
Fig. 1. US Location

Emerald People's
Utility District
Headquarters Building
Eugene, Oregon

Vital Signs case study by University of Oregon
ARCH 407/507 seminar.
Winter 1999

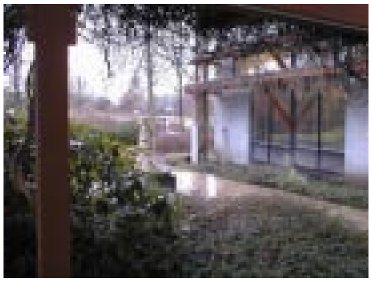


Fig.2. South-facing trellis


Fig. 3. EPUD image poster


Fig. 4: EPUD Headquarters, south entry

EPUD REVISITED: A Post Occupancy Analysis of Thermal and Daylight Design Implementation

ABSTRACT

The Emerald People's Utility District, EPUD, is a publicly-owned utility interested in energy conservation and renewable sources for generation. Two architecture firms: Equinox Design, Inc. and Group Architects & Planners, in addition to a daylighting consultant from the University of Oregon, were brought together to collaborate on the design of EPUD's new headquarters.

The building's design combines several energy conservation strategies such as the integration of daylight with electric light, passive cooling, and supplementary passive heating. A seminar class of graduates and undergraduates of the University of Oregon conducted an investigation of this building during winter term (10 weeks).

We focused on thermal comfort and daylighting. Our hypotheses stated that thermal comfort during the winter is sacrificed by the thermal mass strategies used in the building and that the daylight integrated electric lighting system functions as designed by evenly distributing the light and providing occupant satisfaction. To evaluate the building, the class divided into two teams: thermal comfort group and lighting group. Each group developed a set of inquiry questions.

The success of the building lies in having an group of informed occupants and an outstanding maintenance program. Workers know how the building operates and they have a fairly high degree of control over their thermal and luminous environment. The daylighting strategies in the building work well. There is an even level of illumination provided at the task level and people are satisfied with the general lighting conditions. The daylight-integrated lighting system did not perform as expected by stepping the electric lighting down when there is adequate light. Although people responded with comfortable thermal sensations and did not perceive the surfaces in their environment to be too cold, they were aided by heat from local space heaters. Recalculations of the effective thermal mass (using rule-of thumb) found that much more thermal mass was available than necessary, absorbing too much of the available heat (from equipment and any direct sun) making various locations become too cool.

Fig. 5: Planning

Fig. 9: Trellis over entry walk

BUILDING BACKGROUND & INTRODUCTION

The Emerald People's Utility District (EPUD) provides electricity to communities around Eugene, Oregon. The EPUD Headquarters, is a 24,800 sq. ft. office building, designed in 1986 by Equinox Design Inc., with Virginia Cartwright as the daylighting consultant. The design concept was driven by the idea of using as many energy conservation principles as viably possible. This criteria suggested that the plan should be long and thin, and oriented east to west, so the long facade could take advantage of the southern light. The design is an open-plan with high ceilings. It wraps around a courtyard and has electrical sub-meters spread out through the building to read data monthly. The primary intention of this design was to create a model energy-efficient building and provide a pleasing environment for building occupants. This was achieved in several ways:

Fig. 6:2nd Floor north side

1) Passive heating, cooling and lighting strategies were used in the design to offset excessive HVAC use. In the summer months, when cooling is an issue, the thermal mass of the structure absorbs excess heat during the day and releases it back into the space at night. Night ventilation is used to cool the accumulated warm air from the thermal mass during the unoccupied hours. Also, deciduous vines (Virginia Creeper) growing on trellises over the south-facing windows and clerestory are used to block direct sunlight by shading the windows. To solve the problem of heating in the winter months the direct gain system absorbs daylight on sunny days and radiates it into the space throughout the day.

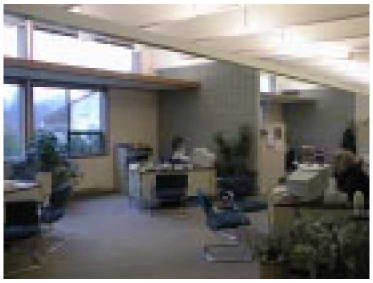


Fig. 7: Work Area

2) Daylighting strategies are used to maximize the amount of daylight used in the building and minimize the energy consumed by electric lights. A 2.5H rule-of-thumb design criteria (Stein and Reynolds, 1992, p. 198) was used to determine target daylight factors that would provide sufficient light during the daylight hours. This rule suggests that daylight will penetrate into a space that is 2.5 times the height of the floor to the top of the window. A 4% daylight factor was the design intent for the spaces near the windows. The T-shaped windows allow light that enters to bounce off the lightshelves and be distributed further into the spaces. This design, augmented by an adjustable indirect lighting system was intended to reduce contrast and potential glare on computer screens.

Fig. 8: Lunch Room

Fig. 10: North offices

Fig. 12: EPUD under construction

Fig. 11: Our team

The primary objectives of our investigation were:

A) To examine a local building that is an acclaimed model designed specifically to be energy-efficient, resource conserving, and able to promote the occupant 's sense of well-being.

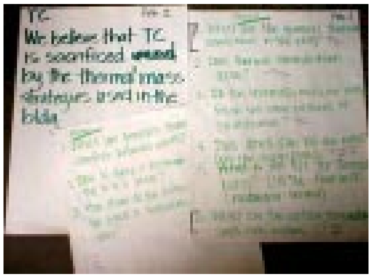
B) To measure, record and analyze the building's physical performance by comparing design intent, actual performance and user perceptions.

C) To gain experience in analyzing a building first hand and an understanding of how energy conscious design is actually realized in an occupied building.

During our first visit to the building on January 14th, we made preliminary measurements in order to familiarize ourselves with the general conditions of the building. We discussed our interests and observations and formed two teams that allowed smaller groups to focus on specific areas of inquiry. At this point, the case study document divides into two sections: Thermal Comfort and Lighting. Many of the issues we will discuss are related throughout our analysis and presentation of the results. Some areas such as the survey response overlap between sections, while other areas such as methods and equipment are combined. Tests and measurements were taken on February 2 and 11, 1999 at approximately 10:00 am. The weather was slightly overcast with occasional breaks of sunlight.

1. HYPOTHESES AND INQUIRY QUESTIONS

Thermal Comfort



TC

We believe that TC is sacrificed by the thermal mass strategies used in the bldg.

Fig. 13: Thermal Comfort hypothesis generation.

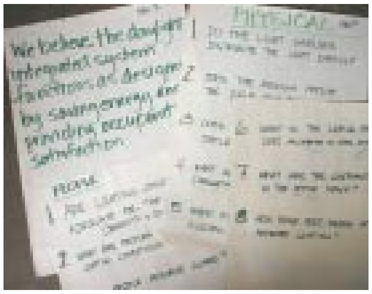
HYPOTHESIS:
We believe that during the winter, the passive heating strategy (direct gain) used in this building does not operate as intended by the designers. As a consequence, we believe that comfort conditions are attained by other means than those provided in the original design.

INQUIRY QUESTIONS:
General Thermal Conditions:
1) What are the general physical conditions of the building? Are these conditions within the comfort zone criteria set by ASHRAE Standard 55-1992?
2) Are people comfortable in the building? Is there a difference in the comfort perception between the north side vs. the south side of the building?
3) Do the high ceilings (designed for the provision of sufficient daylight and passive cooling) cause warm air to stratify?
4) What are the surface temperature patterns of the thermal mass? Do they affect comfort?
5) What are the air temperature patterns of this building? Can thermal comfort be attained in a massive building with lower air temperatures?

Design Intent vs. Actual Conditions:
6) Does the thermal mass function during the winter as intended by the designers? i.e. Does sunlight hit the thermal mass during the winter season? Does the ratio of "actual" south-facing glass-to-floor area correspond to the rule-of-thumb calculations? Does the ratio of thermal mass to south-facing glass correspond to the rule-of-thumb calculation?

2. HYPOTHESES AND INQUIRY QUESTIONS

Lighting



We believe the daylight integrated system functions as designed by saving energy and providing occupant satisfaction.

Fig. 14: Lighting hypothesis generation.

HYPOTHESIS:
We believe that the daylight integrated electric lighting system functions as designed by evenly distributing the light and providing occupant satisfaction.

INQUIRY QUESTIONS:
General Lighting Conditions:
1) What are the general illumination levels with daylight only? With daylight and electric light?
2) Do contrast ratios in the various office spaces create glare conditions?
3) Are people satisfied with the quantity and quality of light in the building?

Design Intent vs. Actual Conditions:
4) Does the 2.5H daylight penetration rule-of-thumb work with the light shelf to provide an even distribution of light? Do the lighting conditions in a typical office bay provide a 4% daylight factor?
5) Is energy conserved by reduced electric lighting use? What is the pattern of use for electrical lights? For task lights?

Fig. 15: Hobo-XT and Taylor sling psychrometer

Fig. 18: Laptop to launch Hobos

METHODS AND EQUIPMENT

Thermal Comfort

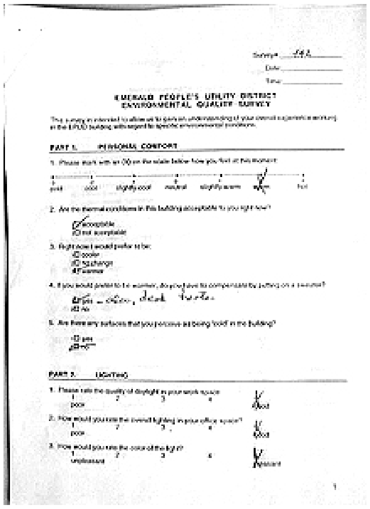


Fig. 16. EPUD environmental conditions survey

General Thermal Conditions:

1) What are the general physical conditions of the building? Are these conditions within the comfort zone criteria set by ASHRAE Standard 55-1992?

- We measured the general comfort conditions (temperature, humidity) using Hobo dataloggers for time-series measurements. Spot measurements of wet and drybulb temperatures were made with a Taylor manual sling psychrometer and globe temperature with a Campbell Scientific 21X datalogger.
- The conditions were plotted on a psychrometric chart to see if they fell within the winter comfort zone criteria of the ASHRAE Standard 55-1992.

2) Are people comfortable in the building? Is there a difference in the comfort perception between the north side vs. the south side of the building?

- We developed a survey (see appendix) and administered it to building occupants with a cover letter from the human resources director explaining our objectives.
- Each response on the survey was entered into an Excel spreadsheet from which we performed various analyses and tabulations.

3) Do the high ceilings (designed for the provision of sufficient daylight and passive cooling) cause warm air to stratify?

- 9 Hobo XTs spaced every 2' were placed vertically on a structural column on the second floor. This measurement provided us with a profile of the air temperature as a function of the height. The Hobo dataloggers were launched to register temperatures every 10 minutes.
- Temperature data from each of the 9 Hobos were analyzed in Excel to compare temperatures at the lower levels with those near the roof of the building.

Fig. 17. Launching Hobos

Fig. 19. RAYTEK infrared temperature gun

Fig. 21: Daylighting study model

Fig. 20: Measurement of thermal mass temperature

4) What are the surface temperature patterns of the thermal mass? Do they affect comfort?

- We created a 2' interval grid on three different walls (the west perimeter of engineering and two interior stem walls of that same bay) and measured the radiant temperature of thermal mass walls using the Raytek Raynger infrared temperature gun.
- Thermal map drawings were developed from these temperature measurements through an Excel chart and then transposed through Photoshop for graphical representation.

5) What are the air temperature patterns of this building? Can thermal comfort be attained in a massive building with lower air temperatures?

- 16 Hobo XTs were placed in three different areas (customer service, second floor office space, and engineering).
- We then compared our results to the surface temperature profiles of the thermal mass taken over the same period of time.

Design Intent vs. Actual Conditions:

6) Does the thermal mass function during the winter as intended by the designers? i.e. Does sunlight hit the thermal mass during the winter season? Does the ratio of "actual" south-facing glass-to-floor area correspond to the rule-of-thumb calculations? Does the ratio of thermal mass to south-facing glass correspond to the rule-of-thumb calculation?

- To answer these questions we compared the calculations made by the designers (Stein and Reynolds, 1992) to the conditions we found in the building.
- A new calculation of the rules-of-thumb was made with the modified south facing glass area.
- A daylighting model was constructed of the engineering section of the building. Using a pocket sundial and stage lamps, the model was tilted and oriented to determine if direct sun strikes the thermal mass during the winter season. The model was also used for daylighting analysis described in the next section.

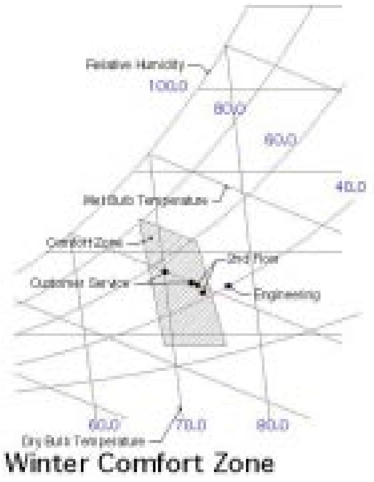


Fig. 22. Air temperatures and relative humidity of all locations except for engineering fell within the winter ASHRAE Standard 55-1992 comfort zone.

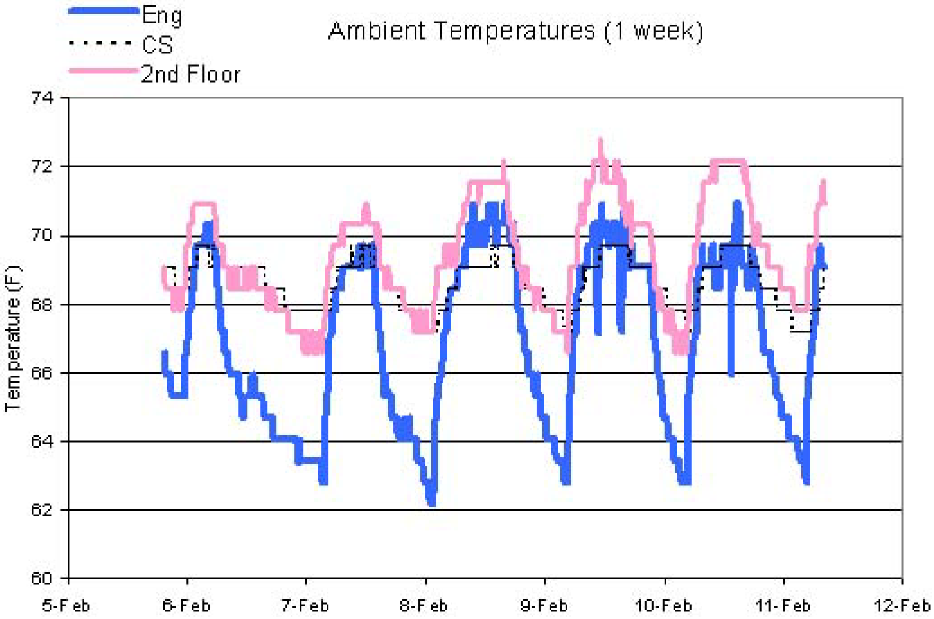


Fig. 23: General thermal conditions over a period of 7 days in the three areas studied in this building: customer services, second floor, and engineering.

General Thermal Conditions:

1) What are the general physical conditions of the building? Are these conditions within the comfort zone criteria set by ASHRAE Standard 55-1992?

Our measurements of temperature and relative humidity on January 14th were plotted and compared to the comfort zone on a psychrometric chart. We found that conditions in the building fall within the winter comfort zone of ASHRAE Standard 55-1992 for all locations except for the engineering zone (Figure 22). Cooler conditions were also observed over our week-long measurements (Figure 23). Nighttime temperatures in the engineering area were more than 4°F cooler than other areas of the building. Perhaps these areas have more exposed thermal mass. Relative humidity was typically between 40 and 50%.

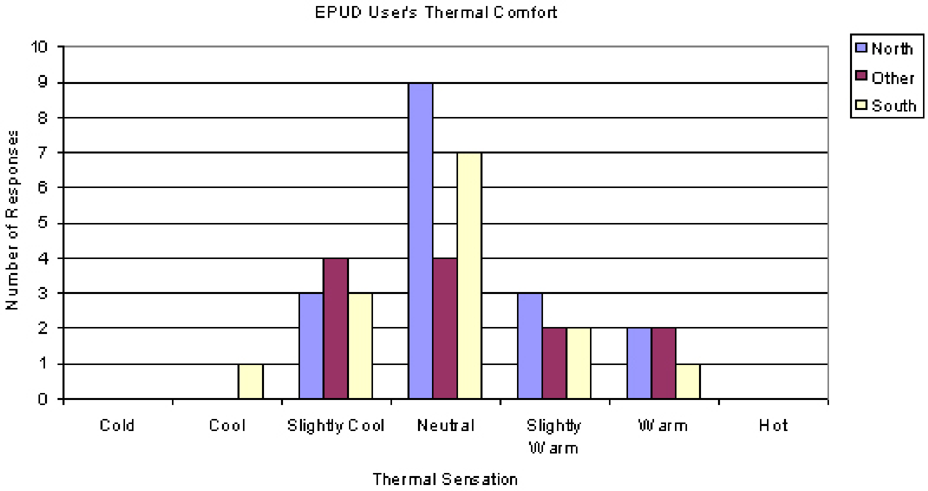


Fig. 24. Our survey showed that the EPUD building provides a comfortable environment (more than 80% of the votes fell between +1 slightly warm and -1 slightly cool).

2) Are people comfortable in the building? Is there a difference in the comfort perception between the north side vs. the south side of the building?
In order to determine if people's thermal sensation corresponded with the results of our physical measurements, we carried out a survey to assess the occupants' perceived sense of well-being. The survey results showed that the environment was acceptable according the ASHRAE thermal sensation scale (Figure 24). More than 80% of the votes were cast between the boundaries of acceptability. The same results were found when we asked the question: Do you find this space acceptable?

Nevertheless, is interesting to note that people who voted "slightly cool" or "slightly warm" also voted "unacceptable". Even though the conditions in engineering fell outside the ASHRAE comfort zone, people's vote followed the same pattern as in the rest of the building. Our survey did not provide evidence of localized discomfort between the north and the south sides, but it did show that on the east side of the engineering area the two occupants of a large office declared that the space was cool.

3) Do the high ceilings (designed for the provision of sufficient daylight and passive cooling) cause warm air to stratify?
An important question in our study was to see whether the high ceilings designed for passive cooling and for a better distribution of daylight were causing warm air to stratify. We placed our HOBO- XTs on a structural column in the space with the highest ceiling (central part of the second floor). To our surprise, we found that there is almost no stratification of air (Figure 25).

The temperature readings from the HOBOs placed every 2 feet, up to a height of 18 feet, show that the average difference between the floor and the ceiling temperatures is close to 1°F. It is interesting to notice that the maximum difference happens between the floor and 2/3 of the total height, where the south slab ends giving way to the south clerestory windows (Figure 25). We think that the clerestory windows cool the air in the highest portion of the space creating a "thermal inversion" effect, allowing the warmest air to remain at about 13 feet above floor level. We can conclude that the high ceilings do not sacrifice thermal comfort in this building, and that they helped to provide daylight and passive cooling (during the "closed" hours of the nighttime ventilation of mass) in the summer time.

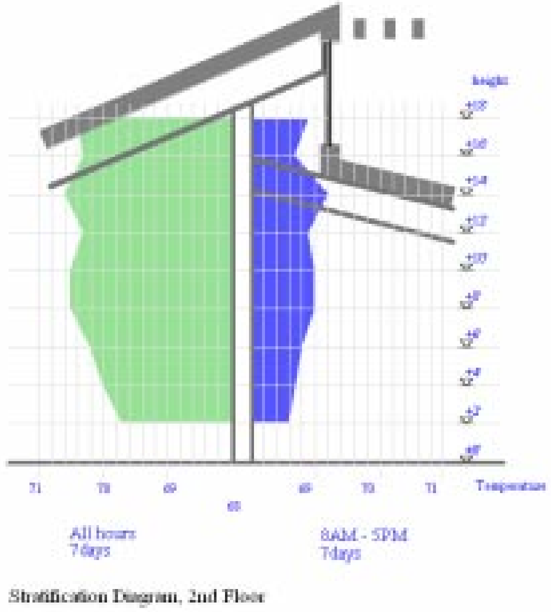


Fig. 25: *Air temperature increased by approximately 1°F toward the high ceiling.*

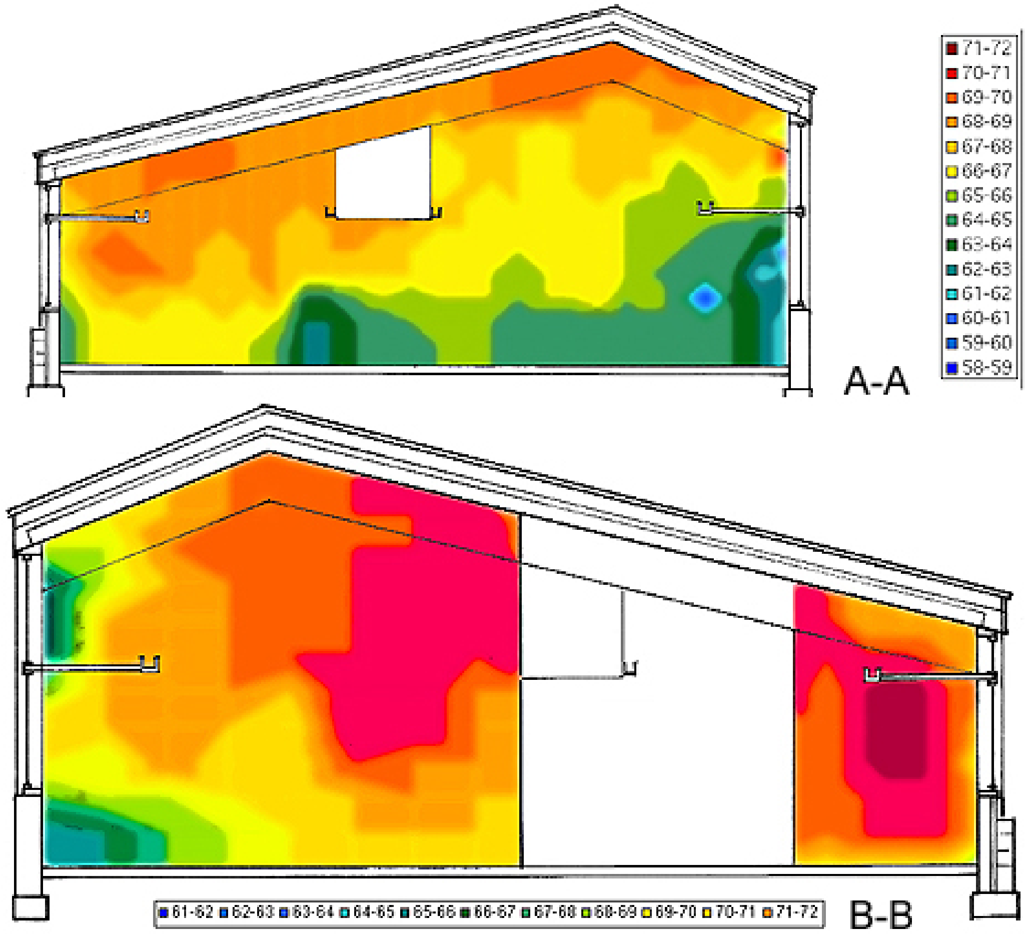


Figure 28. *Surface temperature of the thermal mass. The temperature on the south is higher than the one on the north side. Also, the temperature close to the windows is lower than the one on the center of the space.*

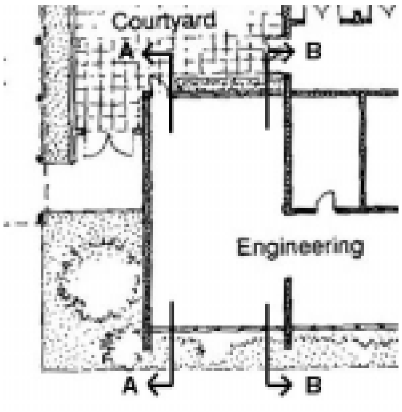


Fig. 26: *The plan shows where these sections were cut through the building.*

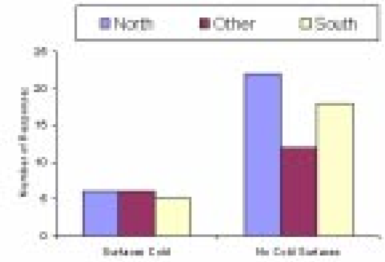


Fig. *27: The results of our survey show that 25% of the occupants of the building perceived surfaces as being cold.*

4) What are the surface temperature patterns of the thermal mass? Do they affect comfort?

After mapping the surface temperatures of the thermal mass (Figure 28) we found that the temperatures around the windows located on the north and south sides of the engineering area were lower than those at the center of the space. The south side of both the west-perimeter wall and the stem walls had higher temperatures under the light shelf area (Figure 28). We attribute this to the direct gain heating strategy.

The north side of the west-perimeter wall and the north stem wall present some stratification of temperatures with the coolest area at the bottom corners. The thermal mass is warmest around the light shelves, the south side being the warmest.

More often than not concrete is perceived as a "cold" material. But despite this perception, concrete is one of the best materials for thermal storage (Mazria, 1979). The EPUD building is characterized as having a high ratio of thermal mass to floor area (1.5 : 1). In a building like this, there is always a risk of people perceiving the surfaces of the building as being cold. To answer this question we used the question: Do you perceive any cold surfaces in the building? Approximately 25% of the occupants perceived the surfaces to be cold (Figure 27). There was not a distinction in perception of cold surfaces between occupants in the north or the south zones.

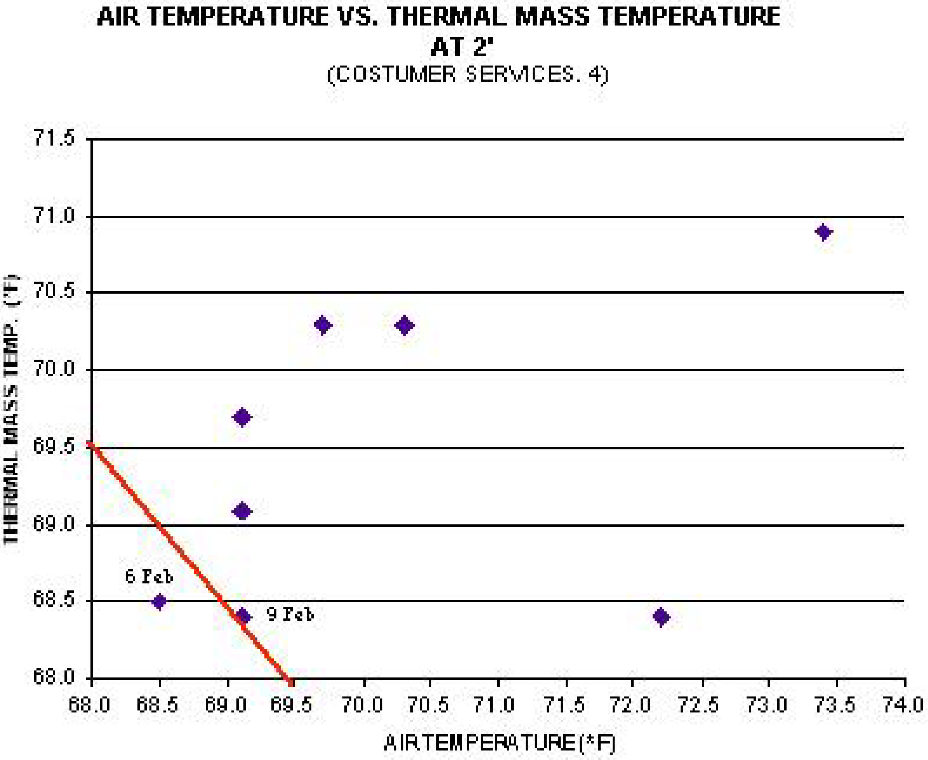


Fig. 30. *Thermal conditions in the custumer services area. The combination of air and radiant temperatures during the working hours produced a satisfactory environment most of the time. The only exceptions occurred at 8:00 AM during two of the 5 days monitored.*

Fig. 29. Behavioral adaptation: EPUD worker warming up with hot tea and a wool sweater.

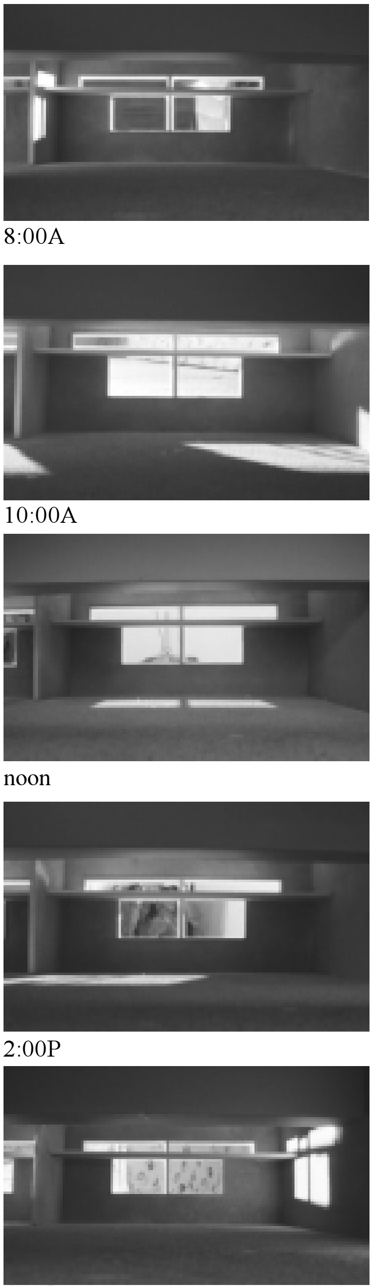
We think that part of the success is due to the use of CMUs with a rough texture. They provide some visual interest, and break the monotony that concrete some times can have. The overall thermal conditions of the space show that the building is thermally stable in all the areas except for engineering. The temperature swings in this area can be attributed to a larger area of exposed "skin".

5) What are the air temperature patterns of this building? Can thermal comfort be attained in a massive building with lower air temperatures?

We studied the radiant and air temperatures in the customer service area by comparing (Figure 30) the minimum and maximum air temperatures against the average radiant temperatures during the working hours, 8:00 am to 5:00 pm.

The results show that during two days (marked Feb. 6 and 9 on Figure 30) at 8:00 am the conditions fell outside the comfort zone (assuming that the radiant temperature of the mass could be used as a "representative" mean radiant temperature). During our winter test period, it appears that thermal conditions are within the comfort zone specifications (noted in Figures 22 and 23). It should be noted that during our test period, task heaters were operational. Although we found the occupants to be comfortable, it would be interesting to monitor the thermal conditions *without* the additional heat provided from these heaters, to see if perceptions might change.

Fig. 31. Solar analysis using a daylight model.



8:00A

10:00A

noon

2:00P

4:00P

***Fig. 32.** Solar analysis for the winter solstice (engineering area).*

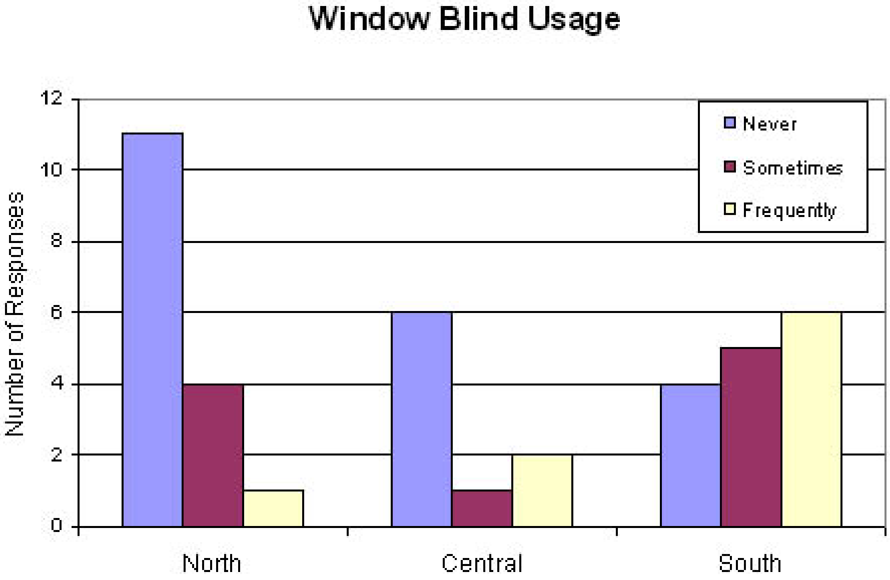


Fig. 33. Survey question: How often do you adjust the blinds near your desk? Results show that people working in the south zone adjust their blinds more frequently than those located in the north-facing zone.

Design Intent vs. Actual Conditions:

6) Does the thermal mass function during the winter as intended by the designers? i.e. Does sunlight hit the thermal mass during the winter season? Does the ratio of "actual" south-facing glass-to-floor area correspond to the rule-of-thumb calculations? Does the ratio of thermal mass to south-facing glass correspond to the rule-of-thumb calculation?

EPUD was designed with extensive thermal mass (concrete ceilings and concrete block stem walls) to absorb excess heat from the areas lit with south facing glass during the winter. In order to evaluate the effectiveness of the direct gain strategy we decided to build a daylighting model to see how many hours the sun would strike the thermal mass during the winter.

To our surprise, we found that the sun strikes only a small portion of the mass for just 4 hours during the winter solstice (Figure 32), provided the blinds were up. The photographs also indicate that the sun hits the stem walls from early morning until 9:00 am and then again at 3:00 pm. During our observation period, there were no occurrences of direct sun -- a typical circumstance with Eugene weather! In our review of climate data for Eugene (ECS I Appendix, p. 5), the month of December has a mean of only 1.5 clear days and 25.7 cloudy days, making it extremely rare for the building to be hit by the direct sun at all.

Our impression is that successful passive heating strategies in the Eugene location can be difficult to achieve because of the amount of sky cover. Furthermore, during the few days that sun might directly penetrate the building during the winter, office workers (although delighted) might respond by adjusting the blinds, further hampering the sun's effectiveness on the thermal mass stem walls. Our survey (Figure 33) showed that people operated the blinds more frequently in the south-facing zone than in the north-facing zone.

Fig. 35. Solar analysis with daylight model showing shading provided by the trellises during the winter solstice.

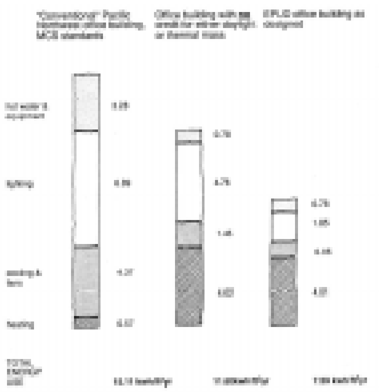


***Fig. 34.** Comparison of energy use in different buildings*

A graphic (Figure 34) from the literature shortly after the building opened, shows the potential for saving total energy use relative to other conventional office buildings. Our winter study examined the effectiveness of the thermal mass as a passive heating strategy and found the increase in effective thermal mass, actually made the building too cool in the winter.

During the equinox the building seems to let in adequate light. The thermal mass is hit by direct sun, but not as much as it is in winter due to the structure of the trellis frames blocking the sunlight (Figure 35). The trellises keep almost all direct sun out of the building during the summer.

The design intent was for summer cooling using the thermal mass and a night flush system which keeps the building cool and comfortable during the summer.. In the calculations for passive heating (Direct Gain DGC1) the designers assumed 97 ft^2 of south window area, and 132 ft^2 of clerestory area, both on a typical bay (Stein and Reynolds, 1992 p. 197). During our visit to the building we found out that screens were placed near the clerestory to prevent glare. Also, there were deciduous vines on a trellis that would provide seasonal shading, but they were removed after a retrofit. These changes modified the "effective" area of south-facing glass, which we estimated reduces the south glass-to-floor area ratio from 0.16 (Stein and Reynolds, 1992 p. 211) to 0.12. Our estimation was based on the transmittance of the clerestories being decreased by about 30% because many people have their blinds down when direct sun is present, lowering the Solar Savings Fraction from 25% to about 20%. Since the Solar Savings Fraction is a measure of a building's conservation advantage (the extent to which a solar design reduces a building's auxiliary heat requirement relative to a reference building) The significance of this means that the instead of having 229 ft^2 of south facing glass we have now 172 (due to the decrease in the transmittances of the clerestories) in a typical bay, decreasing the potential for solar heating. Additionally, the ratio of thermal mass-to-south glass changes from 10:1 to 13:1 -- thus making the large areas of thermal mass a possible explanation for the reason why more heat is absorbed than necessary and certain locations being cooler than expected temperatures in the winter, causing local discomfort.

Fig. 36. Downloading data from Hobo dataloggers.

Fig. 37. Thermal team discussing conclusions.

During our winter observation period, we found that thermal comfort was achieved with the addition of task heaters that were not included in the original design. We believe that the thermal mass absorbs too much of the available heat (from equipment and any direct sun) and various locations become too cool. Consequently, people have brought in task heaters. This hypothesis explains why the building has such a high energy consumption for heating purposes during the year.

We found temperatures on the thermal mass facing the north were lower than those on the south side. This finding indicates that the passive heating strategy of direct gain may function as intended or temperatures are raised by the use of space heaters along the south side of the building. Through our surface temperature measurements of the thermal mass, we also observed the cooler temperatures of the windows. Windows with a higher R-value would help improve the overall thermal performance of the building.

The design intent to passive cooling during the summer via nighttime ventilation of the thermal mass appears from the literature to be successful. As John Reynolds explained, the building utilizes its thermal mass to absorb excess heat during the day, and releases it at night when the building is cooled by "flushing" it with outdoor air. To function successfully this passive cooling strategy requires an even distribution of the mass throughout the building. It seems the opposite happens with the passive heating strategy. To be successful, the mass in a direct gain strategy needs to be exposed to the sun. However, since the client wanted to have a carpeted floor, this reduced the potential for the mass to be hit by direct solar radiation. In addition to the reduced window apertures, lack of clear days in the winter, and consequent “increased” thermal mass by lowered Solar Savings Fraction, has made the building perform differently than what was originally intended.

Fig. 38. Sunlight hitting the thermal mass stem walls in an unoccupied space.

Fig. 39. Sylvania DS2000 light meter.

Fig. 40. Team starting the illumination "sweep".

Fig. 41. Taking luminance readings.

Fig. 42. Minolta LS100 luminance meter.

General Lighting Conditions:

1) What are the general illumination levels with daylight only? With daylight and electric light?

- Illumination measurements were taken along a 4' grid pattern. Each person in the class used a Sylvania light meter held 30" above the floor and performed a simultaneous "illumination sweep" through the entire second floor. Measurements were recorded by each team member onto a prepared plan with gridlines. One team member led the sweep formation by calling out to when to advance to the next grid point. The sweep was performed twice, once with the electric lights on and again for daylight only measurements.
- Isolux drawings were developed from the illumination measurements through an Excel chart and then transposed into Photoshop for graphical representation.

2) Do contrast ratios in the various office spaces create glare conditions?

- A Minolta LS-100 luminance meter was used to take the luminance readings of various surfaces. These readings were then written onto sketches of the study areas.
- Photographs of the same areas were also taken and adjusted in Adobe Photoshop in order to show the contrasts of lighting conditions.
- The measurements taken with the luminance meter allowed us to calculate the brightness ratios. These ratios were then compared to the recommended guidelines from the Illuminating Engineering Society (Stein and Reynolds).

3) Are people satisfied with the quantity and quality of light in the building?

- We developed a survey (see appendix) which included a section about lighting conditions and administered it to building occupants with a cover letter from the human resources director explaining our objectives.
- Each response on the survey was entered into an Excel spreadsheet from which we performed various analyses and tabulations.

Design Intent vs. Actual Conditions:

4) Does 2.5H daylight penetration rule-of-thumb work with the light shelf to provide an even distribution of light? Do the lighting conditions in a typical office bay provide a 4% daylight factor?

- Using a tape measure, we measured the distance from the base of the wall directly below the window to where the daylight qualitatively appeared to fade. Isolux drawings developed from our general illumination measurements were also used to verify the daylight penetration. These measurements were compared to the 2.5H rule-of-thumb guideline to see if the actual design fulfilled the criteria.
- To determine light distribution from the light shelves, we used the daylighting model (constructed to match specularity of materials ensuring similar conditions to the building) to measure illuminance using a LiCor Quantum photometer. Illumination measurements were taken along a grid inside the model, with the lightshelf and without. Photographs also recorded the light quality during overcast conditions.
- Calculations used the formula: $DF_{av} = 0.2$ (window area / floor area), to determine the average daylight factor.

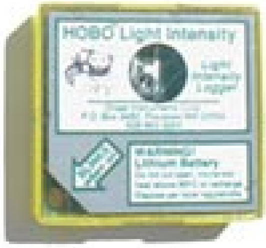


Fig. 43. HOBO light intensity data logger used in Hobopod.

5) Is energy conserved by reduced electric lighting use? What is the pattern of use for electrical lights? For task lights?

- Using Hobo-light dataloggers, we constructed “Hobo-pods” using braces made of foamcore when propped the datalogger sits approximately 8” above the indirect fluorescent light fixtures in the engineering area. The Hobo light intensity dataloggers are not cosine or color corrected and therefore are not accurate to use for actual illumination measurements. However, they are useful to show relative patterns of lighting use, i.e. whether the lights are on or off and relative amounts of light.
- Hobo-pods were placed in the three lighting fixture locations from the window to determine if the lights nearest the windows were used less often because of available daylight.
- Hobo On-Off dataloggers were placed at various task lights to determine their usage patterns.

Fig. 44. Placing Hobopod.

6) What is the lighting power density? How does this compare to the standards?

- Two team members read the labels on each lamp (fluorescent uplights and task lights) and calculated the total wattage. To determine lighting power density (LPD) we divided that quantity by the total square footage and then compared it to the allowable lighting power density by ASHRAE energy Efficient Building Standard 90.1.

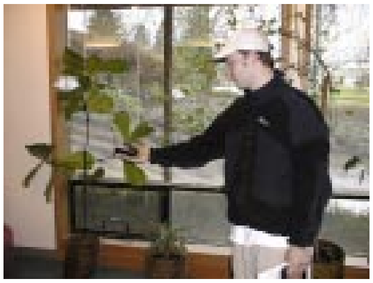


Fig. 45. Light measurements using Sylvania light meter.

Fig. 46. Illumination measurements were taken with the lights off (left) and lights on (right) on the second floor of the EPUD building.

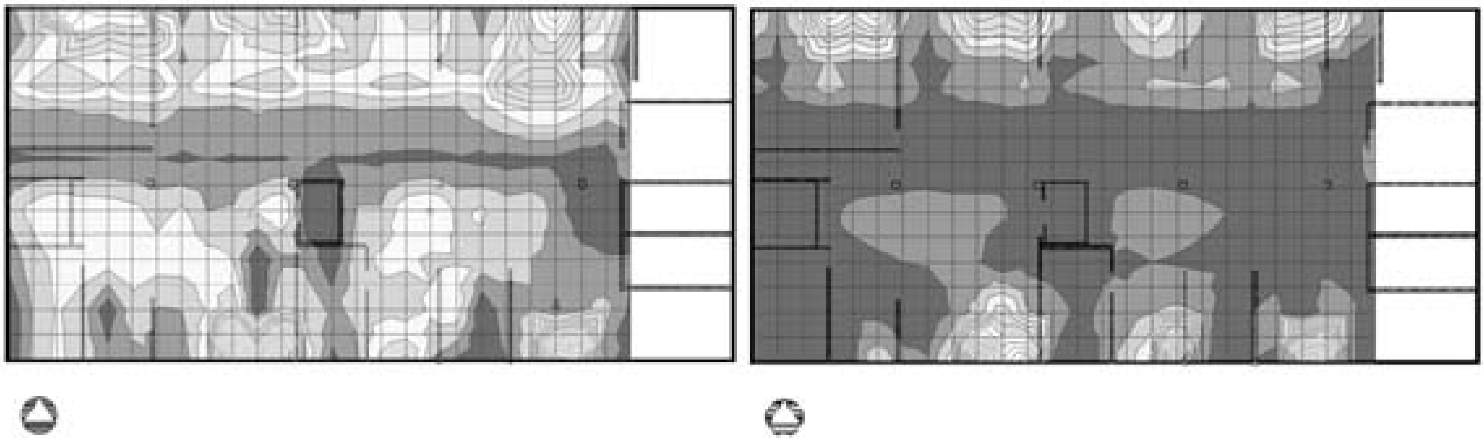


Fig. 47. Isolux diagrams: electric light and daylight (left) and daylighight only (right). Darker areas indicate areas with less light.

Lighting

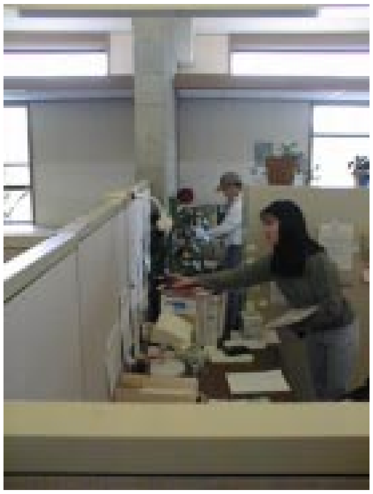


Fig. 48. Illumination sweep

General Lighting Conditions:

1) What are the general illumination levels with daylight only? With daylight and electric light?

Isolux Diagram: Daylight only

The results show that the perimeter bays adjacent to the windows are well lit by daylight on both the south and north side. Daylight penetrates to a depth of approximately 20’ from the north windows and 30’ from the south windows (Fig. 47). This results in an adequate amount of light in the perimeter areas for office tasks. The central corridor has less daylight, but it is still an adequate amount of light for its function as a circulation corridor.

Isolux Diagram: Daylight and Electric Light

Indirect electric lighting enhances the daylight by illuminating the central corridor (Fig. 47). This daylight and electric light-integrated system works well together in creating an even distribution of light throughout the whole second floor area.

The daylight system is not designed to work alone in providing the space with adequate and even distribution of light. This is especially true in the winter season when little direct sunlight is available. Therefore, an indirect electric light system is implemented to supplement light to the middle bays.

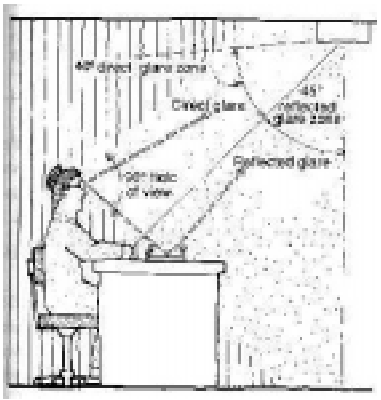


Fig. 49. Various types of glare illustrated.

2) Do contrast ratios in the various office spaces create glare conditions?

Glare conditions were studied in both the engineering department and the customer service areas. The following photos show where glare is concentrated and the sketches indicate actual luminance readings superimposed over the drawings. Because of the use of uplighting, glare conditions are minimized greatly. The fluorescent tubes project light upward, where it is diffused and reflected off of the lightly colored ceiling area down to the work area below. This, along with the large T-shaped windows, allow for an even blanketing of light throughout the space.

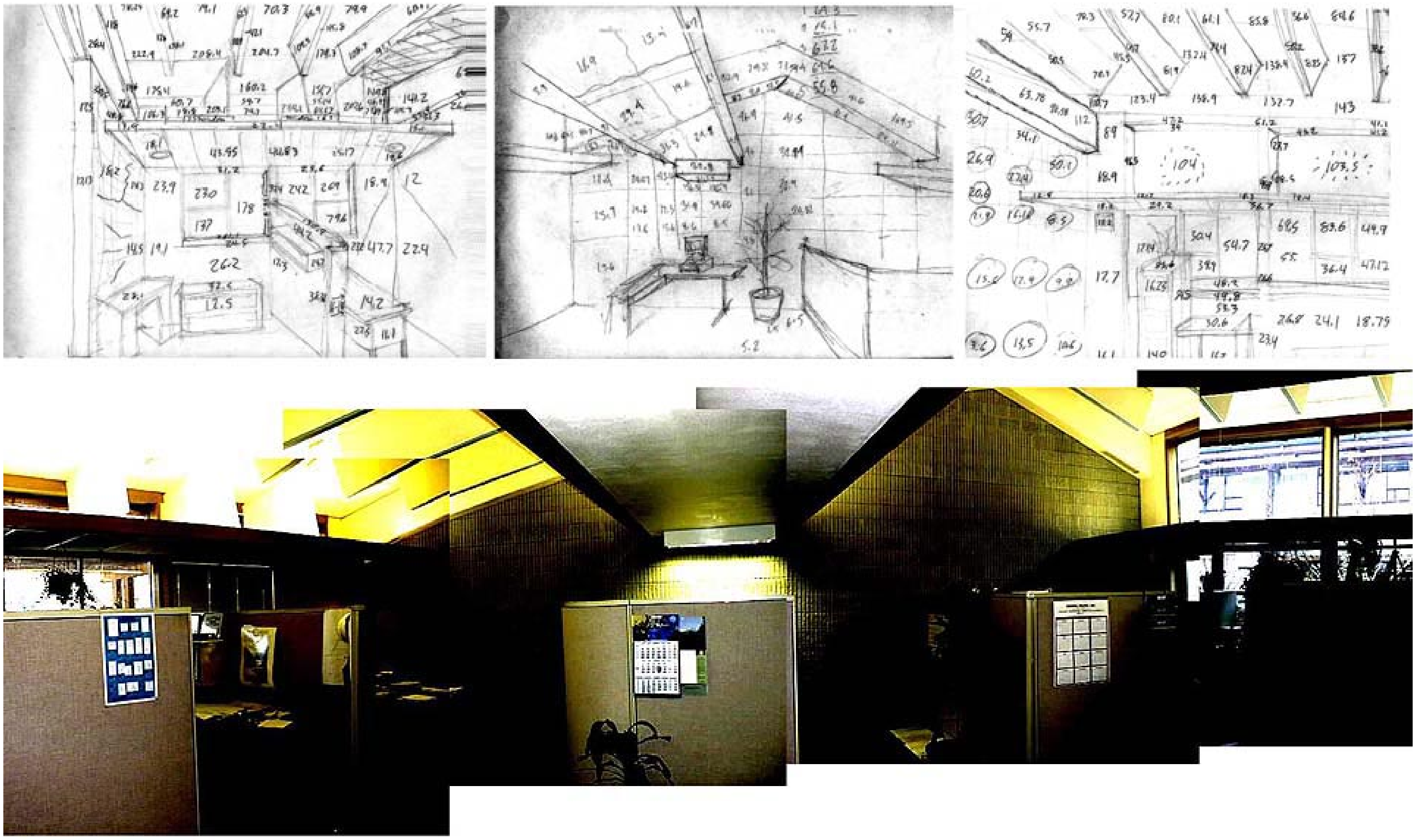
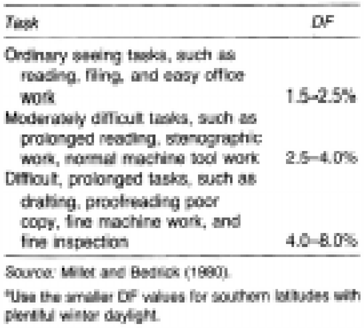


Fig.50. Quantitative data showing luminance readings superimposed over sketches (above) and enhanced digital images to show qualitatively the areas of potential glare.



Task	DF
Ordinary seeing tasks, such as reading, filing, and easy office work	1.5–2.5%
Moderately difficult tasks, such as prolonged reading, stenographic work, normal machine tool work	2.5–4.0%
Difficult, prolonged tasks, such as drafting, proofreading poor copy, fine machine work, and fine inspection	4.0–8.0%

Source: Millet and Bedrick (1980).

*Use the smaller DF values for southern latitudes with plentiful winter daylight.

Fig. 51. Recommended daylight factors (Stein and Reynolds, p. 197)

The recommended maximum luminance ratios (Stein and Reynolds, p. 958) between task surfaces and adjacent surroundings is 1:1/3, however our readings between a desk surface (28 cd/m^2) and a nearby window (182 cd/m^2), presented a ratio of 1:6. These findings show that the brightness ratio is unacceptable and that glare is present. This ratio of 1:6 remains constant throughout the engineering and customer service area.

Through surveying the users of the spaces, we were able to obtain first hand opinions of glare conditions. 50% of the users surveyed stated that they reduce glare from the windows by drawing the blinds. Although glare conditions were measured, people in the south-facing zone perceived those conditions to be poor only slightly more than those seated in the north-facing zone (Figure 52). Overall, most rated conditions in the middle of the scale.

3) Are people satisfied with the quantity and quality of light in the building?

Despite inconsistent measurements of lighting, the majority of the occupants of the building thought the overall lighting conditions were very good, regardless of whether they were located in the north- or south-facing zone (Figure 53).

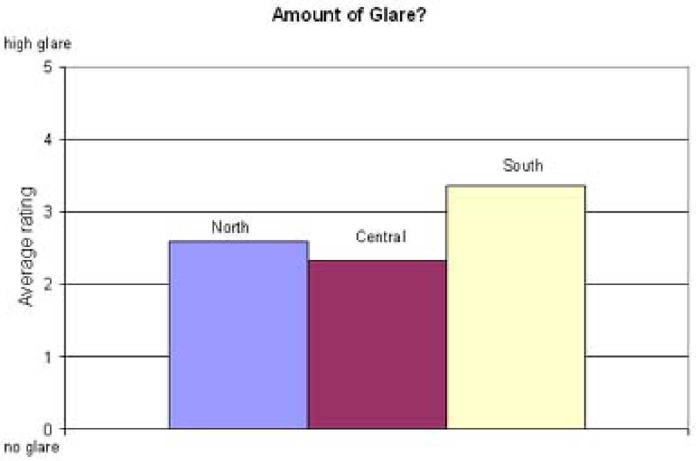


Fig. 52. People seated in the south zone perceive slightly more conditions of glare than those on the north zone.

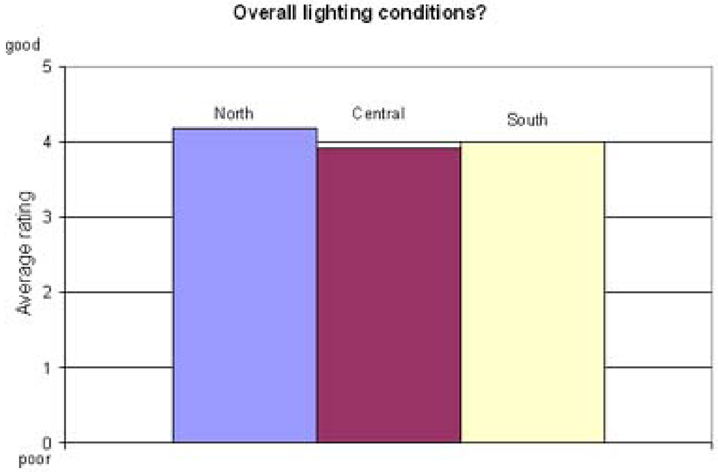


Fig. 53. Overall rating of the lighting conditions were consistently very good in all parts of the building.

Design Intent vs. Actual Conditions:

4) Does the 2.5H daylight penetration rule-of-thumb work with the light shelf to provide an even distribution of light? Do the lighting conditions in a typical office bay provide a 4% daylight factor?

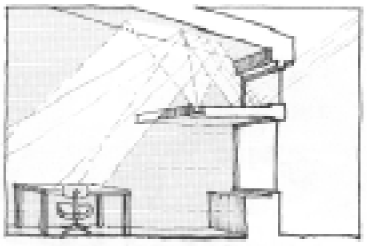


Fig. 54. Light shelf bounces light to the ceiling and reduces the potential for glare.

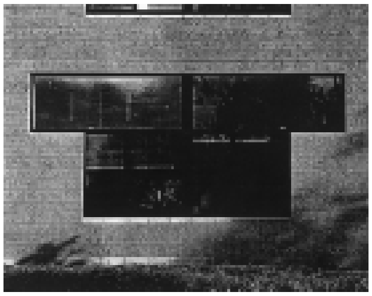


Fig. 55. T-shaped window designed to allow more light in above the light shelf, the lower part of the window for a view to the outside..

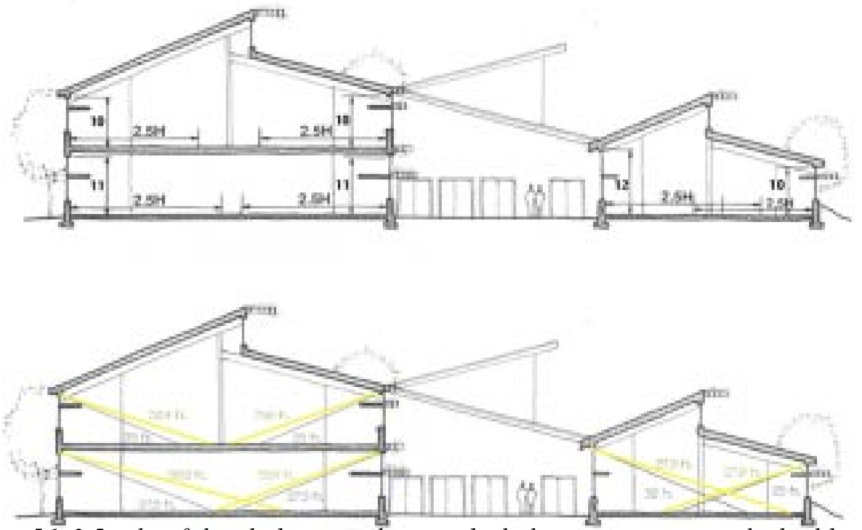


Fig. 56. 2.5 rule-of-thumb diagram showing daylight penetration into the building.

Virginia Cartwright, EPUD's daylight consultant, designed the light shelves to lower the light levels near the window, allowing the light from the shelf to reflect into the central area of the building. Our measurements indicate that the design of the T-shaped windows not only meets the 2.5 H rule-of-thumb for lighting techniques, but exceeds the expected 2.5 H measurements.

Fig. 57. Model with lightshelf at noon during the winter solstice.

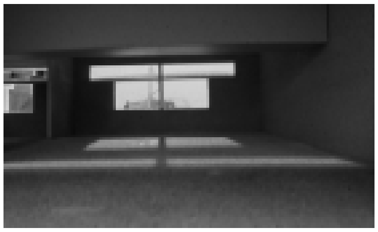


Fig. 58. Model without the lightshelf showing daylight penetration at noon during winter solstice..

To determine the approximate daylight factors of a typical office bay we used the following formula:

FORMULA

$$DFav = 0.2 \ (\text{window area} / \text{floor area})$$

CALCULATIONS

$$DFav = 0.2 \ (97 \text{ ft}^2 \text{ North} + 97 \text{ ft}^2 \text{ South} + 132 \text{ ft}^2 \text{ Clerestory} / 1440 \text{ ft}^2)$$

$$= 0.045, \text{ or } \mathbf{4.5\%}$$

A typical bay does indeed provide the targeted 4% daylight factor. This provides enough light to perform moderately difficult tasks.

Other daylighting strategies helped to distribute daylight evenly. Lighter, more reflective colors and materials were used above the working plane. High ceilings with clerestory windows were used to maximize daylight penetration, and "T" shaped windows with a light shelf were installed to distribute daylight evenly. If direct sunlight floods the building, there is a substantial difference in daylight penetration without the shelves (Figures 57 and 58). At noon on December 21, daylight actually penetrates further into the building *without* the light shelves, however, there are bright spots (from direct sun through the windows) which would give the impression of most of the rest of the floor area being dark. In overcast conditions the light shelves seem to make a negligeable difference in the distribution of daylight.

Fig. 59. HOBOpod in place above light fixture

5) Is energy conserved by reduced electric lighting usage? What is the pattern of use for electrical lights?

To supplement day lighting, an indirect fluorescent lighting system with a controlled stepped dimming system (where 1 lamp of a 2-lamp fixture is turned off) is implemented in EPUD. Our study focuses on one bay in the engineering area that has window openings to the north and south. This aided us in determining if there were differences in lighting use because of window orientation.

Results from the Hobo lighting loggers during the four observation days, indicate that the stepped dimming system was not utilized. All of the indirect fluorescent lights remained "ON" during working hours. The graphs also indicate that even though the fluorescent lights were turned off during non-office hours and weekends, the HOBOs measured a significant amount of daylight penetrating the south and north facing windows. During this observation period our HOBO plot graphs show that the indirect fluorescent lights are always on during working hours and showed lowered illumination levels due to a step-down procedure.

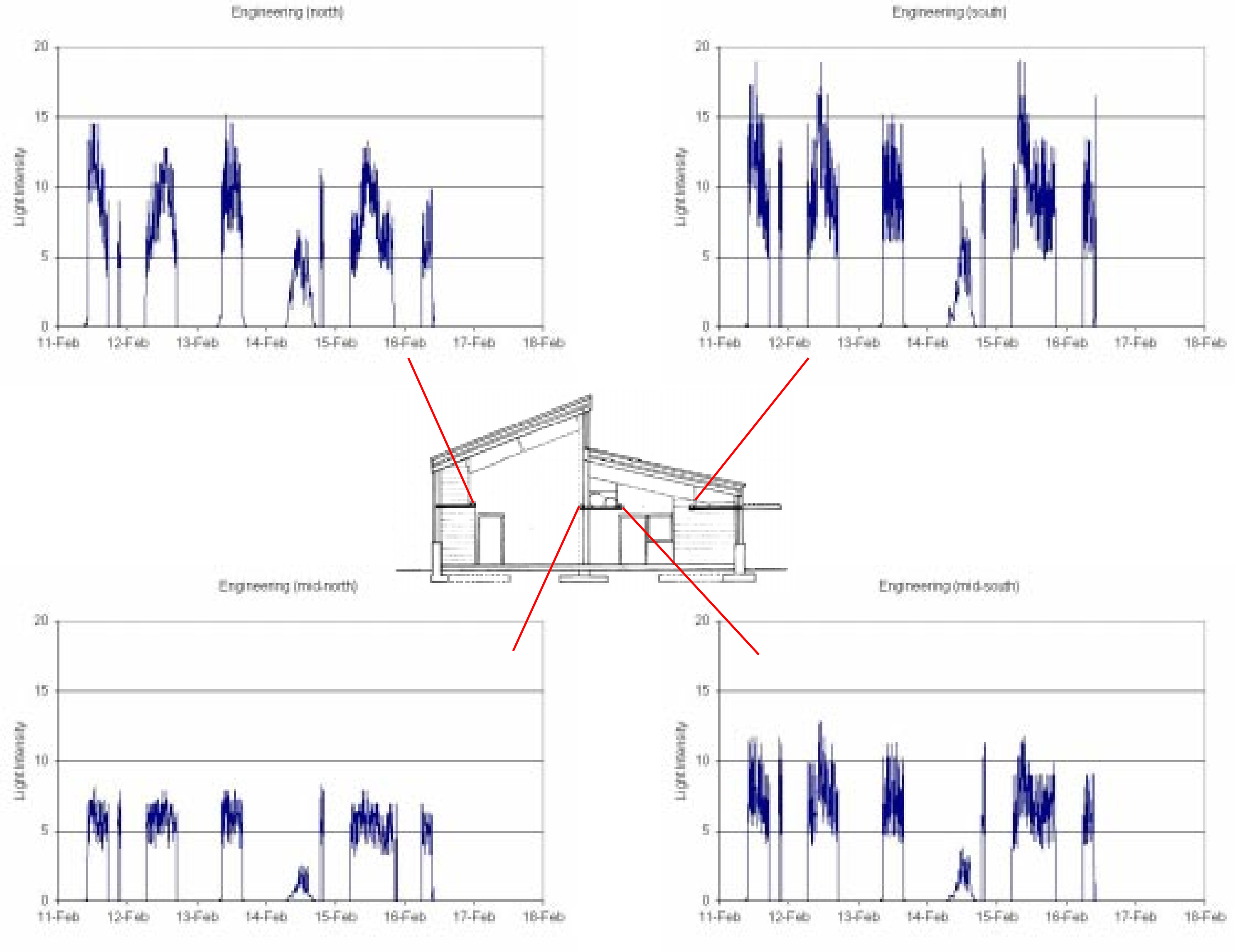


Fig. 60. Lighting use data from fixtures across a north-to-south section of the building. Stepped down usage does not appear, though weekly on-off patterns show relatively consistent readings with occassional influences from daylight.

CONCLUSIONS

Lighting

Fig. 61. Team analysis

1. Daylight integrated system provides a somewhat even distribution of light through out the entire space. The light shelves function as designed by bouncing daylight further into the building.

2. The 2.5H rule of thumb and the 4% daylight factor do apply to the design.

3. Electric lighting during our observation period, did not function as intended by utilizing a stepped down process. The potential for energy savings is reduced by this.

4. Glare is not perceived by occupants..

5. Occupants were satisfied by the general lighting conditions in the building.

Fig. 62. Digesting data.

Fig. 63. Re-checking the data.

Fig. 64. All done!

CASE STUDY CONCLUSIONS

Our study shows that the daylighting design of the T-shaped windows combined with the reflecting light shelves, worked together to provide the majority of EPUD's occupants with ample and pleasing illumination in their work area. Although glare conditions are present, they were not problematic for the occupants since they often controlled the blinds to adjust the lighting conditions.

Thermal comfort conclusions were less clear. Thermal comfort was achieved with the addition of task heaters that were not included in the original design. Although successful as a passive cooling strategy during the summer, we believe that during the winter as a passive heating strategy, the thermal mass absorbs too much of the available heat (from equipment and any direct sun) and various locations become too cool. Consequently, people have brought in task heaters and energy use is much higher than originally predicted.

KEY DESIGN LESSONS LEARNED

Several valuable design lessons were learned during this case study:

The location of the thermal mass in passive heating strategies strongly depends upon the sun's position. For passive heating the floor or walls running east-west are the best candidates for thermal mass. But for passive cooling the story is a bit different. In this case it is desired to have the mass evenly distributed throughout the whole building in order to absorb the excess heat generated.

Temperatures in thermally massive buildings are more stable than those without any thermal mass. Temperature swings are rather slow allowing in massive buildings. This advantage helps in accommodating for different outdoor conditions occurring within the same day.

This building provides a rich set of switches and controls that allow the occupants to manipulate their thermal environment. We believe that by empowering the users to control their environment the thermal satisfaction increases in despite of the physical conditions of the space. A proof of this is the engineering area in which the conditions fell outside the comfort zone and yet people voted to feel comfortable.

Another important lesson is that the users of the building should be well informed about the energy saving strategies of the building and their adequate use. In the EPUD building all the users were well aware of the design strategies utilized by the architect, and that made them respect and follow the instructions for a proper operation.

Adequate maintenance and post occupancy evaluations have proved successful in this building. As part of the Energy Edge program this building was monitored for many years in order to discover its energy consumption patterns. This provided the architects with valuable lessons that allowed them to draw conclusions about this project.

The Vital Signs Project is a way to provide architects with valuable feedback, and students with important design lessons.

FUTURE DIRECTIONS

Clearly a 10-week quarter to complete this case study was inadequate. We could do this case study again given the same topics and still not be able to sift through all the intricacies of the data. Given more time, we offer a few topics as future areas of study:

1. Thermal comfort and performance during the summer months to examine the passive cooling strategy of using thermal mass and night flushing.
2. Actual energy use of the space heaters during the winter season to compare to the predictions and results from the time that the building first opened.
3. The greatest psychological advantage of night ventilation is that large quantities of outdoor air are flushed through the building during a summer night and it’s said that the building stars each day with an aroma of the outdoors. How much outside air is brought in during the evening? What are the perceptions of air quality in the morning vs. the evening.
4. A parametric study of the window design and the light shelves. Would lowering or raising the light shelves change the lighting distribution in the offices? Do the acoustic baffles affect lighting distribution?
5. Actual energy use of the electric lighting system. Is the stepped-dimming system functioning? How much energy does it save?
6. How do the exterior shading devices (trellises) perform in the summer?
7. How might such a building perform in other climates?
8. A big increase in energy use is because of individual space heaters during the winter months. What are the plug loads of the heaters and other office equipment?

Fig. 65. Team weighing in at 1600 pounds on the scale at the EPUD building. All brains!

We think though, that the building has a very ingenious design and that it is very successful through most of its features. After doing this case study we feel that our understanding of this building and its various strategies has grown. We also learned that to study a building component isolated from its context can give erroneous impressions. In this case we have learned that the whole year round performance of the building proves that the design decisions made by the architects were appropriate.

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