

The Analysis of External Shading Effect on Building Energy Conservation

K.H. Yang, Ph.D.
Member ASHRAE

H.T. Lin, Ph.D.
Member ASHRAE

H.S. Chen

ABSTRACT

External shading devices provide a very efficient way to reduce the cooling load of buildings, especially in hot and humid areas.

This paper discusses a methodology that utilizes the thermal response factor method in calculating the perimeter annual load of a typical office building in Taiwan through computer simulation. The result showed an average 25% energy savings by installing 45 cm-long external shading on a full-scale test house sized 17 m X 12 m X 10 m.

The simulation results were extended to a systematic study of external shading designs under different operating conditions. This provides a very powerful tool for the building designer to evaluating the effectiveness of various strategies during the design stage.

The comparison of external shading effect and thermal mass effect on building energy conservation is also discussed in this paper.

INTRODUCTION

The thermal mass of a building envelope can delay the conductive heat gain penetrating through walls. However, it does not vary the total heat flow rate moving indoors, unless the accumulated heat in the walls is dissipated back to the cool night air, or is flushed out during the unoccupied hours, which is unlikely, especially in hot and humid areas (Yang et al. 1989).

There are two alternatives in breaking through this limitation: namely, the external/internal shading device and thermal insulation installed on the building envelope. Installing insulation is effective in areas where cooling and heating are both needed. But its effect is doubtful in hot and humid areas, especially where there is a chance that condensation will occur, which greatly degrades the thermal performance of the building envelope and causes mildew growth problems.

Dr. K.H. Yang, ASHRAE member, associate professor, Institute of Mechanical Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan 80424, R.O.C.

Dr. H.T. Lin, ASHRAE member, associate professor, Dept. of Architecture, National Cheng Kung University, Tainan, Taiwan 70101, R.O.C.

H.S. Chen, Engineer, Energy Committee, Taipei, Taiwan, R.O.C.

On the other hand, a shading device cuts part of the solar heat gain so that the average heat flow is actually reduced, not only delayed. In hot and humid areas, the solar heat gain constitutes the major portion of the perimeter zone air-conditioning (AC) load of a building.

In this study, the external shading effect on the perimeter annual load (PAL) in this area is analyzed, theoretically and investigated experimentally, so that it can be compared with the external mass effect on PAL .

PERIMETER ZONE ANNUAL LOAD ANALYSIS

In the building interior, the region that is approximately 5 meters (15 feet) to the envelope, is defined as the perimeter zone. In this zone, the air-conditioning (AC) load pattern varies accordingly during the diurnal cycle, especially where solar gain constitutes a large portion of it. An external shading device provides an efficient way in blocking out much of the solar gain.

In evaluating the PAL of a building, the Average Weather Year (AWY) was first compiled by the authors, using 10 years of local hourly weather data. The AWY stands for the most statistically representative, long-term local weather conditions, and it was stored on a main-frame computer ready for simulation. Six major cities' AWY of Taiwan were completed by the authors (Lin and Yang 1987). Kaohsiung city, in the southern part of Taiwan with subtropical weather, is considered in this paper.

The solar position and shading area of windows of a typical office building in Kaohsiung were calculated first. Then the shading coefficient was used to calculate solar heat gains. The Weighing factors, as listed in table 1, were then imposed to calculate the portion that becomes room cooling load. For example, for the medium-weight wall structure with internal venetian blinds, 39.9% of its solar gain would immediately become cooling load , while the other 60.1% of heat radiate, and gradually become cooling load according to the function of $0.0629 \times 0.8953^{t-t_0}$, which was experimentally validated (Matsuo et al. 1980). The whole calculation procedure follows the thermal response factor method, as proposed by Stephenson and Mitalas 1967.

EXPERIMENTAL INVESTIGATION

An external shading device, as shown in figure 1, was designed and installed on a university's Energy Test House in Kaohsiung, Taiwan. The test house, sized 17 m X 12 m X 10 m, faced west and had two identical rooms, 5 meters in depth, which simulated the typical perimeter zone of modern office high-rise buildings. Room A had a typical curtain wall (glass block) envelope design, while an external shading device was installed on room B to analyze its energy-saving effect, as shown in Figure 2.

Baseline comparison tests were done in early 1987 to verify that cooling loads and thermal performances of room A and B were almost identical with an average deviation of 5%. So, these two rooms provide excellent opportunities for comparing the effectiveness of various active and passive design strategies on building energy conservation.

The external shading experiments were performed from August 28 to November 30, 1988. Direct air-conditioning power consumption readings indicated an average energy savings of 25% as listed in Table 2.

These encouraging results, which were expected after the simulation, were plotted on a daily basis for October 1988, as shown in Figure 3.

External Shading Effect, a Systemetic Study

The encouraging results of external shading in conserving energy warrant a thorough study of its effectiveness under different design conditions and including annual performances under various shading length, various orientations in different locations.

Figure 4 indicates the cooling load of the perimeter zone is reduced significantly due to various shading lengths in August, when air-conditioning is most needed. Figure 5 further summarizes this effect under various shading lengths. Figure 6 shows this effect in north-facing envelopes in Kaohsiung, in southern Taiwan, while Figure 7 indicates that of Taipei, in northern Taiwan. This methodology provided a very powerful design tool for conserving energy.

External Shading Effect versus Thermal Mass Effect

As stated before, the thermal mass delays the conductive heat gain of building envelopes but cannot actually reduce cooling load except where night ventilation or night dissipation is feasible which is quite unlikely in a hot and humid area like Taiwan.

On the other hand, an external shading device as studied here, actually blocks out some of the solar gains that constitute a significant part of the cooling load. The comparison of these two design strategies in reducing building cooling load is quite interesting. The building for simulation comparison was specified at the following operating conditions: The room conditions were kept at 24-26°C for cooling and at 20-22°C for heating. The outdoor air ventilation rate was 1.5 air change per hour. The illumination was 20 watts per square meter. Sensible and latent heat were 54 kcal/h and 48 kcal/h per person, with 0.18 person per square meter floor area.

The perimeter zone was sized 6 m X 5 m X 3.6 m, with envelope construction listed in Table 3.

Perimeter Annual Load (PAL) of this building was simulated with 45% window area in eastern, western, southern, and northern directions. The light, medium, and heavy wall constructions, as listed in Table 3, were simulated and compared with external shading. Figure 8 shows the west-facing case, with the lightweight wall chosen for the comparison.

In Figure 8, few difference in energy consumption were noticed due to differences in using light, medium, and heavy thermal masses. Annual savings of the external shading averaged around 10% better when compared with lightmass envelopes. Similar results were obtained in east-facing rooms (10%), and south-facing rooms (12%) as listed in Figures 9-11. The north-facing room, has only a minimal 1% advantage in energy savings due to its orientation, which avoids direct solar incidence so only the diffuse solar gain makes a difference. Furthermore, although the different configurations have different percentages in conserving energy, the absolute value of the benefit in utilizing external shading over thermal mass in blocking part of the solar heat gain is constantly around 50 kw in west-facing walls all year round.

CONCLUSIONS

The external shading design provides a very efficient way to reduce building cooling load. In comparison, the thermal mass is much less effective since it only delays and accumulates the heat gain unless night ventilation and/or night dissipation design strategies can be imposed, which is quite unlikely in hot and humid areas.

The methodology developed in this paper provides a powerful design tool to "foresee" the effectiveness of these designs in conserving energy through computer simulation.

The experimental investigation also shows that around 25% energy savings can be obtained by installing a 45-cm-long external shading on a full-scale test house in Kaohsiung, Taiwan, under typical hot and humid weather conditions.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the Energy Committee of Taiwan for granting this research project.

REFERENCES

Yang K.H.; Lin, H.T.; and Hwang, R.L. 1989. "The thermal mass effect of a building envelope in hot areas" presented at the ASHRAE/DOE/BTECC/CIBSE Thermal Performance of the Exterior Envelopes of Building IV Conference, Orlando, Florida, December, 4-7.

Lin, H.T., and Yang, K.H. 1987. "The development of average weather year of cities in Taiwan" National Science Council of Taiwan, Report no. NSC 75-0410-E006-33.

Matsuo et al. 1980. "The calculation of dynamic air-conditioning load" (in Japanese).

Stephenson D.G., and Mitalas G.P., 1967. "Cooling load calculations by thermal response factor method" ASHRAE Transactions, Vol.73, part 2, pp. 1.1-1.7.

Table 1

The Weighing Factors used in this study in calculating solar gains

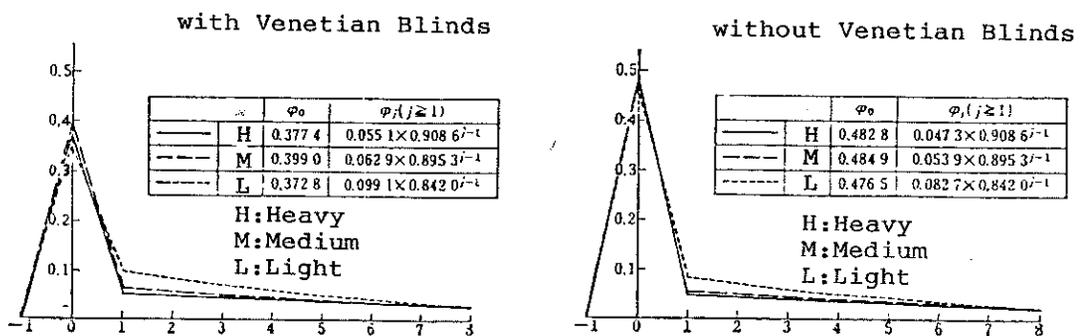


Table 2
The Comparison of Cooling Power Consumptions
of Room A and B

| | September KW | October KW | November KW |
|------------------|-----------------|---------------|----------------|
| Room A | 460.4 | 593.0 | 529.2 |
| Room B | 372.0 | 435.3 | 335.2 |
| Cooling Hours | 436 | 468 | 519 |
| B/A % | 80.8 % | 73.4 % | 63.4 % |

Table 3
The Envelope Construction for Calculation
and Comparison of the PAL used in this paper

External Wall:

| (mm) | finish | plywood | R. Concrete | Mortar |
|--------|--------|---------|-------------|--------|
| Light | 12 | 4 | 60 | 12 |
| Medium | 12 | 2 | 120 | 12 |
| Heavy | 12 | / | 180 | 12 |

Interior:

Roof & Floor -- Reinforced Concrete 110 mm, Mortar 12 mm
 Partition -- Mortar 12 mm, R. Concrete 110 mm, Mortar 12mm

Thermophysical Properties:

| | Density Kg/m ³ | Thermal Conductivity m·C/ W | Thermal Capacity KW / °C·m ² |
|-------------|------------------------------|--------------------------------|--|
| R. Concrete | 2400 | 1.50 | 1982 |
| Mortar | 2000 | 1.50 | 1598 |
| finish | 10 | 0.055 | 87 |

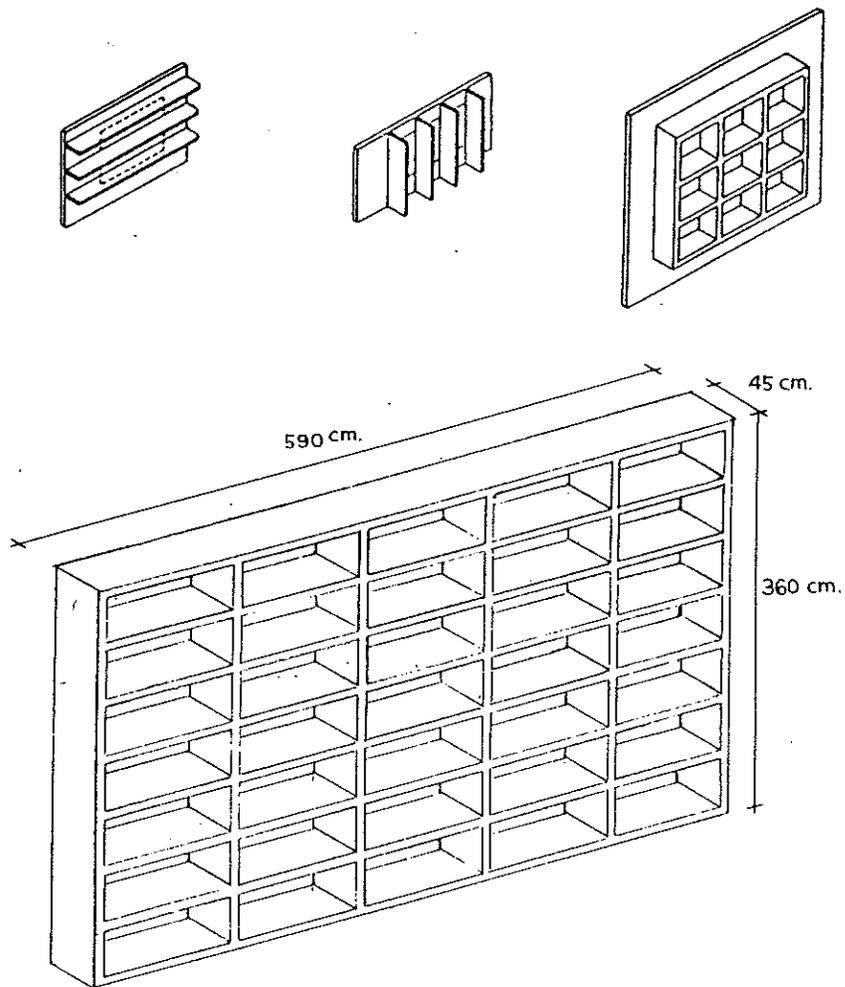


Figure 1. *The External Shading Device studied in this paper*

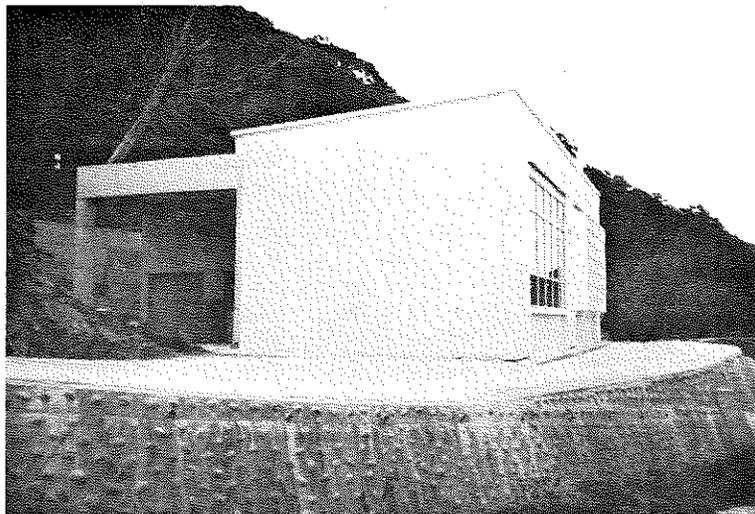


Figure 2. *The comparison of building envelopes on NSYSU test house with and without external shading*

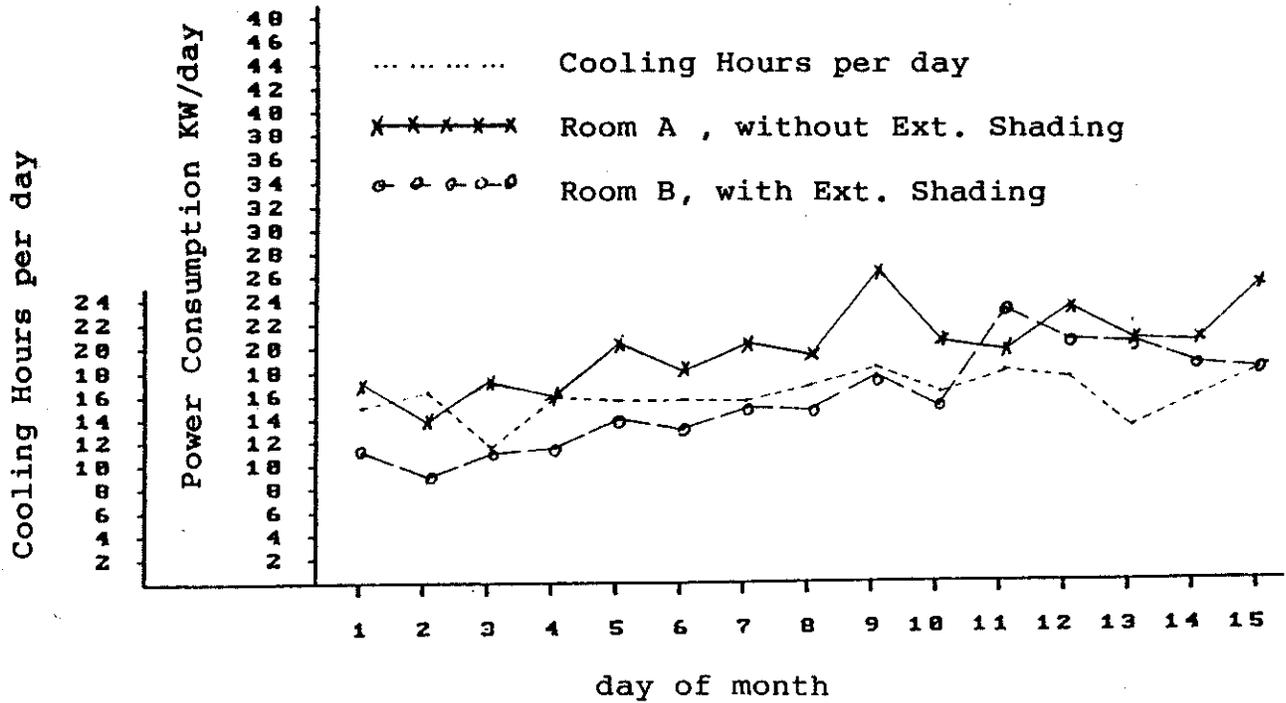


Figure 3a. The comparison of power consumption of Room A and B for cooling in October, 1988

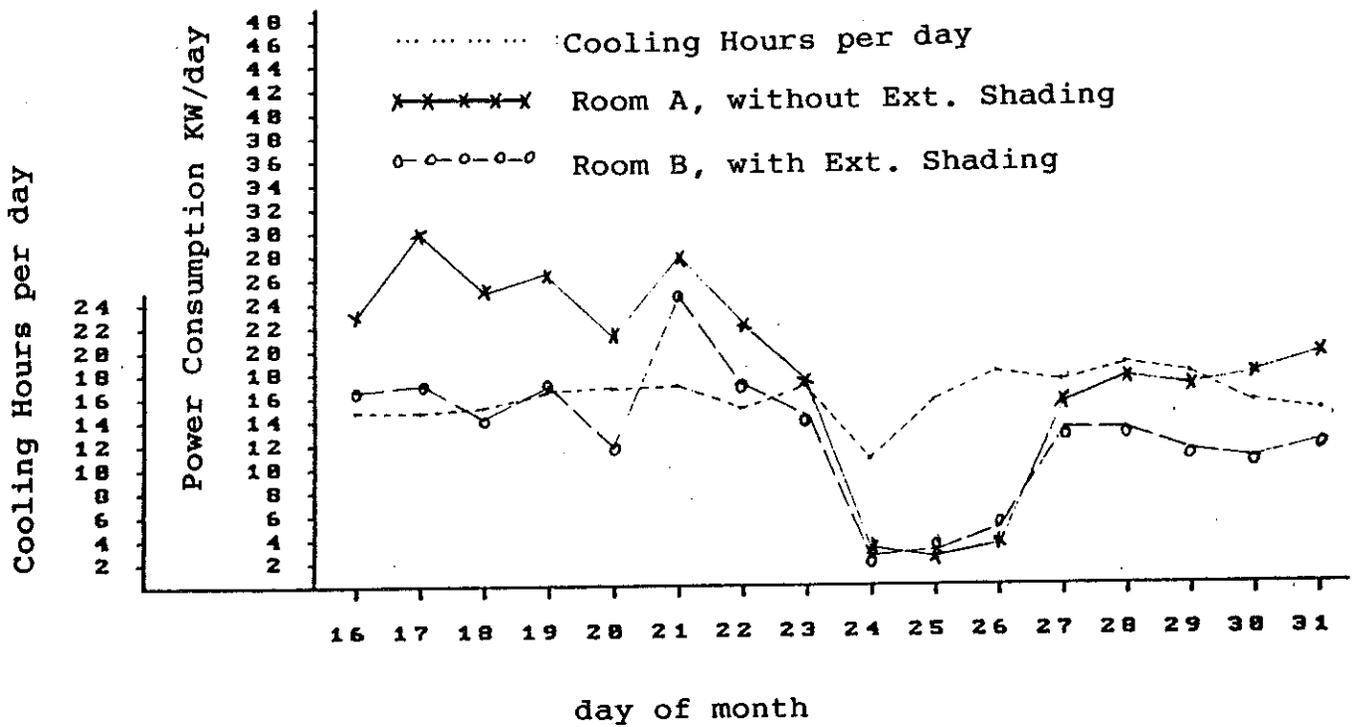


Figure 3b. The comparison of power consumption of Room A and B for cooling in October, 1988

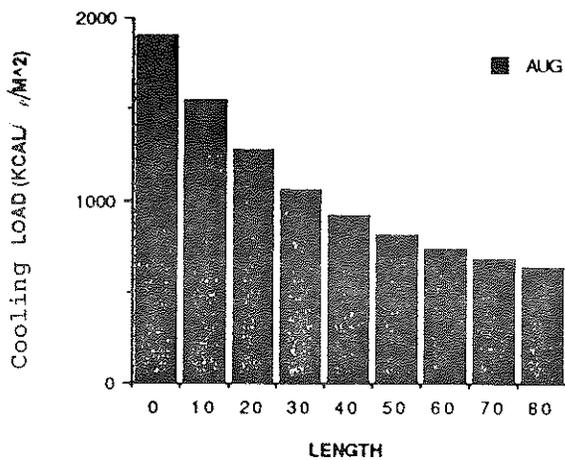


Figure 4. Load of Room B with external shading in August, Kaohsiung

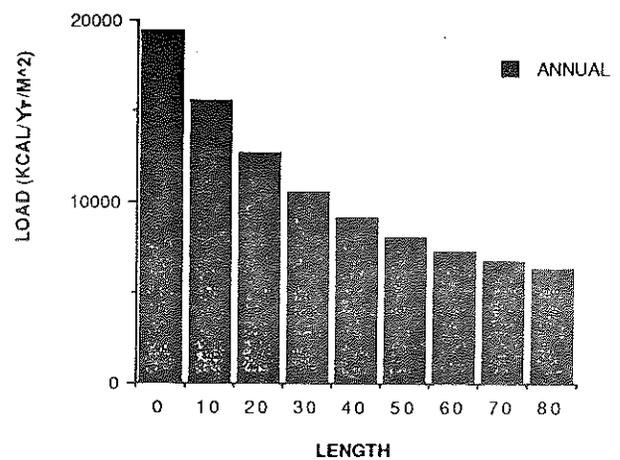
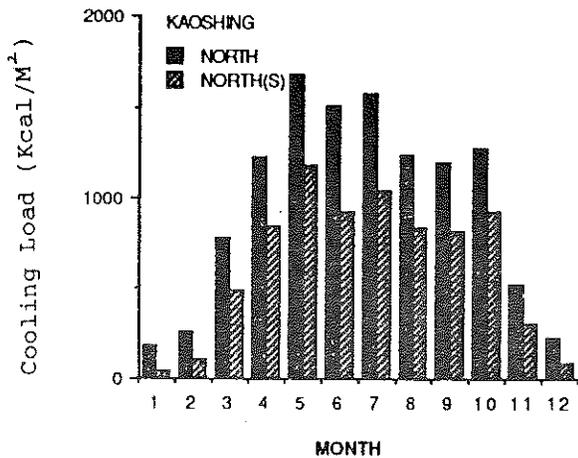
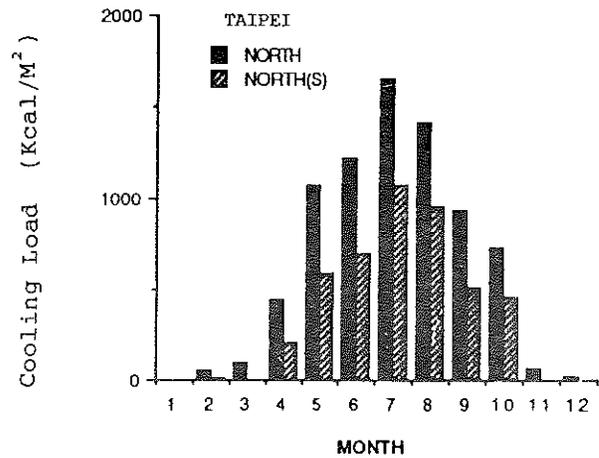


Figure 5. PAL of Room B with external shading in Kaohsiung (west-facing)



* (S) indicates with 45 cm external shadings

Figure 6. The annual cooling load profile of a north-facing wall with and without external shading in Kaohsiung



* (S) indicates with 45 cm external shadings

Figure 7. The annual cooling load profile of a north-facing wall with and without external shading in Taipei

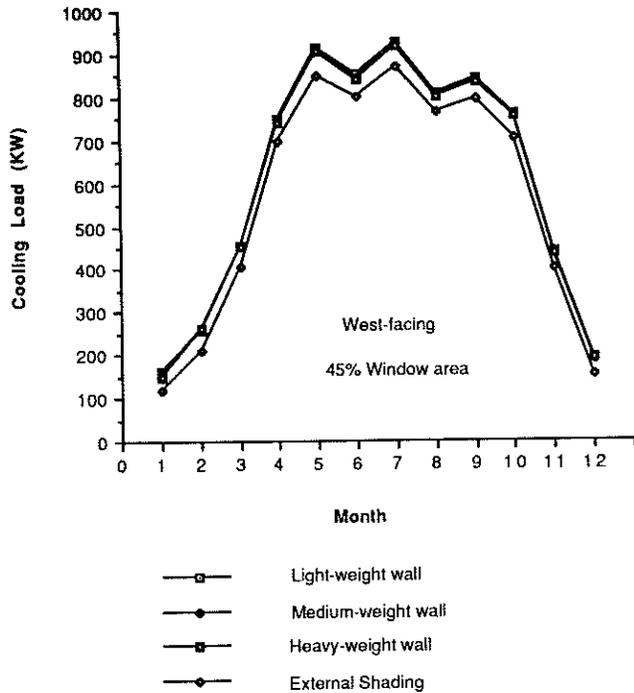


Figure 8. The comparison of cooling loads of various walls and with external shading facing west

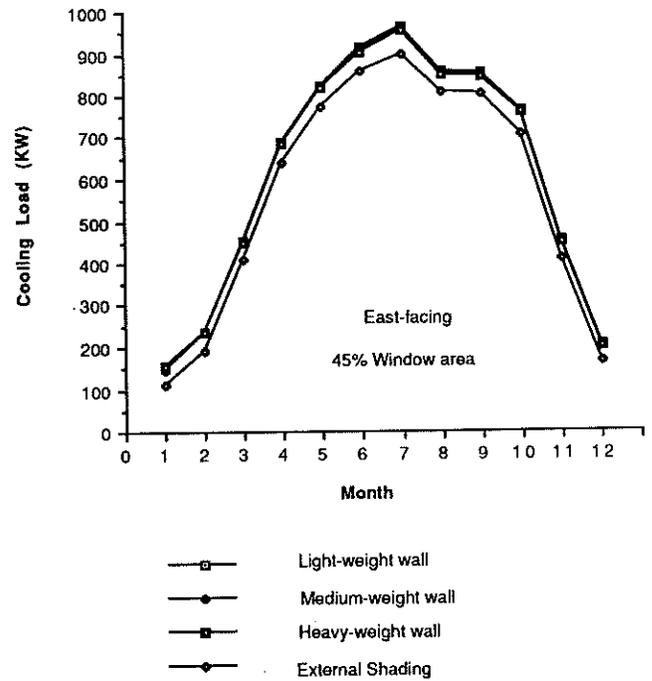


Figure 9. The comparison of cooling loads of various walls and with external shading facing east

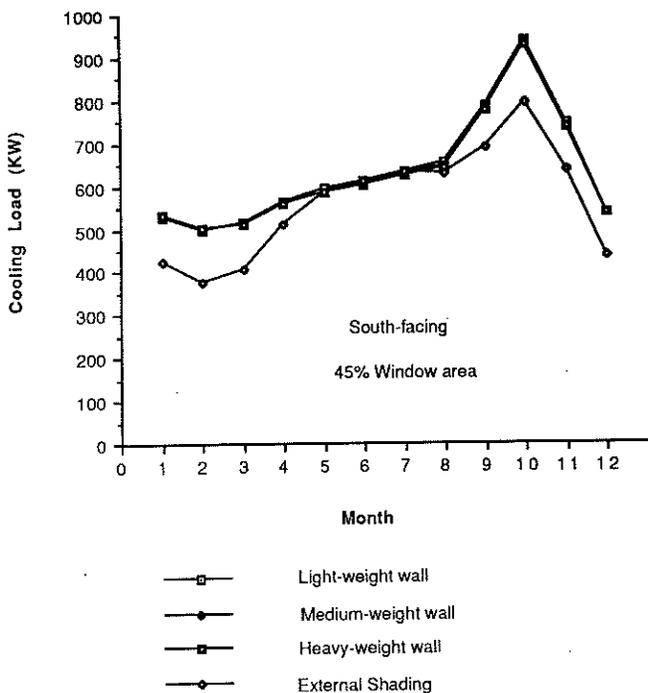


Figure 10. The comparison of cooling loads of various walls and with external shading facing south

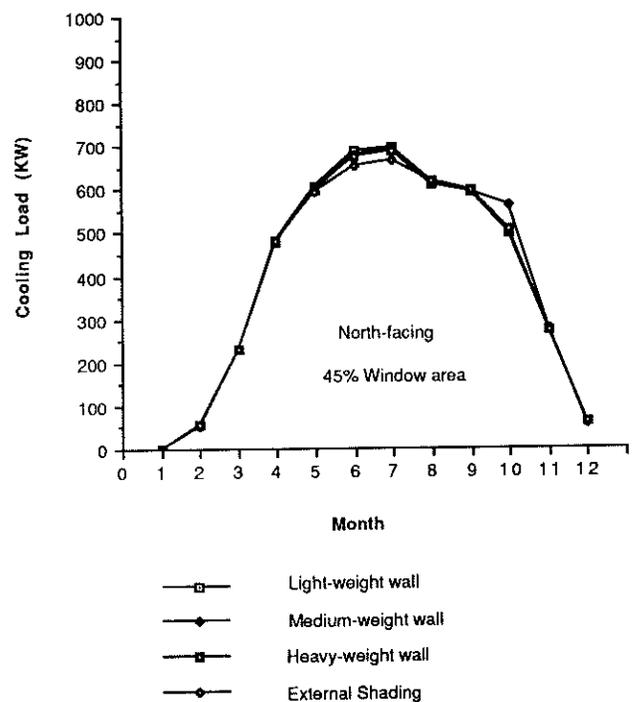


Figure 11. The comparison of cooling loads of various walls and with external shading facing north