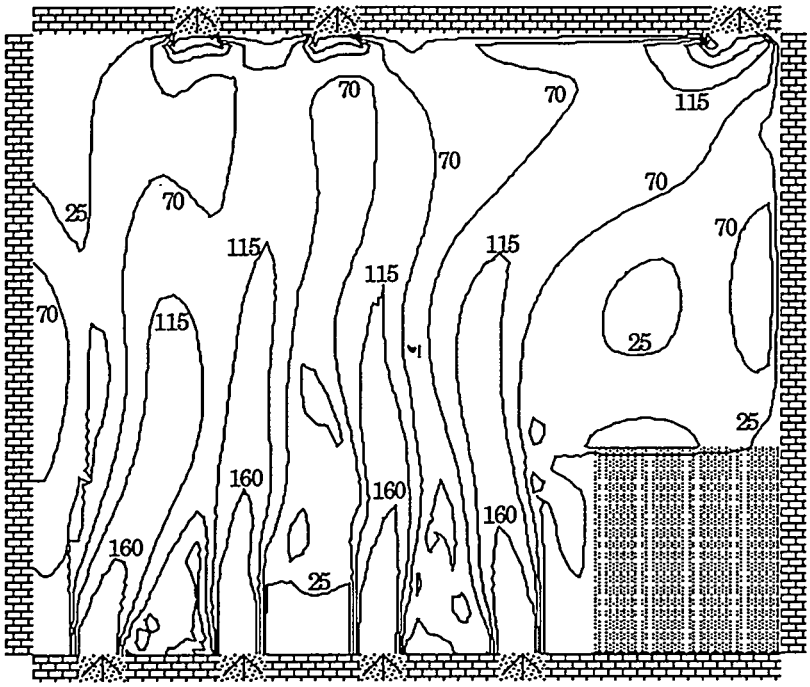


Figure 155, Equal Velocity Contours
(Values in feet per minute)

Ventilation Diagrams for 8040 Units
One North Window, South Windows 2' from Walls, Door Open
Southwest Wind, 180 fpm Through Windows

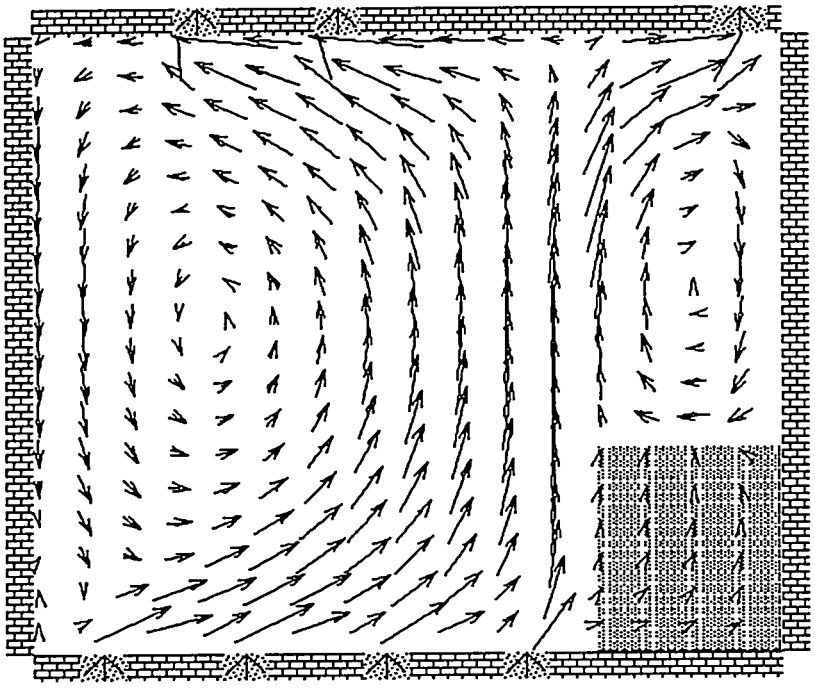


Figure 156, Velocity Vectors
(Length of arrow indicates relative air speed)

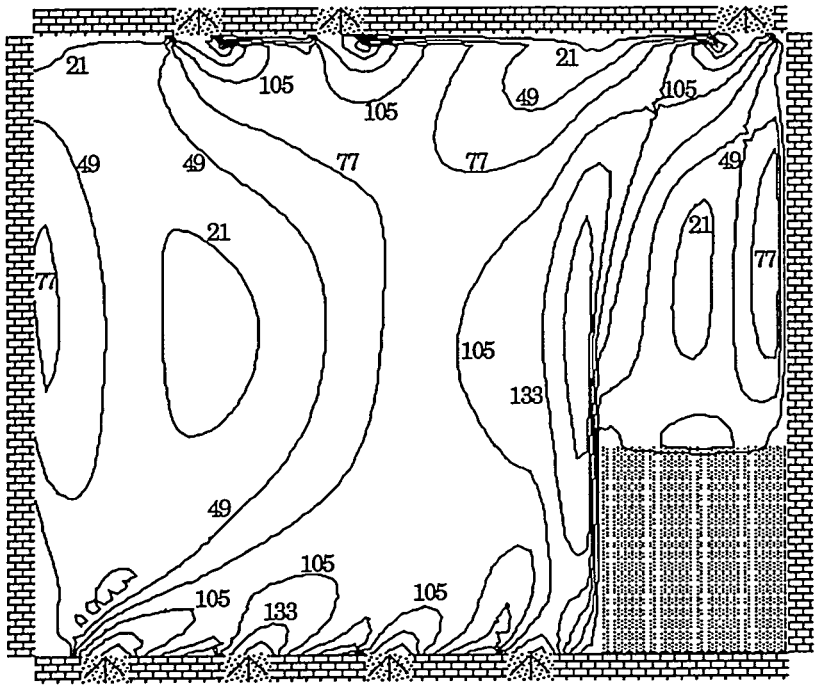


Figure 157, Equal Velocity Contours
(Values in feet per minute)

2.1.5.2 Illuminance on Vertical Surfaces.

Objective

The objective this task was to determine the adequacy of vertical and horizontal work surface illuminance distribution.

Methodology

Radiance (a Unix based ray-tracing software package from Lawrence Berkeley Laboratory) was used as the primary illuminance evaluation tool. Illuminance output consisted of a falsecolor picture of the two interior walls without windows and a floor plan with work surfaces. Examples of this output are given below:

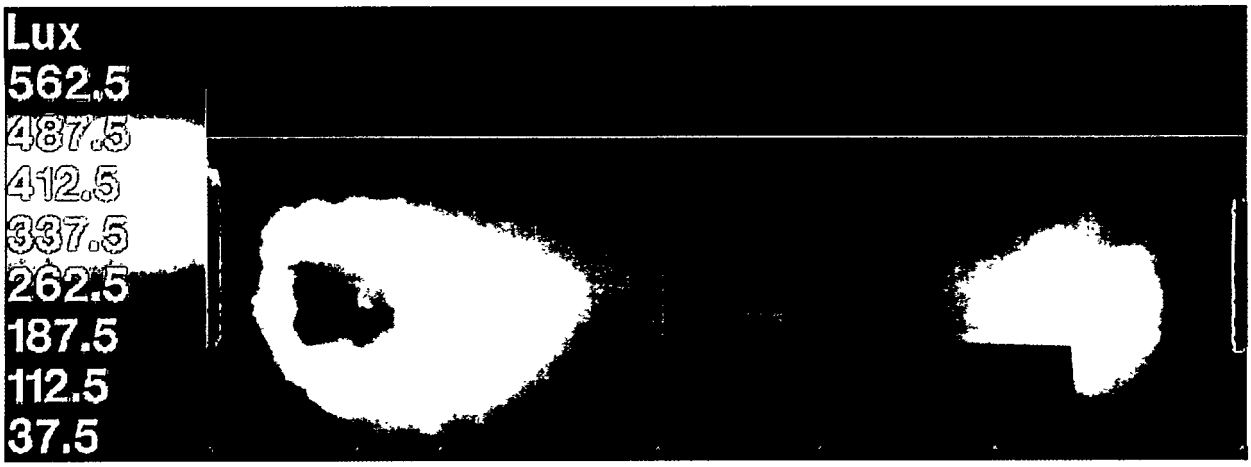


Figure 158, Interior Elevation of End Wall Illuminance Values

Figure 159, Interior Elevation of Common Wall (and Bathroom Wall)
Illuminance Values

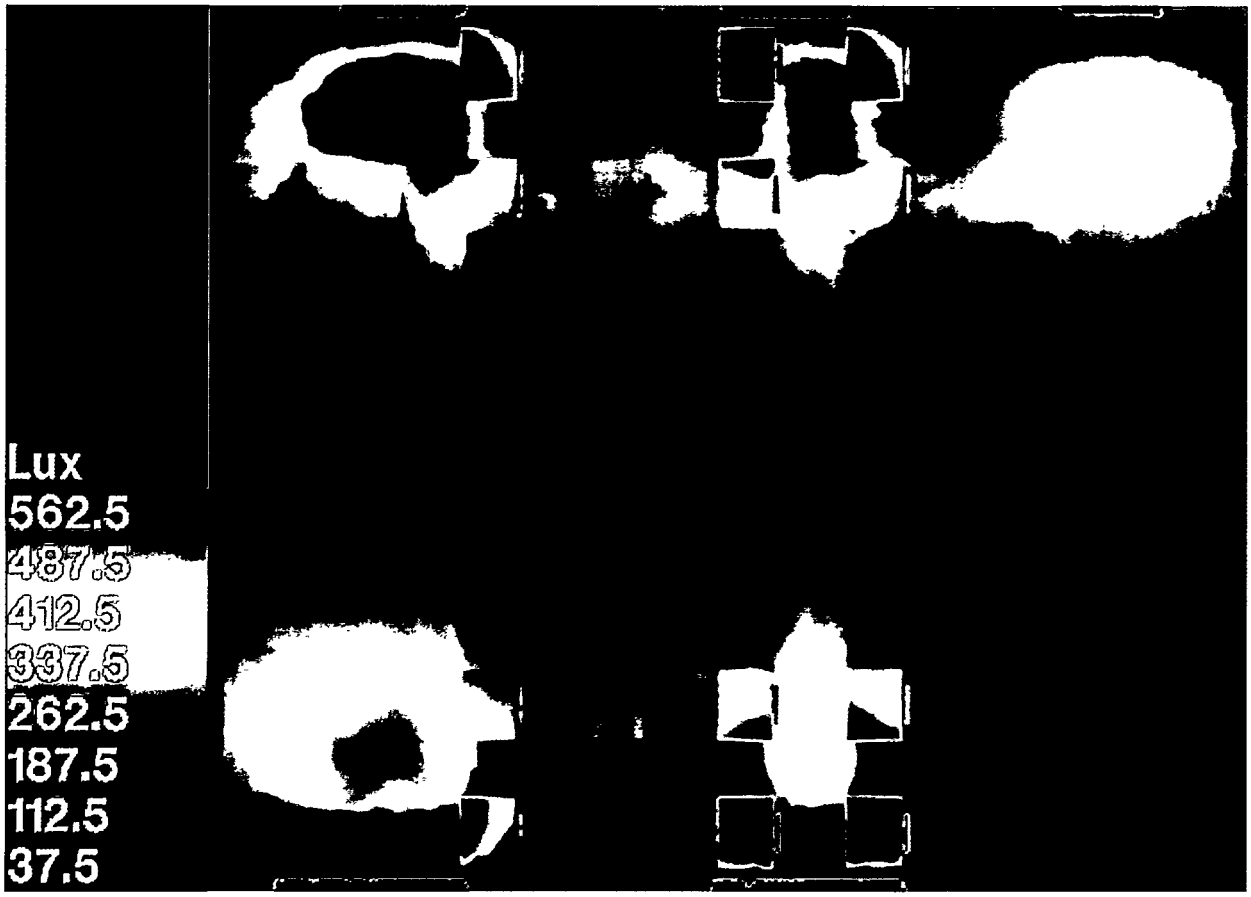


Figure 160, Floor Plan Illuminance Values

A design goal of 500 Lux (50 fc) was set as recommended by both the Illuminating Engineering Society of North America (IESNA) and Britain (IES) (Reynolds, 943).

An initial round of runs was conducted using the various shading conditions tested in the first runs of Task BU1S5: Evaluate Visual Comfort on a cloudy June day at 44° N latitude. The tested conditions were: venetian blinds (reflectance = 60%), vertical blinds (ref. = 60%), exterior roll-down shades (transmittance = 25%) and no shades. The results of these runs were used to make a recommendation for the shades to use from a lighting distribution standpoint.

To determine south window placements, a series of runs varying the locations of the southern windows was done. The windows in these runs were placed 0', 2', and 4' from the end wall and bathroom wall for the 6040 unit, 2', 4', 6', and 8' for the 2040 unit, 2' and 4' for the 4040 unit, and 2' for the 8040 unit. These runs were carried out for a cloudy June day with overhangs but no interior blinds.
In addition, a run with the north window split and one half placed near the end wall was conducted on the 4040, 6040, and 8060 units to determine if better lighting could be achieved on the wall.

Results

6040 Unit

Without any active shading strategy (but with overhangs), the various 6040 window locations gave the following ranges of illuminance values (Work surface values are for middle of room):

Window Location	End Wall	Bathroom Wall	Work Surfaces
0' from walls	10-70	35-70	15
2' from walls	10-50	35-50	15
4' from walls	10-40	40-35	15

Figure 161, 6040 Illuminance Ranges in Lux

Using southern windows 2' from the walls splitting the north windows gave the following ranges:

Window Location	End Wall	Bathroom Wall	Work Surfaces
North Split	35 - 20 - 50	35-50	15

Figure 162, 6040 Illuminance Ranges in Lux

Illuminance Values for 6040 Units: Cloudy, No Blinds, Overhangs
One North Window, South Windows 0' from Walls

Figure 163, End Wall

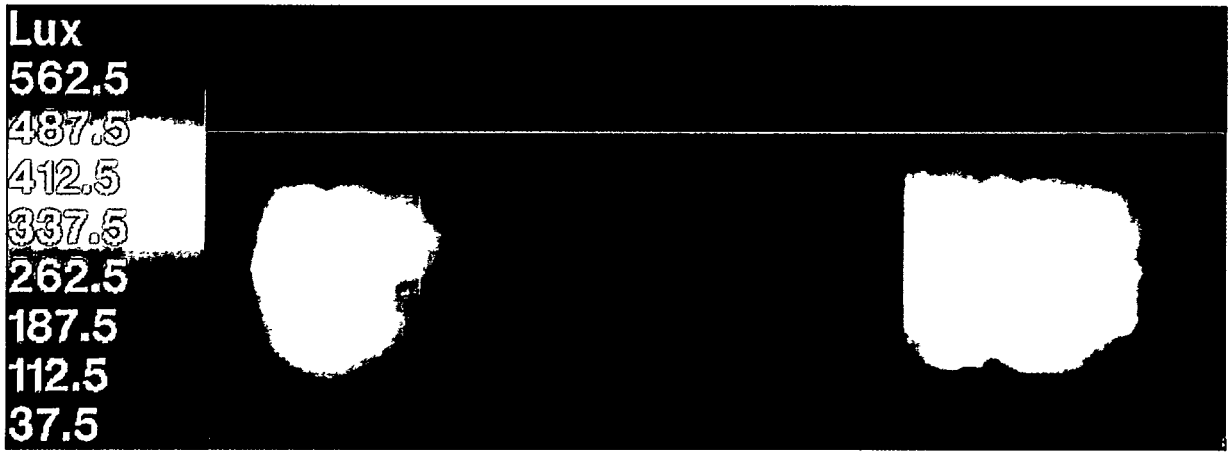


Figure 164, Common Wall and Bathroom Wall

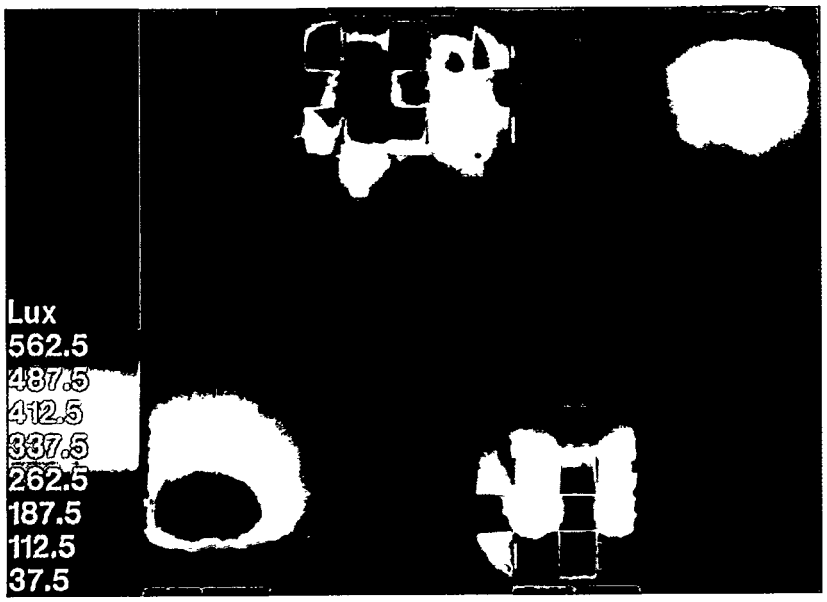


Figure 165, Horizontal Work Surfaces and Floor

Illuminance Values for 6040 Units: Cloudy, No Blinds, Overhangs
One North Window, South Windows 2' from Walls

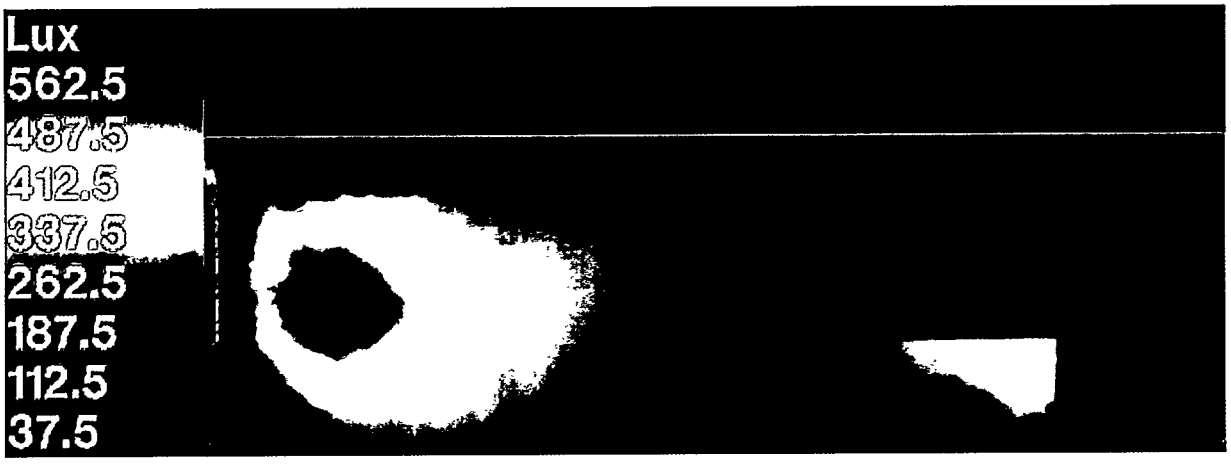


Figure 166, End Wall

Figure 167, Common Wall and Bathroom Wall

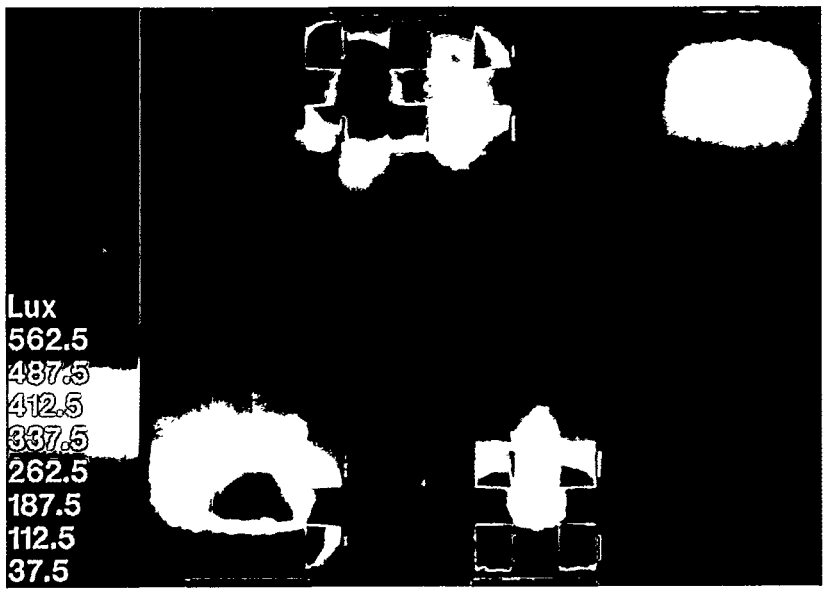


Figure 168, Horizontal Work Surfaces and Floor

Illuminance Values for 6040 Units: Cloudy, No Blinds, Overhangs
One North Window, South Windows 4' from Walls

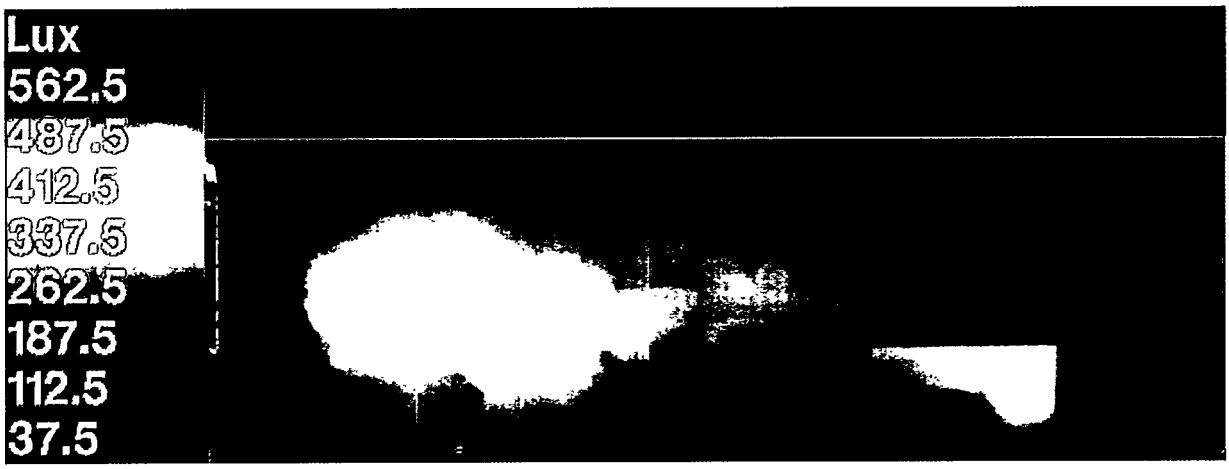


Figure 169, End Wall

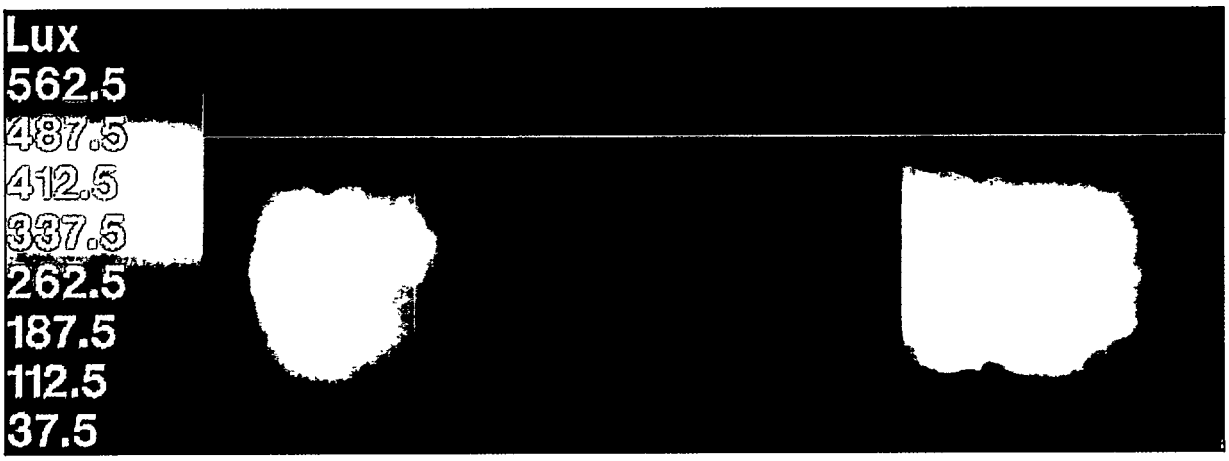


Figure 170, Common Wall and Bathroom Wall

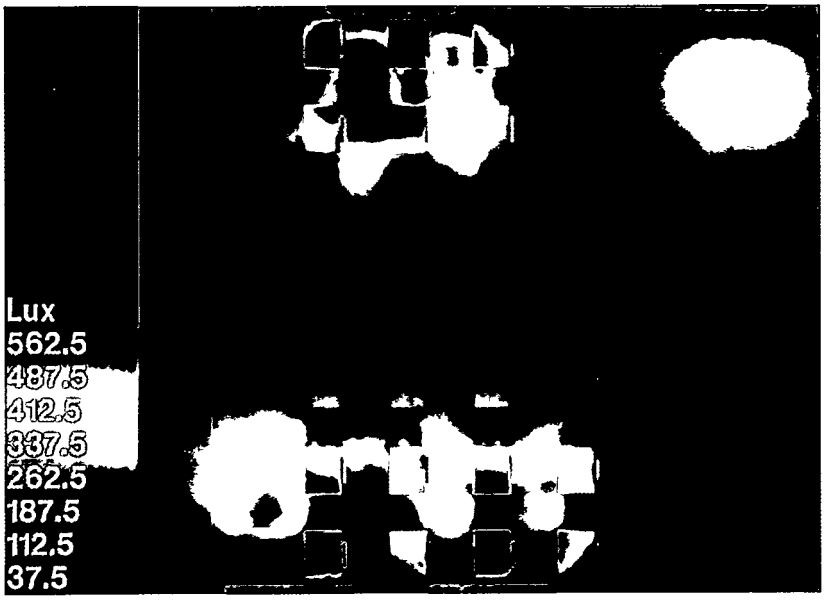


Figure 171, Horizontal Work Surfaces and Floor

Illuminance Values for 6040 Units: Cloudy, No Blinds, Overhangs
Two North Windows 4' and 16' from End Wall, South Windows 2' from Walls

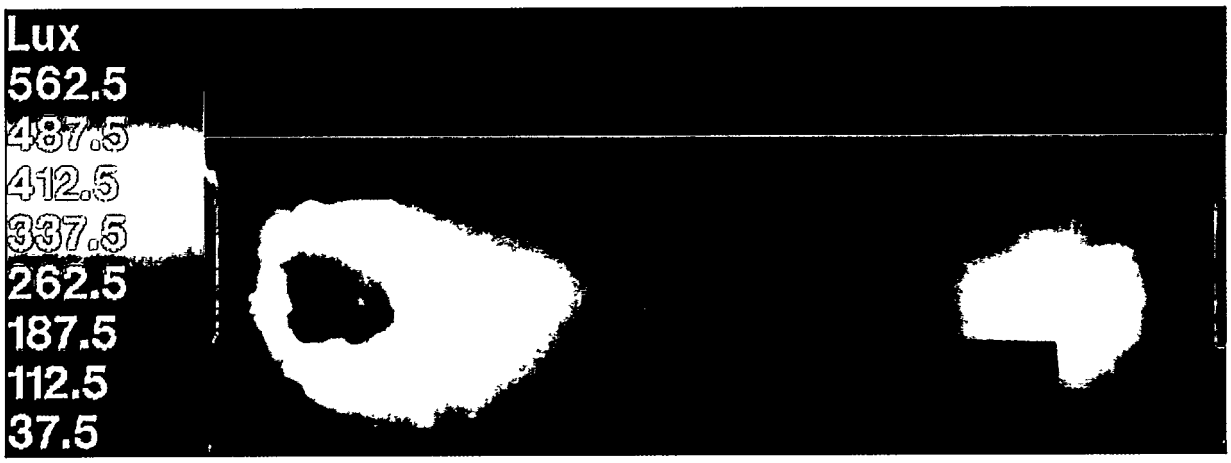


Figure 172, End Wall

Figure 173, Common Wall and Bathroom Wall

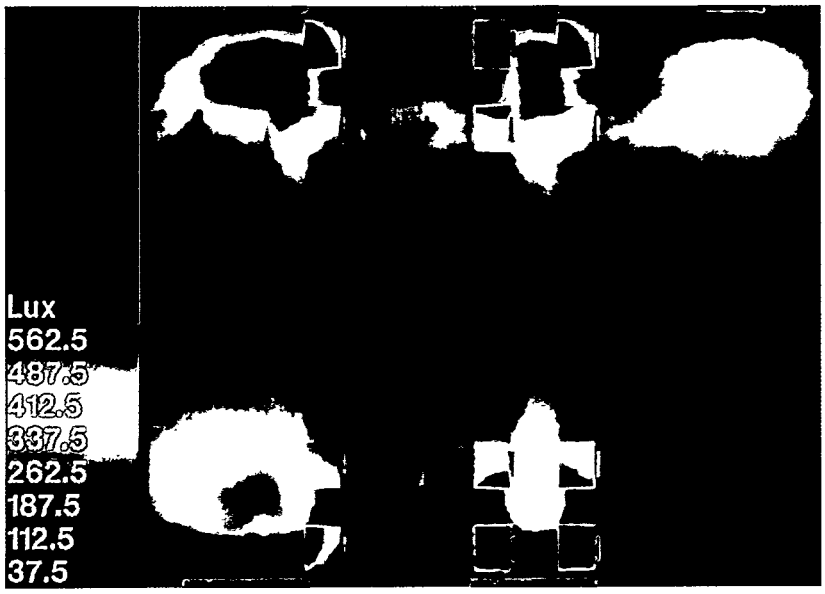


Figure 174, Horizontal Work Surfaces and Floor

2040 Unit

The 2040 illuminance ranges for the three surfaces were:

Window Location	End Wall	Bathroom Wall	Work Surfaces
2' from walls	3 - 30	7 - 35	7
4' from walls	6 - 15	9 - 15	7
6' from walls	4 - 10	10 - 10	7

Figure 175, 2040 Illuminance Ranges in Lux

Illuminance Values for 2040 Units: Cloudy, No Blinds, No Overhangs
One North Window, South Windows 2' from Walls

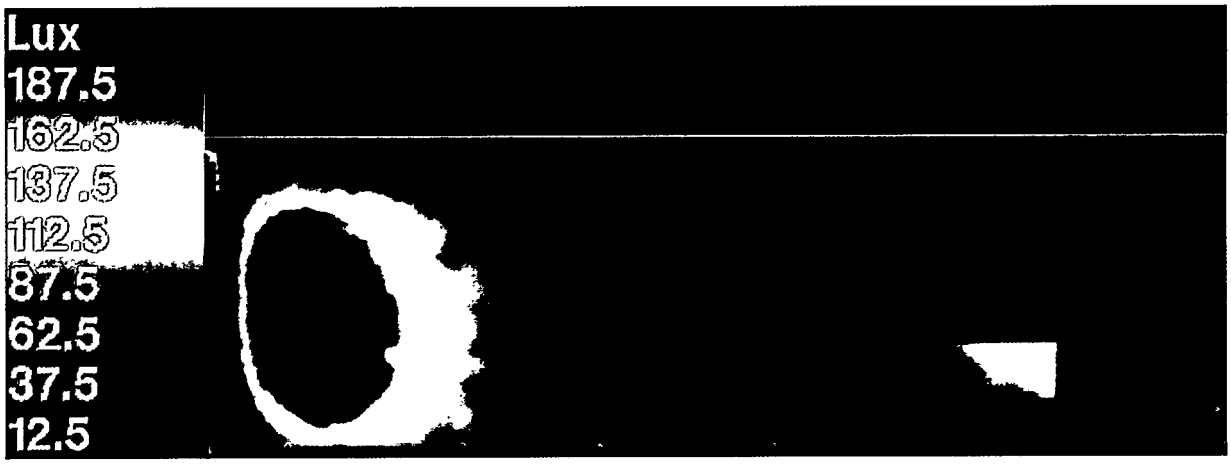


Figure 176, End Wall

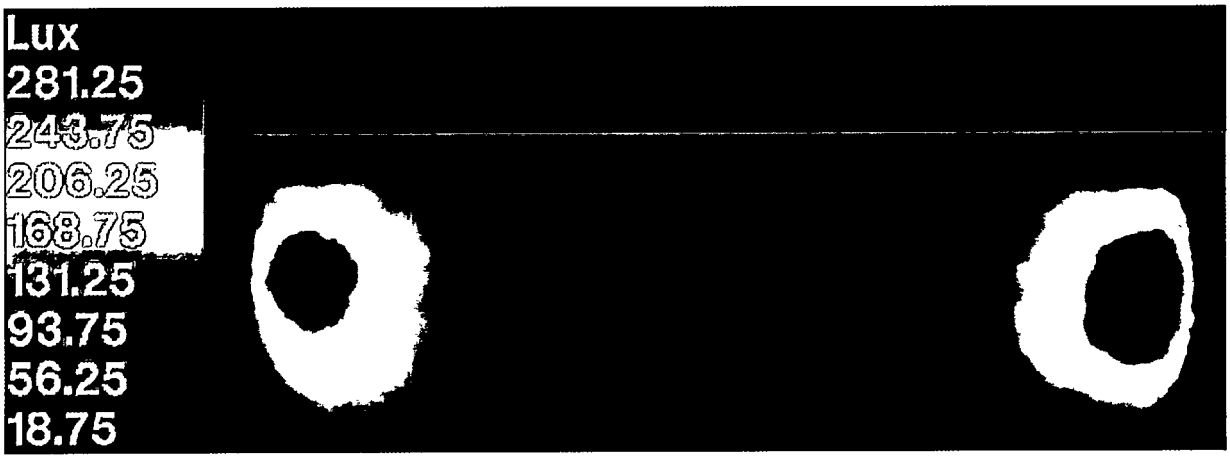


Figure 177, Common Wall and Bathroom Wall

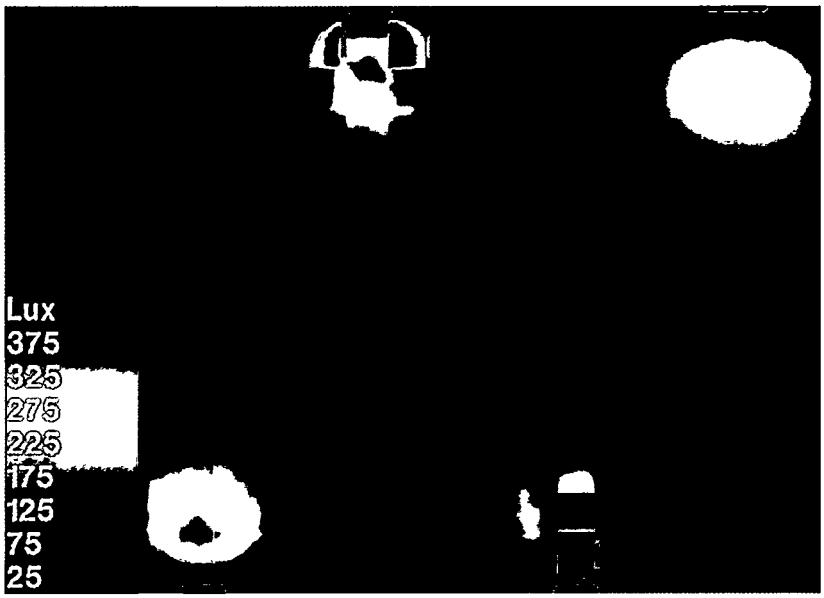


Figure 178, Horizontal Work Surfaces and Floor

Illuminance Values for 2040 Units: Cloudy, No Blinds, No Overhangs
One North Window, South Windows 4' from Walls

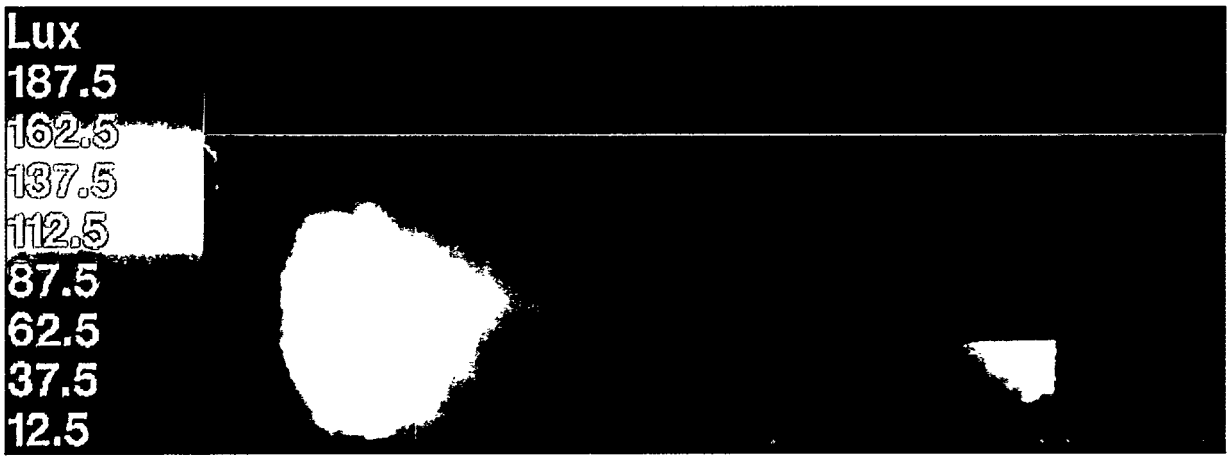


Figure 179, End Wall

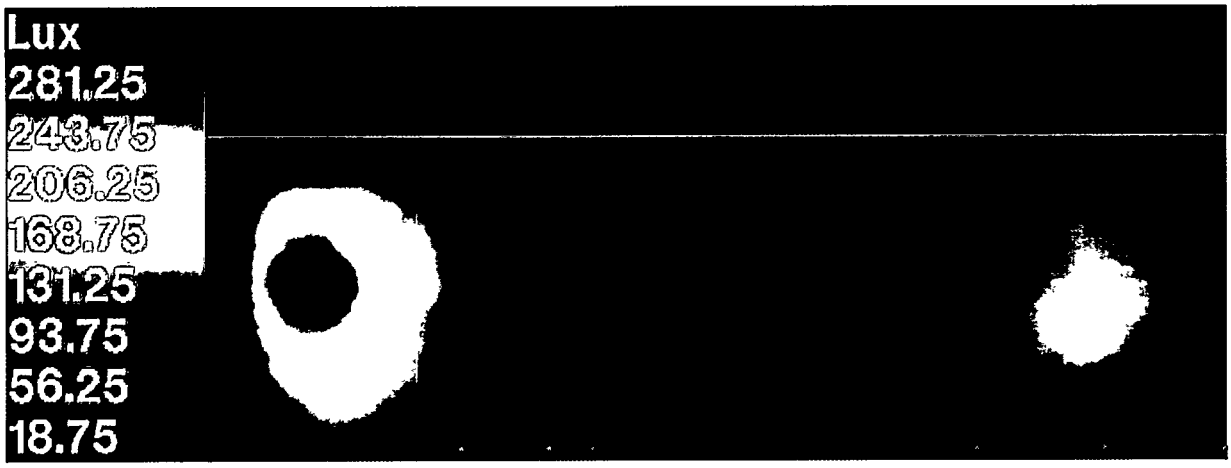


Figure 180, Common Wall and Bathroom Wall

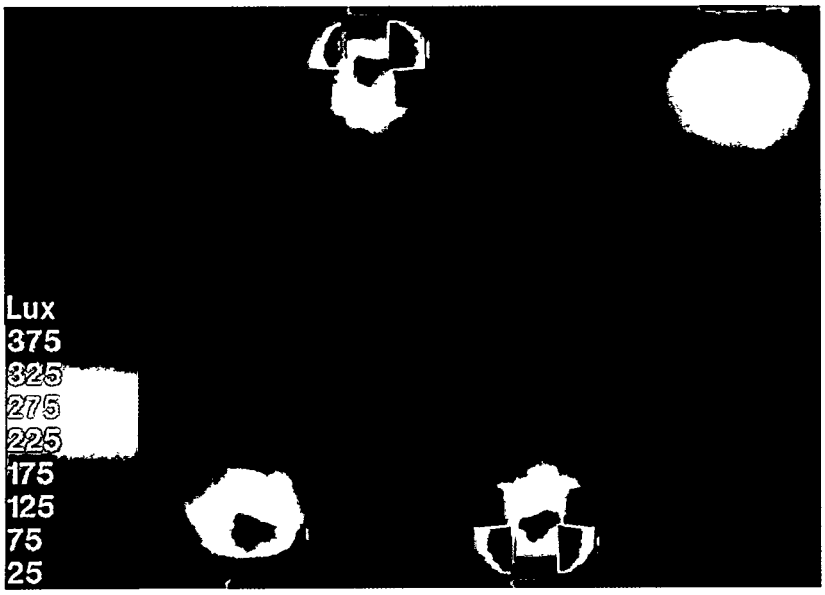


Figure 181, Horizontal Work Surfaces and Floor

Illuminance Values for 2040 Units: Cloudy, No Blinds, No Overhangs
One North Window, South Windows 6' from Walls

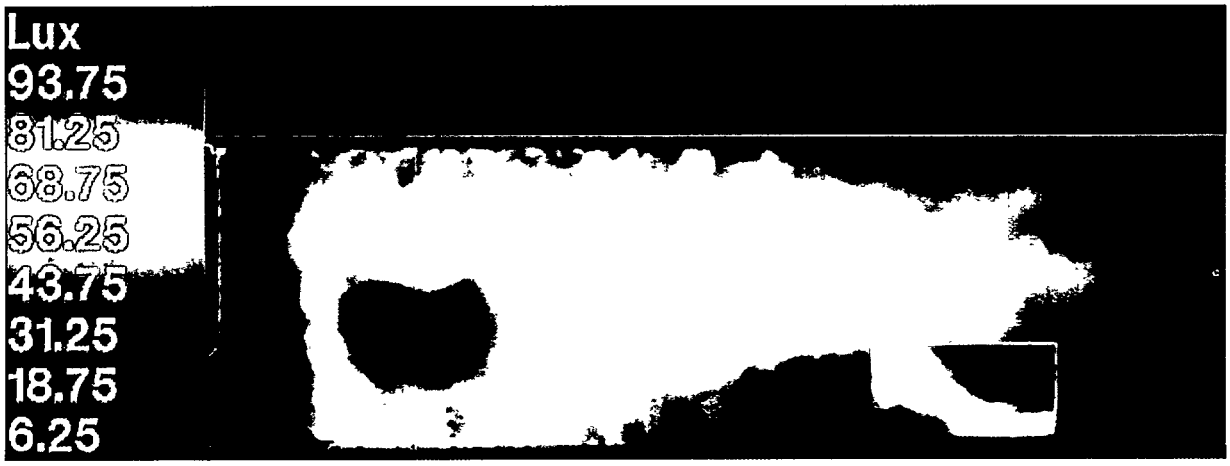


Figure 182, End Wall

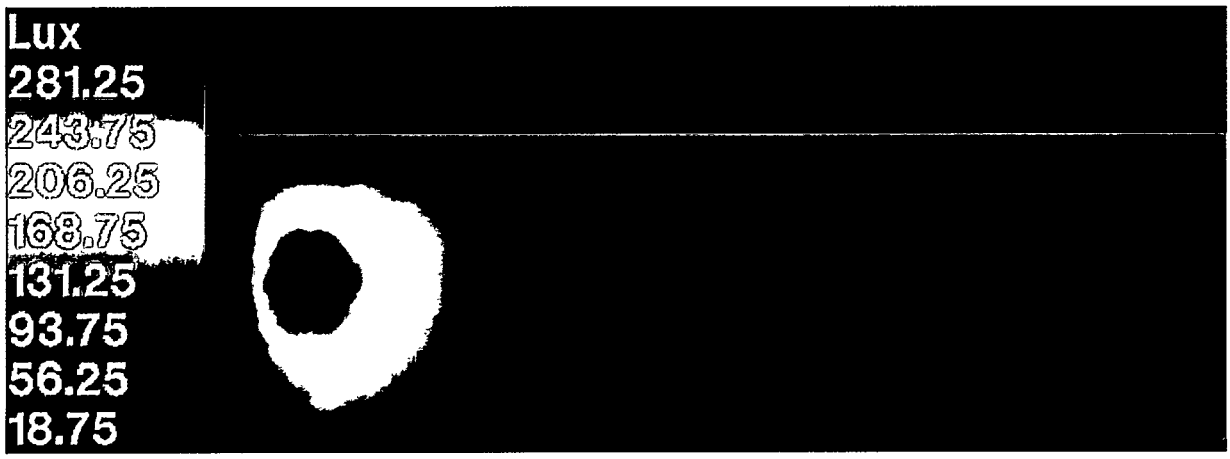


Figure 183, Common Wall and Bathroom Wall

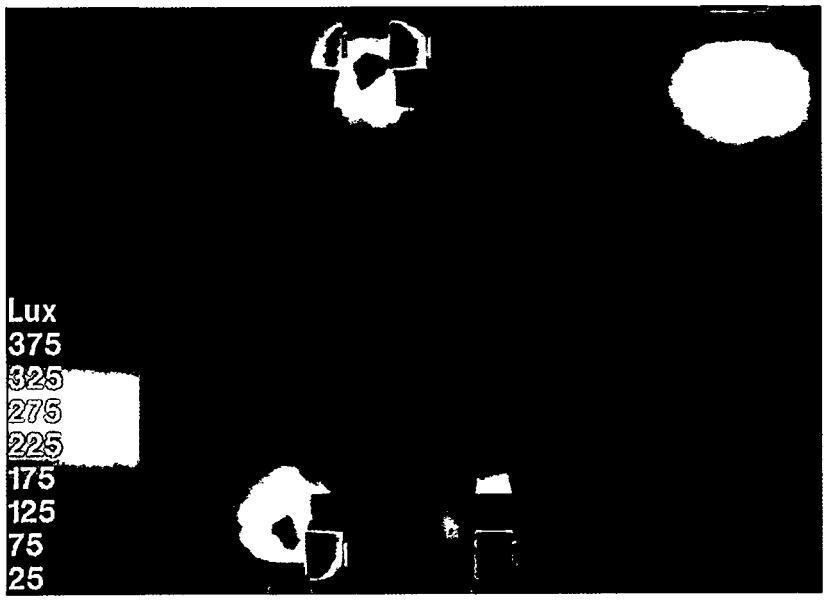


Figure 184, Horizontal Work Surfaces and Floor

4040 Unit

The 4040 illuminance ranges for the three surfaces were:

Window Location	End Wall	Bathroom Wall	Work Surfaces
2' from walls	3 - 40	20 - 50	10
4' from walls	7 - 30	15 - 30	10
North Split	30 - 10 - 40	20-50	10

Figure 185, 4040 Illuminance Ranges in Lux

Illuminance Values for 4040 Units: Cloudy, No Blinds, Overhangs
One North Window, South Windows 2' from Walls

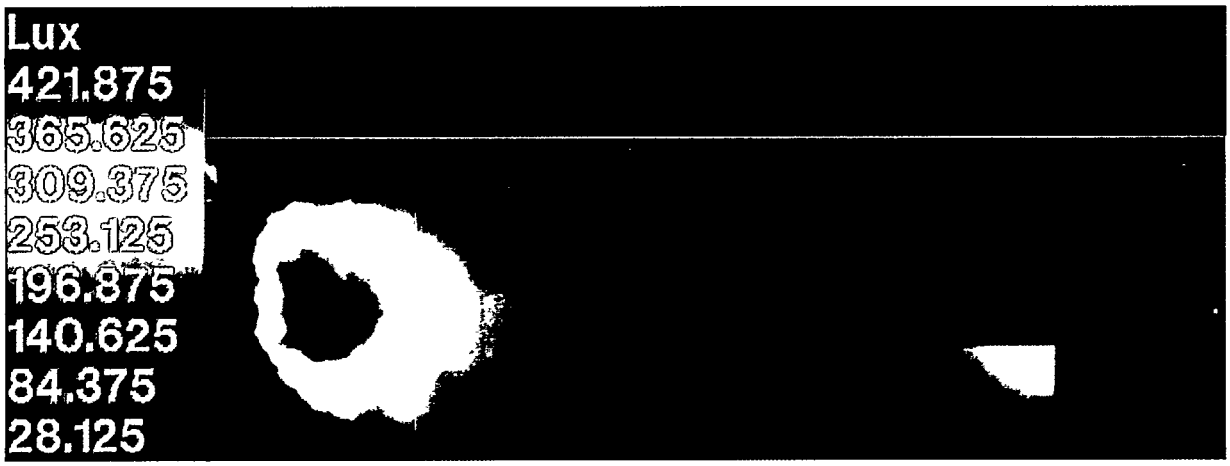


Figure 186, End Wall

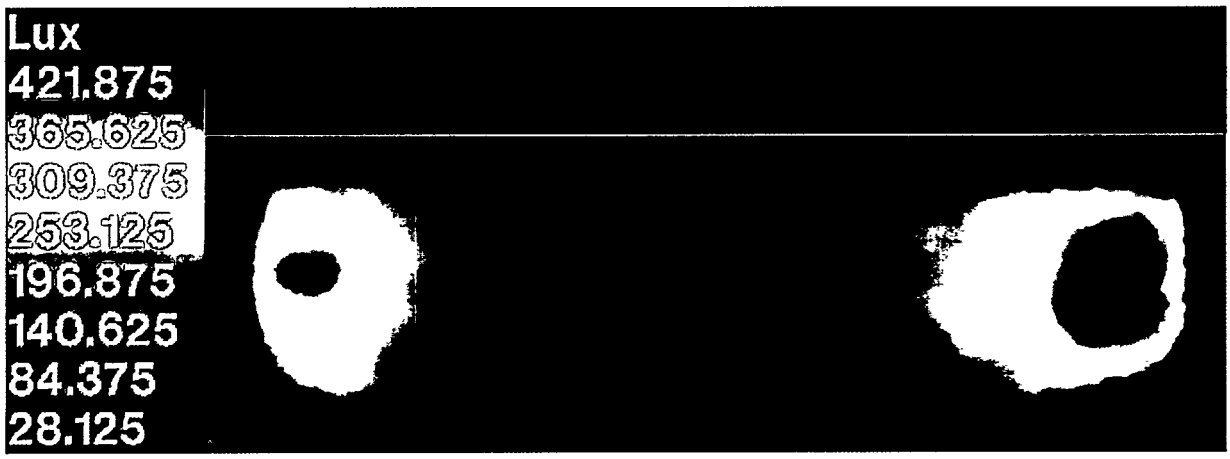


Figure 187, Common Wall and Bathroom Wall

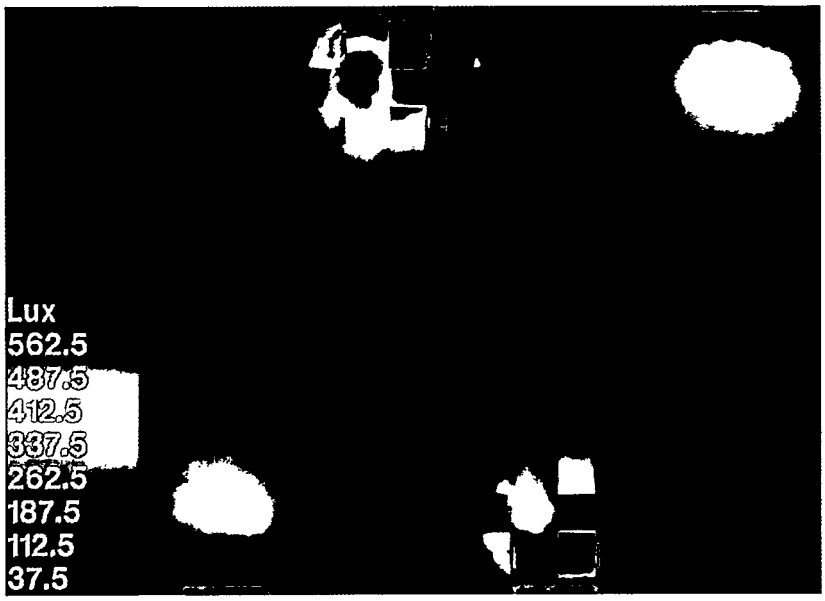


Figure 188, Horizontal Work Surfaces and Floor

Illuminance Values for 4040 Units: Cloudy, No Blinds, Overhangs
One North Window, South Windows 4' from Walls

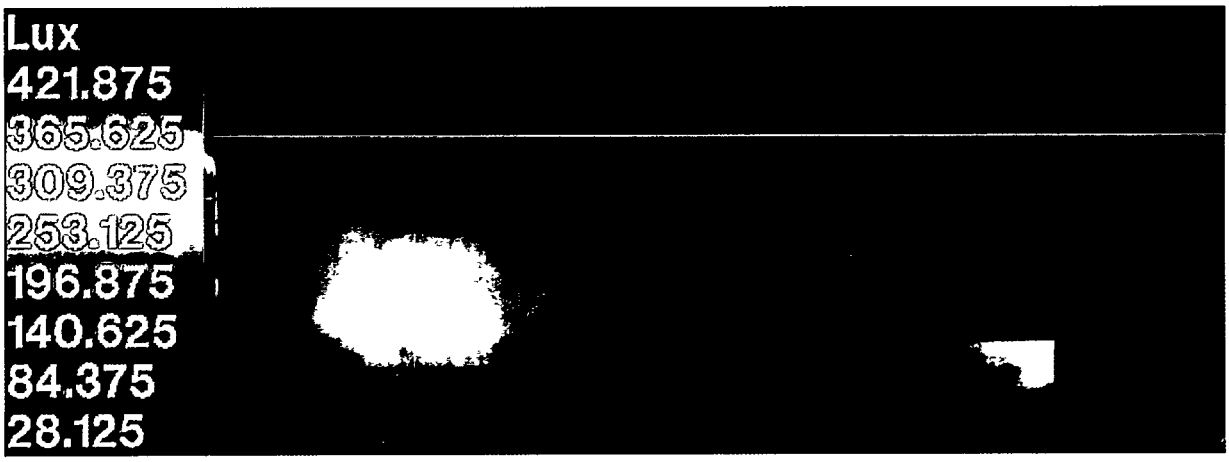


Figure 189, End Wall

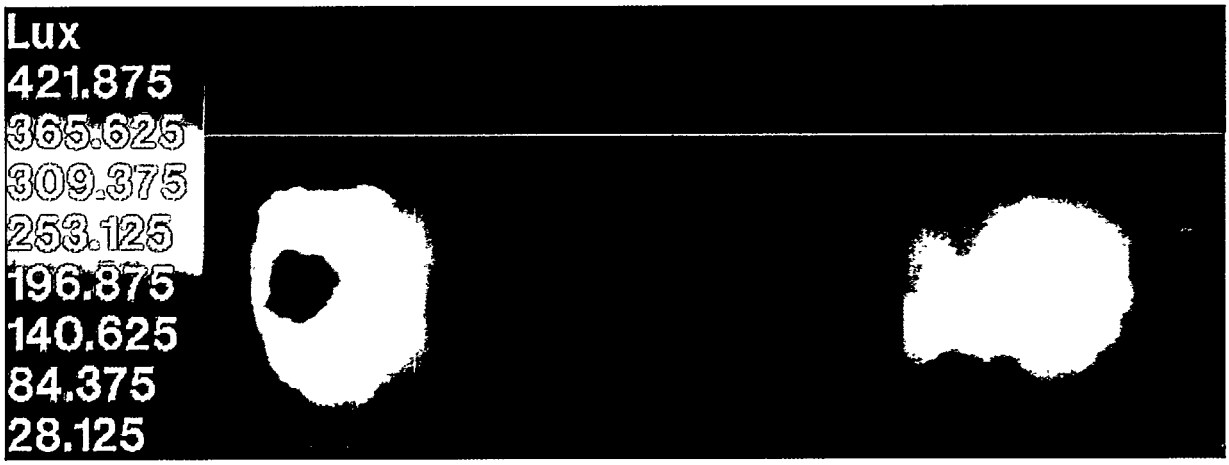


Figure 190, Common Wall and Bathroom Wall

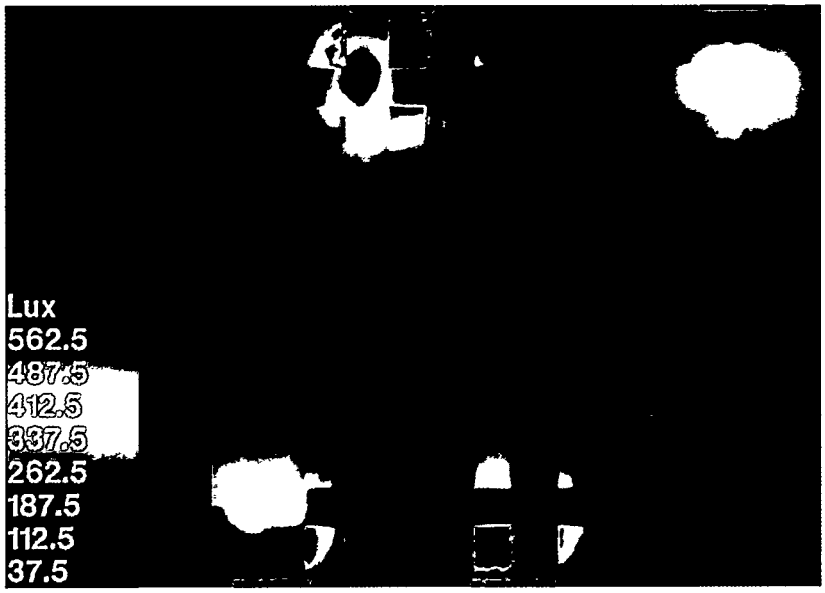


Figure 191, Horizontal Work Surfaces and Floor

Illuminance Values for 4040 Units: Cloudy, No Blinds, Overhangs
Two North Windows 4' and 14' from End Wall, South Windows 2' from Walls

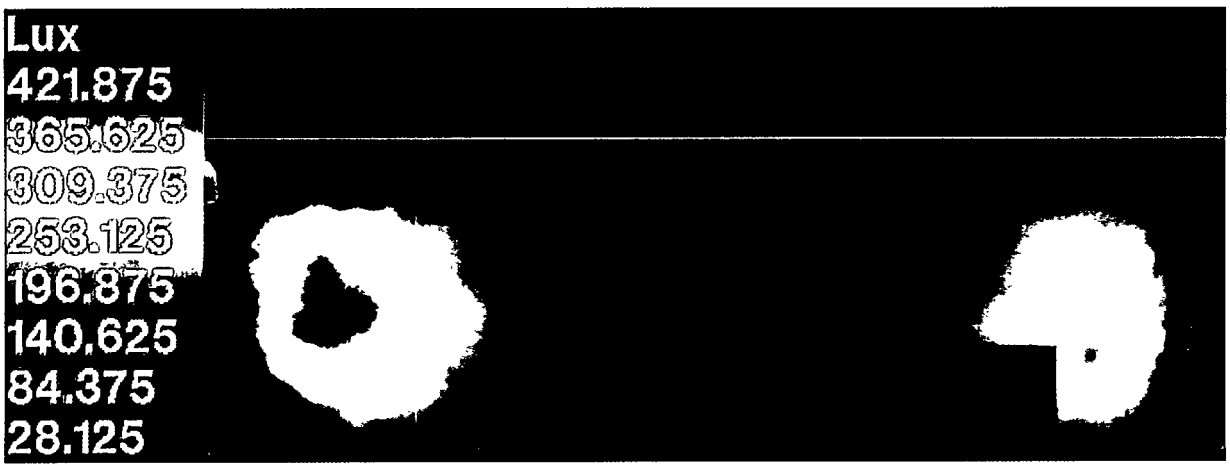


Figure 192, End Wall

Figure 193, Common Wall and Bathroom Wall

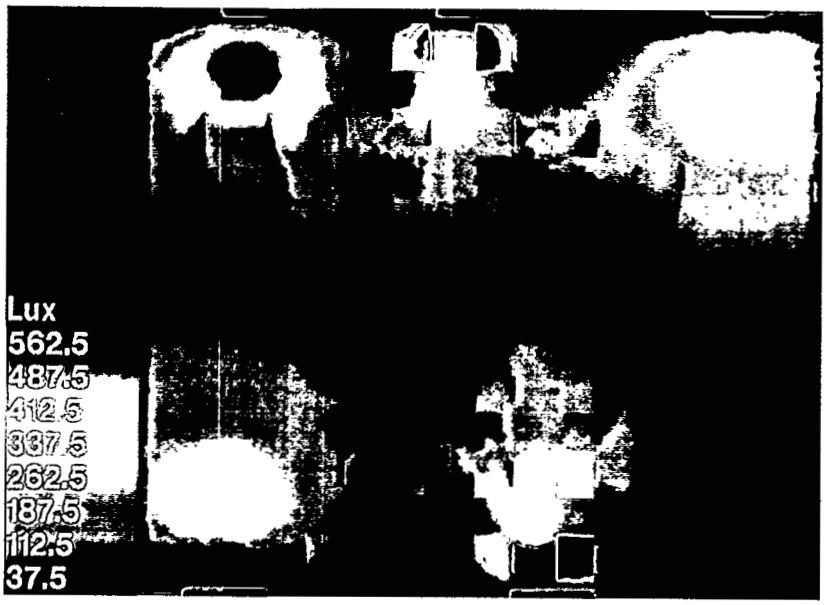


Figure 194, Horizontal Work Surfaces and Floor

8040 Unit

The 8040 illuminance ranges for the three surfaces were:

Window Location	End Wall	Bathroom Wall	Work Surfaces
2' from walls	18 - 60	40 - 60	20
North Split	40 - 30 - 50	40-60	20

Figure 195, 8040 Illuminance Ranges in Lux
(Please see Appendix Volume II for additional 8040 Illuminance Graphics)

Each shading strategy in the 6040 shaded runs provided similar illuminations of approximately 50 Lux (5 fc). Venetian blinds, however, provided the most even distribution upon the two vertical surfaces tested and the horizontal work spaces. Placing the southern windows 2 ft. from the end walls provided the best distribution on those walls. Closer placement produced a sharp gradient in illumination, while further than 2 ft. provided a decrease in overall illumination.

Conclusions

2040 Unit

The best layout for the 2' by 4' windows is 4' from the end wall and 2' from the

bathroom wall on the south and 10' from the end wall on the north:

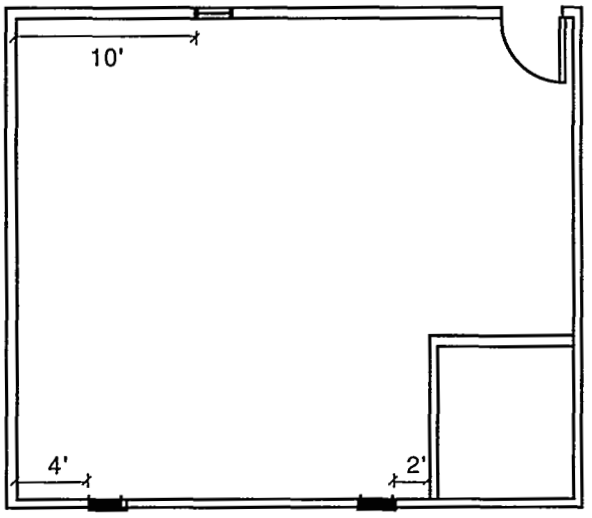


Figure 196, Optimal Window Layout for 2040 Unit

4040 Unit

The best layout for the 4' by 4' window unit is 2' from both the end wall and the bathroom wall on the south and splitting the north window into two 2' by 4' windows and placing them 4' and 14' from the end wall:

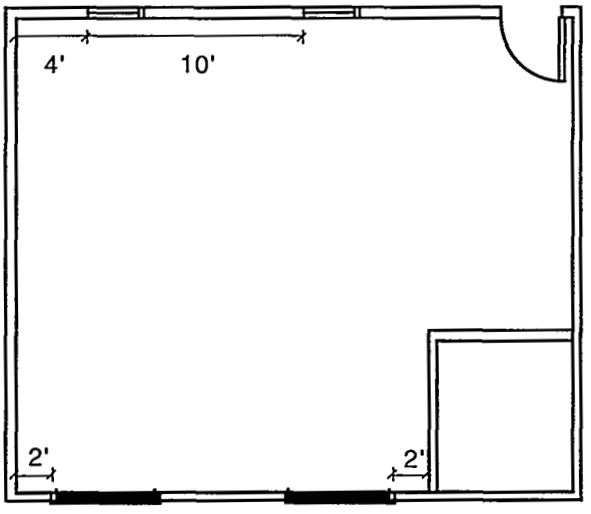


Figure 197, Optimal Window Layout for 4040 Unit

If for other reasons splitting the northern window in this fashion is not acceptable, a single 4' by 4' window may be used 10' from the end wall:

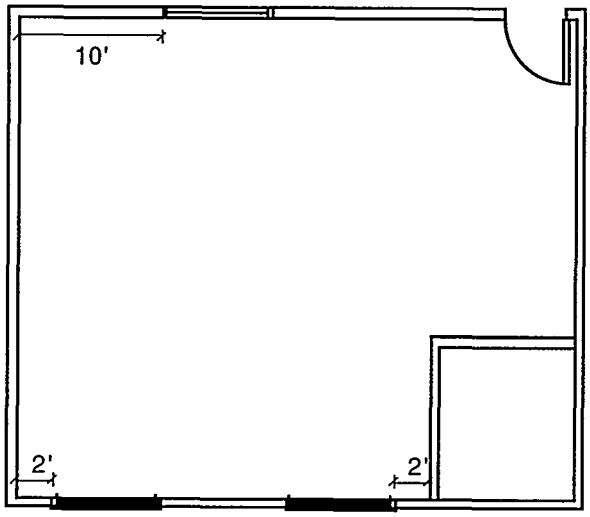


Figure 198, Alternative Window Layout for 4040 Unit

6040 Unit

Placing windows 2 ft. from end walls on the south side and splitting the north window into two 3' by 4' windows and placing them 4' and 16' from the end wall provides the best distribution of light in the 6040 window classroom:

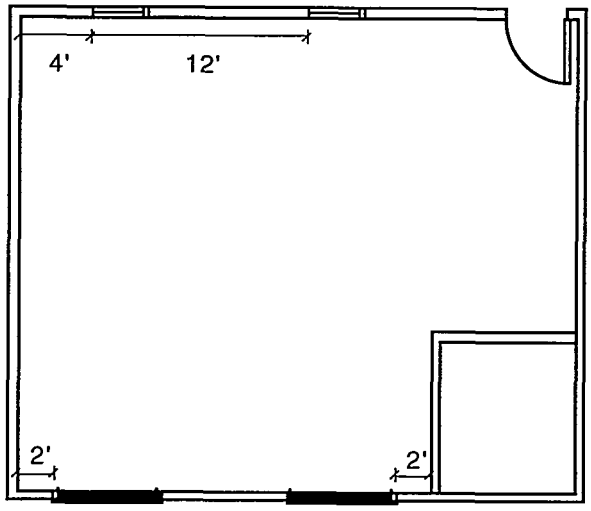


Figure 199, Optimal Window Layout for 6040 Unit

If for other reasons splitting the northern window in this fashion is not acceptable, a single 6' by 4' window may be used 10' from the end wall:

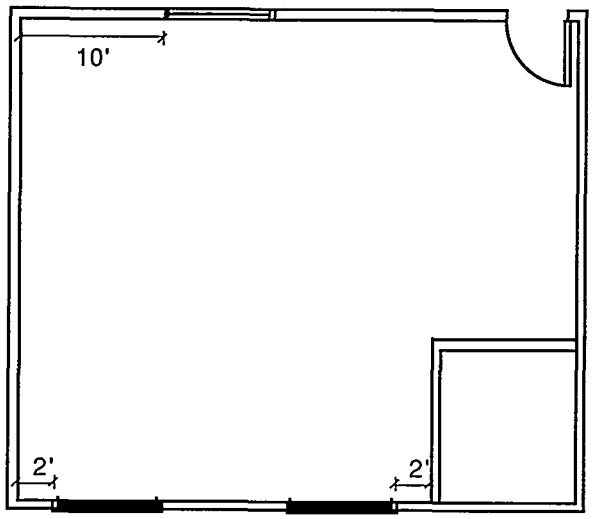


Figure 200, Alternative Window Layout for 6040 Unit

8040 Unit

The best layout for the 8' by 4' window unit is 2' from both the end wall and the bathroom wall on the south and splitting the north window into two 4' by 4' windows and placing them 4' and 14' from the end wall:

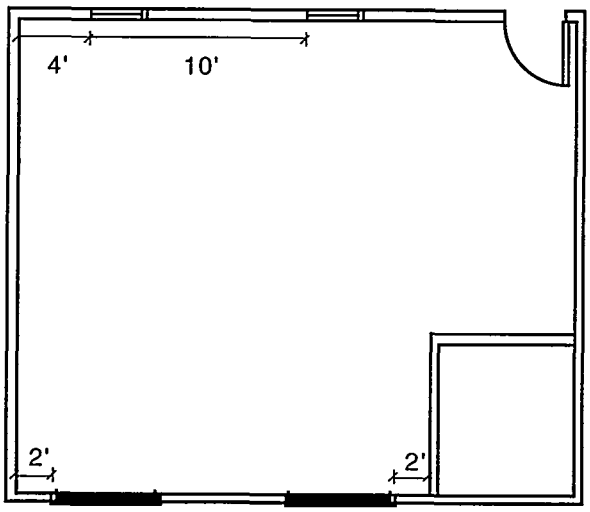


Figure 201, Optimal Window Layout for 8040 Unit

If for other reasons splitting the northern window in this fashion is not acceptable, a single 8' by 4' window may be used 8' from the end wall:

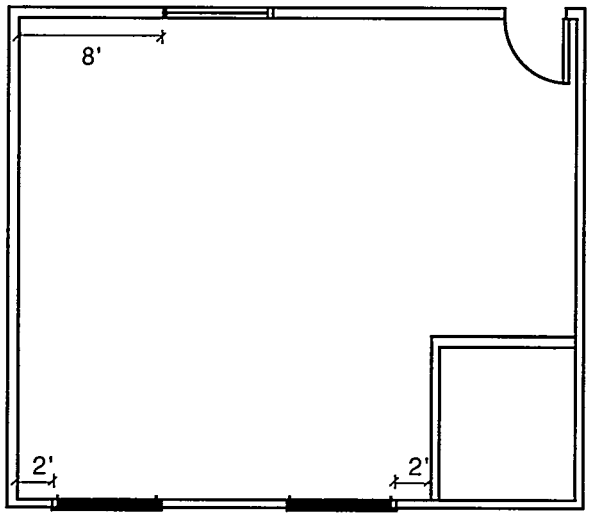


Figure 202, Alternative Window Layout for 8040 Unit

Use of shading devices significantly reduces the illumination within the room. Thus, use of a very flexible shading device such as venetian blinds is desirable so that occupants can fine-tune the blinds to provide a balance between glare and day lighting.

2.1.5.3 Optimize window location for Ventilation and Light

Objective

The objective of this task was to determine the optimum window, tack board, and chalk board locations considering both ventilation and day lighting together.

Methodology/Results

The results of Task: Evaluate Visual Comfort and Task: Fangers Comfort Criteria stated that there was no noticeable effects of slight east/west movements of windows. Glare was most effectively controlled with shading devices while ventilation comfort depended more on window size than window placement. The smaller the windows, the greater the air movement for a given ACH, and the higher the discomfort caused by air motion. Thus, neither of these two tasks played a role in determining window layout.

Task: Illuminance on Vertical Surfaces showed that two north windows provided better illumination on the end walls than did one window while Task: Classroom Air Distribution revealed that the one north window produced better air movement than did two north windows. However, this problem could be rectified by using the front door as a ventilation inlet/outlet. Thus, it was decided to recommend using 2 north windows for all climates using 4040 or larger windows.

Conclusions

The best window layouts are given below. However, when running the DOE2 parametrics there are some general findings to keep in mind:

1. Larger windows provide for greater air changes per hour for a given air speed through the windows. This allows for greater occupant comfort when ventilating with cool outside air (for low outside air speeds).
2. Overhangs provide for better visual comfort.
3. Windows near end walls provide for better illumination on those walls.

2040 Unit

The best layout for the 2' by 4' windows is 4' from the end wall and 2' from the

bathroom wall on the south and 10' from the end wall on the north:

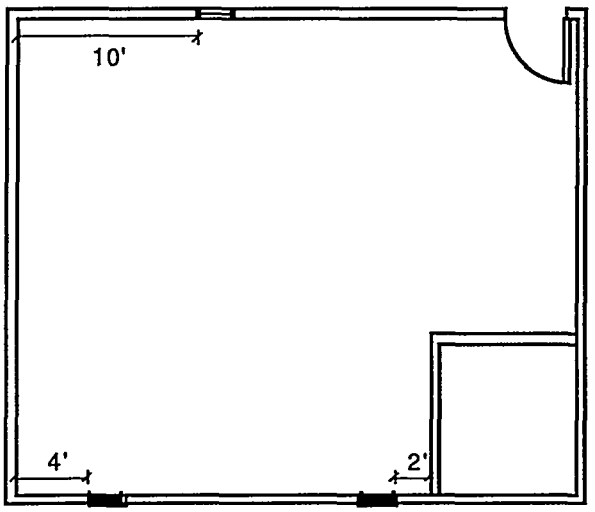


Figure 200, Optimal Window Layout for 2040 Unit

4040 Unit

The best layout for the 4' by 4' window unit is 2' from both the end wall and the bathroom wall on the south and splitting the north window into two 2' by 4' windows and placing them 4' and 14' from the end wall:

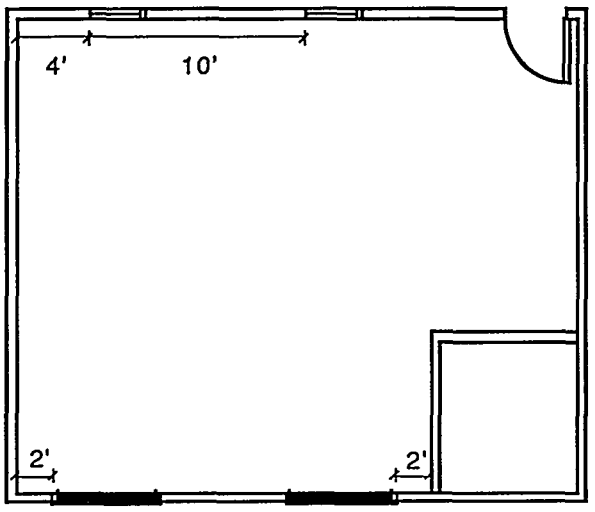


Figure 201, Optimal Window Layout for 4040 Unit

If for other reasons splitting the northern window in this fashion is not acceptable, a single 4' by 4' window may be used 10' from the end wall:

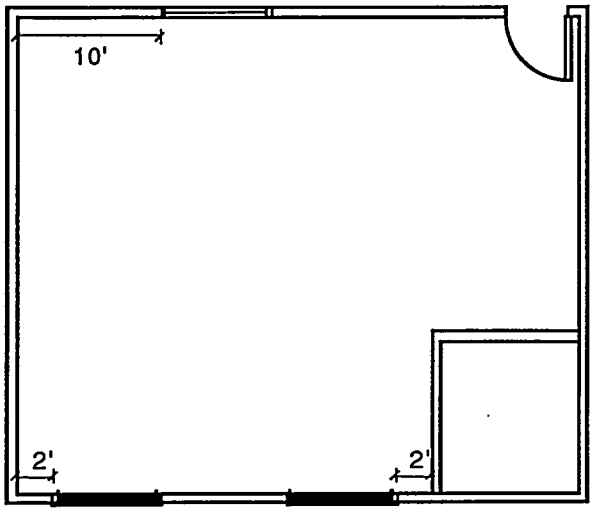


Figure 202, Alternative Window Layout for 4040 Unit

6040 Unit

Placing windows 2 ft. from end walls on the south side and splitting the north window into two 3' by 4' windows and placing them 4' and 16' from the end wall provides the best distribution of light in the 6040 window classroom:

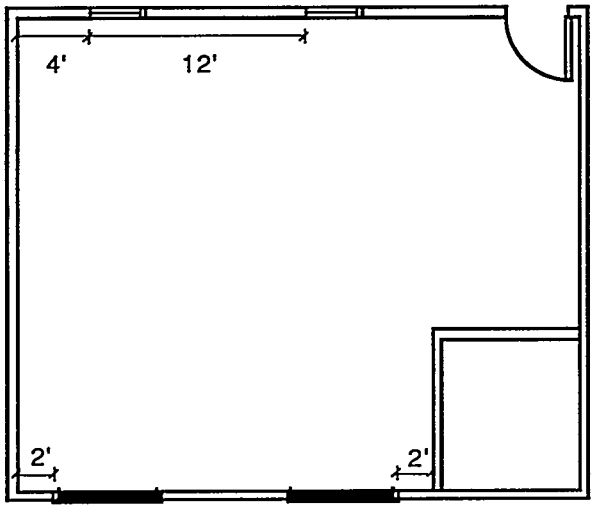


Figure 203, Optimal Window Layout for 6040 Unit

If for other reasons splitting the northern window in this fashion is not acceptable, a single 6' by 4' window may be used 10' from the end wall:

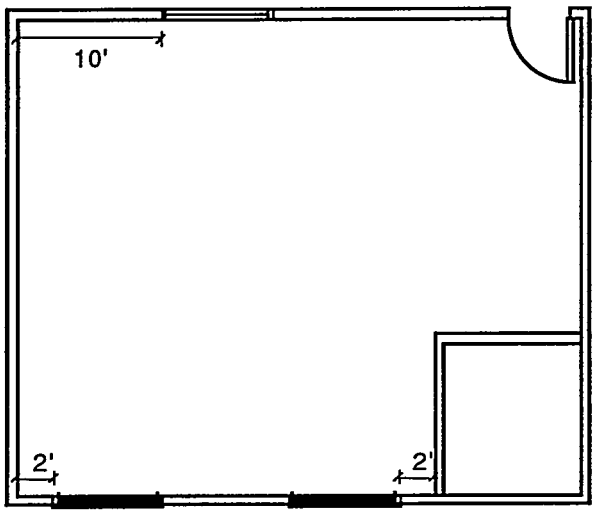


Figure 204, Alternative Window Layout for 6040 Unit

8040 Unit

The best layout for the 8' by 4' window unit is 2' from both the end wall and the bathroom wall on the south and splitting the north window into two 4' by 4' windows and placing them 4' and 14' from the end wall:

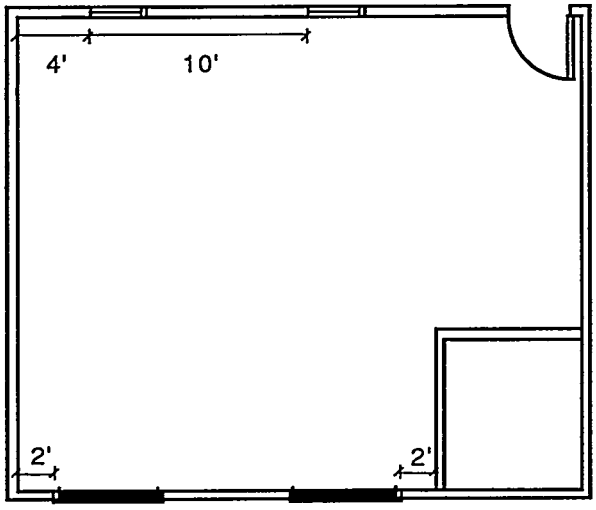


Figure 205, Optimal Window Layout for 8040 Unit

If for other reasons splitting the northern window in this fashion is not acceptable, a single 8' by 4' window may be used 8' from the end wall:

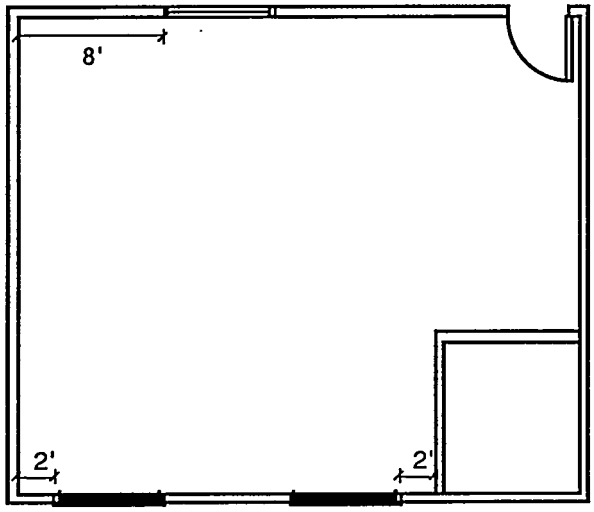


Figure 206, Alternative Window Layout for 8040 Unit

Use of shading devices significantly reduces the illumination within the room. Thus, use of a very flexible shading device such as venetian blinds is desirable so that occupants can fine-tune the blinds to provide a balance between glare and day lighting.

Chalk and Tack Board Locations

From the printouts of Task: Illuminance on Vertical Surfaces, it was determined that the best location for tack boards is the bathroom wall followed by the common wall as close to the half-lite door as possible. The best location for instructional chalk boards was found to be on the end wall beginning approximately 5' from the south wall:

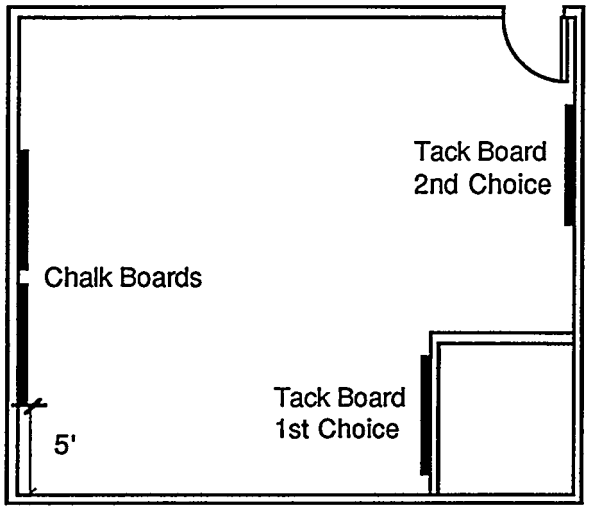


Figure 207, Optimum Chalk and Tack Board Locations

2.2 TECHNICAL OBJECTIVE #2: DESIGN, BUILD, AND TEST COMPONENTS

Design the phase II building based on the results of the simulations and cost to evaluate the buildings performance. Using the data obtained from this phase II building to adjust the simulations and cost if needed.

2.2.1 Manufacturer's Drawings and Specifications

Develop working drawings of the phase II design to be used for to manufacture the full scale building.

2.2.1.1 Architectural drawings and specifications

Objective

The objective of this task is to design detailed architectural drawings and specifications for a component building, build and test all the components associated with energy savings.

Methodology

Production drawings and specifications were created using Modern Building

Systems, Inc.'s standard construction practices following the current Uniform Building Code with Oregon State Amendments, Uniform Mechanical Code with Oregon State Amendments, Uniform Plumbing Code with Oregon State Amendments, National Electric Code, Uniform Fire Code with Oregon State Amendments and the American with Disabilities Act. The component building was designed to compare two different energy efficient features, a solar wall and a heat exchanger.

Results

The plans were created by Modern Building Systems, Inc. and approved by the State of Oregon on January 12, 1998.

2.2.2 Construct component building

Objective

To construct a component test building, install and begin testing.

Methodology

Standard Modern Building Systems, Inc. construction practices were used with modifications to certain energy saving features. The component building was constructed following the current Uniform Building Code with Oregon State Amendments, Uniform Mechanical Code with Oregon State Amendments, Uniform Plumbing Code with Oregon State Amendments, National Electric Code, Uniform Fire Code with Oregon State Amendments and the American with Disabilities Act.

Results

The component building was constructed and site installed at Modern Building Systems, Inc.'s property in Aumsville, Oregon.

2.2.2.2 Videotape and analyze

Objective

Video tape the construction and installation of new components to the modular

classrooms to get a better estimate of labor, material, and suggestions for improvement to reduce either labor or materials. Things that were identified as new to the Modular Building Systems, Inc. (MBS) normal manufacturing process and evaluated with this time study were the heat exchanger and the solar wall. These two components showed advantages in some of the climates based on the computer simulations of energy performance and were incorporated into the full size prototypes for further evaluation.

Methodology

The installation and construction of the heat exchanger and solar wall that was different than MBS's normal manufacturing process was with a hand-held video recorder. The video tapes were then reviewed and the activity of each of the workers for the duration of the construction was summed up.

Results

The 9 foot tall by 32 feet long non transpired solar wall air preheater was mainly constructed by a two person crew with assistance at times by two other employees. The total time of construction was 18.6 man-hours not including breaks. The heat exchanger consisting of a 100 feet of 18 inch R8 flexible ducting and 12 inch non insulated flexible ducting was mainly constructed by a two person crew with assistance at times by another employee. The total time of construction was 16.5 man-hours not including breaks.

Conclusions

Since this was the first time these crews constructed these components there would be an expected improvement in the amount of time required to construct them and the quality of construction when this task is done again.

2.2.3 Analyze results and adjust simulations

2.3 TECHNICAL OBJECTIVE #3: DESIGN, BUILD, AND TEST PROTOTYPES

With the results of previous tasks to develop the phase II design for each of the regions a complete design specific for each region was developed. A number of

school districts were contacted and two phase II buildings were built and installed. Actual cost of the building was collected. At the site the phase II building was tested to evaluate its as built performance with the projected performance. Long term monitoring was established for the building to evaluate its performance over time.

2.3.1 Identify school districts

Objective

To identify as many school districts in Modern Building Systems, Inc.'s marketing areas that are willing to purchase an energy efficient prototype building.

Methodology

Send out a mass mailer to all public and private schools in Modern Building Systems, Inc.'s marketing area. Follow up with phone calls to explain energy saving features and their benefit to the school district.

Results

To date, St. Helens School District purchased one building. The school district has agreed to do monitoring for one year.

2.3.2 Manufacturer drawings and specifications

Objective

The objective of this task is to create detailed construction drawings for all of the prototype buildings.

Methodology

Create production drawings using Modern Building Systems, Inc.'s standard construction practices, following the Uniform Building Code, Uniform Mechanical Code, Uniform Plumbing Code, National Electric Code, Uniform Fire Code and the American with Disabilities Act.

Results and Conclusions
Modern Building Systems, Inc. created construction drawings for all of the seven climate zones. The plans were created following all current applicable codes.

2.3.2.1 Architectural drawings and specifications

Objective
The objective of this task is to create detailed architectural drawings for all of the prototype buildings.

Methodology
Create production drawings using Modern Building Systems, Inc.'s standard construction practices, following the Uniform Building Code, Uniform Mechanical Code, Uniform Plumbing Code, National Electric Code, Uniform Fire Code and the American with Disabilities Act.

Results
Modern Building Systems, Inc. created production drawings for the seven climate zones. The plans were created following all current applicable codes.

2.3.2.2 Testing drawings and specifications

2.3.3 Construct prototypes

Anticipate construction using the inputs listed above to develop detailed construction drawings. Integrate the design, schedules, construction/ manufacturing drawings and construction of prototypes. Verify UBC/ADA codes and develop the specified tasks. Analyze the results and construct the baseline prototypes.

2.3.3.1 Construct

Site #1: Astoria
Site #2: Bakersfield
Site #3: Spokane

Site #4: Honolulu
Site #5: Fairbanks
Data missing from MBS

2.3.3.2 Shipping Baseline Tests

Decided that it was more hassle than what it was worth to set up the buildings complete. Test the building. Then dismantle the building for shipping. Then repeat the testing on site for the short term monitoring. The review of the Sheldon buildings did not show evidence of insulation shifting during transportation so it was assumed that this was true in general.

2.3.3.3 Ship and install

Missing MBS

2.3.3.4 Revise cost estimate

Missing MBS

2.3.4 Testing and short term monitoring

2.3.4.1 Site #1: Component

2.3.4.1.1 Infrared Imaging–Solar Wall Air Collector

The non-transpired solar air collector on the building preheats the outside air being brought into the classroom thus saving energy in heating climates. The effectiveness is less than a transpired solar air collector.

The solar wall air collector consists of dark bronze corrugated sheet metal held out from the south wall three inches by supports. The top and bottom of the wall is capped and sealed. An outside air intake is in the lower corner while diagonally opposite an exhaust is in the upper corner. The solar wall is 9 feet tall and 32 feet wide mounted on the south side of the east classroom. By measuring the temperature going into the collector and the temperature of the air being expelled

from the collector, varying the flow rate of air through the collector by a variable speed blower, and measuring the insolation levels falling on the collector surface we where able to establish an effectiveness for the collector at different flow rates.

The monitored data tended to be scattered due to partly cloudy days causing unsteady insolation levels and thermal lag of the building materials. The effectiveness reported is also inflated since not all the heat being claimed by the collector is coming from the sun, some is due to envelope losses through the wall the collector is on and being reclaimed by the collector flow.

flow rate (cfm)	effectiveness	standard deviation
136	13%	9%
312	29%	14%
333	53%	19%
515	60%	53%

Figure 2.3-1, Measured effectiveness of the non transpired solar wall air collector

2.3.4.1.2 Fan Pressurization–Blower Door Testing of Component Building

Objective

By performing a fan depressurization test we will be able to quantify the amount of infiltration for the component test building located at the factory in Aumsville Oregon. By performing a smoke leakage test we will be able to find out where the leaks are and a relative flow rate for each of the leaks. Air infiltration accounts for a significant portion of the thermal space conditioning load, affects the occupants comfort, and indoor air quality.

Methodology

Infiltration testing was performed by fan depressurization, blower door testing, according to ASTM E779-74 with some modifications (we did not record the relative humidity, barometric pressure, and we tested the building in a closed and open conditions). The test data for a variety of conditions was least squares fit to

(1) $\log_{10}(\text{flow})=\text{slope}*\log_{10}(\text{house pressure difference}) + \text{intercept}$

and the following parameters of the buildings performance were derived.: CFM_4, CFM_{10}, ELA, EqLA, CFM_{50}, ACH_{50}, $ACH_{50}/20$, and ACH_{50}/N. CFM_4 is the flow rate into the building caused by a 4 pascal pressure imbalance. CFM_{10} is the flow rate into the building caused by a 10 pascal pressure imbalance. Effective Leakage Area (ELA) is the LBL infiltration model to estimate the natural infiltration. The ELA may be physically interpreted as the area in in^2 of a specially shaped bell mouthed nozzle that at a pressure of 4 pascals would leak the same as all the house leaks at 4 pascals.

(2) ELA=.2835 x cfm at a building pressure difference of 4 Pa.

Equivalent Leakage Area (EqLA), developed by National Research Council of Canada, is the area in in^2 of a round shaped orifice that at a pressure of 10 Pa would leak the same as all the building leaks at 10 pascals.

(3) EqLA=.2939 x cfm at a building pressure difference of 10 Pa.

ACH_{50} is a general measure of the house tightness. It is the number of air changes the house would experience with a 50 Pa pressure difference. $ACH_{50}/20$ is an estimate of the average natural infiltration rate developed by Persily. ACH_{50}/N is an estimate of the average natural infiltration rate developed by Sherman at LBL. It is a derived theoretical correlation between pressure tests at 50 pascals and annual average infiltration rates. N is a climate factor to reflect the influence of the environment that the building is in.

(4) N=CxHxSxL with C being a climate factor being a function of annual temperature and wind, H being a building height correction factor, S being a wind shielding correction factor, and L being a leakiness correction factor.

While depressurizing the building to -50 pascals air leakage paths were established using a titanium tetrachloride smoke pencil. Major and minor leakage areas of infiltration were noted based on visual examination of the speed and quantity of the smoke dispersion.

Results

Two sets tests were performed on 4/11/98 and 11/14/98. The first set of test were performed before the HVAC system was installed and holes in the wall where the solar wall air collection was to take place being masked off. The building proved to be relatively tight with the ACH50 being 7.28±0.19, the ELA being 91.2±2.2 in^2, and

the ACH_{50}/N being 0.25±0.05. During the second part of the test, the smoke visualization, the location a number of leaks in the ceiling plane where the T-bar ceiling support wires penetrated the vapor barrier and at the marriage of the ridge and floor beam. It is a normal installation practice of MBS to seal these leaks upon completion of the installation of the building so it was decided to correct these problem areas and retest the building. Other strong leaks occurred at the door frame, some of the electrical outlets, and in the mechanical room wall which is unfinished for these tests.

For the second set of tests the leaks n the ceiling plane where the T-bar ceiling support wires penetrated the vapor barrier and at the marriage of the ridge beam had been taped up while the HVAC system was installed. First a measure of the building with the damper closed on the solar wall, the return grill ,diffusers, and building pressure relief vents masked off. The building again proved to be relatively tight with the average of two sets of measurements resulting in the ACH_{50} being 6.34±0.63, the ELA being 61.7±5.4 in^2, and the ACH_{50}/N being 0.22±0.05. Next a measure of the building with the damper closed on the solar wall, but the masking of the return grill ,diffusers, and building pressure relief vents removed. The building again proved to be relatively tight with the ACH_{50} being 7.20±0.11, the ELA being 90.8±1.0 in^2, and the ACH50/N being 0.24±0.05. More details are in the appendix.

type	make	model	accuracy	range
blower door	The Energy Conservatory	3	-	-
digital manometer	The Energy Conservatory	DG-3	±1% or ±2 counts whichever is greater	0-2,000 Pa 100-6,995 cfm
hand held thermo-anemometer	Extech Instruments	407112	±(2%+1digit) ±1.5 °F	0.9-55.9 mph 32-140 °F
smoke pencil	Hill Incorporated	titanium tetrachloride (T-T Puffer)	-	-

Figure 2.3-2, Testing Equipment Used for Fan Pressurization

Conclusions

The building proved to be relatively tight with an ACH_{50} of 7.20±0.11. With an estimated infiltration rate (ACH_{50}/N) being 0.24±0.05 there is a need to bring in additional outside air to maintain occupants comfort. The building could be tightened up further relatively easily by finishing the mechanical room (the lack of finish in the mechanical room is not a normal practice of MBS and was only done here since it was a component testing building) and sealing the marriage of the floor beam. Additional sealing could be done around all electrical outlets and the doors.

2.3.4.1.3 Lighting Study

Objective

Evaluate the amount of daylight and electric lighting, from 3 tube 32 watt T8 fluorescent fixtures, used in classroom.

Methodology

Using a datalogger with photometric sensors we measured the irradiance at 1 square foot intervals of the interior of the classroom at a height of 31 inches from the finished floor. The data collection was on 4/4/98, 5/9/98, and 6/26/98. The fluorescent lamps are in the suspended ceiling 96 inches above the finished floor. One of the photometric sensors was located on the weather station located on the roof of the building, mounted in the horizontal position. Measurements where also taken on the vertical surfaces at 60 inches from the finished floor in center of each east and west wall. For the electric lighting study, since the testing was done during the day, the windows where masked with black construction paper to simulate the worst case since the black construction paper has a lower reflectance than either the venetian blinds or the windows them selves.
Data was sampled every 6 seconds and averaged every 18 to 60 seconds depending on length of time held at the location.

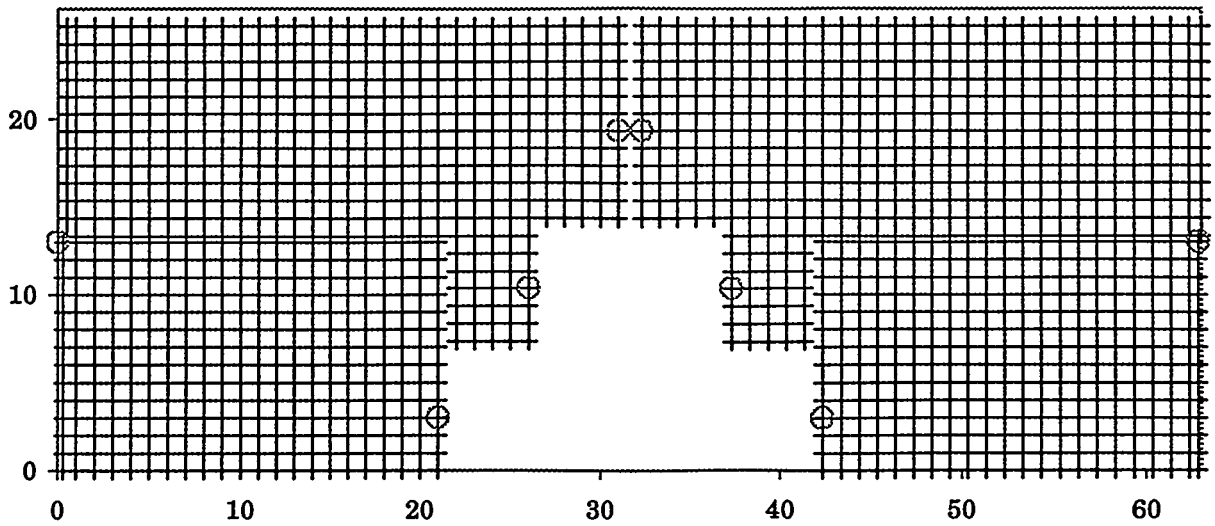


Figure 2.3-3, Building Drawing with Lighting Grid

type	make	model	accuracy	range
datalogger	Campbell Scientific	CR10	-	-
expansion peripheral	Campbell Scientific	AM416	-	-
photometric	LI-COR	LI-PZ210	5%	0 to 100 klux
East room glazing		3 at 2x4 + 1 half lite door	-	-
West room glazing		3 at 6x4 + 1 half lite door	-	-
East room fixtures	GE	Star Coat F32T8-SP35	-	-
West room fixtures	Sylvania	Octron 4100K F032/741 32W	-	-

Figure 2.3-4, Testing Equipment for Lighting Study

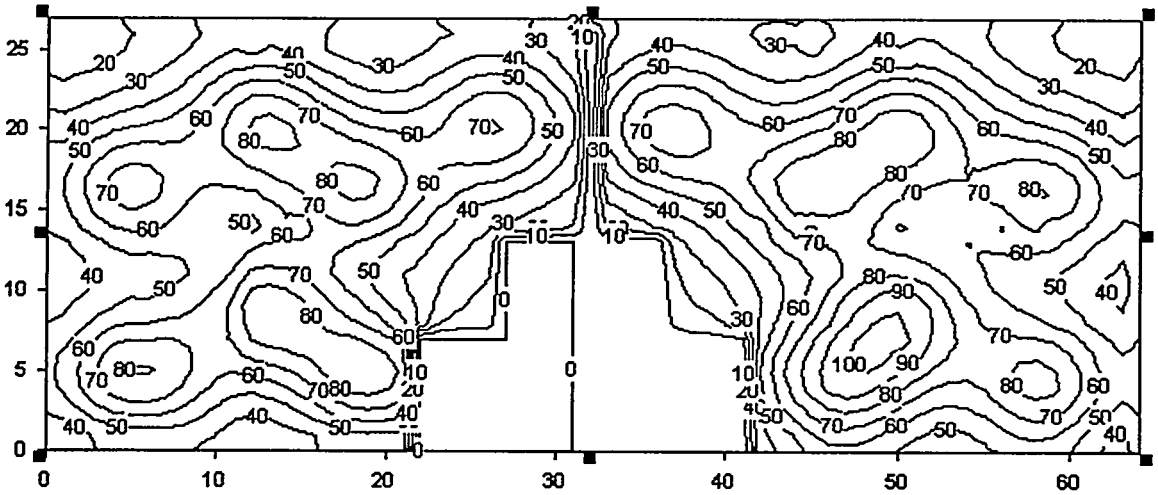


Figure 2.3-5, Electric Lighting Contour in Footcandles as is

Results

Note that the room with the larger, 6x4, windows has a lower lighting distribution, 43% less than 50 foot candles, than the smaller, 2x4, windows, 32% less than 50 foot candles. However the area most likely to have desks is at 50 foot candles or greater when the lights are on.

There is more lighting at desk height in the east classroom where the smaller windows are used. If the space is used with visual display terminal, such as computer then the locations with higher lighting levels may cause glare problems.

Electric lighting level	West Classroom	East Classroom
maximum foot candles	88	107
minimum foot candles	10	12
average foot candles	52	58
percent of the classroom greater than 50 foot candles	57%	68%

Figure 2.3-6, Electric Lighting Level, Horizontal

The lighting at the vertical walls may not be adequate depending on the tasks at the walls. For example Illumination Engineering Society (pg. 543) recommends that walls be not less than five times the task luminance and the chalk board area be not less than one third of the task luminance, thus at a 50 foot candles task luminance the walls should be greater than 10 foot candles and the chalk board area 17 foot candles.

Electric lighting level	West Classroom	East Classroom
large wall	23	18
bathroom wall	64	24
mechanical room wall	17	14
partition wall	29	27

Figure 2.3-7, Electric Lighting Level, Vertical

There is more daylighting when the larger windows are used.

Daylight factor	West Classroom	East Classroom
maximum	14.4%	9.2%
minimum	0.1%	0.1%
average	1.9%	0.6%

Figure 2.3-8, Daylight Factors

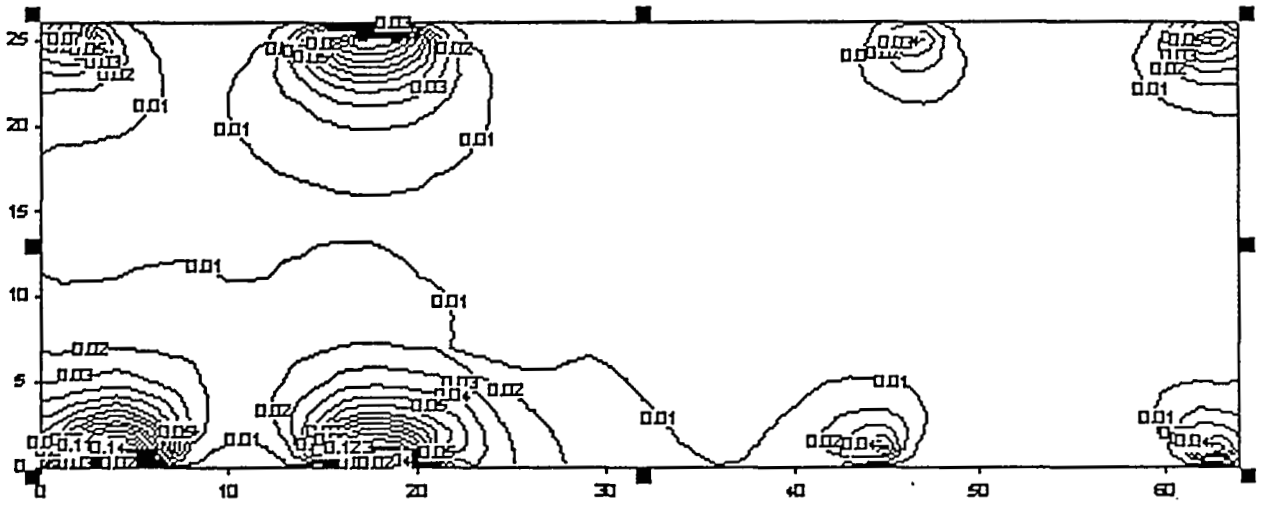


Figure 2.3-9, Daylight Contour of Building, 0.01=1% Daylight Factor

The continuous dimming lights in the west classroom worked well and where unobtrusive while the step dimming in the east classroom worked well it was disruptive every time the lights stepped up or down.

Conclusions

The lay out of these luminaries does give 50 foot candles, or more, of light at desk level for most of the places where desks would be located. The lighting at the vertical walls may not be adequate depending on the tasks at the walls. For example Illumination Engineering Society (pg. 543) recommends that walls be not less than five times the task luminance and the chalk board area be not less than one third of the task luminance, thus at a 50 foot candles task luminance the walls should be greater than 10 foot candles and the chalk board area 17 foot candles. With 6x4 windows perimeter dimming could work however the 2x4 windows do not have as much penetration into the space to make it cost effective for the classroom.

2.3.4.1.4 Coheating

Objective

Determine the overall thermal transmittance (UA) of the component building and the three rooms of the building with a coheating test.

Methodology

The building was divided into three zones (East classroom, West classroom, and Mechanical room) and each monitored separately then the entire building was monitored. Thermocouples where suspended form the ceiling four feet above the floor and two feet from the exterior wall. Two thermocouples per exterior wall where wired in parallel to recorded the average temperature at that location. These thermocouples monitored the room temperature and controlled the electric resistance heaters via the datalogger and a relay. The outdoor temperature, wind speed and wind direction was recorded by a weather station located on the roof of the building. Monitoring was performed for seven consecutive nights for each of the four tests with the exception of the full building test in which the test was run for 14 consecutive nights. The temperature in each zone was maintained at 75 degrees Fahrenheit while the power consumption was monitored. Data was monitored every 3 seconds and the average was recorded every 6 minutes. The night time data, from midnight to civil twilight, was analyzed in the following ways to evaluate the thermal transmittance:
the three hour periods prior to civil twilight and the periods when the temperature difference between the building and the outside (delta T) was the most stabile for a three hour period. The thermal transmittance was calculated by UA=Q/delta T. Attempts to remove infiltration from the data was accomplished two ways. The first was to use the blower door results for the natural infiltration rate ACH50/N and remove that portion. The second is to use the blower door results for the ELA and the monitored wind speed data. These results where compared to the theoretical UA values which where determined by possible conduction paths through the building envelope. The U values for each of the paths where then multiplied by there corresponding areas. The sum of these various paths is the UA for each of the zones or building.

type	make	model	accuracy	range
datalogger	Campbell Scientific	CR10	-	-
expansion peripheral	Campbell Scientific	AM416	-	-
wind speed and direction	Campbell Scientific	?	?	?
temperature	Pyrocom	type T thermocouple 20 gauge shielded	1ºC	-200 to 350ºC

Figure 2.3-10, Testing Equipment for Coheating

Results

UA (BTU/hr F)	3 hours prior to civil twilight		most stable outdoor temperature and windspeed for 3 hours	
Building	average	standard deviation	average	standard deviation
measured	339	43	332	36
infiltration removed by sherman	272	43	264	36
infiltration removed by ELA and windspeed	261	44	269	42
theoretical (without infiltration)	339	8		

Figure 2.3-11, UA of Building

UA (BTU/hr F)	3 hours prior to civil twilight		most stable outdoor temperature and windspeed for 3 hours	
East	average	standard deviation	average	standard deviation
measured	134	13	132	15
infiltration removed by sherman	104	13	101	15
infiltration removed by ELA and windspeed	118	15	114	18
theoretical (without infiltration)	147	4		

Figure 2.3-12, UA of East Classroom

UA (BTU/hr F)	3 hours prior to civil twilight		most stable outdoor temperature and windspeed for 3 hours	
West	average	standard deviation	average	standard deviation
measured	153	15	155	15
infiltration removed by sherman	123	15	125	15
infiltration removed by ELA and windspeed	82	40	73	38
theoretical (without infiltration)	160	4		

Figure 2.3-13, UA of West Classroom

UA (BTU/hr F)	3 hours prior to civil twilight		most stable outdoor temperature and windspeed for 3 hours	
Mechanical room	average	standard deviation	average	standard deviation
measured	28.9	5.7	28.8	5.8
infiltration removed by sherman	20.4	5.7	20.3	5.8
infiltration removed by ELA and windspeed	24.5	6.3	24.5	6.4
theoretical (without infiltration)	32.0	1.2		

Figure 2.3-14, UA of Mechanical Room

Conclusions

Measured values correspond with theoretical values within one standard deviation, however the theoretical values do not have infiltration factored in. When infiltration is removed from the measured data by using measured blower door results the thermal transmittance of the building is lower than the theoretical, however the measured is within two to three standard deviations of the theoretical values.

2.3.4.2 Testing of St. Helens prototype building

Objective

The testing of the prototype building designated for the Astoria, Oregon climate that was installed at St. Helens, Oregon had three components. First by performing a fan depressurization test we will be able to quantify the amount of infiltration for the building. Second by performing a smoke leakage test we will be able to find out where the leaks were and a relative flow rate for each of the leaks. Third we determine the overall thermal transmittance (UA) of the building with a coheating test.

Methodology

Infiltration testing was performed by fan depressurization, blower door testing, according to ASTM E779-74 with some modifications (we did not record the relative humidity, barometric pressure, and we tested the building in a closed and open conditions). The test data for a variety of conditions was least squares fit to

(1) log10(flow)=slope*log10(house pressure difference) + intercept

and the following parameters of the buildings performance were derived.: CFM4, CFM10, ELA, EqLA, CFM50, ACH50, ACH50/20, and ACH50/N. CFM4 is the flow rate into the building caused by a 4 Pascal pressure imbalance. CFM10 is the flow rate into the building caused by a 10 Pascal pressure imbalance. Effective Leakage Area (ELA) is the LBL infiltration model to estimate the natural infiltration. The ELA may be physically interpreted as the area in in2 of a specially shaped bell mouthed nozzle that at a pressure of 4 Pascals would leak the same as all the house leaks at 4 Pascals.

(2) ELA=.2835 x cfm at a building pressure difference of 4 Pa.

Equivalent Leakage Area (EqLA), developed by National Research Council of Canada, is the area in in2 of a round shaped orifice that at a pressure of 10 Pa would leak the same as all the building leaks at 10 Pascals.

(3) EqLA=.2939 x cfm at a building pressure difference of 10 Pa.

ACH50 is a general measure of the house tightness. It is the number of air changes the house would experience with a 50 Pa pressure difference. ACH50/20 is an estimate of the average natural infiltration rate developed by Persily. ACH50/N is an estimate of the average natural infiltration rate developed by Sherman at LBL. It is a derived theoretical correlation between pressure tests at 50 Pascals and annual average infiltration rates. N is a climate factor to reflect the influence of the environment that the building is in.

(4) N=CxHxSxL with C being a climate factor being a function of annual temperature and wind, H being a building height correction factor, S being a wind shielding correction factor, and L being a leakiness correction factor.

While depressurizing the building to -30 Pascals air leakage paths were established using a titanium tetrachloride smoke pencil. Major and minor leakage areas of infiltration were noted based on visual examination of the speed

and quantity of the smoke dispersion.

For the coheating thermocouples where suspended form the ceiling four feet above the floor and two feet from the exterior wall. Two thermocouples per exterior wall where wired in parallel to recorded the average temperature at that location. These thermocouples monitored the room temperature and controlled the electric resistance heaters via the datalogger and a relay. The outdoor temperature, wind speed and wind direction was recorded by a weather station located on the roof of the building. Monitoring was performed for seven consecutive nights. The temperature inside the building was maintained at 75 degrees Fahrenheit while the power consumption was monitored. Data was monitored every 3 seconds and the average was recorded every 6 minutes. The night time data, from midnight to civil twilight, was analyzed in the following ways to evaluate the thermal transmittance:

the three hour periods prior to civil twilight and the periods when the temperature difference between the building and the outside (delta T) was the most stabile for a three hour period. The thermal transmittance was calculated by UA=Q/delta T. Attempts to remove infiltration from the data was accomplished two ways. The first was to use the blower door results for the natural infiltration rate ACH50/N and remove that portion. The second is to use the blower door results for the ELA and the monitored wind speed data. These results where compared to the theoretical UA values which where determined by possible conduction paths through the building envelope. The U values for each of the paths where then multiplied by there corresponding areas. The sum of these various paths is the UA for each of the zones or building.

type	make	model	accuracy	range
blower door	The Energy Conservatory	3	-	-
digital manometer	The Energy Conservatory	DG-3	±1% or ±2 counts whichever is greater	0-2,000 Pa
100-6,995 cfm				
hand held thermo-anemometer	Extech Instruments	407112	±(2%+1digit) ±1.5 °F	0.9-55.9 mph 32-140 °F
smoke pencil	Hill Incorporated	titanium tetrachloride (T-T Puffer)	-	-

type	make	model	accuracy	range
datalogger	Campbell Scientific	CR10	-	-
expansion peripheral	Campbell Scientific	AM416	-	-
wind speed and direction	Campbell Scientific (R.M. Young)	05305-5	±0.2 m/s ±3 degrees	0-40 m/s 0-360 degrees
temperature	Pyrocom	type T thermocouple 20 gauge shielded	1ºC	-200 to 350ºC

Figure 2.3-15, Testing Equipment for Prototype Building

Results

Two depressurization tests were performed on 3/20/99. The first set of test were performed with the HVAC off and none of the registers masked. The building results were the ACH50 being 13.11±1.03, the ELA being 81.16±6.35 in2, and the ACH50/N being 0.45±0.10. The second set of test were performed with the HVAC off and the registers for the HVAC and the air-to-air heat exchanger masked. The building results were the ACH50 being 9.03±2.00, the ELA being 35.25±7.78 in2, and the ACH50/N being 0.31±0.09.

During the second part of the test, the smoke visualization, the location a number of strong leaks occurred at the electrical outlets and light switches, exterior door

frame and threshold, windows in the middle where the fixed and sliding part meet, spots of the ceiling and wall intersection normally near the roof ventilation, east classroom's thermostat, electrical panel box at the conduit, window header of the north east window, and at the marriage of the ridge beam. The largest leak was the marriage of the ridge beam where the gap between the ridge beams varied from nothing to about 3/4 inch over it 64 foot length.

The third set of results was for the buildings overall thermal transmittance (UA).

UA (BTU/hr F)	**3 hours prior to civil twilight**		**most stable outdoor temperature and windspeed for 3 hours**	
Building	average	standard deviation	average	standard deviation
measured	302	20	300	23
infiltration removed by sherman	216	20	214	23
infiltration removed by ELA and windspeed	286	18	279	26
theoretical (without infiltration)	273	7		

Figure 2.3-16, UA of Prototype Building

2.3.5 Long Term Monitoring

2.3.5.1 Site #1 St. Helens

Monitoring by sub meters
monitoring period / analysis
down load and archive of data
monthly analysis of data

2.3.5.2 Site #2 Yet to be built

Monitoring by sub meters
monitoring period / analysis
Additional tasks
down load and archive of data
monthly analysis of data

2.4 TECHNICAL OBJECTIVE #4: MARKETING, OPERATING, SITING, EDUCATIONAL MATERIALS

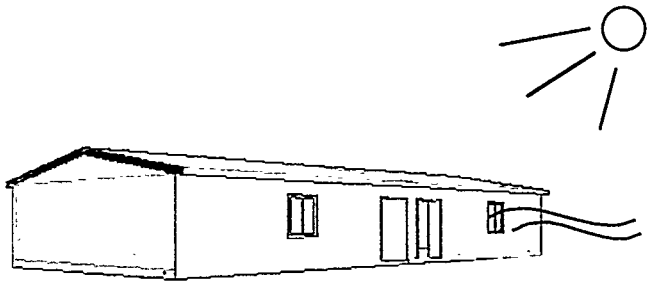
Promotional material was developed for marketing the phase II buildings to the school districts. A siting and design manual was prepared to educate and assist the customer to features of the phase II building. An operation manual for the phase II building was prepared. An educational packet was prepared for use by the teachers to incorporate the phase II building design features into lesson plans.

2.4.1 Marketing Materials

Siting Guidelines

for the **MBS Modular Classroom**

The placement of the MBS Modular Classroom may affect its energy consumption!
The MBS Modular Classroom has been carefully designed to use energy efficiently for lighting, heating and cooling throughout the school year.



The classroom depends to some extent on natural systems such as the sun and wind through the windows to light, heat, shade or cool the building. The siting and orientation of the classroom affects its ability to effectively let in the sun during the heating season, or block the sun and/or use breezes during the cooling season. Use the following pages to guide the placement of the Classroom.

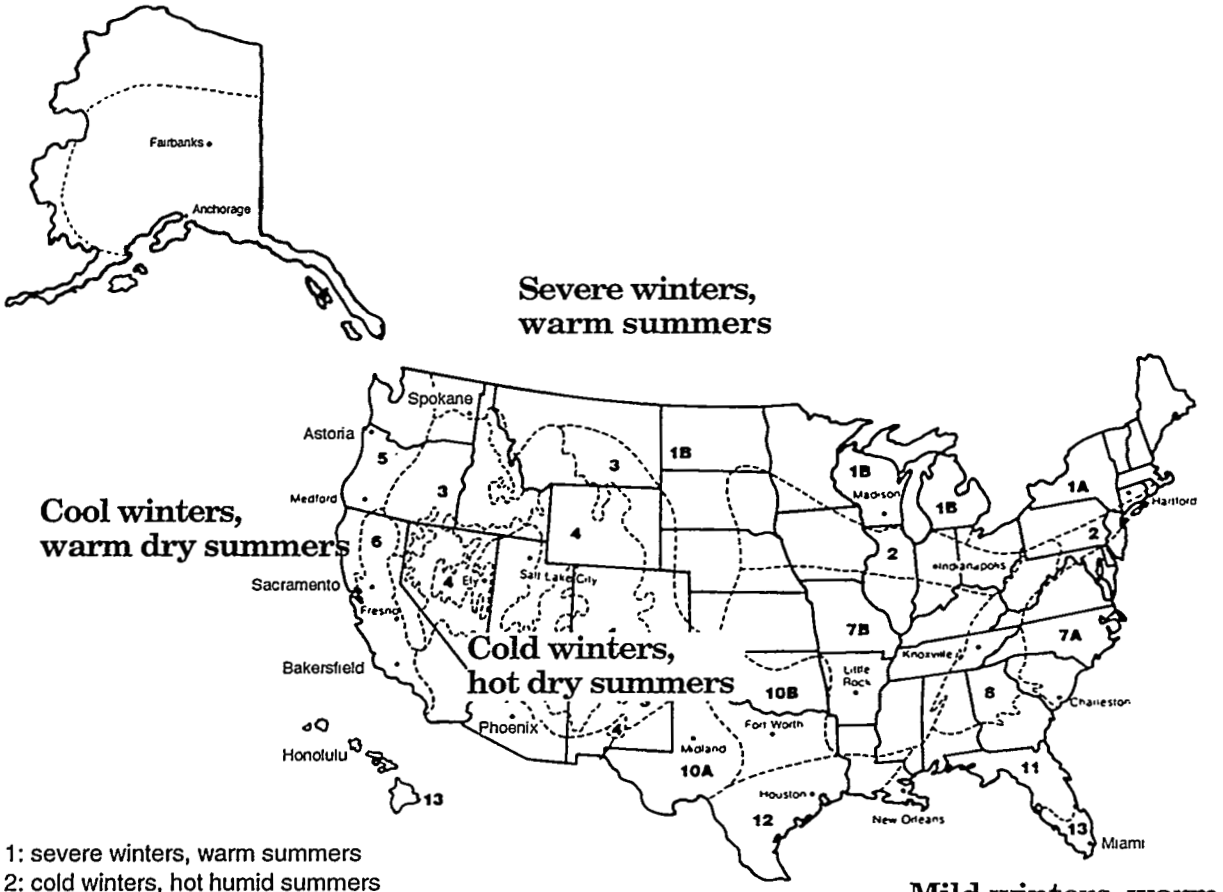
	Page
CLIMATE The local climate affects the recommendations for orientation of the classroom.	2
SUN The long axis of the classroom should face south for optimum heat gain and shading.	4
LIGHT The classroom should be adequately spaced from adjacent trees and buildings; surface reflection from the ground and adjacent buildings may affect light quality and quantity.	7
WIND Orient the classroom with respect to prevailing winds during warm months.	8
Appendix	9

☐ What is your climate like?

The MBS Classroom unit was modelled and refined using an energy simulation software tool (DOE 2.1) to choose the most cost effective energy conservation measures for particular climates.

Action: Of the following cities, pick the city closest to where the classroom will be located. In the table on page 3, follow the directions under *Recommendations*.

Example: Davis, California is closest to Sacramento, California.



1: severe winters, warm summers
2: cold winters, hot humid summers
3: cold windy winters, warm dry summers
4: cold winters, warm dry summers
5: cool wet winters, warm summers, large diurnal Temp. swing
6: moderately cold wet winters, hot dry summers
7: cold winters, hot humid summers
8: cold winters, hot humid summers, large diurnal Temp. swing
9: moderately cold winters, extremely hot summers
10: cool-cold winters, warm-hot summers
11: mild winters, hot humid breezy summers, large diurnal Temp. swing
12: mild winters, hot humid summers
13: mild, warm humid summers

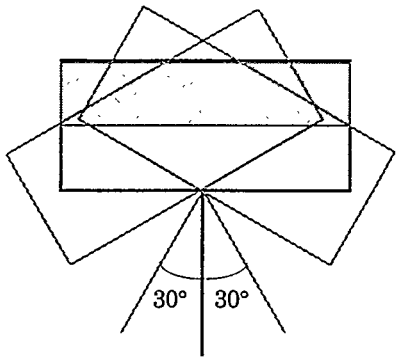
Pick the city closest to where the classroom will be located, and follow the directions under *Recommendations*. For Allow Sun, see page 5, Block sun see page 6, and Cross-Vent, see page 8.

Cities Studied	*Climate*	*Priority*	*Recommendations*			
			Winter	Summer		
			Allow Sun	Block Sun	Cross-Vent	
Fairbanks, Alaska	Boreal: severe winters, mild summers	Heating (99% of total load)	Let sun in	Don't Shade	Don't Vent	Solar preheater covers south wall (see solar orientation)
Phoenix, Arizona	Steppe or Semi-Arid: moderately cold winters, extremely hot summers	Cooling (80%)		Must Shade		Some cross ventilation when not too hot (see cross vent orientation)
Bakersfield, California	Steppe or Semi-Arid: moderately cold wet winters, hot dry summers	Heating and Cooling (53%/47%)				Some cross ventilation when not too hot (see cross vent orientation)
Sacramento, California	Steppe or Semi-Arid: moderately cold wet winters, hot dry summers					Some cross ventilation when not too hot, economizer
Miami, Florida	Subtropical Humid: mild, warm humid summers	Cooling (98%)	Don't let sun in			Humidity a problem
Honolulu, Hawaii	Subtropical Humid: mild, warm humid summers	Cooling (99.9%)	Don't let sun in			Some cross ventilation when not too hot (see cross vent orientation)
Astoria, Oregon	Temperate Oceanic: cool wet winters, warm summers, ΔT	Heating (96%)				Cross ventilation
Spokane, Washington	Steppe or Semi-Arid: cold windy winters, warm dry summers	Heating (98%)	Let sun in			Solar gain in winter, dimmable electric lights (daylighting), cross ventilation, economizer

☐ Solar Orientation: Allow or Block Sun

Open up to the sun

Even if your climate doesn't require solar heating assist in the winter months, orienting the long axis of the classroom facing south ensures the best shading to prevent overheating.



True south

Action: Use a map to site the classroom unit within XX° of south according to the table.

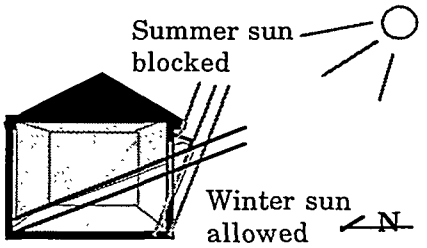
Note: Topographic and site maps often used in siting buildings usually show true north (which does not necessarily coincide with magnetic north where a magnetic compass points). If you don't have a map with true north, and will use a compass to site the building, see True North, page 7 of the appendix.

In the left column of the following table, choose the climate closest to where the classroom will be sited. For the best performance, site the building within the angle shown in the column on the right.

Cities Studied	*Degrees of South*	*Comments*
Fairbanks, Alaska		*4 windows south, southeast, NOT north /north east*
Phoenix, Arizona		*long axis southeast, NOT southwest*
Sacramento, California		*4 windows south, southeast, NOT north, northwest*
Miami, Florida		*4 windows south, NOT northeast or northwest*
Honolulu, Hawaii		*4 windows southeast, southwest, south, NOT NNE or NNW*
Astoria, Oregon		*2 windows south, southeast, NOT north, north northwest*
Spokane, Washington		*Door/2 windows southsouth east, NOT axis facing WSW*

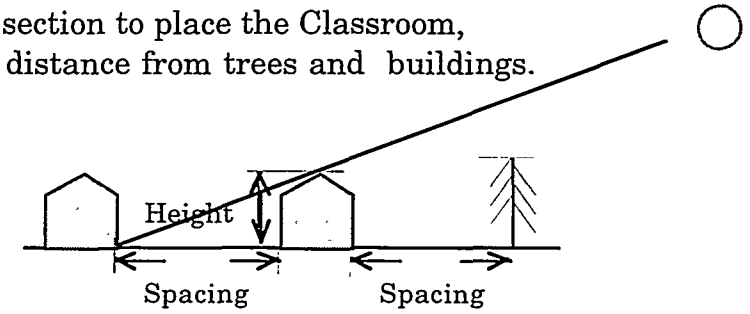
Allow Sun: Avoid obstructions

Allowing sunshine into the building as a source of heat reduces the furnace load. The Classroom should be sited with enough space from trees and adjacent buildings so its access to daylight and sunlight is not compromised.



Action: Use a site map and section to place the Classroom, allowing the proper distance from trees and buildings. (See Appendix B)

Spacing = x times Height
(for x, see table below)



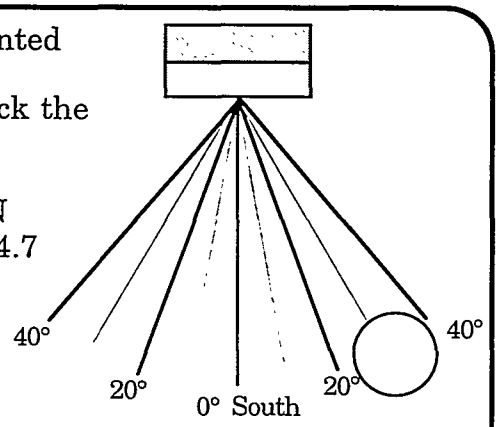
Values of x for December 21

	Latitude	*Angle from true south* 0	10°	20°	30°	40°
Honolulu, HI (21.3°N)	20	0.9	1.0	1.0	1.1	1.4
Miami, FL (25.7°N)	24	1.1	1.1	1.2	1.3	1.7
	28	1.2	1.3	1.3	1.5	2.0
Phoenix, AZ (33.5°N)	32	1.4	1.5	1.6	1.8	2.5
Bakersfield, CA (35.4°N)	36	1.7	1.7	1.9	2.1	2.7
Sacramento, CA (38.6°N)	40	2.0	2.1	2.2	2.6	3.7
Astoria, OR (46.2°N)	44	2.4	2.5	2.6	3.3	4.7
Spokane, WA (47.7°N)	48	2.9	3.1	3.5	4.7	7.1
Anchorage, AK (61.2°N)	60	8.1	11.4			
Fairbanks, AK (64.8°N)	64	19.1				

Example: A 20 foot tall non-deciduous tree is planted 30° east of south from the proposed site for the classroom in Spokane, Washington. Will this block the sun in the winter?

Step 1: Look in the table for the value of x for 48°N (closest to Spokane) and 30° from true south. x = 4.7

Step 2: Spacing = x times Height
= 4.7 * 20 feet
= 94 feet

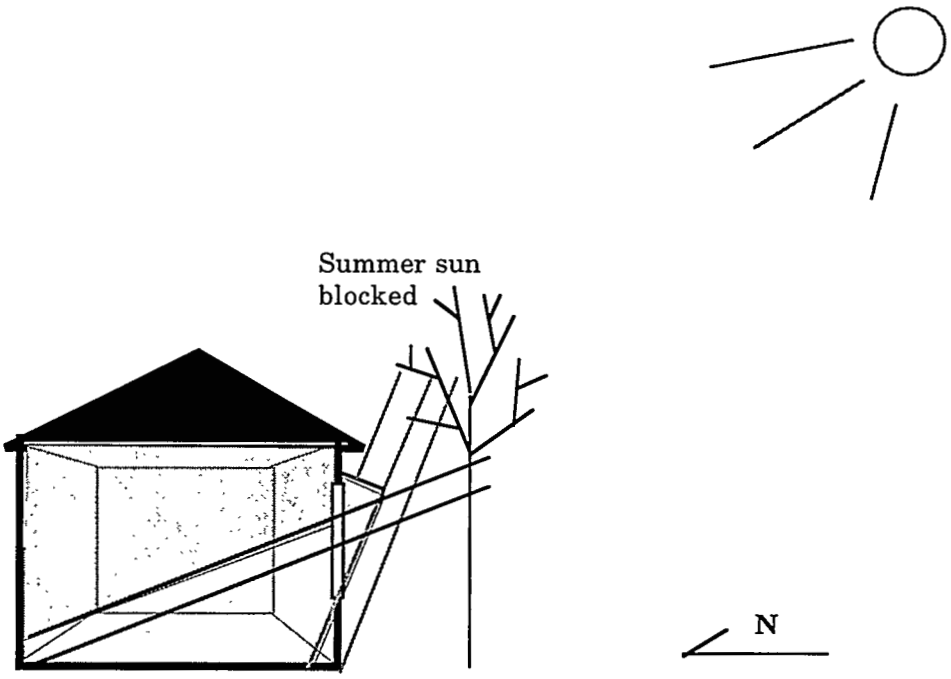


Answer: The building should be sited at least 94 feet in a direct line from the tree to ensure no shading in the depths of winter. (Or building could be moved west).

Block sun: Plant trees

In warmer climates, heat from the sun may sometimes make the classroom too warm. The classroom may be sited near trees to block the sun's heat in the summer, or use the interior Venetian blinds to help reduce unwanted heat gain.

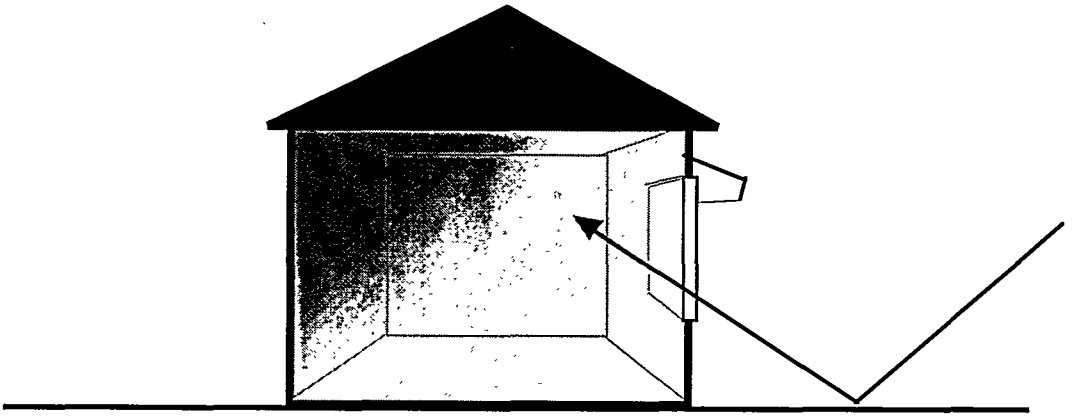
Trees planted close to the classroom can block the sun in the summer, yet still allow winter sun under or through the canopy (if deciduous).



Open up to the light

Letting in more natural light in a building means that sometimes the electic lights can be dimmed or turned off to save energy. Natural daylight through the windows is affected by shade from nearby trees and buildings and surface reflection from ground.

The Classroom should be sited with enough space from trees and adjacent buildings so its access to daylight and sunlight is not compromised.

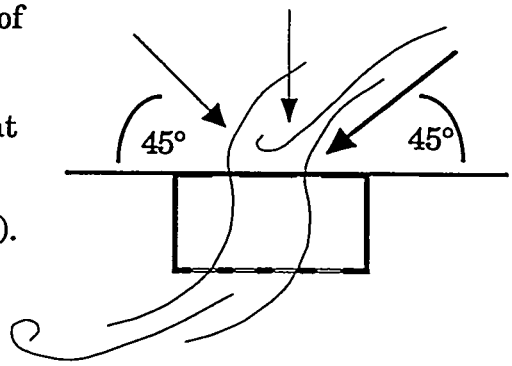


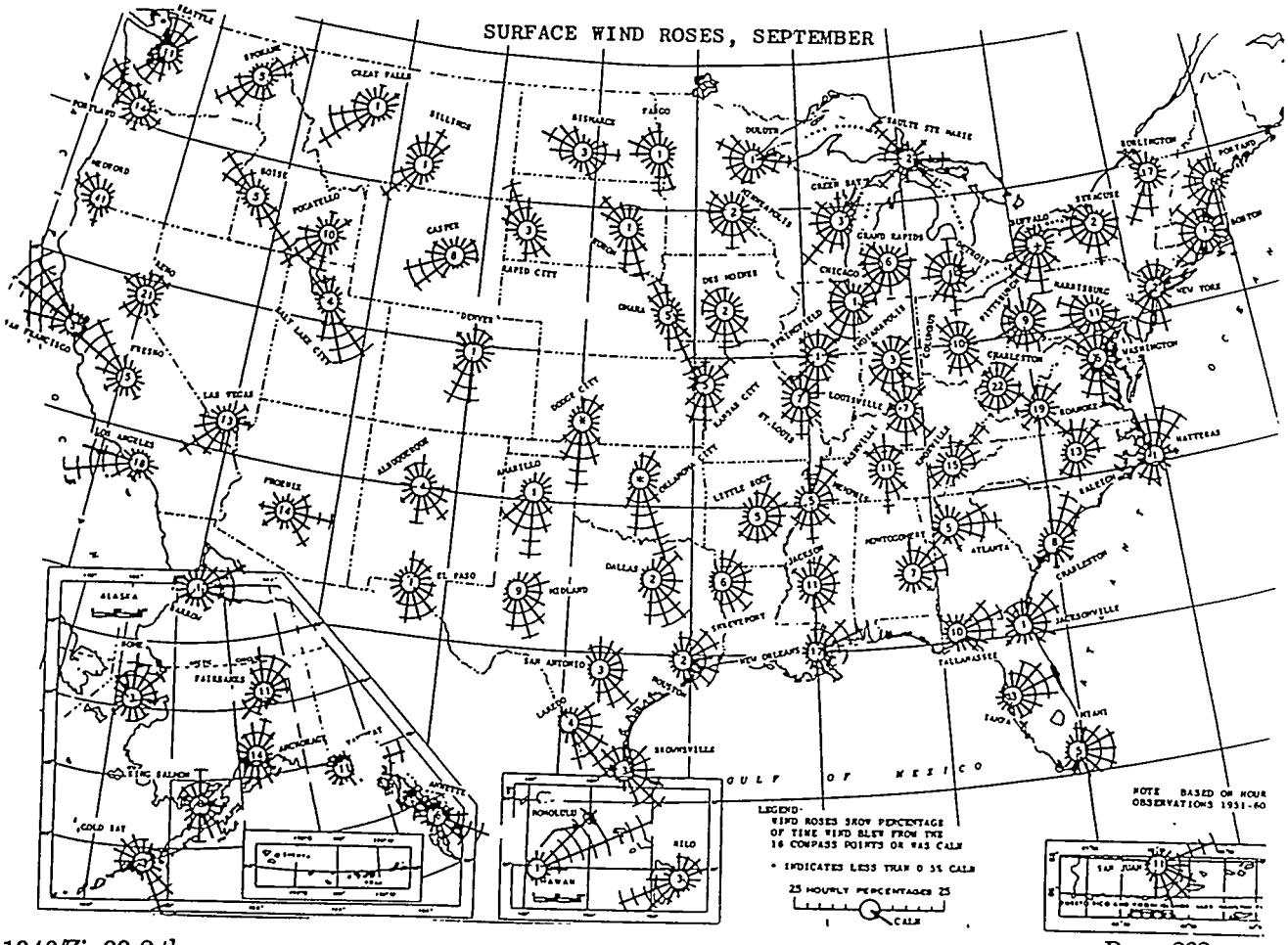
☐ Wind: Cross Ventilation

Open up to fresh breezes

In warm climates, the internal heat gains from electric lighting and occupants combined with the exterior air temperature adds up to an overheated classroom. Opening up the windows can encourage prevailing breezes to remove excess heat and make the occupants feel cooler. Siting the classroom to face these breezes will allow cross ventilation to reduce the load on the cooling system and save energy.

Action: Find the prevailing wind direction of the proposed location for the classroom in the map below. Try to site the long axis of the classroom at least 45° from the direction of the wind, and within range of the suggested solar orientation (page 4).





Appendix A: True North

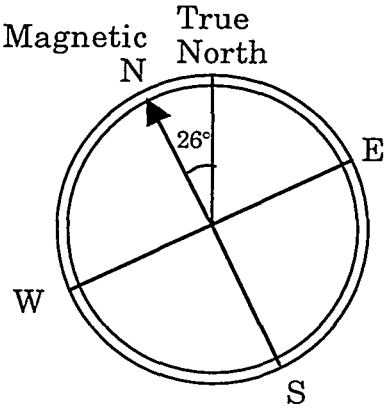
A magnetic compass does not point true north, but at some angle east or west of true north depending on the location on the planet. Magnetic north refers to the direction to which the compass needle points. The angle between true north and magnetic north is called the magnetic declination. Magnetic declination is not constant, but varies in time.

Action: Of the following cities, choose the closest in location to where the classroom unit will be placed. Use the magnetic declination listed and a compass to determine true north.

Cities Studied	*Magnetic Declination*
Fairbanks, Alaska	26° 5.2' E
Anchorage, Alaska	23° 29.4' E
Phoenix, Arizona	12° 20.5' E
Bakersfield, California	14° 21.2' E
Sacramento, California	15° 43.9' E
Miami, Florida	4° 37.4' W
Honolulu, Hawaii	10° 22' E
Astoria, Oregon	18° 54.1' E
Spokane, Washington	18° 5' E

NOAA web site, June 1997

Example: Magnetic Declination for Fairbanks, Alaska: 26° East of North

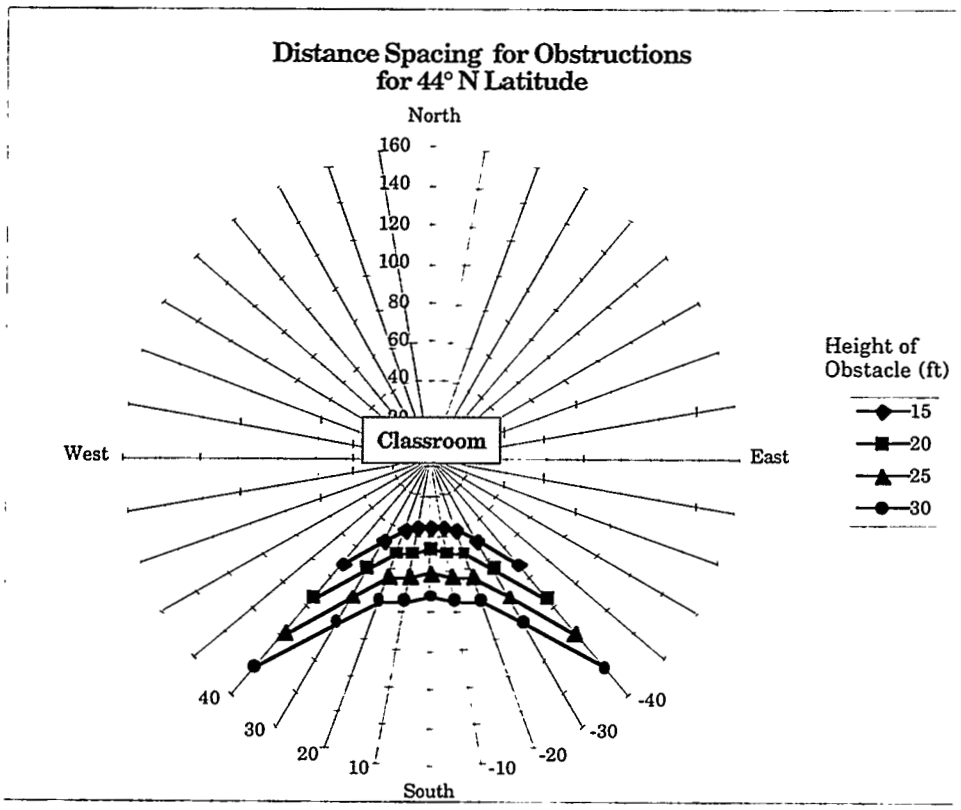


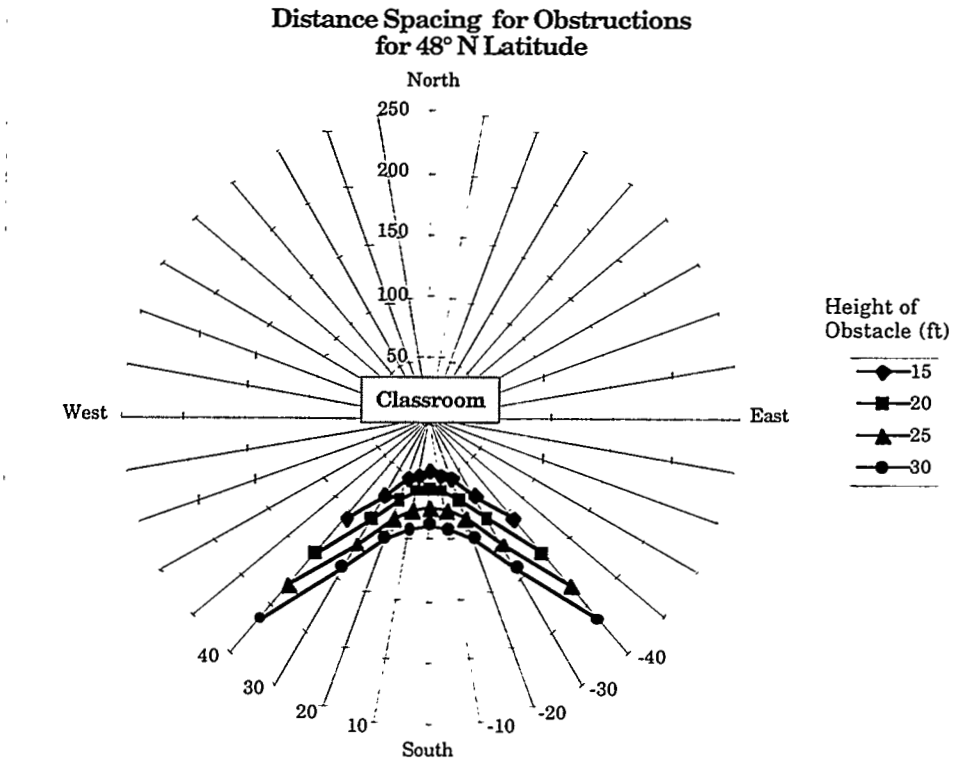
If time:

Determine the exact magnetic declination for the current date and exact location:

1. Find the exact longitude and latitude of the location in question. (This web site gives longitude and latitude for various cities in the United States: http://www.census.gov/cgi-bin/gazetteer).
2. Using the longitude and latitude, find the exact magnetic declination. (This web site gives magnetic declination given longitude and latitude: http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/fldsnth1.pl).

Appendix B: Distance from obstructions for no shading on Dec 21





2.4.3 Operations manual

MBS to supply

2.4.4 Educational packet

Lesson Plans Related to the MBS Classroom

Prepared by: Energy Studies in Buildings Laboratory
Center for Housing Innovation
Department of Architecture
University of Oregon
Eugene, OR 97403

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Introduction and General Information

Introduction

Buildings use approximately 1/3 of the energy consumed in the United States. Constructing more energy efficient buildings and using buildings more wisely can significantly reduce the amount of energy consumed by the U.S. each year thereby reducing environmental damage and reducing building operating costs. The modular classroom you have purchased is a result of more than three years of research into improving the energy performance of portable classrooms.

Influences on Building Energy Usage

There are three major influences on how much energy a building will use: 1) climate; 2) building design; 3) occupants. Climate is probably the most obvious of influences. If a building is in a hot, humid climate, more of its energy usage will likely go towards cooling the interior than heating it. If a building is located in a cold climate, more of its energy usage will likely go towards heating the interior than cooling it. Building design influences energy use in that it defines the materials to be used in the building which allow heat to be gained and lost to the exterior. Building design also defines the efficiency of the heating and cooling systems and determines the amount of potential daylight use by defining window sizes. Probably the most overlooked influence on building energy use is occupant behavior. By wearing an extra layer of clothing and turning down the thermostat a few degrees, one can reduce building energy consumption in a cold climate. One can save energy in any climate by turning off the lights when there is sufficient daylight.

The MBS Modular Classroom

The modular classroom your school has purchased is the result of over three years of research into improving modular classroom energy performance. Depending on the climate, your building may have one or more of the following energy saving features: 1) optimized insulation values; 2) radiant barriers; 3) solar gain windows; 4) daylighting windows; 5) air-to-air heat exchanger; 6) solar wall air preheater; 7) optimized building orientation; 8) thermostat with night temperature set-back.

Lesson Plans

The following pages contain lesson plans about the topics mentioned above using the building and other props as teaching aids. There are two types of lesson plans: 1) schematic lessons plans and 2) detailed lesson plans. The schematic lesson plans provide background information on the physical phenomena taught in the lesson and briefly outline activities to be carried out with the students. These lesson plans are meant to form the skeleton around which teachers can develop more complete lessons tailored to the specific needs of their class. The detailed lesson plans are examples of how the schematic lesson plans can be expanded into more complete lesson plans. Not all of the schematic lesson plans have been expanded into detailed lesson plans; there are a total of 3 detailed lesson plans.

Schematic Lesson Plans

Schematic Lesson Plan #1: Insulation

Materials:
- metal bar, rod, sheet, etc.
- swatch of cotton or wool material
- paper
- tape-measure

Objective: To learn that the amount of heat lost or gained by a building is affected by the conductivity of the envelope materials.

Background:

Just as you might wear a sweater or coat to retain body heat on a cold day, a building "wears a sweater" of insulation to retain heat during cool months and keep the heat out during hot months. And just as you would make a sweater from wool rather than metal, insulation is better made from certain materials than others. The primary consideration in choosing a material from which to make insulation is the material's U-value (closely related to conductivity). U-value is the amount of heat a material will allow to flow through it per unit area per unit time per degree temperature difference across the material. The lower the conductivity of a material, the better its insulating performance. Some common insulating materials are fiberglass batt, polystyrene, and cellulose.

One can calculate the conductive heat flow through a building element using the equation below (heat flow will be from the warmer side to the cooler side):

$$\text{Heat Flow} = \Delta T * U * \text{Area}$$

where, Heat Flow = heat lost or gained through a building element in Btu/hour

ΔT = | inside temp. - outside temp. | (°F)

Area = area of the building element in square feet

U = Btu/(°F, hour, square foot)

Adding up the heat flows for each building element, one can determine the total heat flow in or out of the building. An important property of the heat flow equation is that the heat flow is proportional to both the area and the U-value of the element. Thus, if one had two times the quantity of material A as material B, the conductivity of material A would have to be half that of material B to allow the same heat flow through both materials. This is why windows play such a significant role in the energy performance of buildings even though they are usually only a fraction of the entire building envelope's area. The U-value of windows are typically an order of magnitude higher than the U-value of walls, floors, and roofs causing their role in the overall heat flow equation to be significant.

Lesson Outline:

1) Tape a piece of paper to a window and another piece of paper to a wall.
2) Feeling the temperature of the wall and window through the pieces of paper, have the students come to a consensus as to whether the window feels "much colder" than the wall, "colder" than the wall, "a little colder" than the wall, or "the same" as the wall. (For a discussion of the papers' roles in this lesson see the Detailed Lesson Plan #1)
3) Ask the students which building element has the lower conductivity (Answer: wall).
4) If the school were to extend the walls of the classroom, would it be more energy efficient to use wall material or glazing material? (Answer: wall material)

Schematic Lesson Plan #2: Radiant Barriers and Thermal Mass

Materials:
- clear plastic soda bottles
- black and white paint
- aluminum foil
- rubber balloons
- water
- cotton balls

Objective: To learn about the effect color has on solar heat gain. To learn about the purpose of radiant barriers in buildings. To learn about the effect of mass on the rate of temperature change.

Background:

An object's color depends on the range of the visible light spectrum that the object reflects. Darker colors absorb more of the visible spectrum than do light colors. The energy from the absorbed light heats up the object which then reradiates the heat to the object's surrounding. With all other things being equal (orientation, mass, etc.) a dark object in the sun tends to heat up faster than a lighter object in the sun because it absorbs more light energy. We use the verb "tends" here, because the electromagnetic radiation emitted from the sun is not limited to the visible spectrum. Thus, the amount of energy absorbed by an object is not solely dependent on color, but rather on it's absorptivity of the entire spectrum. For most objects however, color is a good indicator of overall absorptivity.

All materials rise in temperature in response to heat gain. However, not all materials rise in temperature at the same rate in response to the same amount of heat gain. For example, a tea kettle full of air rises in temperature quicker than the same tea kettle full of water. As a rule-of-thumb, the denser a material is, the more heat it must absorb to rise in temperature a certain amount. As with most rules-of-thumb, there are exceptions, but in general this rule-of-thumb

holds.

Though not very influential on building performance, another physical phenomena relevant to the lesson activities is the fact that air expands as its temperature rises. If one begins with a sample of air at some volume, temperature, and pressure and then increases the temperature, the pressure of the sample will increase if the volume is held constant. Alternatively, the volume with increase if the pressure is held constant.

Lesson Outline:

1) Take three identical bottles: paint one bottle black, one bottle white, and cover one with aluminum foil.
2) Stretch a balloon over each bottle opening.
3) Set the bottles outside in the sun or under a lamp in the classroom.
4) Record what and when things happen (the black bottle's balloon should inflate before the white bottle's which should inflate before the foil's).
5) Speculate why events occurred as they did. (Answer: the darker color absorbed more energy, raising the interior air temperature more than the others causing the balloon to inflate quicker and to a greater extent)
6) Fill a black bottle half full with water and fill another black bottle half full with cotton balls.
7) Repeat steps 2-5 on the bottles prepared in step 6. (Answer to #5: Water is denser than cotton so the water bottle rose in temperature less quickly than the cotton bottle)

Schematic Lesson Plan #3: Windows

Materials: • incandescent task light

Objective: To gain an appreciation of windows as a source of light and heat. To learn that daylight produces relatively little heat per unit of light delivered.

Background:

There are three major ways in which windows can affect a building's energy consumption:

1) Conduction losses and gains. As with all the exterior components of a building, a window will conduct heat from its hotter side to its cooler side. The equation governing this heat transfer is:

Heat Transfer = $\Delta T*U*Area$ (see schematic lesson #1 for details)

Because windows generally have a higher U-value than walls, floors, and roofs, a given area of window will conduct more heat into or out of a space than the same area of wall, floor or roof..

2) Radiation gains. A property of glass is that certain spectra of solar radiation pass through it easily - the visible spectrum is an obvious example. This radiation contains energy which, depending on the reflectivity of the objects, is partially absorbed by the objects it hits. The energy is then reradiated by the objects in the infrared spectrum. Glass is generally not as transmissive to this spectrum as to the overall solar spectrum. Thus, windows can provide a net heat gain to a space by allowing direct sun penetration into the space, thereby reducing the heating load on the space.

3) Reduction in electric light usage. As pointed out in #2, an obvious property of glass is that it allows light to pass through itself fairly

easily. If enough light is allowed to enter a space through its windows, the amount of electric lighting needed to illuminate the space can be reduced. Besides the obvious benefit of using less electricity to light the space, reducing electric lighting can also reduce the amount of energy used to cool the space; less electric lighting means less heat generated by the lights which means less heat to remove from the space.

Lesson Outline:

1) On a sunny day, have students stand in the direct sun coming through a south window, stand in the indirect daylight coming through a north window, and place their hand under an incandescent task light.
2) Notice that standing in the south sun and placing ones hand near an incandescent light feels warmer than standing in the north indirect daylight.
3) Which kind of light would be least expensive to heat a building with? (Answer: direct sunlight)
4) Which kind of light would be least expensive to illuminate a space in which heat was not wanted? (Answer: indirect daylight)

Schematic Lesson Plan #4: Heat Exchanger

Materials:
- large plastic tub
- long tube through which air can travel (preferably of a conductive material, i.e. metal)
- fan or other means to force air through the tube
- thermometer

Objective: To learn the principles behind an heat exchanger.

Background:

To keep classroom air healthy, most codes require a certain amount of fresh air be brought into a classroom per hour. If the temperature of the outside air is not at a comfortable level, energy must be expended to condition the air. Depending on your climate, your modular classroom may utilize a heat exchanger to reduce the energy required to do this.

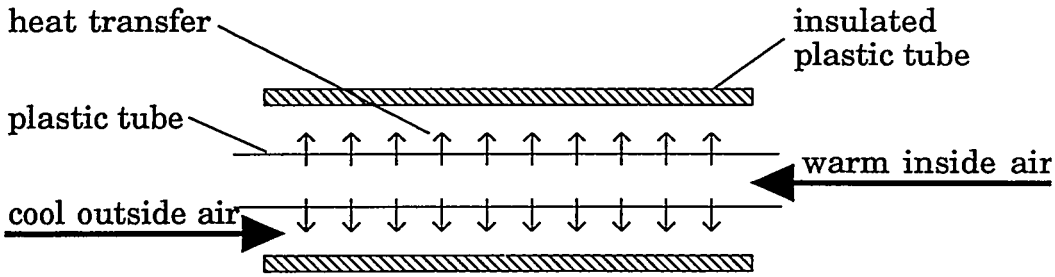

Figure 2.4-1, Heat Exchanger Diagram

Located in the crawl space, the heat exchanger consists of two plastic tubes, one inside the other. The outer tube carries fresh outside air to the room's air handling system, while the inner tube carries stale inside air to the outside (a diagram of the heat exchanger running during the winter is shown above). Assuming the outside air is cooler than the inside air, heat will flow across the thin plastic inner tube from the inside air to the outside air (see schematic lesson #1 for details on conductive heat transfer). This raises the temperature of the fresh air being drawn into the room and reduces the energy

required to bring its temperature up to a comfortable level. If the outside air is hotter than the inside air, the reverse occurs and less energy is needed to cool the fresh air.

Lesson Outline:

1) Create an ice bath by filling the plastic tub with ice and water.
2) Place the tube in the ice bath such that both ends extend outside the bath.
3) Use a fan or some other means to force air through the tube.
4) Measure the temperature of air entering the tube and exiting the tube.
5) Discuss with the students the principles behind the loss in temperature seen in the experiment.
6) Draw the diagram of the building heat exchanger on the chalk board.
7) Discuss why using a heat exchanger could save energy and money in a building.

Schematic Lesson Plan #5: Solar Wall Preheater

Materials:
- medium sized piece of black metal
- medium sized piece of white metal

Objective: To learn the principles behind a solar wall preheater.

Background:

The principles behind a solar wall preheater are the same as those learned in the radiant barrier lesson and the heat exchanger lesson. Thus, this lesson is best done in conjunction with the other two lessons. Please read the background sections of the other two lessons before carrying out this lesson.

As with the heat exchanger, the idea of the solar wall preheater is to reduce the amount of conditioning needed to be done to the classroom's fresh air intake. However, unlike the heat exchanger, the solar wall can only reduce the amount of heating required. It can not reduce the amount of cooling.

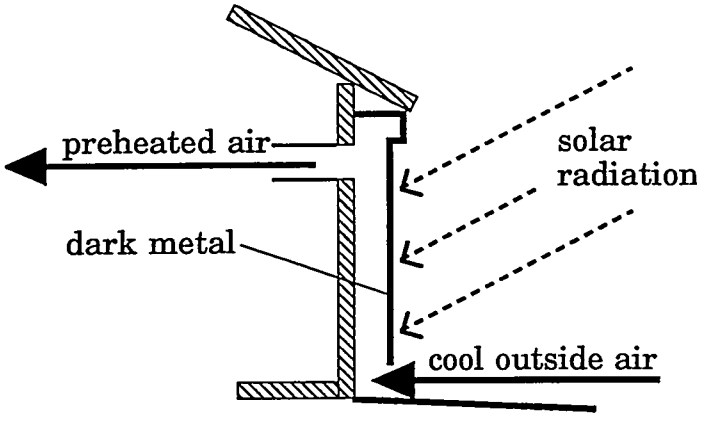

Figure 2.4-2, Solar Wall Preheater

The solar wall preheater consists of a small air gap formed by the south exterior wall and a dark colored metal sheet (see diagram above). Solar radiation strikes the dark metal sheet causing its temperature to rise. A fan in the classroom's air handling system

pulls outside air into the air gap at the bottom of the wall, draws it along the metal sheet, and directs it into the air handling system. As the fresh air travels along the sheet, heat is transferred from the hot metal sheet to the cooler intake air. A bypass vent is provided for times when heated intake air is not required.

Lesson Outline:

If you have previously done schematic lessons #2 and #5:

1) Draw a diagram of the solar wall preheater on the chalk board.
2) Compare and contrast with the diagram of the heat exchanger.
3) Using knowledge gained in lesson #2, have students speculate as to why the solar wall is a dark color (absorbs more solar energy).
4) Discuss why the solar wall cannot cool the outside air like the heat exchanger.

If you have <u>not</u> previously done lessons #2 and #5:

1) Do lessons #2 and #5 and continue with step #1 above.
2) If you really cannot do lessons #2 and #5, draw a diagram of the solar wall preheater on the board and discuss its use.
3) Place the two pieces of metal in the sun.
4) Have the students feel the relative warmth of the two metal pieces. The black piece should feel warmer than white piece.
5) Ask the students why they think the solar wall is a dark color. (Answer: dark colors absorb more solar energy than light colors)

Schematic Lesson Plan #6: Building Orientation

Materials:
- wood blocks approximately the same proportion as your modular classroom building and markers

OR

- construction paper, markers, and tape or glue

Objective: To learn what effects building orientation can have on building heat gain.

Background:

The sun's position in the sky can be accurately calculated on both a daily and a seasonal basis. Knowing the sun's position at various times of the day and year, we can size exterior walls and locate windows in those walls to take advantage of the sun's potential for heating and daylighting.

In North America, at all times of the year, the sun is relatively low in the eastern sky in the morning, and relatively low in the western sky in the afternoon. This makes it difficult to control sun penetration through east and west facing windows on a seasonal basis. However, at solar noon, the sun is fairly high in the southern sky in the summer and relatively low in the winter. This makes shading south windows fairly easy. A properly sized overhang can shade the window much of the day during the summer months while letting in direct sun during the winter months. Except for the early mornings and late evenings around the summer solstice, the sun's position does not get very far north of due east or north of due west in much of the lower 48 states. Thus, north windows have great potential for allowing daylight into a space without the accompanying heat gains from direct sun penetration.

Lesson Outline:

1) Do this lesson only on a sunny day.

2) Create an exterior model of your modular classroom building using a wood block, construction paper, or other material.
3) Draw windows on the model using a marker.
4) Place the models outside; one with its long axis oriented east/west and one with its long axis oriented north/south.
4) At various times during the day, count the number of windows on each model that are in the sun. Alternatively, you can use a sun peg chart to mimic the sun's position relative to the models for any time of day or year (Brown, p. 8-13).
5) Have the students think of ways to shade these windows keeping in mind the sun's position (Brown, p.140-147).
6) Do these shading strategies preserve the view out the windows?
7) Windows facing which direction are easiest to shade throughout the day? (Answer: south windows; using an overhang)

Schematic Lesson Plan #7: Occupant Behavior

Materials: • coats, sweaters

Objective: To learn what effects occupant behavior can have on occupant comfort in a building and how certain occupant behaviors can save energy.

Background:

For a given combination of temperature, relative humidity, wind speed, and solar radiation, a person will feel a certain level of comfort. Changing one or more of these environmental variables may change the person's feeling of comfort. For example, increasing air movement around a person's skin will cause the person to feel cooler, while increasing solar radiation incident on a person's skin will cause the person to feel warmer.

While not completely obvious, each of the aforementioned environmental variables can be altered through occupant behavior. For example, one can open a window to increase air movement through a room; one can move from the sun into the shade to cool down; one can put on a sweater to increase the temperature right next to one's skin; one can mist the air to increase the relative humidity of one's environment. Changing one's comfort level through behavior has obvious implications for the heating and cooling requirements of a space. If a person can increase his or her warmth by way of some change in behavior, the building's heating system does not have to provide as much heat to the person.

Outline:

1) Have students record their comfort level (comfortable, very cold, warm, etc.).
2) Have students put on their coats/sweaters or exercise.
3) After a few minutes, have students record their comfort level again.

4) Speculate as to what could be done to the thermostat settings to return students to their original comfort level (Answer: lower the minimum temperature).
5) Will these suggestions save energy? (Answer: yes)

Detailed Lesson Plans

Detailed Lesson Plan #1: Insulation

Materials:
- metal bar, rod, sheet, etc.
- swatch of cotton or wool material
- paper
- tape-measure

Objective: To learn that the amount of heat lost or gained by a building is affected by the conductivity of the envelope materials.

Outline:

1) Ask students what they do when they feel hot or cold. Possible answers include A) put on a sweater; B) put on shorts; C) exercise; D) turn up the thermostat; E) move into the sun; F) move into the shade, etc.
2) Use responses such as A and B above as a starting point to discuss why putting on or removing clothing should make any difference in how hot or cold people feel. In this discussion, be sure to mention that humans do not sense the actual temperature around them, but rather the rate at which they are gaining or losing heat. The faster people lose heat, the colder they feel. This is why a hot bath might feel extremely hot when you first get in, but just right after you have been in the water a few minutes and your skin temperature rises reducing the flow of heat to your body.
3) Demonstrate the fact that people feel heat flow rates rather than actual temperature. Pass out pieces of cloth and metal objects to the students. State that both the cloth and the metal have been in the room a long time and therefore must be very close to room temperature. Have the students touch both types of objects and notice that the metal object feels cooler than the cloth.
4) Discuss why the metal felt cooler than the cloth. Again, this discussion should include the fact that people feel heat flows not temperature. Also, the idea of conductivity should be introduced. Different materials have different conductivities. Cloth conduct heat less readily than metal.

5) Extend the clothing analogy to buildings. Ask students what they think a building designer should do to allow less heat to travel though its walls, floor, and roof. "Put a sweater on the building." (Add insulation).
6) With more advanced students, try to come up with situations in which one would want to use very much insulation and very little insulation. Possible influencing factors include economics, climate, culture, occupant activity, etc.
7) Introduce the equation (see schematic lesson plan #1 for explanation):

Heat Flow = ΔT*U*Area

where, Heat Flow = heat lost or gained through a building element in Btu/hour
ΔT = | inside temp. - outside temp. | (°F)
Area = area of the building element in square feet
U = Btu/(°F, hour, square foot)

The rest of the lesson is geared towards calculating a hypothetical heat flow value for the walls and windows in your classroom. This involves assuming values for each of the terms in the heat flow equation based on simple observations made about the walls and windows.

9) Tape a piece of paper on a window and on a wall. Have the students place their hands on the papers and record whether the window feels "the same" as the wall, "a little cooler" than the wall, "colder" than the wall, or "much colder" than the wall. (The paper reduces the effect of different surface conductivities as seen in steps #3 and #4.)
10) Measure the total wall area (A_{wall}) and total window area (A_{window}) of the room.
11) Assume ΔT to be 1, the wall to have a U-value of 1 and the window to have a U-value dependent on the records from step #9:
"same" = window U-value of 1

"a little cooler" = window U-value of 3

"colder" = window U-value of 6

"much colder" = window U-value of 9

12) Compute the hypothetical heat loss through the walls and windows of your classroom using the actual area of the elements:
Heat Loss #1 = $1*A_{wall}*U_{wall} + 1*A_{window}*U_{window}$

13) Compute the hypothetical heat loss through the walls of your classroom as if the windows were actually wall:
Heat Loss #2 = $1*(A_{wall} + A_{window})*U_{wall}$

13) Compare the two heat loss values. What happens if you use a different value for window U-value? What conclusions can you draw from these results?

Detailed Lesson Plan #2: Radiant Barriers

Materials:
- clear plastic soda bottles
- black and white paint
- aluminum foil
- rubber balloons
- water
- cotton balls

Objective: To learn about the effect color has on solar heat gain. To learn about the purpose of radiant barriers in buildings. To learn about the effect of mass on the rate of temperature change.

Outline:

1) Ask students if they have noticed any difference in how quickly black cars and white cars get hot while in the sun. Ask students if they notice any difference in how hot they feel while wearing black clothes in the sun as opposed to white clothes in the sun. As a class, make a hypothesis as to whether black or white objects absorb more heat when in the same solar environment. (Answer: black objects)
2) As a class, in groups or individually, paint one bottle black, one bottle white, and cover one with aluminum foil.
3) Stretch a balloon over each bottle opening.
4) Set the bottles outside in the sun or under a lamp in the classroom.
5) Record what and when things happen (the black bottle's balloon should inflate before the white bottle's which should inflate before the foil's).
6) Discuss the results of the experiment with the class. Was the class's hypothesis correct? If not, why not? (Answer: the darker color absorbed more energy, raising the interior air temperature more than the others causing the balloon to inflate quicker and to a greater extent)
7) Fill a black bottle half full with water and fill another black bottle half full with cotton balls.

8) Form a hypothesis about what will happen with these two bottles.
9) Repeat steps #3-#6 on the bottles prepared in step #7. (Answer to #6: Water is denser than cotton so the water bottle's temperature rose less quickly than the cotton bottle's)

10) Summarize what has been learned so far: i) dark objects about solar energy more readily than light objects; ii) dense materials absorb more energy per unit rise in temperature than less dense materials.
11) Why might one want to paint a building a dark or a light color? (Answer: to absorb more or less heat from the sun, thereby decreasing the building's dependence on artificial heating or cooling)
12) If your building has a solar wall preheater, discuss why it is painted a dark color. (Answer: to absorb solar energy more efficiently)
11) Many homes in sunny regions of the U.S. use a layer of foil (called a radiant barrier) in their roof construction as shown in the diagram below. Speculate as to the purpose of this layer. (Answer: to reduce solar radiation into the home) Why do you suppose the radiant barrier is not located on the very exterior of the roof? (Possible answers: 1) weather protection; 2) esthetics; 3) prevent blinding glare from the shiny surface, etc.)

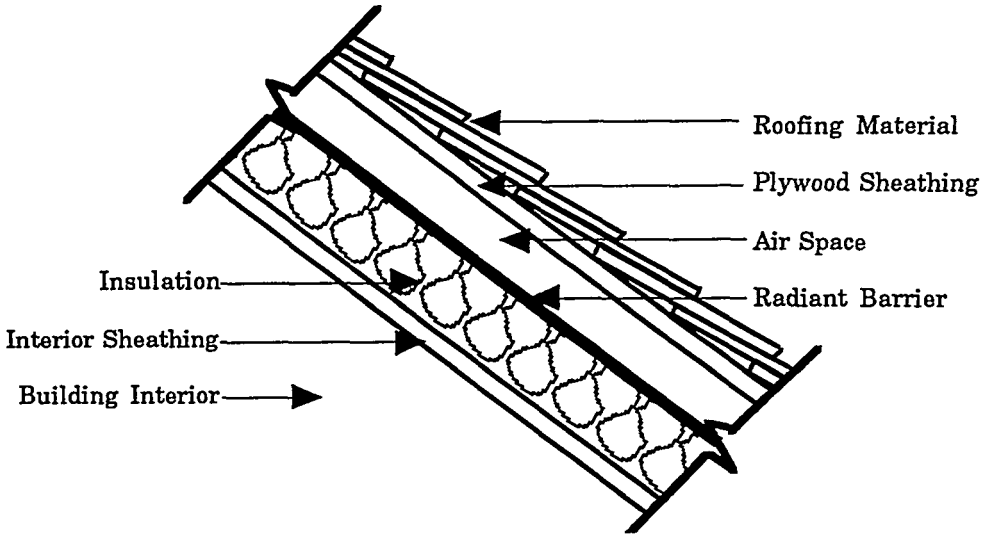

Figure 2.4-3, Sample Roof Section with Radiant Barrier

9) There are many cultures with traditions of building white-washed concrete or stone buildings (reference). This lesson can be a starting point to exploring these cultures. Are there other reasons for particular building traditions other than climate? Political? Economic? Social?

Detailed Lesson Plan #3: Daylight Windows

Materials: • incandescent task light

Objective: To gain an appreciation of windows as a source of light. To learn that daylight produces relatively little heat per unit of light delivered.

Outline:

1) Have the students look about the room and see if they can find any signs of automatic controls for the electric lights in the classroom. (Depending on your climate, your classroom may or may not have automatic lighting controls.)
2) If controls were found in your classroom, discuss possible reasons why automatic controls were used. Possible answers: 1) reduce the amount of electricity used when full electric lighting is not required; 2) maintain an optimum level of lighting in the room -- not too much, not too little; 3) reduce the amount of heat produced by the lights when electric lighting is not needed. Leaving lights on when they are not needed costs us double: we must pay for the extra electricity to run the lights and we may also pay for removing the excess heat created by the lights.
3) Ask students for possible ways to reduce the energy electric lights use in a building. Possible answers: 1) reduce the lighting level; 2) replace existing lights with more efficient lights; 3) add windows while decreasing use of electric lights, etc.
4) Discuss the advantages and disadvantages of each suggestion from step #3. For example, adding windows may also increase the heat lost from the building during cold times of the year since windows are relatively poor insulators. Adding windows may also increase the heat gain during hot, sunny times of the year due to direct sun penetration through the windows (see Lesson Plan #3: Solar Windows). A building designer must weigh each of these effects on building performance to determine the best building design.
5) Have the students situate one desk next to a north window, one

desk next to a south window with direct sun penetration, and one under an individual incandescent task light.

6) Have the students observe whether there is too much, too little, or just enough light to read by.
7) Have the students feel the relative heat gained from the three light sources by placing their hands in the direct sun, in the indirect light, and just above the incandescent lamp.
8) Discuss the relative ratios of light levels to heat gain for the three sources. This qualitative experiment should reveal that north light produces the least heat per unit of light.
9) Have the students look around the room and notice if there is more window area on the north side or the south side of the room. Speculate as to why this is. Possible answers: "We are in a climate that requires a lot of heating." "We are in a hot, sunny climate which requires little heating."

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3.0 FILLER STRIP

Another design for the modular classrooms was developed to increase the energy performance, increase the use of daylighting, and improve on the architectural features of the building. The main switch is to use a three module building rather than a two module building and incorporating better daylighting through clerestory windows to maximize the daylighting and lower energy consumption. Architectural drawings, a cost analysis, and energy performance were developed for this design in each of the seven regions.

3.1 TECHNICAL OBJECTIVE #1: DEVELOP PHASE I DESIGN

3.1.1 Architectural and engineering design and analysis

Architectural and engineering drawings were prepared to each of the seven regions that included details on the vaulted ceiling, connection of the filler strip to the classroom modules, clerestories for daylighting and ventilation.

3.1.1.1 Vaulted ceiling

MBS to supply

3.1.1.2 Module to filler connections

MBS to supply

3.1.1.2.1 Architectural and preliminary structures

MBS to supply

3.1.1.2.2 Structure

MBS to supply

3.1.1.3 Skylights

MBS to supply

3.1.1.4 Roof deck ventilation

MBS to supply

3.1.2 Cost Analysis

Preliminary and detailed cost analysis of the design was prepared for each of the seven climates.

MBS to supply

3.1.2.1 Preliminary analysis of alternates

MBS to supply

3.1.2.2 Detailed analysis for all climates

3.1.3 Simulations

Each of the filler strip designs was simulated parametrically in each of the seven climates to develop the energy performance of the final design.

Objective
Removing some of the constraints of cost to see what design would be more energy efficient and include a better looking building were explored.

Methodology
After a brainstorming session to develop the look of the building and a range of energy design parameters to vary, a series of DOE 2.1E analysis were performed to develop the final climate specific designs. The energy parameters evaluated for the building were adding thermal mass to the building, increased insulation,

radiant barriers, cross ventilation and stack ventilation, smaller more efficient HVAC systems, a variety of glazing and frame options, insulated window shades, and air-to-air heat exchangers. For energy production the use of photovoltaic (PV) panels were evaluated on the south roof of the monitor.

Results

The design of the building was a three module unit building that is 30 feet wide by 60 feet long, with a 10 feet wide by 9 feet tall monitor on top running the length of the building.

The changes to the building design caused a reduction in energy consumption from that of the base case building. When PV panels are added to the south roof of the monitor, parallel to the plan of the roof, it will produce more electricity than the building consumes during the year. This assumes a net metering arrangement (no batteries for storage of excess energy production), average PV module efficiency of 12%, and a direct current (DC) to alternating current (AC) inverter efficiency of 79%.

Climate	Basecase energy consumption (kWh/yr.)	Filler strip energy consumption (kWh/yr. except as noted)	PV energy production (kWh/yr.)
Fairbanks, AK	36,945	4,144 kWh and 616 gallons of fuel oil	5,066
Phoenix, AZ	9,946	5,060	10,036
Sacramento, CA	10,931	4,120	8,452
Miami, FL	10,260	5,210	7,980
Honolulu, HI	10,473	5,5145	8,530
Astoria, OR	13,830	4,746	5,682
Spokane, WA	17,053	4,928	6,916

Figure 3.1-1, Comparison of energy consumption and energy production for each of the climates.

The general design parameters for all climates is a concrete floor, insulated

window blinds, three tube T8 fluorescent lamps with continuously dimmable ballasts. Other climate specific details are shown in figure 3.1-2.

Climate	R-value of floor	R-value of walls	R-value of roof	radiant barriers	smaller more efficient HVAC systems	windows	air-to-air heat exchangers effectiveness
AK	80	60	81	no	oil furnace, 70,000 BTU/hr input 83.8% AFUE	quad pane low-e glazing	60%
AZ	0	28	51	no	electric heat pump 3 ton, SEER 15.6	double pane low-e	80%
CA	50	28	51	no	electric heat pump 3 ton, SEER 15.6	quad low-e glazing	80%
FL	0	11	11	wall and roof	electric heat pump 1/2 ton, SEER 15.6	double pane low-e, no south windows	80%
HI	0	28	51	no	electric heat pump 1/2 ton, SEER 15.6	double pane low-e, no south windows	60%
OR	50	28	51	no	electric heat pump 1/2 ton, SEER 15.6	quad low-e glazing	60%
WA	50	28	51	no	electric heat pump 1/2 ton, SEER 15.6	quad low-e glazing	80%

Figure 3.1-2, Summary of Filler Strip Modeling Components

Conclusions

It is possible to reduce the energy consumption of modular classroom buildings by 49 to 71% from one that meets the energy code. When PVs are used on the south monitor it produces more energy than the building consumes, in some cases more than double.

4.0 PERIMETER INSULATING FOUNDATION SYSTEM

Removing the insulation from the floor of the modular classroom and relocating it to the side walls of the crawlspace showed promise of reducing the cost with minor effect on the performance of the building in some climates. The phase I design was reviewed for code constraints, variation in site and ground conditions, infiltration with pier foundation system, moisture control, radon mitigation, and method of shipping the wall modules. From the results of the design analysis a set of architectural and manufacturing drawings were prepared for the construction of a prototype to do side by side testing with a reference building. These results were used to adjust the simulation.

4.1 TECHNICAL OBJECTIVE #1: DEVELOP PHASE I DESIGN

The phase I design was reviewed for code constraints, variation in site and ground conditions, infiltration with pier foundation system, moisture control, radon mitigation, and method of shipping the wall modules.

4.1.1.1 Code review

Objective

The objective of this task is to design / develop a perimeter insulation foundation system from Phase I, with consideration to design improvements, stability and cost effectiveness.

Methodology

Revise the design using a perimeter insulation foundation system for the different climate zones that meets all of the current applicable building codes.

Results

This task is not feasible for requirements applicable to design methods used by Modern Building Systems, Inc. Modern Building Systems, Inc. and the classroom modular industry refers to the following code section due to the fact that the floors are designed using wood joists and sheathings.

As stated in the 1997 Uniform Building Code, Section 2306.7 Under-floor Ventilation. "Under-floor areas shall be ventilated by an approved mechanical means or by openings into the under-floor area walls. Such openings shall have a net area of not less than 1 square foot for each 150 square foot (0.067 m_ for each 10 m_) of under-floor area. Openings shall be located as close to corners as practical and shall provide cross ventilation. The required area of such openings shall be approximately equally distributed along the length of at least two opposite sides. They shall be covered with corrosion-resistant wire mesh with mesh openings of _ inch (6.4 mm) in dimension. Where moisture due to climate and groundwater conditions is not considered excessive, the building official may allow operable louvers and may allow the requirement area of vent openings to be reduced to 10 percent of the above, provided the under-floor ground surface area is covered with an approved vapor retarder."

Conclusions

Using the formulas above, it is concluded that 4% of the perimeter skirting would be left open. This meaning that any warm air trapped by the additional insulation would leak out of the vents. There are no code remedies for this requirement. In conclusion it is determined that it is not worth the additional cost for material and site labor.

The perimeter insulation foundation system will be changed to a heat exchanger due to less cost in construction and larger potential energy savings.

4.1.1.2 Radon Mitigation

Objective

To determine alternative methods for control of radon and moisture for the MBS classroom buildings for the various underfloor options: 1) Crawl space unvented with perimeter insulation; 2) Crawl space vented by pressure differential; 3) Crawl space used as return plenum; and 4) Crawl space used as a supply plenum, also the current type--vented, but not with pressure difference. We addressed free flowing surface water as well as underground moisture. We then determined relevant code requirements.

Radon

Radon occurs naturally; it seeps up through soil and rock from subterranean uranium deposits. There is some minute level of radon in the air everywhere. Radon decays into radioactive particles that stick in the lungs and cause cancer; it is the second leading cause of lung cancer in the U. S. Four picocuries per liter (4 pCi/l) is considered by EPA to be the maximum level before action should be taken to reduce the level (0.4 pCi/l is the average ambient radon level). UBC does not address the radon problem now, but it probably will be the future. The EPA recommendations were considered for the 1997 UBC, but were not approved (they have been approved for CABO for the 1997 CABO code).

Research has not identified a reliable way to predict radon problems. If the building is to be built in an area where radon is prevalent in nearby buildings it is more likely to be a problem than if it is built where radon is not prevalent. Radon occurs unexpectedly in pockets that have not been predicted. Generally it is less prevalent in clay type soils than in more porous soils, such as sand or gravel because the porous soils permit the passage of gasses. If a soil is permeable to water it is also permeable to gas.

EPA has developed a U. S. Map of Radon Zones based primarily on reading at the lowest level of 5 or more houses in almost all of the counties. The zones are 1, 2 and 3. Zone 1 is most critical with an average predicted screening level of more than 4 pCi/l; zone 2 has an average predicted screening level of between 4 pCi/l and 2 pCi/l; zone 3 has an average predicted screening level of less than 2 pCi/l. It also has developed maps of most or all the counties in the U. S. Only one of our buildings for which we have information (Spokane) is located in zone 1 (the most radon prone area). Hawaii is located in zone 3 (the least prone area) and the remainder are located in zone 2.

Radon is cumulative over a lifetime. One unit for 10 hours has the same effect as ten units over one hour. It appears that if a space is not occupied much it can safely have higher levels of radon than a space that is occupied continuously. It is estimated that about 6% of the homes in the US has radon levels high enough (4

units) to require action. Schools will not be occupied as much as homes and the levels should not be as critical except that some believe young children may be more at risk than adults.

The levels of radon vary greatly from state to state and from neighborhood to neighborhood; it even varies from month to month and usually more critical in winter. The problem is always more severe in basements and below grade habitable spaces. It is not so much of a problem on the upper floors of a building. The EPA Map of Radon Zones only identifies the probability in general areas; there will be pockets in each area that do not correspond to the general map.

Methodology

Excessive radon is dangerous; it is easy to detect in buildings, and may be relatively easy to reduce if the problem is faced before the building is built. Ventilation to the outside air is a way to reduce radon; if a space is well ventilated the radon problem is reduced, but at a substantial cost in heat lost in all except warm climates. To reduce the amount of radon entering an enclosed space the space should be sealed in the same way it is sealed from moisture penetration (vapor or liquid). In most areas a 6 mil poly sheet is adequate if the membrane is sealed where it is penetrated (such as by plumbing pipes). The membrane must be protected from breaks or tears. A sand fill over the membrane is one such method of protection where there will be danger of damage such as could happen in an accessible underfloor space. By itself the membrane may not be adequate.

In areas where ground cover is required for moisture control the cover also serves to mitigate the radon problem. In some areas a ground cover is not required for moisture control, but may be required for radon mitigation.

Because of the nature of buildings' ventilation systems the air pressure in the buildings is normally slightly less than the outside air; this pressure differential causes radon to migrate to the area of reduced pressure. Radon needs to be barred or intercepted before it migrates into the interior space.

Three strategies to control soil gasses containing radon:

1. Barrier approach. Essentially this approach provides a membrane to prevent soil gasses from entering the building. Theoretically this method should solve the problem; however research has shown that in practice it only reduces the entry of radon from 10% to 60%. One reason is that it is impractical to provide a perfect seal that will not be damaged during construction or normal building maintenance. In most building locations such a membrane is also required for moisture control. Satisfactory barriers are barriers that are also vapor retarded barriers such as 6 mil polyethylene, 45 mil EPDM, or 55# smooth roll roofing. This method is the most cost effective, but by itself it has been shown to not be reliable. The barrier is usually required with the other two approaches. The barrier should be used for all buildings except it may not be necessary in warm, very dry climates where no radon problems have been encountered.

2. Air management approach. This approach includes ventilation of the interior space, or pressurization of the space, or both. It is generally the least practical approach in cold climates; it can work in some warm climates that do not require air conditioning.

The ventilation of the space dilutes the gas and results in a greater heat loss because of the volume of ventilation air required. To be effective in the occupied space it requires a substantial increase in the ventilation rate. Assume, for example, a space is ventilated at the rate of 0.25 ACH and has an indoor radon concentration of 8 units. If the rate is doubled to 0.50 ACH the concentration will be cut in half to 4 units; if the rate is again doubled to 1.0 ACH the concentration is now 2 units. If the ventilation rate in doubled again to 2.0 ACH the concentration is reduced to 1 unit. This strategy should be limited to warm, dry climates where ventilation without air conditioning is practical.

The pressurization of the occupied space tends to keep the gas out of the space by the pressure differential. It forces the moisture laden interior air into the building structure where condensation problems are intensified during heating seasons; It is most feasible where cooling is required.

If the crawl space is pressurized it tends to prevent the soil gas from entering the crawl space. If the crawl space is depressurized by an exhaust fan to the exterior it will tend to draw soil gas into the space, but with adequate ventilation the gas will be diluted; this system should be used only if adequate ventilation air is provided from the classroom, or the outside air.

3. Soil gas interception approach

This approach has been demonstrated to be by far the most effective; it is sometimes referred to as the "suction system". This method intercepts and sucks the soil gas from the ground before it gets into the building and discharges it outside. The gas is usually intercepted in a gravel bed below a membrane that separates the building from the ground. The process of sucking the gas from reduces the pressure below the membrane to reduce the flow of the gas to the space above. Such systems use a stack in the building extending from the below the membrane through the roof. In the "passive" system the stack depends on stack action to reduce the pressure; a 4" or 6" sewer drainage pipe is the usual stack material; in small areas a 3" stack is sometimes used with a fan. The "active "system adds a small capacity fan in the stack that is ideally placed above the roof or in a ventilated, unheated attic space. The fan can be added to the stack in the passive system when radon concentrations are too high.

Results

For slabs on grade a membrane under the slab as described above may be adequate for many conditions. For more severe conditions 4" of pea gravel (1/2" to 1-1/2") should be placed below the membrane and vented to the outside by the soil gas interception method. For the MBS classrooms there is no slab on grade for the types of construction now being considered.

MBS present system

Using a crawl space with cross ventilation should be adequate for most conditions when a membrane is used on top of the ground. The vents must be kept open. This is particularly true in winter when radon problems are greatest and when the vents are most apt to be closed.

Crawl space unvented with perimeter insulation
This air tight condition is serious in areas of moderate or high radon hazard; it should be used only with the soil gas interception system.

Crawl space vented by pressure differential
This system exhausts classroom air into the crawl space and then through vents to the outside. If the underfloor space is pressurized by air being forced into it the pressure tend to keep out the soil gasses. A membrane on top of the ground should be adequate for most conditions. The system requires strategically located vents to be open at all times. If the fan pressurizing the crawl space is not operating there is a danger of radon build up. If a fan in the foundation wall is used to assist in exhausting the underfloor there is a danger caused by the exhaust fan reducing the pressure in the underfloor space and drawing soil gas from the ground.

Crawl space used as return air plenum
If radon is apt to be present in the ground this condition is the most serious. The membrane is necessary to reduce the amount of radon entering the crawl space where it will be circulated into the classrooms. In effect the radon laden air in the underfloor is under reduced pressure and draws gas from the ground and is vented to the classroom. This system is not feasible where radon is present unless an active gas interception system is used; the pressure must be less under the membrane than it is above. This return air system should not be used in where radon is a problem without the gas interception system.

Crawl space used as a supply plenum
The nature of the system pressurizes the plenum while it is operating and mitigates the entry of radon into the space. A passive soil gas interception method should be should probably be added in areas of high radon concentrations.

The use of the crawl space for a supply plenum requires the floor and skirt to be fire protected by gypsum board which will add substantially to the cost.

Retrofit

Due to the uncertainty of radon concentrations a retrofit solution for a soil gas interception system may be a reasonable strategy. Assume that no preparations have been made for radon control except the normal 6 mil polyethylene ground cover and the radon concentrations are excessive. A 3" or 4" perforated drain pipe can be added on top of the ground under the membrane and the membrane patched where it is necessary to penetrate it. Most of the pipe can be forced between the ground and membrane from the end of the building without cutting the membrane much. The drain pipe can then be attached to a 4" or 6" PVC pipe extending up the exterior of the building past the roof and a fan added. To provide power for the fan an electrical conduit can exposed on the wall between the panel and the fan. The fan must operate continuously and a warning device should be mounted in one of the classrooms to signal if the system is not operating properly.

The retrofit strategy has the advantage of not adding to the first cost of the building, but still provides a satisfactory solution for an excessive radon build-up problem, should one occur. It also has the advantage of being appropriate if the building is relocated to another site. This system will cost more than if it is installed initially; it should work well for any underfloor space use under consideration. The exposed pipe on the exterior of the building will be unsightly.

Conclusions

Rely on the retrofit strategy for zones 1 and 2, and possibly for zone 3 because most buildings should not have an excessive radon build-up.

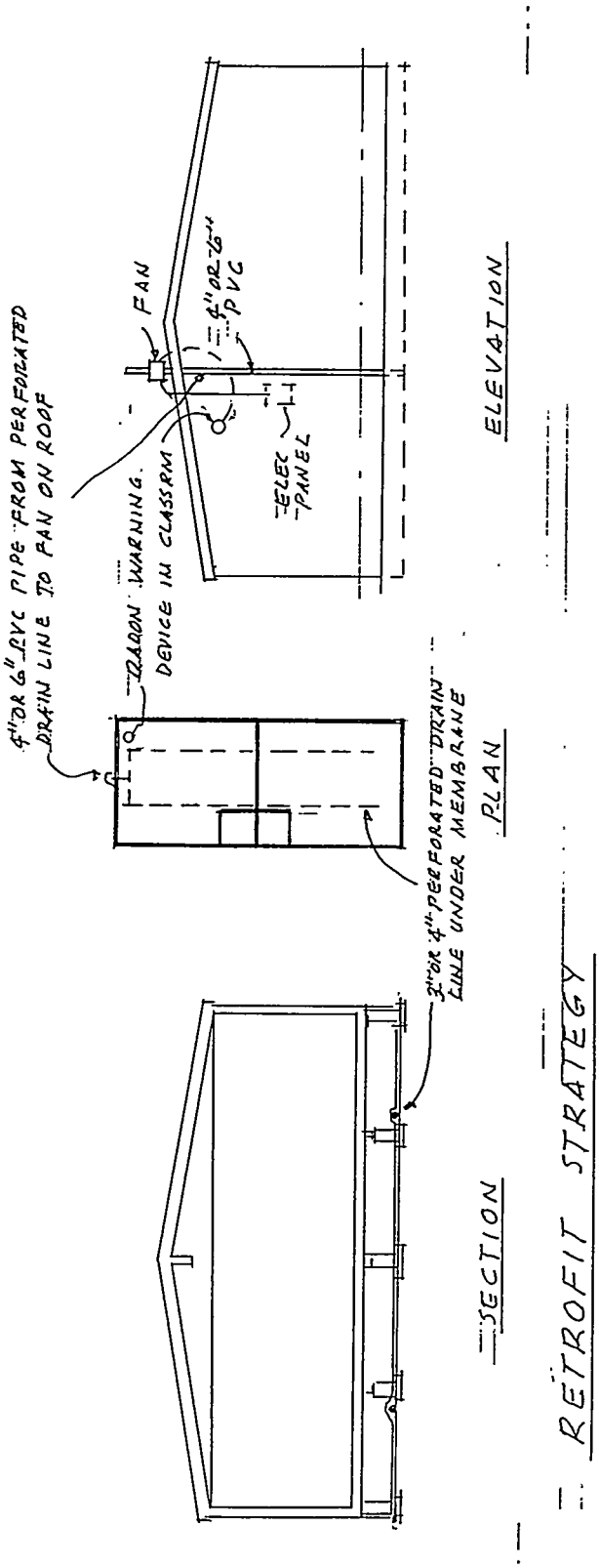

Figure 4.1-1, Retrofit Strategy

4.1.1.3 Moisture Control

Objective

There are two types of water problems to be solved to control the moisture: 1) Surface water; and 2) Evaporation of soil moisture from the ground under the building.

The solution of these problems is essentially the same for all types of underfloor options being considered for the MBS classrooms.

Results and Conclusion

Surface water

It is essential to divert the water away from the building to prevent it from finding its way under the building into the crawl space. If the grade of the crawl space is below the exterior ground surface and the exterior crawl space wall is not impervious to water penetration the water must then be eliminated. Evaporation in an unvented crawl space will not happen. Water can be eliminated by a drainage system. A typical drainage solution is to provide a 4" gravel fill with drainage pipes to carry the water by gravity outside the building. In worst cases the pipes can lead to a sump where the free water is pumped out. A ground cover is placed above the pipes and gravel. Another solution is to provide a gravel drainage system around the perimeter which may or may not include drainage pipes; ideally it will be daylighted (rather than to a sump) and water eliminated by gravity.

Evaporation of soil moisture under the building

This is the most common water problem and the easiest to solve. Its solution also serves to mitigate the radon problem. A durable ground cover such as 6 mil polyethylene, or 45 mil EPDM membrane or 55# smooth roll roofing are recommended. If it is anticipated that there will be free water from surface run off that will find its way to this space a drainage system as described above will be needed.

4.1.2 Algorithm for Perimeter Insulation Foundation System

Objective

Develop an algorithm to simulate the perimeter insulation foundation system (PIFS) in DOE 2.1E.

Methodology

Since similar work has already been done by Huang et. al. (1988) we used their results as a first look at the problem. The buildings are similar in size and envelop with difference being in the use, occupancy (internal loads), duct leakage, HVAC system, and lighting. By comparing the vented crawlspace building with the parametrics for perimeter insulated systems we could get an idea of the magnitude of the potential savings for our case. First we needed to establish which climates in the study best represent our seven climates that we are studying based on climate data. By evaluating the climate data we chose from the study Bismark to represent Fairbanks, Phoenix to represent Phoenix, Fortworth to represent Sacramento, Miami to represent Miami, Seattle to represent Astoria, and Denver to represent Spokane. Comparing the results for a ventilated crawlspace to various PIFS it was found that PIFS did not save more energy than the base case and were not pursued further in Fairbanks, Describes scope of task and how it was performed.

Results

The buildings are similar in size and envelop as seen in figure 4.1-2.

Comparison	Study	MBS
Building's		
Length	55.0	64.0
Width	28.0	28.0
Height	8.0	8.0
Floor area	1540.0	1792.0
House volume	12320.0	14336.0
Gross wall area	1328.0	1472.0
Net wall area	1123.7	1334.0
Window area	184.8	114.0
Door area	19.5	24.0
Perimeter	166.0	184.0

Figure 4.1-2, Comparison of MBS Classroom Building to Building Studied by Huang

Climates in the study best represent our seven climates that we are studying based on climate data as seen in the figure below.

	Study	MBS	Study	MBS	Study	MBS	Study	MBS	Study	MBS	Study	MBS
Compar-ison	ND	AK	AZ	AZ	TX	CA	FL	FL	WA	OR	CO	WA
Climate	Bis-mark	Fair-banks	Phoe-nix	Phoe-nix	Fort-worth	Bakers-field	Miami	Miami	Seattle	Astoria	Denver	Spo-kane
Latitude	46.0	64.0	33.0	33.0	32.0	35.0	25.0	25.0	47.0	46.0	39.0	47.0
Eleva-tion	1647.0	436.0	1112.0	1112.0	537.0	475.0	7.0	7.0	20.0	8.0	5283.0	2357.0
Winter 99%	-23.0	-51.0	31.0	31.0	17.0	30.0	44.0	44.0	22.0	25.0	-5.0	-6.0
Winter 97%	-19.0	-47.0	34.0	34.0	22.0	32.0	47.0	47.0	27.0	29.0	1.0	2.0
Sum-mer DB 1%	95.0	82.0	109.0	109.0	101.0	104.0	91.0	91.0	85.0	75.0	93.0	93.0
Sum-mer WB 1%	68.0	62.0	71.0	71.0	74.0	70.0	77.0	77.0	68.0	65.0	59.0	64.0
Sum-mer DB 2.5%	91.0	78.0	107.0	107.0	99.0	101.0	90.0	90.0	82.0	71.0	91.0	90.0
Sum-mer WB 2.5%	68.0	60.0	71.0	71.0	74.0	69.0	77.0	77.0	66.0	62.0	59.0	63.0
Sum-mer DB 5%	88.0	75.0	105.0	105.0	97.0	98.0	89.0	89.0	78.0	68.0	89.0	87.0
Sum-mer WB 5%	67.0	59.0	71.0	71.0	74.0	68.0	77.0	77.0	65.0	61.0	59.0	62.0

Figure 4.1-3, Comparison of Climates Studied by Huang and Report

Comparing the results for a ventilated crawlspace with floor insulation to non ventilated crawlspaces with various PIFS it was found that PIFS did not save more energy than the base case (and were not pursued further) in Fairbanks, Sacramento, Astoria, and Spokane. There was a slight advantage in energy in Phoenix and Miami.

Conclusions

The project was thus turned to a more energy savings option, the air to air heat exchanger.

5.0 AIR-TO-AIR HEAT EXCHANGER

Due to the size of the ventilation load in the classrooms a design for an inexpensive and efficient air to air heat exchanger was developed. The initial development included a review of codes, cost analysis, and computer simulations. Once this showed promise manufacturing drawings and specification were prepared for the construction of a full size prototype to be tested for thermal performance and installation costs. The results of the testing were used to improve the building simulations with the heat exchanger and the establishing of long term monitoring of the product for performance over time.

5.1 TECHNICAL OBJECTIVE #1: DEVELOP PHASE I DESIGN

The initial development included a review of codes, cost analysis, and computer simulations.

5.1.1 Architectural and engineering design and analysis

MBS to supply

5.1.1.1 Code review

MBS to supply

5.1.2 Cost analysis

MBS to supply

5.1.2.1 Refine preliminary cost estimate

MBS to supply

5.1.3 Computer Simulations

A computer model of the heat exchanger was developed to look at the effect of different design parameters on the performance of the heat exchanger. The results of these simulations were incorporated into the whole building energy analysis.

Results of the following tasks were combined in section 2.1.4.9.

5.1.3.1 Simulate Heat Exchanger

5.1.3.2 Parametric studies

5.1.3.3 Simulate final design

5.2 TECHNICAL OBJECTIVE #2: DESIGN, BUILD, TEST HEAT EXCHANGER COMPONENTS

The favorable results during the first phase lead to the development of manufacturing drawings and specification for the construction of a full size prototype to be tested for thermal performance and installation costs. Long term monitoring of the product for performance over time was established for the phase II designs.

5.2.1 Manufacturer's Drawings and specifications

5.2.1.1 Architectural drawings and specifications

MBS to supply

5.2.1.2 Testing drawings and specifications

MBS to supply

5.2.2 Construct prototype

5.2.2.1 Test of Heat exchanger thermal effectiveness

Objective

Measure the effectiveness (ε) of the proposed flexible thin film air to air heat exchanger. Ventilation air is a major component of the building space load and by using a air to air heat exchanger to reclaim some of the energy from the stale exhaust air the resulting load of the building will be diminished.
The heat exchanger consists of 100 feet of 18" diameter flexible ducting with an R8 insulating jacket and an inner tube of 100 feet of 12" diameter flexible ducting laying in the 18" flexible ducting. The effective length of heat exchanger is reduced to 64 feet due to room under the building and use of the 12" flexible ducting for connections.

Methodology

Utilizing ANSI/ASHRAE standard 84-1991: method of testing air-to-air heat exchangers as the basis for the testing of the heat exchangers. A datalogger was used to measure the temperature, pressure, and relative humidity over the time of the experiment, while a hand held anemometer was used to measure the flow rate periodically. The temperature of the flow was controlled by the outdoor air on one side and the HVAC equipment of the building on the other side. By varying the temperature in the room, which is where the heat exchanger was drawing it air from and the flow rate of air through the heat exchanger by variable speed blowers we where able to establish an effectiveness for the heat exchanger. We did not include the parasitic losses of the blowers used to control the flow. For a set flow rate and difference in temperature run the heat exchanger until equilibrium is observed then take readings. Repeat with different flow rates and differences in temperatures. At the fresh air inlet measure temperature (4 point average), relative humidity, and velocity (both entering the air inlet and leaving the exhaust) (measure nine points in the face of the grill and average the value). At the fresh air outlet measure the temperature (4 point average) and the static pressure drop. At the classroom measure the temperature (2 point average) and relative humidity. At the exhaust inlet measure the temperature (4 point average) and the static pressure drop. At the exhaust outlet measure the temperature (4 point average).

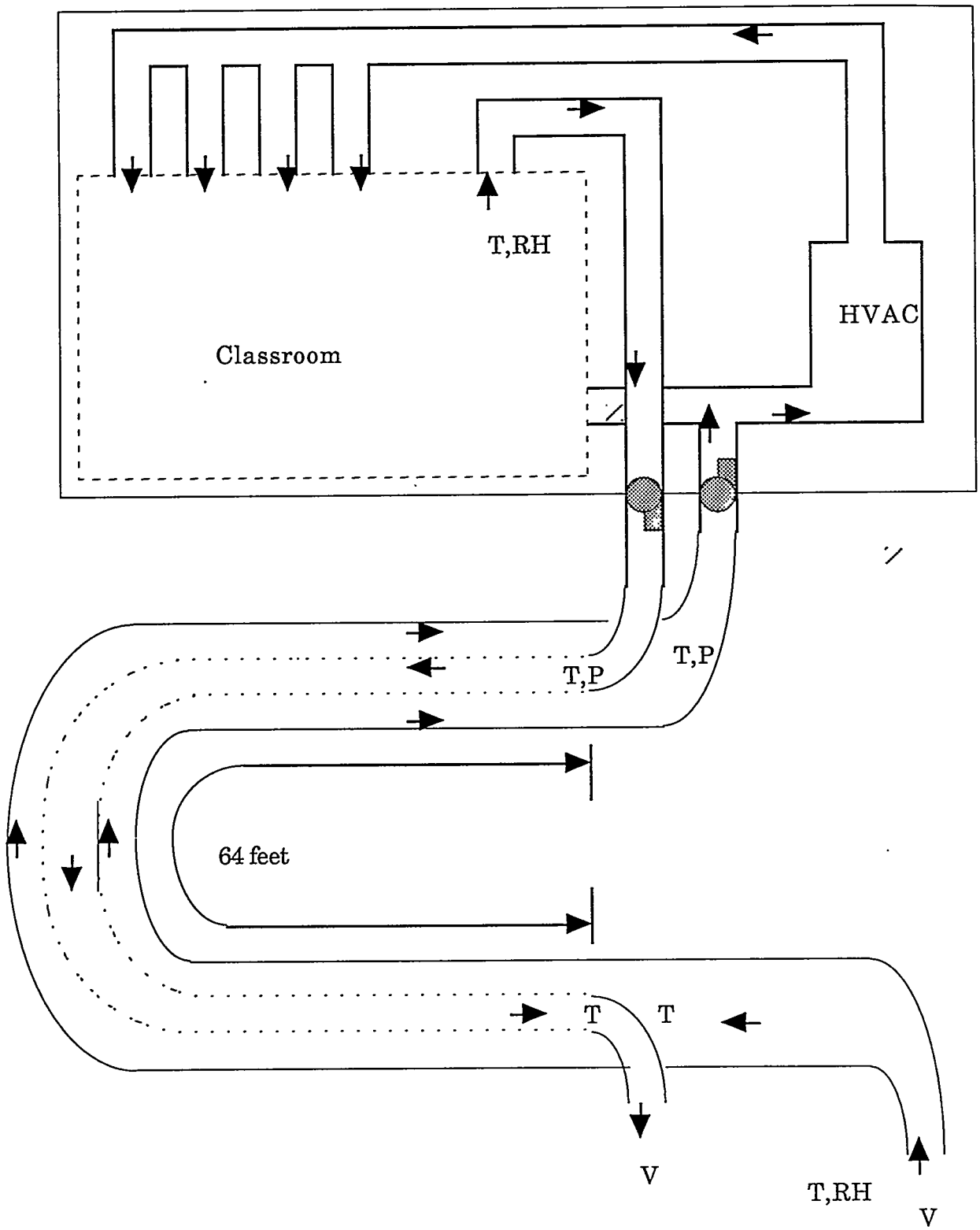

Figure 5.2-1, Testing diagram showing locations of the sensors.

Some assumptions are made in the calculations: only sensible heat transfer, velocity constant through heat exchanger tube, average velocity through tube is ok for calculations, and no leaks between the heat exchanger tubes.

The effectiveness of the heat exchanger is calculated by , where is the volumetric flow rate of the air being brought in from the outside to the room through the 18" diameter tube, is the minimum of (where is the volumetric flow rate of the air being removed from the room through the 12" diameter tube), Tsupply in is the dry bulb temperature of the outdoor air which is entering the heat exchanger, Tsupply out is the dry bulb temperature of the outdoor air, after it has gained some energy by going through the heat exchanger, which is exiting the heat exchanger and entering the HVAC system, Texhaust in is the dry bulb temperature of the room air which is entering the heat exchanger.

type	make	model	accuracy	range
datalogger	Campbell Scientific	CR10	-	-
expansion peripheral	Campbell Scientific	AM416	-	-
pressure difference	General Eastern	RH-2-I-S	2%	0 to 99%
relative humidity	Elan Technical Corporation	HM2000 with HT 1010 transmitter	3%	0 to 100%
temperature	Pyrocom	type T thermocouple 20 gauge shielded	1ºC	-200 to 350ºC

Figure 5.2-2, Testing Equipment Used to Evaluate Heat Exchanger Effectiveness

Results and Conclusions

See figures 5.2-3 through 5.2-8 for results.

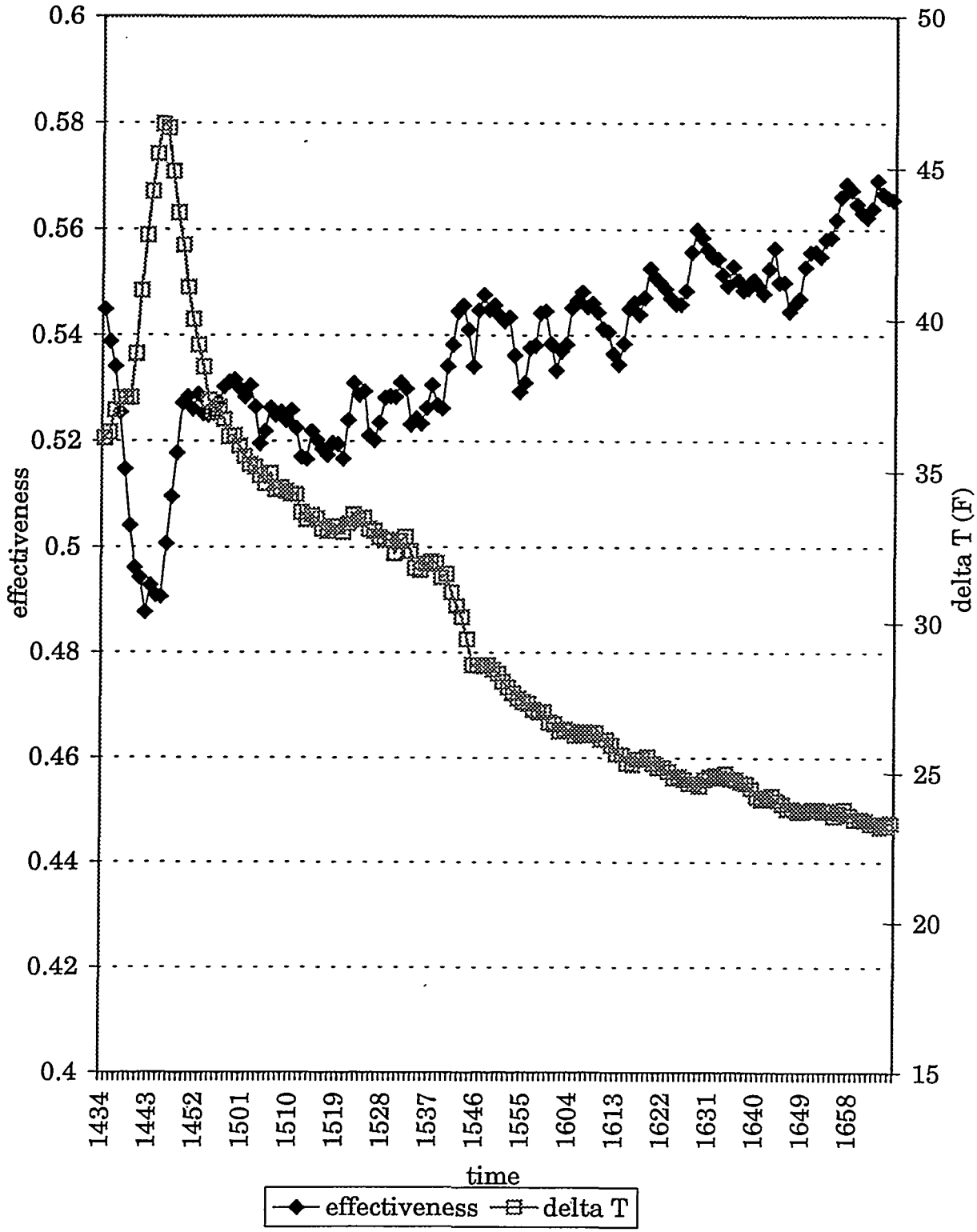

Figure 5.2-3, Test Results for Heat Exchanger at 224 cfm

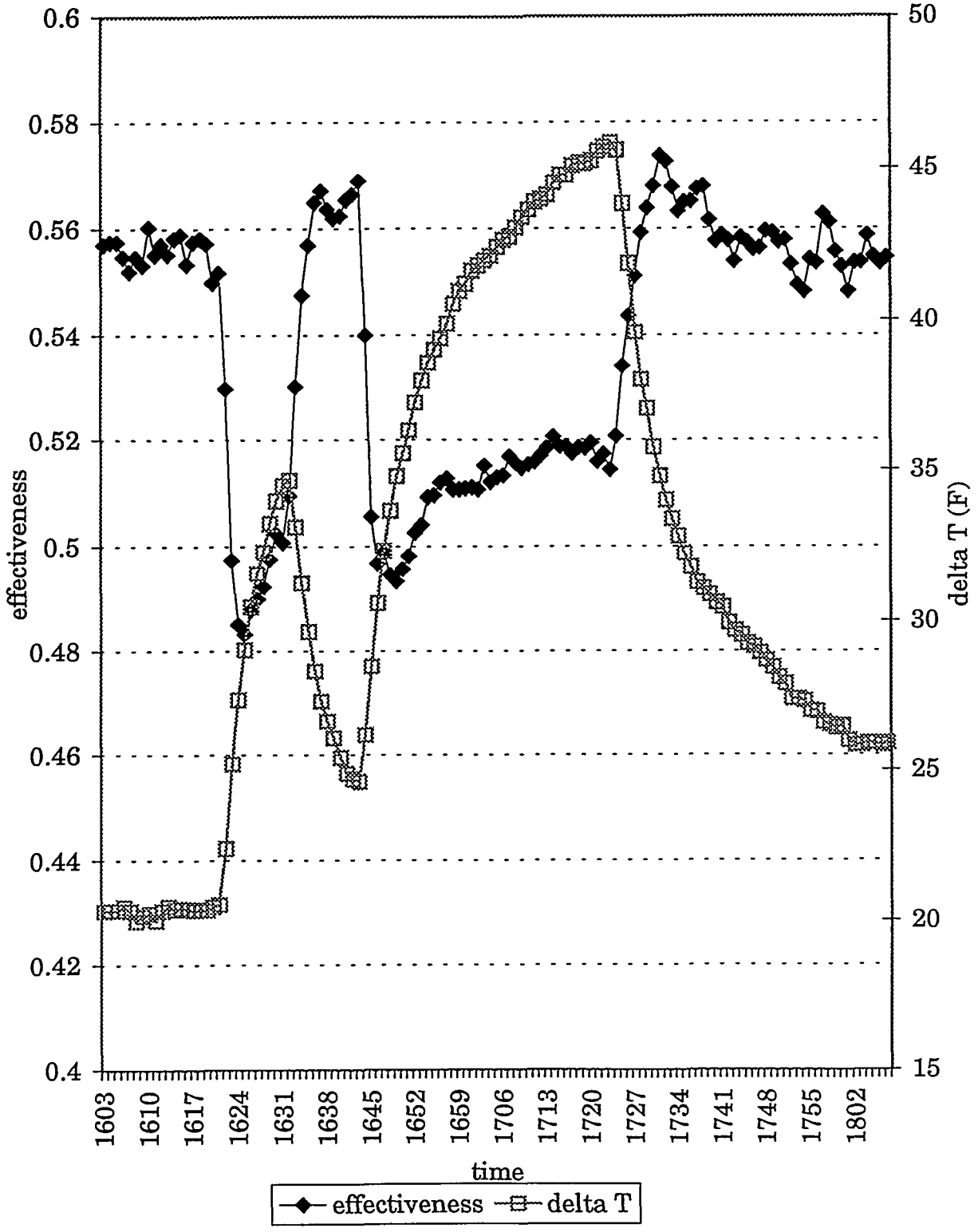

Figure 5.2-4, Test Results for Heat Exchanger at 237 cfm

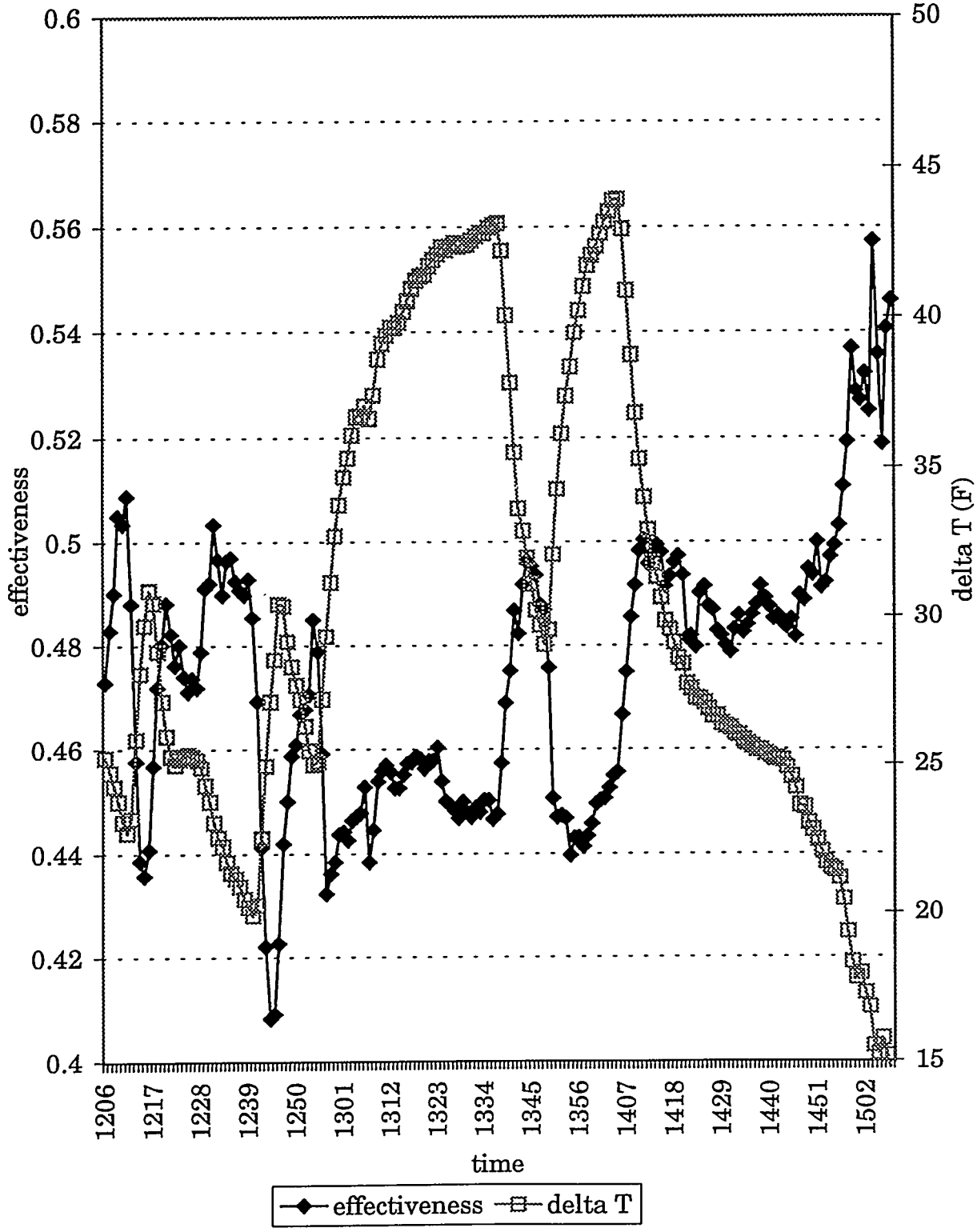

Figure 5.2-5, Test Results for Heat Exchanger at 375 cfm

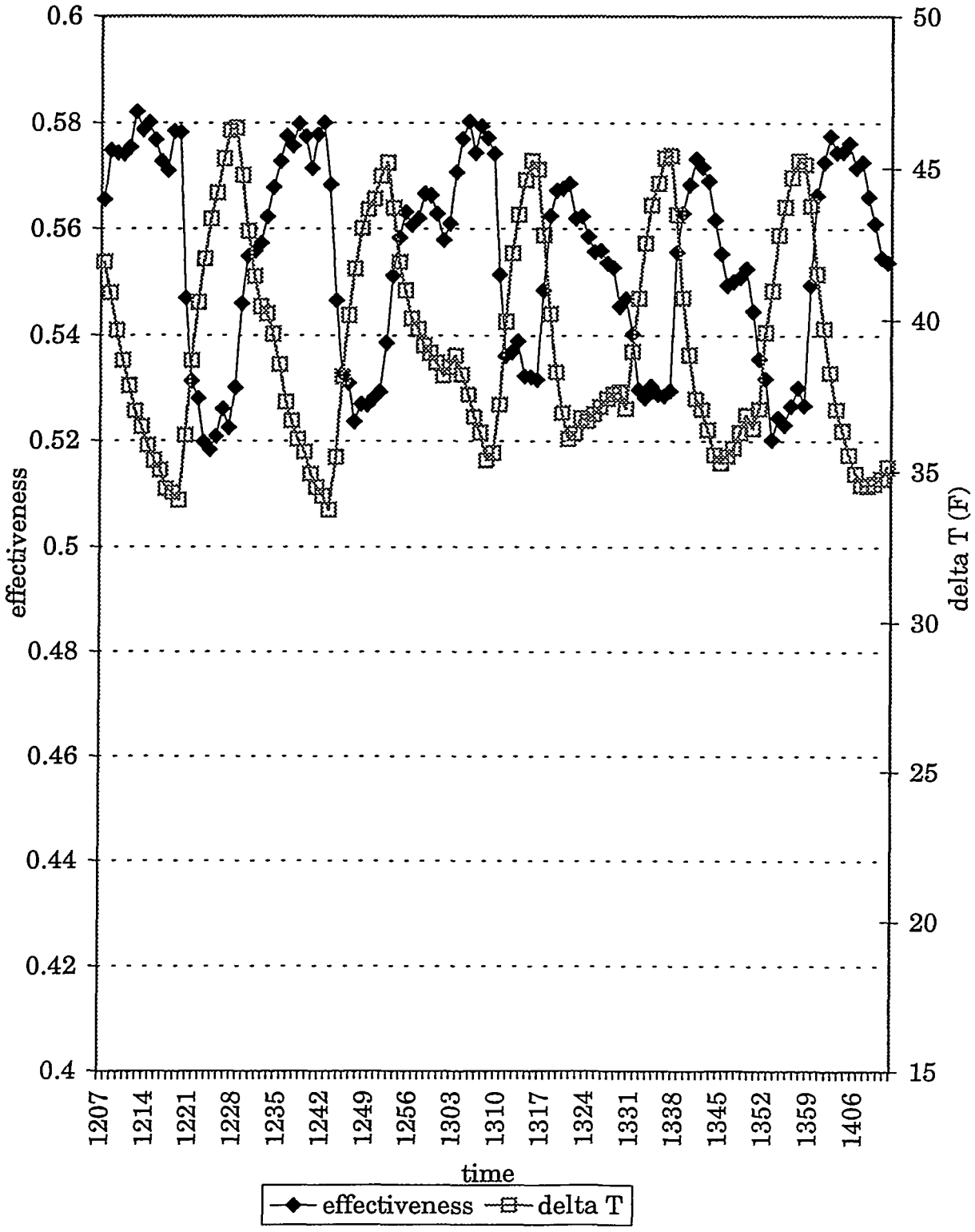

Figure 5.2-6, Test Results for Heat Exchanger at 422 cfm

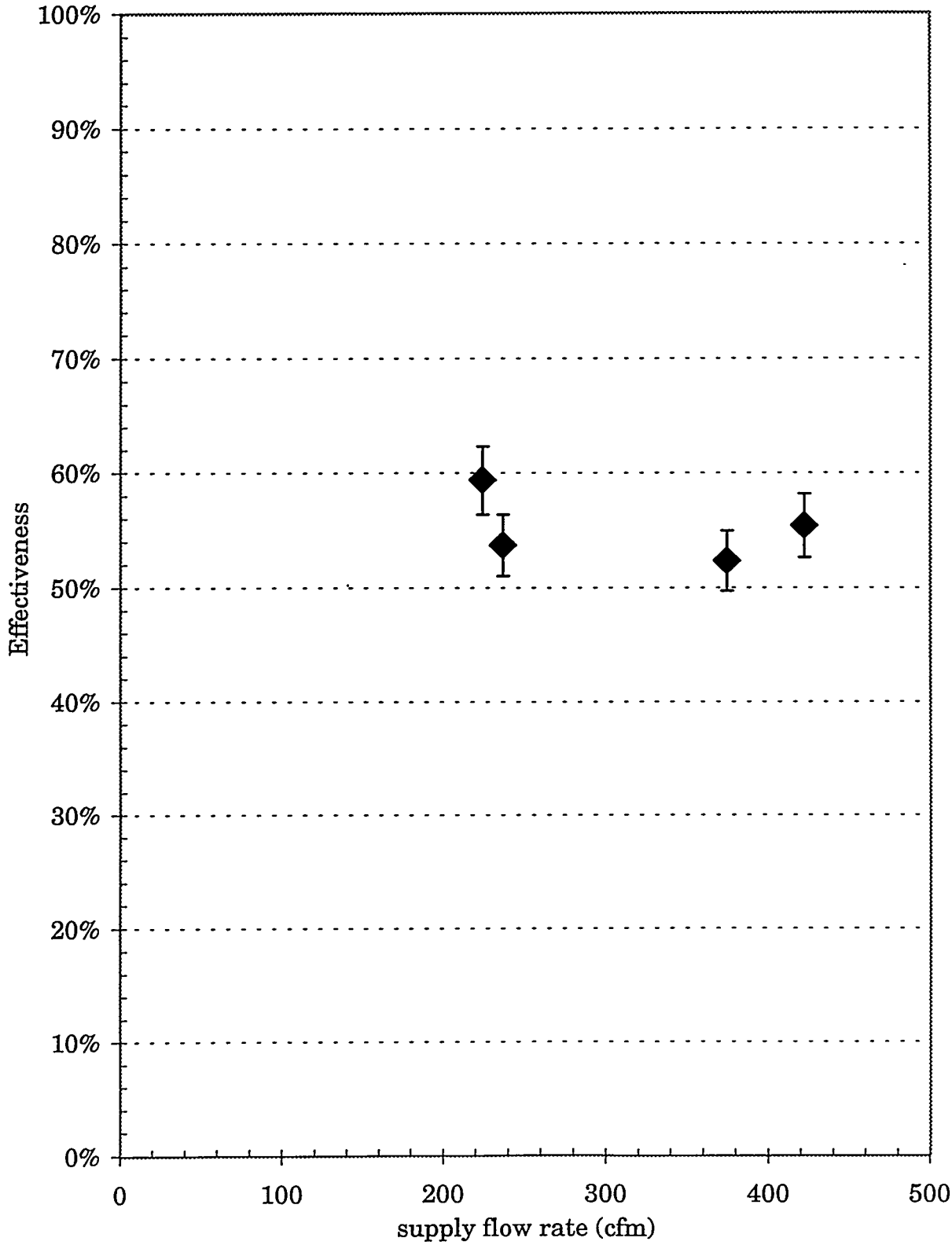

Figure 5.2-7, Average Effectiveness at the Four Flow Rates Tested

Test one 10/31/1998		
Exhaust pressure drop (average)	0.47	inches of water
standard deviation	0.01	inches of water
Exhaust flow rate (average)	339	cfm
standard deviation	15	cfm
Supply pressure drop (average)	0.79	inches of water
standard deviation	0.01	inches of water
Supply flow rate (average)	375	cfm
standard deviation	3	cfm
E1 (average)	47%	±5%
E1*Vsupply/Vmin (average)	52%	±6%
Test two 10/31/1998		
Exhaust pressure drop (average)	0.37	inches of water
standard deviation	0.01	inches of water
Exhaust flow rate (average)	280	cfm
standard deviation	8	cfm
Supply pressure drop (average)	0.42	inches of water
standard deviation	0.01	inches of water
Supply flow rate (average)	237	cfm
standard deviation	17	cfm
E1 (average)	54%	±5%
E1*Vsupply/Vmin (average)	54%	±5%
Test three 11/7/1998		
Exhaust pressure drop (average)	not recorded	inches of water
standard deviation	not recorded	inches of water
Exhaust flow rate (average)	461	cfm
standard deviation	2	cfm
Supply pressure drop (average)	0.78	inches of water
standard deviation	0.004	inches of water
Supply flow rate (average)	422	cfm
standard deviation	26	cfm
E1 (average)	55%	±4%
E1*Vsupply/Vmin (average)	55%	±4%
Test four 11/7/1998		
Exhaust pressure drop (average)	0.31	inches of water
standard deviation	0.008	inches of water
Exhaust flow rate (average)	203	cfm
standard deviation	10	cfm
Supply pressure drop (average)	0.36	inches of water
standard deviation	0.005	inches of water
Supply flow rate (average)	224	cfm
standard deviation	8	cfm
E1 (average)	54%	±3%
E1*Vsupply/Vmin (average)	59%	±4%

Figure 5.2-8, Summary of Test Results

5.2.2.2 Analyze results, adjust simulations

Results were analyzed and no adjustments to simulations were necessary.

5.2.3 Long-term Monitoring

Although funding was not designated for long-term monitoring, MBS continues long-term monitoring for additional information.