Title

ENERGY AND ECONOMIC ANALYSES IN SUPPORT OF ENERGY CONSERVATION STANDARDS FOR NEW COMMERCIAL BUILDINGS IN MALAYSIA

Permalink

https://escholarship.org/uc/item/70x3098c

Authors

Deringer, J.J.
Busch, J.F.
Hall, J.

Publication Date

1987-04-01

LBL-23279

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE
DIVISION

Energy and Economic Analyses in Support of Energy Conservation Standards for New Commercial Buildings in Malaysia

J.J. Deringer, J.F. Busch, J. Hall, K.S. Kannan,
M.D. Levine, A.C. Ayub, and I. Turiel

April 1987

APPLIED SCIENCE
DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

LBL-23279

ENERGY AND ECONOMIC ANALYSES IN SUPPORT OF ENERGY CONSERVATION STANDARDS FOR NEW COMMERCIAL BUILDINGS IN MALAYSIA

April 1987

J. J. Deringer, J. F. Busch, J. Hall,* K. S. Kannan,*[†]
M. D. Levine, A. C. Ayub,[‡] *and I. Turiel*

Energy Analysis Program
Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

This work was supported by the U.S. Agency for International Development through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

* The Deringer Group, P.O. Box 299, Riva, MD 21140

[†] Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia

[‡] Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

LBL-23279

ENERGY AND ECONOMIC ANALYSES IN SUPPORT OF ENERGY CONSERVATION STANDARDS FOR NEW COMMERCIAL BUILDINGS IN MALAYSIA

April 1987

J. J. Deringer, J. F. Busch, J. Hall, K. S. Kannan,
M. D. Levine, A. C. Ayub, and I. Turiel

INTRODUCTION

PROJECT BACKGROUND

This report documents energy and economic analyses in support of Malaysian efforts to develop an energy standard for buildings. The Malaysian research discussed in this report has been developed exclusively for new commercial buildings. Research on this project has been carried out by a team of Energy Consultants from Malaysia and from Lawrence Berkeley Laboratory in close consultation with the Malaysian Government.[1]

Since September 1986, the team has conducted numerous computer simulations and analyses of energy consumption in typical buildings based on Malaysian weather, building construction, and cost data. The energy conservation policies evaluated in this research include criteria for:

- lighting power and controls;
- air conditioning (A/C) equipment;
- building envelope thermal performance; and,
- credits for the use of daylighting.

---

[1] Under the Fourth ASEAN-US Dialogue on Development Cooperation in March 1982, the U.S. Government sponsored three energy-related subprojects for the Association of Southeast Asian Nations (ASEAN; ASEAN includes Indonesia, Malaysia, The Philippines, Singapore, and Thailand) through the United States Agency for International Development. One subproject studied energy conservation in buildings, to appraise the potential energy savings in ASEAN buildings through computer simulation and to recommend the framework for setting building conservation standards in the ASEAN context.

PROJECT OBJECTIVES

The primary objective of this project is to provide analytical support for the development of an energy standard for new commercial buildings in Malaysia.[2] This includes developing analytical procedures useful for a Malaysian standard (such as a new overall thermal transfer value (OTTV) formulation) and determining cost-effective levels of conservation for the standard. Developing an energy standard for new commercial buildings is viewed as a first step toward a comprehensive energy conservation policy for Malaysian buildings. The high rate of development of commercial buildings in Malaysia (about 8%/year) indicates that building energy standards will be important in controlling the growth in electricity demand and in maintaining stable utility costs.

In order to meet these objectives, several other tasks needed to be completed:

- evaluation of the applicability to Malaysia of existing building energy standards in other countries;
- evaluation of building design practices in Malaysia and the resulting levels of energy consumption;
- evaluation of the potential energy savings achievable through the implementation of improvements in building design and construction techniques; and
- economic analyses of various energy conservation strategies.

The details of each of these tasks are discussed in the following sections of this report.

IMPORTANCE OF COMMERCIAL BUILDING ENERGY USE

Commercial buildings consume almost a third of Malaysia's electricity (about 32%)[MOE, 1986]. This estimate is conservative; it does not include non-process energy use in industrial buildings. Between 1981 and 1985 commercial building energy use increased at an average annual rate of approximately 8%, which corresponds to a *doubling* of commercial sector demand every nine years.[3] Total electricity consumption in 1985 was approximately 12,500 GWh.

The major commercial building energy end uses are air conditioning and lighting for offices, stores, hospitals and hotels. Significant energy conservation opportunities exist for these end uses in Malaysian buildings. This potential has been well-documented in recent studies [Dangroup & J&A, 1985] and audits of existing buildings [G&FC,1984]. The potential can also be seen in a comparison

---

[2] Standards for the operation and retrofit of *existing* commercial buildings in Malaysia are viewed as the subject of future analyses and development, based on experience to be gained from use of the proposed standard for new buildings.

[3] This compares, for example, with an average annual electricity use growth rate for commercial buildings in the United States of less than 2% with a *doubling* time of 38 years.

of new building construction practices in Malaysia with practices in countries with energy standards in place.

Also, there is a trend toward increasing energy loads in new building construction. Designers are creating more comfortable, functionally efficient, and visually appealing interior environments, which consume more energy than older designs because of higher lighting levels, higher solar-heat loads resulting from increased use of curtain-wall construction in larger commercial buildings, and additional utilization of air conditioning to offset the resulting higher cooling loads.

PROPOSED STANDARD

Effectiveness of Standards in Other Countries

Building energy standards form important elements of energy policy in numerous countries in Europe, the Americas, and the Pacific. Countries with energy standards for commercial buildings include the United States, Canada, England, France, Germany, Sweden, Denmark, Norway, Switzerland, Australia, New Zealand, and Singapore. In many cases, the countries listed (and others as well) have standards for both new and existing buildings.

Available information about the experience of these countries indicates that such energy standards have been effective in reducing unnecessary energy costs and have not been unusually difficult to implement. As a result, a number of countries are now engaged in their second or third updates of building energy standards.

For example, in the United States, the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) developed a voluntary energy standard in 1975 (ASHRAE 90-75). This standard was estimated to produce energy reductions of 40% from pre-1973-oil-embargo commercial building designs [A.D. Little, 1976] and energy reductions of 25-40% from typical mid-1970s building designs [AIA, 1980]. In the late 1970s and early 1980s, all 50 states in the U.S. adopted some modified form of this standard as mandatory state energy codes, usually for new buildings and major retrofits. Often, codes and standards for existing buildings were based on modifications of ASHRAE 90-75[4].

Currently, ASHRAE is developing separate major revisions to the standards for commercial buildings (ASHRAE 90.1P) and for residential buildings (ASHRAE 90.2P). The proposed ASHRAE 90.1P standard for commercial buildings is expected to produce an additional 10-20% energy reduction over the

---

[4] In 1980, ASHRAE issued a slightly revised version (ASHRAE/ANSI/IES 90A-1980) of the original standard, but this revision was minor and had little impact on building energy use.

requirements of the 1980 version [Crawley & Briggs, 1986]. Major portions of the proposed draft standard 90.1P for commercial buildings have already been adopted in at least one state code (Massachusetts), even before the standard has been finalized by ASHRAE. Several other states are also considering adopting portions of ASHRAE 90.1P.

Another example is provided by the energy standard implemented by Singapore in 1979 [PWD, 1979]. This standard adapted the requirements of ASHRAE 90-75 to Singapore climate conditions and construction practices. In developing the standard, Singapore researchers did considerable original work in developing overall thermal transfer value (OTTV) concepts to reduce heat gains through building envelopes. Singapore researchers also focused on lighting and air conditioning standards, and implementation aids to facilitate use of the standards, including the production of a valuable handbook [PWD, 1983].

Status of Malaysian Standards Development

Malaysia has not previously had a building energy standard. In this context, the energy criteria in the proposed standard are intended to eliminate the most energy intensive design practices, while not adversely impacting construction practices. The proposed criteria have been selected to reflect typical current energy conservation measures practiced by the Malaysian building construction industry. Implementation of such a standard will save energy on a cost-effective basis, and will raise the consciousness of the nation about the benefits of energy conservation practices in commercial buildings.

A draft of a proposed standard has been developed along with supporting analysis and submitted to the Ministry of Energy (MOE) for review [UTM, 1986]. The goal of the development effort was to keep the standard as simple as possible in order to encourage its acceptance by the Malaysian building design community. The proposed standard constrains only the most important energy factors — solar load on the building envelope, energy use by and heat gain from lighting systems, and the efficiency of the air conditioning system.

The proposed energy standard for new commercial buildings may be viewed as an initial effort. After several years' experience has been gained using the proposed standard for new buildings, then energy criteria might be considered for operation and retrofit of existing Malaysian buildings.

Resources Used in Developing the Proposed Malaysian Standard

The proposed Malaysian standard has benefited both from substantial expertise within Malaysia as well as from the latest advances in standards development in other countries. In addition to extensive analysis and evaluations conducted by the Universiti Teknologi Malaysia (UTM), and inputs from other Malaysian consultants, the proposed Malaysian new building energy standard incorporates the most current concepts and implementation formats and techniques from two important similar efforts: 1) the current ASHRAE 90.1P effort, and 2) the Singapore standard.

Three members of the ASHRAE 90.1P Committee in the U.S. worked as consultants to Lawrence Berkeley Laboratory (LBL) to distill from the current draft of ASHRAE 90.1P the most important concepts and requirements applicable to Malaysia [ASHRAE, 1986].[5] This material was presented to UTM for review and further modification. One member of the 90.1P committee worked with UTM in developing, refining, and incorporating those modifications. This revised material formed the basis for many specific requirements in the proposed Malaysia energy standard.

The major concept applied from the Singapore standard is the OTTV approach to limiting thermal transmission through the building envelope. The lessons learned from more than six years of using the OTTV approach in Singapore indicate that major improvements can be made to the earlier Singapore approach. The approach proposed for Malaysia is similar to a new approach being considered by Singapore as part of the planned revision to its 1979 standard. The improvements include recognition of advances in energy conservation technologies that have become more readily available in recent years (including a credit for daylighting controls). In addition, coordination between MOE and LBL is proceeding to develop a Standards Handbook intended to assist building designers in applying the criteria of the proposed standard to specific building designs.

The remainder of this paper discusses the analyses conducted to support the development of the standard. Readers interested in the text of the proposed standard should read the November 1986 UTM report.

KEY FINDINGS

Energy Standards Have Potential for Substantial Economic Benefits

Upgrading the design of a prototypical "Base Case" Malaysian new commercial office building to comply with the proposed energy standards results in an annual energy reduction of 18%. (This analysis considers four different cases of buildings, corresponding to different levels of energy efficiency. These are defined in the Basis for Analyses section of this paper.) This upgrading has the following

---

[5] This work was conducted under the auspices of the ASEAN/US project on energy conservation in buildings funded by the U.S. Agency for International Development.

impacts on cost effectiveness:

- Construction Cost: an increase of $Malaysian ($M) 9.46 per square meter of building floor area;
- Annual Energy Cost Savings: an annual savings of $M 5.94 per square meter of building floor area.
- Payback Period: 1.6 years.

Clearly, the energy criteria in the proposed standard are very cost effective.[6]

Commercial building energy use increased by an average of about 8 percent per year between 1981 and 1985.[7] If the standards are fully implemented in 1988, and if commercial sector floor space continues to increase at a rate of 8% per year, then, as Table 1 shows, commercial sector energy use in 1993 will be reduced by 424 GWh (5.4%) compared to projected energy use without energy standards.

The cumulative energy cost savings to the consumer is $M 85 over a six-year period. Additional savings result from avoided new power plant construction. In 1993, the reduction in power demand is 141 MW. Assuming a cost of $M 2,000/kW, the avoided cost of construction is $M 280.

The magnitude of savings will increase over time. If standards were implemented in the future for operation and retrofit of existing buildings, the energy savings potential would about double.

Major Sources of Energy Use

Malaysia's year-round hot and humid climate causes the energy consumption profiles of buildings to be significantly different from the profiles exhibited by buildings located in temperate or cold climates such as those in most of North America. Using the building energy simulation program, DOE-2.1C, the major components of the energy usage in Malaysia were evaluated for a typical reference, or Base Case, office building. The results of this analysis are shown in Figure 1.

Considered by itself, space cooling is the single largest consumer of energy in the Base Case building—40% of total annual energy use. The two largest sources of heat gain to the building that require space cooling are solar heat gain and heat gain from lighting fixtures. The combined effect of these two sources of heat gain account for over one half of the cooling load on typical Malaysian buildings.

---

[6] By way of comparison, in the U.S., private investors typically invest in conservation opportunities with paybacks of less than three years, and many owners use five year (or longer) simple payback periods.

[7] It is assumed here that this increase is due solely to new building construction.

Lighting is the second largest user of energy in the Base Case building; lighting consumes 38% of the total annual energy use. However, since waste heat from the lights is also a significant cause of cooling energy consumption, lighting energy use and lighting heat gain together constitute the most significant contributors to energy use in commercial buildings in Malaysia.

Largest Immediate Savings

Some specific measures to reduce lighting and cooling energy consumption, and extent of their energy savings, are introduced briefly below and detailed in the Methodology and Results sections.

Lighting. Lighting energy use can be reduced in several general ways:

1) use of more efficient systems (ballasts, lamps, fixtures);
2) use of controls;
3) use of daylighting; and,
4) decreasing illumination levels.

To maintain productivity of building occupants, the first three techniques are preferable to the fourth. For purposes of analysis for the proposed standard, more efficient systems were used to convert lighting from the Base Case building's 21 W/m^2 to the level proposed for the standard of 17 W/m^2. Using more efficient systems results in an 11% reduction in total building annual energy and a 9% reduction in peak demand.

Daylighting. DOE-2 analyses indicate that the use of daylighting has the potential to be one of the most effective energy conservation strategies for Malaysian office buildings. The simulations indicate that daylighting controls for the electric lighting system can save an additional 20% total annual energy in an office building that *already* meets the criteria of the proposed standard.

The proposed standard does not require that daylighting be used since it is a new conservation strategy in Malaysia. Rather, the standard provides a credit for the use of daylighting controls for an electric lighting system. The credit is in the form of a relaxation of the standard's envelope requirements. This relaxation allows the building designer to trade off the increased costs of the daylighting controls for lower costs of envelope elements, or to use more fenestration. The credit is "conservative;" it does not relax envelope requirements by the full amount of savings derived from the use of daylighting. Thus, a building using daylighting will still use less energy even though its envelope may be somewhat less efficient than the envelope of a non-daylit building.

A/C Efficiency. A modest upgrading of air conditioning Electric Input Ratio (EIR) from 0.244 to 0.222 yields a total building annual energy and peak demand reduction of about 3 percent from the Base Case building. Greater energy savings are achievable using a lower EIR.[8]

Envelope Performance. The combined effect of heat and solar energy gain through the building envelope has a significant effect on the cooling load. Since the most extreme weather parameter in Malaysia is the solar gain, the building envelope features which most directly affect the building energy demand are: fenestration area, type of glazing, shading of the fenestration (and other building surfaces) from direct solar rays, and the absorptance (e.g., color) of the exterior walls and roof.

While all of these features have been analyzed in this study, only one envelope characteristic was changed in assessing the cost effectiveness of the proposed standard's envelope provisions. The shading coefficient of the fenestration was reduced from SC = 0.69 to SC = 0.53, which resulted in a total building annual energy reduction of 4% and a peak demand reduction of 5%. An additional 4% annual energy reduction resulted from other envelope feature changes.

The Analyses Support Relatively Simple Energy Relationships for the Proposed Standard.

Designing buildings that conserve energy can be extremely complex and involved, taxing the skills of even seasoned energy experts. However, the most important energy design factors can be represented quantitatively in a relatively simple equation. Examples of the simple, key relationships in the proposed standard focus on:

- the development of a simplified, improved, OTTV expression for envelope criteria;
- lighting power criteria for major space functions; and
- EIR (COP) criteria for A/C chillers.

If the complexity of the proposed criteria for evaluating the performance of building energy components is increased, and if additional criteria are considered, then even greater energy savings are possible. For example, criteria for A/C fans and pumps could be included, and would result in additional potential savings. However, such complexity has been considered undesirable for this first Malaysian energy standard.

---

[8] EIR at full capacity is defined as follows: EIR = 1/COP. Three levels of EIR are discussed in this report: EIR = 0.244 (COP = 4.1), EIR = 0.222 (COP = 4.5), and EIR = 0.185 (COP = 5.4).

Similarity to Singapore Standards

The analyses performed in support of the proposed Malaysian standard are generally similar to those done for the existing Singapore standard in approach and format, but with some important differences. The differences include the incorporation of the most recent U. S. standards development work, refinement of the OTTV methodology to make it both easier to use and more accurate, and the recognition of advances in energy conservation technologies that have become more readily available in recent years (including a straightforward credit for daylighting controls). Likewise, the analyses reported in this document generally substantiate and refine the results of the 1984 Singapore analysis [Turiel, *et al.*, 1984].

METHODOLOGY

GENERAL APPROACH

The analytical approach in this work was based on the identification of a small number of commercial building prototypes that represent the range of energy-efficiencies encountered in Malaysia. The overall energy and economic performance and the effect of key individual measures on the performance, of each prototype were assessed using a computer simulation tool. Comparisons among the prototypes, or "cases", yield estimated savings resulting from design improvements. Cost estimates of specific measures, developed in Malaysia, provide the basis for the economic assessment.

Two separate analyses were undertaken using a more extensive parametric simulation approach. One, to develop the form of the envelope portion of the proposed standard, combined simulation results with regression techniques. The second evaluated the use of natural light to displace artificial lighting for a range of control technologies and fenestration choices.

The following discussion of methodology is presented in two parts. The first part, the "Basis for Analyses," describes the basic elements of the methodology used: the buildings analyzed, the DOE-2.1C computer program used to perform the analyses, and the local weather data used. The second part, the "Types of Analyses," describes the purpose and methodology of each of the four types of analyses performed using the basic building, weather, and computer program elements.

BASIS FOR ANALYSES

Reference Building Approach and Description

Lack of substantial data bases restricted the scope of research that could be completed in a reasonable length of time.[9] Data bases are needed for both the level of energy consumption in Malaysian buildings and for building construction/design procedures that are unique to Malaysia. In the absence of such data bases, the analyses used a "reference building" approach.

Definition of the Four Building Cases Used. To analyze the energy and cost impacts of the proposed standard, it was necessary to identify various levels of energy performance that could be expected in new Malaysian commercial buildings. This was done by identifying four levels of energy performance. Four prototypical buildings were defined to represent different expected levels of building energy use in Malaysia. The relative levels of energy efficiencies of the four building cases are shown in Figure 2.

Throughout the remainder of this report, these four levels are referred to as:

- Worst Case
- Base Case
- Proposed Standard Case
- Good Practice Case

Professional judgment and experience were used to select appropriate building features for each of the four building cases, based on the limited data available on building characteristics.

Worst Case: This case represents the most energy intensive buildings that might be encountered in Malaysia today. A "Worst Case" building wastes considerable energy. There are relatively few buildings at this extreme. However, there are at least some buildings in Malaysia that use considerably more energy than that produced by the Worst Case scenario.

Base Case: A "reference" or "Base Case" building was developed to reflect a typical range of construction features and energy use now prevalent in new Malaysian commercial building construction. The Base Case building is not intended to represent the "average" energy design in Malaysia today. Rather, it represents a building design that is between the average and a "worst-case"

---

[9] Available data included a report by Dangroup International in association with J & A Associates containing energy audits for 15 Malaysian buildings. Unfortunately, the information presented in that document was not sufficiently detailed to generate building characteristics at the level of detail needed for the analyses conducted here. In addition, four energy audits conducted by the Gas and Fuel Corporation of Victoria, Energy Management Centre, were available in sufficient detail, but constituted a small data set.

energy design that might be expected to be built today.

Proposed Standard Case: This case reflects the level of energy efficiency expected to be achieved by the proposed standard. The energy reduction possible through the implementation of the proposed standard can be evaluated relative to either the Base Case building or the Worst Case building. Buildings meeting the proposed energy standard will use less energy than that of the Base Case Building. The standard leads to little change in energy use for a building constructed to "average" current Malaysian practice.

Good Practice: This building case represents a combination of energy-efficient practices that exceed the requirements of the proposed standard This level of performance is to be expected of building owners and designers who have a reasonable knowledge of and concern for energy-efficient design. It is expected that the greatest number of buildings now being built in Malaysia will use less energy than the Base Case building and more energy than the Good Practice building. On the other hand, relatively few buildings are very energy efficient, as indicated at the left end of the curve in Figure 2.

Development of the Malaysian Base Case Building. The Malaysian Base Case building is based on a similar prototypical "reference" building developed for a 1984 parametric energy study for Singapore [Turiel *et al.*, 1984]. The Singapore building was developed to reflect typical building practices in Singapore, which are similar to those encountered in Malaysia today. However, modifications were made to the Singapore model to make it more accurately reflect contemporary construction practices in Malaysia. The changes can be categorized as falling into three types: 1) physical changes to the building, 2) changes to the A/C equipment, and 3) changes to the building and equipment operation strategies. In all, 17 changes were made. The rationale for each modification is discussed in Appendix A, and a complete DOE 2.1C input listing for the Malaysian Base Case building is given in Appendix B.

The Malaysian Base Case building is a 10-story office building with a total conditioned area of 5200 m^2. A schematic typical floor plan is shown in Figure 3. The unconditioned core zone has a floor area of approximately 1000 m^2. The core region is assumed to be thermally insulated from the interior conditioned zone. The Base Case Building has a window-to-wall ratio of 0.40 and the shading coefficient of the windows is 0.69 (e.g., single pane tinted glass). The lighting power density installed in the occupied areas is 21 W/m^2. The OTTV of the walls of the building envelope is 66 W/m^2.[10] A variable air volume (VAV) system

---

[10] This is calculated using the proposed new Malaysian OTTV equation (Equation 3) described in the Results section below. The wall OTTV value calculated for the Proposed Standard Case in 54 W/m^2. Interestingly, the same value is reached using the current Singapore OTTV equation for the Proposed Standards Case. However, in other cases the two OTTV formulations yield different results.

was modeled with a minimum air flow rate ratio of 0.5. A chiller with an EIR of 0.244 (COP of 4.1), excluding fans and pumps, provides chilled water to the cooling coils. The construction characteristics of the building envelope, the space conditions and the A/C equipment specifications are summarized in Table 2.

DOE-2.1C

The DOE-2.1C Building Energy Simulation Program [BESG, 1985] is the computer simulation program employed in the analysis of energy conservation in Malaysian buildings. The DOE-2 program estimates the total and component energy consumption associated with a particular building design.

A building, examined thermodynamically, involves non-linear flows of heat through and among all of its surfaces and enclosed volumes, driven by a variety of heat sources (e.g., the sun, the lights, the occupants, various types of equipment, etc). Mathematically, these flows correspond to a set of coupled integral-differential equations with complex boundary and initial conditions. DOE-2 simulates the thermodynamic behavior of the building by approximately solving the mathematical equations.

The simulation process in DOE-2.1C is performed sequentially in three programs. The first program (called LOADS) uses weather data, user input regarding the building envelope characteristics, and the schedule of occupancy in order to calculate the heating addition and/or cooling extraction rates for each building space. The energy performances of daylighting, lighting, domestic hot water, and elevators are also calculated in LOADS. The second program (SYSTEMS) uses the LOADS input and calculates the demand for ventilation air, hot and cold water, electricity, etc., to maintain the temperature and humidity set points. In addition, controls equipment, HVAC auxiliary equipment, and energy recovery equipment are also evaluated in the SYSTEMS program. The final program (PLANT) simulates the behavior of the primary HVAC systems (boilers, chillers, cooling towers, etc.) as they meet these demands and predicts the fuel and electrical energy consumed.

Versions of DOE-2, up to DOE-2.1C, have been verified against manual calculations and field measurements of existing buildings [LANL, 1981, Diamond *et al.*, 1985, Birdsall, 1985]. These studies all show that, with few exceptions, the DOE-2 predictions agree well with ASHRAE calculation methods, manufacturers' data, and measured annual building energy consumption. DOE-2 results also agree well with predictions of other building energy analysis computer programs (BLAST, NBSLD). These extensive testing and validation studies have culminated in a program which, within the limits of its design, is capable of simulating the performances of a wide variety of building types and HVAC systems.

Weather Data

All weather data used in the DOE-2 computer runs, except solar radiation data, are actual hourly data recorded at Kuala Lumpur for the year 1985. Solar data from Singapore were merged with the other weather data from Kuala Lumpur to form a composite weather file. The measured Singapore solar data are shown in Figure 4. The measured Singapore solar data were used because adequate solar data for Kuala Lumpur were not available and conditions in Singapore are comparable to those in Kuala Lumpur. Using the available cloud cover measurements in Kuala Lumpur causes the DOE-2 cloud cover model to significantly underpredict (by 70%) the direct normal component of solar radiation, as shown in Figure 4.

Singapore Solar. The measured hourly Singapore solar data were collected in 1979. The most relevant solar statistic in building energy use is solar radiation impinging on vertical surfaces. The average daily total vertical solar radiation is about 7,200 kJ/m^2 for north and south orientations and about 25% more (9,600 kJ/m^2) for east and west. There is little difference in the annual *totals* falling on north or south walls because Singapore and Malaysia are both very close to the equator. However, seasonal variation in the total direct solar radiation for north and south orientations is about 60%. The solar gains for east and west orientations vary by about 30% over the year.

Because of the frequent presence of clouds and high humidity in both Singapore and Kuala Lumpur, diffuse light makes up about two-thirds of total solar radiation.

Temperature. The 1985 measured hourly temperature data for Kuala Lumpur are presented in summarized form in Figure 5. Daily average minimum, maximum, mean dry bulb, and mean wet bulb temperatures for each month are plotted. The temperature patterns are fairly constant over the year. Diurnal dry bulb temperature swings are about 9 °C. The wet bulb temperatures are within 2-3 °C of the dry bulb temperature, which indicates that the relative humidity is always very high.

Climate Implications for Energy Standards. Since the climate of Malaysia is significantly different from that in most countries for which current energy standards exist, the applicability of those energy standards needed to be thoroughly reevaluated for use in Malaysia. Within the limits of available Malaysian climate data described above, the analyses reported here present such a re-evaluation.

TYPES OF ANALYSES

The design parameters that most significantly affect the energy requirements of a building were analyzed in four separate studies:

- Cost Effectiveness — Single measures;
- Cost Effectiveness — Combinations of measures;
- OTTV parametric analysis; and
- Daylighting parametric analysis.

Each is discussed below.

Cost Effectiveness: Single Measure Analyses

The three building subsystems that most significantly affect the energy performance of the whole building are: lighting, A/C system, and the exterior envelope. For each of these subsystems, specific parameters were identified as most significant to changes in building energy use and peak demand. For each parameter, a few key values were selected.

Each parameter and value was selected based upon professional judgment and prior experience with similar studies (including the Singapore study). This approach was used to minimize analysis time, given the short time-frame for conducting the analysis. It was felt that, in many cases, complete parametric analyses using wide ranges of values for each variable were unnecessary because the basic relationships were already known from previous studies by members of the analysis team.

The values selected for each building subsystem were chosen to be representative of the efficiency level that might be expected for each of the building cases being modeled (Worst Case, Base Case, Proposed Standard Case, and Good Practice Case). The values selected for each of the parameters were used as input to the DOE-2 computer program, to evaluate the energy impact of these individual design variables. The parameters and values selected for each building subsystem are identified below.

The cost effectiveness of single changes in building characteristics was determined, when possible. The objective was to be able to determine the economic effectiveness of each of the changes independently. In all cases, a simple payback analysis was conducted by dividing the change in construction cost by the annual energy savings. In several cases, construction costs were lower as a result of an energy conservation strategy than they would have been without it. In cases where both first cost of construction and energy operating costs were reduced, the energy-saving measure is assumed to be completely cost effective. No economic calculations were done in these cases.

Two different electricity rate schedules for commercial buildings are now in effect in Malaysia. The energy rate used in the analyses ($M 0.19/kWh) was for larger customers. This customer class also incurs a demand charge of $M 12/kW.

Although the rate for smaller customers does not include a demand charge, the higher energy use charges paid by these customers make the economic impacts of the cost effectiveness measures examined roughly equivalent. Thus, the choice of rate schedule used does not impact the overall results or conclusions of this study. The effect of the "inverted" utility rate tiers was not examined here, but they would only improve cost effectiveness.

Insofar as possible, construction cost estimates were obtained from recent experience within Malaysia. The construction cost estimates were mostly provided by Dr. Akram Che Ayub, Universiti Kebangsaan Malaysia. Such cost estimates were obtained for most single conservation measures analyzed. In a few cases, no construction cost estimates were generated.

No cost estimates were made for the OTTV parametric analyses. For the daylighting parametric analyses, Malaysian costs are not known, because there are no daylighting installations in Malaysia. Therefore, reasonable U.S. construction costs were used.

The Results section of this report presents the construction costs used and the resulting cost effectiveness of the measures and combinations of measures.

Lighting. Lighting energy use can be reduced in several general ways:

1) use of more efficient systems (ballasts, lamps, fixtures);
2) use of controls;
3) use of daylighting; and,
4) decreasing illumination levels.

For maintaining productivity of building occupants, the first three techniques are preferable to the fourth. The overall result of these strategies is three-fold:

1. The overall lighting power per square meter of floor area (watts per square foot) for the building as a whole is reduced.
2. The heat gain from the lights to the interior spaces of the building is reduced.
3. The amount of time that the installed lighting is on (using energy and generating heat) is reduced.

Extensive or systematic data on installed lighting system characteristics were not available for Malaysia. In the absence of such data, lighting system characteristics were selected based on professional experience in both Malaysia and the United States, as well as data for lighting systems in Singapore.

For the cost effectiveness analyses, the primary modification considered was the use of more efficient lighting systems, which are described below. The proposed standards contain several basic lighting controls criteria, but separate cost effectiveness analyses of these were not done. The controls provisions are assumed to represent good, cost-effective design practice.

Recent data tabulations from Singapore indicate that the connected lighting load in buildings varies from a high of 27 W/m^2 to a low of 13 W/m^2.[11] The connected lighting loads used in these cost effectiveness analyses reflect this range.

The Worst Case building is lighted with four-tube fixtures, with lenses, spaced every 6.8 m^2 to provide the high lighting power level of 27 W/m^2. The Base Case building is lighted with standard four-tube fluorescent fixtures spaced every 7.8 m^2 to provide an installed lighting power of 21 W/m^2.

The Proposed Standard Case has an installed lighting power of 17 W/m^2. One way to achieve this level is by using three-tube fluorescent fixtures, spaced every 7.1 m^2, with high efficiency ballasts. The Good Practice building uses an installed lighting power of 13 W/m^2, roughly equivalent to the use of two-tube fixtures spaced every 6.2 m^2. Several buildings designed and constructed recently in Malaysia attain this level of installed power through the use of such types of systems.[12]

Cooling Set Point Temperature. A/C system operation can significantly influence the cooling energy usage. Assuming that hours of operation are restricted to hours of building occupancy, and that the ventilation air is properly controlled, the cooling set point is the most significant operation variable.

ASHRAE criteria suggest that comfortable space conditions exist when the thermostat set point ranges between 21.1 °C (70 °F) and 25.6 °C (78 °F). In the Base Case building, the cooling set point temperature is 24 °C (75.2 °F). In the Proposed Standard building, the set point is raised to 25 °C (77 °F). This is a "no-cost" measure.

Chiller Efficiency. Since energy for cooling accounts for a significant portion of total energy use, the use of high-efficiency A/C equipment offers a major opportunity for energy savings.

A review was conducted of the EIR for various types of A/C equipment in use in Malaysia. From this review, three levels of practice for water-cooled centrifugal chillers were selected for use in the cost effectiveness analyses:

---

[11] Similar data on installed lighting power in Malaysian buildings is not available. However, visual inspection of lighting systems in a number of Malaysian buildings suggest that the data from Singapore are very applicable to Malaysia. Interested readers should refer to the National University of Singapore memorandum: "Daylight and Artificial Lighting in Buildings", by Prof. Bill Lim *et al.*, 1986. This memorandum documents results of a 1984-1985 lighting survey of approximately 100 buildings constructed after 1980.

[12] Informal survey conducted by Dr. Akram Che Ayub, Universiti Kebangsaan Malaysia, Bangi, Selangor, in the fall of 1986 and reported by telephone to the LBL team.

EIR = 0.244 (COP = 4.1)	low end of existing equipment
EIR = 0.222 (COP = 4.5)	representative of typical current practice
EIR = 0.185 (COP = 5.4)	good practice

Both the Worst Case and Base Case buildings have a chiller with an EIR of 0.244. The Proposed Standard building has a chiller with an EIR of 0.222. The Good Practice building has a chiller EIR of 0.185.

Envelope Performance. The combined effect of heat and solar energy gain through the building envelope has a significant effect on cooling load. Since the most extreme weather parameter in Malaysia is the solar gain, building envelope features of particular interest are:

- fenestration area;
- type of glazing;
- shading of the fenestration (and other building surfaces) from direct solar rays; and
- the absorptance (e.g., color) of the exterior walls and roof.

The heat energy transferred through the building envelope is dominated by the solar gains through the fenestration. These solar gains can be reduced in the following three ways.

- Choosing a glass type that has a relatively low solar thermal transmittance. The shading coefficient (SC) of a piece of glass is a measure of the transmittance of solar energy through that glass relative to a standard type of glass.
- Using a small amount of glazing area relative to the gross wall area of the building. This parameter is defined by the window-to-wall-area ratio (WWR).
- Reducing the amount of solar thermal gain entering the conditioned space through the fenestration by using shading devices external to, integral with, or interior to the glazed surface(s).

For the single-measure and combined-measure cost effectiveness analyses, only the shading coefficient (SC) of the glazing was changed.[13] The basic change was to replace single-pane tinted glass (SC = 0.69) with single-pane reflective glass (SC = 0.53).

Reflective glass was used as the example in the Proposed Standard Case building for convenience purposes only. The study team does not mean to imply that reflective glass is the appropriate solution in all situations. In fact, several alternate approaches are considered more acceptable across a range of possible

---

[13] For an assessment of the impacts of other strategies, see the description of the OTTV parametric analysis, below.

building designs. These include new "high-performance" glazing technologies that reduce solar thermal gain and at the same time allow higher levels of visible light to penetrate, and the use of shading devices (overhangs, fins, solar screens, etc).

Cost Effectiveness: Combinations of Measures

Upon completion of the computer simulations of the individual measures, the effects of combinations of measures on the level of energy utilization was evaluated. The purpose of simulating combinations of measures was to identify incremental levels of possible overall energy savings, and the relative difficulties of achieving each. One of the key objectives of the proposed standard is to achieve a reasonably good level of energy efficiency, using design techniques that are commonly practiced. The process of identifying various combinations of conservation techniques aided in identifying the target level of conservation.

For these "combined measure" analyses, the Base Case building was used as the starting point. It was then modified in specific ways to attain each of the other building situations being examined.

Base Case to Worst Case. To attain the Worst Case building from the Base Case, the following three measures were combined:

- A/C system static pressure changed from 7.6 to 12.7 cm. water;
- Lighting power changed from 21 W/m^2 to 27 W/m^2; and
- WWR changed from 0.4 to 0.6.

A second estimate of the Worst Case was developed in which the above three changes were incorporated into the Base Case, and the A/C system was changed from the Base Case variable air volume (VAV) to a constant volume variable temperature (CV) system.

Base Case to Proposed Standard Case. To attain the Proposed Standard Case building from the Base Case, the following four measures were combined:

- A/C chiller EIR changed from 0.244 (COP = 4.1) to 0.222 (COP = 4.5);
- Lighting power changed from 21 W/m^2 to 17 W/m^2;
- Glass shading coefficient changed from SC = 0.69 to SC = 0.53; and
- Cooling set point temperature changed from 24 °C (75.2 °F) to 25 °C (77 °F).

Worst Case to Proposed Standard Case. Another assessment that was desired was the energy savings from the Worst Case to the Proposed Standard Case. This was accomplished by combining both sets of changes described above, for the Worst Case building with VAV and with CV systems.

Proposed Standard Case to Good Practice Case. The final combined analysis assessed the energy savings from a combination of measures that would improve the Proposed Standard Case sufficiently to represent the Good Practice Case.

The following four measures were combined to do this:

- 2.3 m window overhangs were added;
- Lighting power changed from 17 to 13 W/m^2;
- A/C chiller EIR changed from 0.222 (COP = 4.5) to 0.185 (COP = 5.4); and
- Lighting schedule was made to follow the occupancy schedule.

OTTV Analyses

Introduction. To develop appropriate criteria for the building envelope for Malaysia, the concept of OTTV was used. This concept was first developed for ASHRAE 90-75, and refined for the Singapore standard. In this study for Malaysia, the primary concentration has been on refining the OTTV formulation for walls. This focus was chosen because of the great importance of fenestration to cooling loads and building energy use. The wall analysis will be discussed first, followed by a brief description of the approach to developing roof criteria.

Wall Analysis. An improved and simplified version of the OTTV approach for walls is proposed for the Malaysian Standard as a result of the analysis described below. The objective is to provide a simple, flexible, and reliable method for determining the energy impacts of wall envelope design choices for commercial buildings. This work builds upon considerable experience with OTTV concepts in the United States and Singapore, including the 1984 Singapore study [Turiel *et al.*, 1984, Turiel & Rao, 1986].

The OTTV formulation is performance-based. It allows a building designer freedom to vary important wall characteristics to meet specific design objectives and still comply with the wall OTTV requirements. A designer can select many different combinations of values from a wide range of options (opaque wall U-values and colors, types of glazing, window-to-wall ratios and external shading devices) as long as the total value of the resulting OTTV meets the standards' requirements.

The approach involves evaluating the correlation between selected envelope parameters known to be important to energy use and the resulting changes in the energy consumption of the Base Case building. The approach accounts for the most important envelope characteristics affecting the solar heat gain to the inside of the building. A set of DOE-2.1C simulations was developed by varying the most important energy-related design variables over the full range of expected values for each variable.

Among the envelope features, fenestration characteristics dominated the cooling load. The fenestration features examined were:

- the shading coefficient (SC) of the window system

- the window area in the form of the window-to-wall ratio (WWR); and,
- the glass conductance (U_f).

Opaque wall parameters also have a measurable impact on the cooling loads. The characteristics varied in the simulations were:

- thermal mass (heat capacity);
- the solar absorptance in terms of the exterior surface color (α); and
- insulation levels in the walls (U_w).

Initial Wall Strategy and Problems With Results. The initial analytic strategy was to vary the DOE-2 input variables of interest over a broad enough range to ensure that the correlation results would be directly comparable with the 1984 Singapore OTTV approach [Turiel *et al.*, 1984]. The rationale was that the analysis would in all likelihood result in only a slight modification of the Singapore work due to the similarity of the climates and building types. Another consideration was to have a sufficient number of runs to adequately define the unknowns in the OTTV equation.

However, in the first analysis, some of the input parameters were not varied throughout their range of likely occurrence. The result was that the full impact of these parameters on cooling loads was either significantly under- or overestimated. These initial results were incorporated into the late 1986 draft proposed Malaysian standard [UTM, 1986].

To eliminate these distortions, the approach was altered using a technique in experimental design called factorial analysis. Factorial analysis is a systematic way of covering an entire factor space by first defining the range of each key parameter and then combining the parameter extremes with each other, and with the midpoint of them all. This results in $(2^n + 1)$ cases to run (n being the number of parameters) to determine the full effect of each parameter in combination with the others.

Reasonable minimum and maximum values for the key wall parameters were chosen based on a combination of observed conditions in Malaysia and professional judgment. The range of each parameter is shown in Table 3.

The form of the OTTV equation for walls developed originally for ASHRAE 90-75 and used also in the Singapore work [Turiel *et al.*, 1984] is:

$$\mathrm{OTTV} = \Delta \mathrm{Teq} \times U_w \times (1-\mathrm{WWR}) + \Delta T \times U_f \times (\mathrm{WWR}) + \mathrm{SF} \times \mathrm{SC} \times (\mathrm{WWR}) \qquad (1)$$

where:

ΔTeq = equivalent indoor-outdoor temperature difference for the opaque wall (°C);

U_w = U-value of the opaque wall (W/m^2- °C);

WWR = window-to-wall ratio;

ΔT = indoor-outdoor temperature difference for the fenestration (°C);

U_f = U-value of the fenestration (W/m^2- °C);

SF = solar factor (W/m^2); and

SC = shading coefficient.

The U_w, WWR, U_f, and SC are all known design parameters. The unknowns in the equation are SF, ΔTeq, and ΔT. The SF is determined by an independent analysis of the measured solar data, described below. The values for ΔTeq and ΔT can then be determined by regression analysis. The original ASHRAE equation used a slightly different format for areas; instead of WWR, the areas of opaque walls and fenestration were specified. Then the whole right side of the equation was divided by A_0, the gross area of the exterior walls above grade. The two formats are functionally equivalent.

Solar Data Used, and Determining the Solar Factor (SF). Solar data collected at Universiti Sains Malaysian, Penang, were used to calculate the value of the solar factor term in the initial OTTV analysis. The solar factor is the average hourly rate at which solar radiation is incident upon a vertical surface; it is expressed in W/m^2. Both diffuse and direct radiation are included in the solar factor. Penang is located at 5.3°N latitude and 100.3°E longitude. Monthly and yearly averages of hourly and daily sums of diffuse and global solar radiation were collected at that location.

Standard ASHRAE equations were used to convert diffuse and global horizontal radiation to direct vertical radiation for eight orientations. Total vertical radiation is equal to the sum of the direct vertical, 0.5 times the diffuse horizontal, and 0.11 times the global horizontal. Table 4 shows the magnitude of the solar factor for each of the eight orientations and both its direct and diffuse components.[14] The vertical radiation is averaged over the time period 7:30 am to 5:30 pm. The average (over eight orientations) solar factor is equal to 222 W/m^2.

However, since the OTTV formulation uses the solar factor in combination with the shading coefficient, the solar factor needs to be related to the solar transmission of single-pane clear glass. Using a typical value of 0.87 for the fraction of incident solar radiation transmitted through such glazing, the solar factor becomes 194 W/m^2. This is the value of SF used in the regression analysis, from

---

[14] Anomalous patterns occur in the solar data east and west orientations. For that reason it is not recommended that the SF values *by orientation* shown in Table 4 be used. However, the average SF over all orientations was assumed to be reasonably accurate for the following OTTV analysis. Further examination of these data is warranted, but was beyond the scope of this study.

which ΔTeq and ΔT could then be determined.

Analysis of Need for Additional Variables in OTTV Equation for Malaysia. It was suspected that, in addition to those parameters used in the Singapore analysis, that both thermal mass and absorptance could have significant impact on energy use in Malaysia. Thermal mass impacts were embedded in the ΔTeq term of the original ASHRAE and Singapore equations. However, absorptance was not included in either the original ASHRAE or Singapore wall OTTV equations. Therefore, analyses were conducted to determine how much either the thermal mass or the exterior wall solar absorptance parameters (or both) would contribute to the accuracy of the OTTV equation for Malaysia. Separate simulations were done by varying the wall mass and roof mass at solar absorptances of 0.2 and 0.8.

The results of these separate simulations for thermal mass and absorptance are shown in Figures 6 and 7. The exterior wall thermal mass had relatively little effect on the chiller load, changing it only 1-2% over the range. This was not considered a large enough impact to increase the complexity of the OTTV equation by adding a separate thermal mass term. Neither roof mass nor roof color had a significant impact on chiller load.

However, opaque wall color, as indicated in the solar absorptance, had a 8-9% effect on chiller load. This result confirmed the initial suspicion that wall color is an important design decision factor in the type of climate encountered in Malaysia. This is especially true given the typical Malaysian construction practice of using little or no insulation in the walls. Therefore, the original ASHRAE and Singapore OTTV equation has been modified to include the solar absorptance term.

Determining Best Way to Add Absorptance Term to OTTV Equation. A new form of the OTTV equation was needed to incorporate the solar absorptance term. To evaluate the best configuration, two sets of 20 DOE-2 runs with various combinations of the key design variables were executed. In one set, the solar absorptance was varied, and in the other, it remained constant. The purpose of these two sets of runs was to evaluate the variation in the chiller load which was attributable to the changing absorptance. The computed variations in the chiller load were then compared to several different methods of incorporating the absorptance term, shown in Figures 8 through 10.

The first two figures show that neither the solar absorptance nor solar absorptance multiplied by a measure of the opaque wall area (1-WWR) has a discernable mathematical relationship to chiller load. The last figure, however, shows a strong linear relationship between chiller load and solar absorptance multiplied by the opaque wall area ratio and the conductive heat loss factor (U-value) for the wall. This relationship clearly indicates that the appropriate way to incorporate the solar absorptance term into the OTTV equation is to include it as a multiplicative constant in the opaque wall term.

Relating OTTV Values to Chiller Loads. The addition of the solar absorptance term brings the total number of independent variables for the simulations up to five. Thus, 33 DOE-2.1C runs (i.e., $2^5 + 1$) were done, varying WWR, SC, U_f, U_w, and α in accordance with the factorial analysis design scheme. The chiller loads from these runs were recorded. The five independent building envelope parameters were combined into different trial expressions for the OTTV and related to the building chiller load with the following equation:

$$\text{Chiller Load} = k_1 + k_2 (\text{OTTV}_x), \tag{2}$$

where k_1 and k_2 are regression coefficients, and OTTV_x is the particular form of the equation being investigated, expanded into all of its terms. The coefficients were determined by the method of least squares. The constant k_1 embodies internal gains from lights, people, equipment, etc. Since the value of SF is known, the k_2 constant can be isolated from each physical coefficient in the OTTV equation, revealing the estimated values of ΔT and ΔTeq.

Regressions were run for several different forms of the OTTV equation. The final form of the Malaysian OTTV equation was chosen on the basis of the statistical regression results and the predictability of the actual chiller loads with the regression equation. The selection process along with the recommended final form of the OTTV equation are described in the Results section below.

Roof Analysis. For roof design, both the analyses and the provisions of the proposed standard are generally much simpler than those for walls because the roof does not typically contain large amounts of glazing, whereas the walls do. No parametric runs were conducted for the roof. Instead, the basic criteria used both by ASHRAE and Singapore were adapted and simplified. Credits were developed for roofs that are shaded or that use reflective surfaces that are reasonably impervious to moisture and mold degradation. The proposed roof criteria are discussed in the Results section.

Daylighting Analyses

The fourth type of analysis involves the evaluation of the magnitude of energy savings that can be achieved with the use of natural lighting, or daylighting. The objective was to test daylighting in a case for which savings were not so easily achieved (e.g., in a case where the building is already somewhat energy efficient). For this reason, the building prototype was the Malaysian Proposed Standard Case building. The results of this analysis are meant to support the inclusion of daylighting as a credit in the proposed standard.

Natural lighting reduces the need for costly artificial electric lighting. However, the use of natural lighting can often allow significant levels of solar energy to enter the building through the fenestration. These solar gains need to be traded off with savings from the heat gains and energy consumption of artificial lights. The design of daylighting systems thus involves optimizing the fenestration choices in such a way as to minimize the *total* energy use.

The approach was to simulate daylighting performance over a range of assumptions using DOE-2.1C. The study focused on fenestration choices and on strategies for controlling artificial lighting in order to utilize natural lighting. Three artificial lighting control strategies were selected: stepped lighting controls at 0%, 50%, and 100% of rated power; continuous dimming controls; and on/off controls. Four fenestration features were tested: window size, glazing characteristics (including the visible transmittance and shading coefficient), overhangs, and window management.

The daylighting parametric results are evaluated in terms of effective aperture. The effective aperture (EA) is a relative measure of the total amount of natural lighting energy entering a room through the glazed window area. The EA of a window is the product of the window-to-wall-area ratio (WWR) and the total visible light (Tvis) admitted through the glass.[15] A rule of thumb for most commercially available glazings is that Tvis is equal to about 67% of the shading coefficient. However, some U.S. manufacturers are marketing "high-performance" glass with low-emittance coatings that significantly increase the visible portion of transmitted light energy. Therefore, some cases were tested whose visible transmittance is 125% of the shading coefficient. The issue of the optimal level of daylighting over a range of assumptions is discussed in the Results section.

RESULTS

The results of the various analyses have been subdivided into two main sections. In the first section, the energy and economic results are presented for the single-measure and combinations-of-measures cost effectiveness analyses. In addition to indicating which measures are most cost effective, these results are useful for identifying the relative levels of energy efficiency of the Worst Case building, the Base Case building, the Proposed Standard Case building, and the Good Practice building. The results of the two parametric analyses (i.e., daylighting and OTTV) are discussed in the second half of this section.

---

[15] This definition of EA is for daylighting purposes. One can also define a *different* EA, for thermal purposes, as $EA = WWR * SC$.

COST-EFFECTIVENESS: ENERGY AND ECONOMIC RESULTS

The energy results of the cost effectiveness analyses are summarized in Figure 11. Two different estimates of the Worst Case building were made. The Worst Case with a CV A/C system has an energy use of 240 kWh/m^2, whereas the Worst Case with a VAV A/C system has an energy use of 216 kWh/m^2, for an energy reduction of 9%. In terms of cost effectiveness, switching from the CV system to the VAV is expensive because the VAV system costs about 25% more than the CV system, which results in a simple payback period of four years. However, the VAV system offers greater comfort and control capabilities than the CV system, so the VAV system is currently preferred in new office building construction in Malaysia and elsewhere.

The Base Case building, with an energy use of 166 kWh/m^2, is 31% more efficient than the Worst Case building with CV. The payback period is about one year, and most of this cost is the transition from CV to VAV. The Base Case building (with VAV), at 166 kWh/m^2, is 23% more efficient than the Worst Case building with VAV and costs less to construct than the Worst Case building. For the Base Case and Proposed Standard Cases, the figure also shows the impact on energy use of varying the window to wall ratio (WWR) from 0.2 to 0.6.

The Proposed Standard Case building at 136 kWh/m^2 is 18% more energy efficient than the Base Case building. Increased construction costs result in a payback of 1.6 years. The Proposed Standard Case building is 38% more efficient than the Worst Case building with VAV and 43% more efficient than the Worst Case building with CV. These energy reductions to the Proposed Standard Case from the Base Case and the two Worst Cases give an indication of the levels of energy savings and cost effectiveness that could be expected by implementation of the provisions of the proposed building energy standard.

The proposed standard is intended to set minimum energy efficiencies. It is possible to design buildings that are considerably more energy efficient than the levels resulting from the proposed standard. Two additional analyses were done to indicate some of this additional energy conservation potential beyond that of the proposed standard. These are shown in Figure 11 as well. A Good Practice Case building was analyzed with five energy conservation strategies added to the Proposed Standard Case building. This resulted in an energy use of 98 kWh/m^2/year, and a 28% percent energy reduction from the Proposed Standard Case building. Daylighting was then added as a final conservation strategy. This resulted in an energy use of 82 kWh/m^2/year, and a 40% energy reduction from the Proposed Standard Case building.

For a comparison of extremes in the analyses conducted, the Good Practice Case building with daylighting is much more efficient than the Worst Case building. The Good Practice building uses only 38% of the energy of the Worst Case building with VAV (a total reduction of 62%) and only 34% of the energy of the Worst Case building with CV (a reduction of 66%).

Table 5 shows energy and cost summaries for each of the cases discussed above. The table also shows the energy and cost impacts of each of the single-measure changes that were made to each of the building cases. These individual impacts, and their combined effects, are discussed in more detail in the following subsections.

Cost Effectiveness - Worst Case to Base Case

There is a 31% reduction in energy use from the Worst Case building with the CV system to the Base Case building, as shown in Figure 12. The figure also shows the impact of the change to VAV from CV, and the impacts of the two additional measures applied *individually* to the Worst Case with VAV. Their combined impacts produce the energy level of the Base Case building with a WWR of 0.4.

(1) The air conditioning system type was changed from CV to VAV. Since the VAV system is about 25% more expensive than the CV system, a construction cost increase of $M 18.23 per square meter results. The payback period resulting from the energy savings was four years.

(2) Reducing the lighting power from the 27 W/m^2 level of the Worst Case building to the 21 W/m^2 level of the Base Case building results in a construction cost *savings* of $M 3.68 per square meter of floor area as well as an annual energy cost savings of $M 9.59 per square meter of floor area.

(3) The A/C air distribution system static pressure was decreased from 12.7 to 7.6 cm water, which represents a change from a high-velocity air distribution system to a low-velocity system. No change in construction cost was estimated for this measure.

The total increase in construction costs to improve the energy consumption from the Worst Case level of design to the Base Case level is $M 14.55 per square meter of floor area. The majority of this cost is to upgrade the A/C equipment. The payback period for the transition from Worst Case with CV to Base Case is about one year.

Cost Effectiveness - Base Case to Proposed Standard Case

The Proposed Standard Case building is 18% more energy efficient than the Base Case building. This variation is shown in Figure 13. It is 43% more efficient than the Worst Case building. Four building characteristics were changed to improve the building from the Base Case level of energy performance to the level of the standard:

(1) The installed lighting power was decreased from 21.5 W/m^2 to 17 W/m^2. This change required a slight increase in construction costs of $M 0.33/square meter of floor area. The reduction in lighting power resulted in annual energy cost savings of $M 3.17/square meter. Thus, the payback period for this construction measure is 0.1 years (slightly more than one month).

(2) The cooling set point temperature was increased from 24 °C to 25 °C. This is a no-cost measure that results in annual energy savings of $M 1.87 per square meter of building floor area.

(3) The centrifugal chiller EIR was reduced from the value 0.244 (COP = 4.1) to the EIR value of 0.222 (COP = 4.5). This measure involved an estimated 0.5% increase in construction costs ($M 2.20) per square meter of building floor area. The measure produced an annual energy cost saving of $M 0.94 per square meter. The payback period for this measure is 2.3 years.

(4) Solar energy gains through the fenestration were reduced by changing the glass shading coefficient. The Base Case value of SC = 0.69 was reduced to the value of 0.53. This resulted in an estimated construction cost increase of $M 6.94 per square meter of floor area. The resulting payback period for this conservation measure is 4.9 years.

The total increase in construction costs to upgrade from the Base Case to the Proposed Standard Case is $M 9.46 per square meter of floor area. The payback period is about 1.6 years.

The total increase in construction costs to upgrade from the Worst Case building to the level of the proposed standard is estimated to be $M 24.01 per square meter of floor area. The payback period for this upgrade is about 2.5 years.

Cost Effectiveness - Proposed Standard to Good Practice Building

Several measures (depicted in Figure 14) are used to attain the 28% energy savings from upgrading the Proposed Standard building to the Good Practice building. These are:

(1) The installed lighting power is reduced from 17 W/m^2 to 13 W/m^2. This is accomplished by changing from three-tube to two-tube lighting fixtures, with a slight increase in number of fixtures. Also, low-loss ballasts are used. This conservation measure reduces both

construction cost (\$M 0.96 M/m^2) and energy cost (\$M 2.30 M/m^2).

(2) The efficiency of the chiller is increased from 0.222 (COP = 4.5) to 0.185 (COP = 5.4). This measure has a payback period of 0.3 years, or slightly under four months.

(3) Occupancy sensors are used to reduce the amount of time that lighting systems are turned on.

(4) Variable speed fan control is used instead of inlet vane control.

(5) External shading devices are used to reduce solar gains. Overhangs are used that have a depth equal to the height of the windows.

The cost effectiveness of the last three measures above has not been assessed because it is difficult to determine the amount of energy savings attributable to each of them. The two measures that have been assessed have an overall payback period of less than four months.

RESULTS OF SPECIAL ANALYSES

OTTV Analysis Results

This section reports the results of the effort to develop OTTV equations for walls and roofs for Malaysia.

Determining the Final Form of the Wall OTTV Equation. Using chiller load estimates from 33 DOE-2.1C simulations, a regression analysis was used to evaluate:

- the proper format of the OTTV equation; and
- the unknown terms in the OTTV equation (ΔT, ΔTeq).

In all, six alternate forms of the OTTV equation were evaluated. These are shown in Table 6. For each configuration, selected regression statistics are compiled, such as the coefficients, their significance (Student's t-score), and an estimate of the goodness of the straight-line fit of the data to the equation (R^2).

The first form of the equation shown in Table 6 (with all three terms) provides the best fit to the data. Almost all (99%) of the variation in the chiller loads is accounted for by the functional relationships of the independent variables shown. In this equation, the solar absorptance is treated as a multiplicative constant within the wall conduction term.

The Student's t-score for each of the three terms indicates that all three are significant. The solar radiation term is by far the most significant term in the equation with a t-score of 47 while the window conduction term is barely significant at 2.6.

The use of all three terms more closely matches actual chiller loads than using the one- or two-term formulations (i.e., Form #s 2 and 3, Table 6). With Form #1, and using the solar factor value determined above (SF = 194 W/m^2), the calculation of the temperature differences to use with the wall and window conduction terms can proceed. From the coefficients in this OTTV formulation, $\Delta Teq = 20.3\,^{\circ}C$ and $\Delta T = 1.5\,^{\circ}C$.

Simplifying the OTTV Equation. In the interest of developing an equation that is both accurate and simple to use, the possibility of ignoring one or more terms in the OTTV equation was examined. The reduction in R^2 in going from a three- to a two-term equation is small (0.990 to 0.987). However, the R^2 drops significantly in the case of the one-term formulation (0.933).

The discrepancy (in percentage terms) between predicted and observed chiller loads for the OTTV equation with one, two, and three terms is shown in Table 7. This is also depicted graphically in Figures 15 through 17, where terms are successively removed. Points in the figures in perfect agreement fall directly on the diagonal line. The scatter increases slightly going from three to two terms, but is more pronounced in the one-term formulation. Thus, ignoring the heat gain contribution from window conduction in the OTTV equation results in little loss of accuracy. Eliminating this term reduces the calculation complexity by almost one third.

Proposed Wall OTTV Equation and Criteria. An improved and simplified version of the OTTV approach for walls is proposed for the Malaysian Standard. The proposed wall OTTV equation for Malaysia is shown below:

$$OTTV = 19.1\,\alpha\,(1-WWR)\,U_w + 194\,(WWR)\,SC \qquad (3)$$

It requires the input of four variables:

- Window-to-wall ratio (WWR);
- Shading coefficient of the glazing (SC);
- U-value for the opaque wall (U_w) ($W/m^2\text{-}^{\circ}C$); and
- Solar absorptance of the exterior wall (α).

Note that the input of solar absorptance is a new, not required in OTTV equations used by ASHRAE or Singapore. Also, an input for the U-value for glazed areas is not required in the Malaysian equation because the analysis indicates that conductance (as distinct from radiative) gains through windows do not contribute substantially to changes in energy use for the climate conditions.

A good way to see the impacts of these changes is to compare the results obtained from the new proposed Malaysian wall OTTV equation with the results obtained by the ASHRAE and Singapore equations for a set of typical building designs. Tables 8 and 9 show such a comparison for the Base Case building and Proposed Standard Case building used in the analyses in this study.

As the results show, one must be careful when attempting to compare directly OTTV numbers generated with the Malaysian equation against those generated by the earlier ASHRAE or Singapore formats. Note that the Malaysian equation can reflect the important contribution that opaque wall absorptivity (e.g., color) can have, whereas the ASHRAE or Singapore formulations cannot reflect this design choice. On the other hand, the Malaysian equation does not account for changes in the wall thermal mass. However, the DOE-2.1C analyses suggest that the ASHRAE and Singapore equations overestimate the benefits relative to Malaysian climate conditions.

The wall OTTV analysis has demonstrated that a relatively simple envelope standard can accurately capture major impacts of envelope design choices on cooling loads.

Proposed Roof Approach and Criteria. The proposed roof criteria for Malaysia are different from the ASHRAE and Singapore criteria in two main ways:

- Simpler: If there is no fenestration in the roof, no roof OTTV calculation is required.
- Additional Factors: Because solar gain is so important for roofs as well as walls in the Malaysian climate, credits are provided for fully shaded roofs, and for roofs with reflective coatings.

Thus, the proposed envelope criteria for roofs in Malaysia share the same attributes as the criteria for walls. The procedure has been simplified, yet additional design factors have been added to reflect the important energy impacts of shading and the absorptance (and color) of opaque roof surfaces in Malaysian climate conditions.

If no fenestration is used in the roof structure, the proposed roof criteria simply require a certain level of insulation, depending upon roof color. Several color and insulation options are provided that meet the criteria. At this point credits are provided for fully shaded roofs or roofs that contain reflective surfaces reasonably impervious to moisture degradation.

A roof OTTV calculation is required only if a designer includes atria or skylights in the building design. This calculation permits tradeoffs similar to the wall tradeoffs. The roof OTTV equation to be used with skylights or atria retains the original Singapore formulation. It is more complex than the wall equation because more factors are important to roof thermal impact.

Daylighting Results

The parametric DOE-2 simulation results of daylighting using the Malaysian Proposed Standard Case building are shown in Table 10 and Figure 18. Table 10 shows the savings resulting from the introduction of daylighting rather than the exclusive use of artificial lighting. These savings are in cooling and lighting, total and peak power, and sizing of the chiller and fans. A subset of the runs contained in the table are plotted as a function of effective aperture (EA) in Figure 18.

Daylighting produces lighting energy savings that range from 0% to as high as 59%. However, the larger lighting savings are achieved at the expense of substantial increases in the cooling load. Total energy savings range from 5 to 29% for the various values of the effective aperture and control technologies, but are typically about 20%. Low total savings result when the building has a large window area and a high shading coefficient. None of the daylighting parametrics produced increases in energy use (negative savings).

Comparison of Lighting Control Strategies

Three types of artificial lighting controls were analyzed: continuous dimming, step control, and on/off. Except for very low levels of effective aperture, the step controls generally produce more energy savings than the continuous dimming controls. Continuous dimming controls produce smaller energy savings than stepped and on/off controls at higher levels of effective aperture because of the 30% minimum power draw modeled for these controllers. This minimum power draw is typical of control devices available in the U.S. today.[16] To establish the sensitivity of this factor, two additional cases were run, at low and high effective aperture levels with a hypothetical 0% minimum power draw. This assumption improves the performance of daylighting with continuous dimming controls by about 9%. At high levels of effective aperture, the overall energy requirements for the on/off, stepped, and continuous (with 0% minimum power draw) control strategies were all within 1% of one another because more than the required amount of light is provided by daylighting when the windows have large effective aperture values.

The optimum effective aperture in Malaysia for the control technologies analyzed is about EA = 0.10. With available glazing technologies, various combinations of WWR and Tvis can accomplish this level of effective aperture. For instance, assuming that Tvis is 67% of shading coefficient, then an all-glass facade

---

[16] With this control system, the lights stay on at 30% power draw even though daylight may be available to satisfy 100% of the task lighting needs. This is due to aesthetic considerations. If the lights were completely off for a period of time, then, when artificial lighting was again needed, the fluorescent bulbs would flash on to 100% illumination, then back to 30%.

would need a shading coefficient of 0.15 (reflective glazing) or extensive overhangs, fins, or sunscreens. Or at the other extreme, clear glazing with a shading coefficient of 1 would require 10% glass area. Note that ratios of Tvis and shading coefficient other than 0.67 are possible and will alter the optimum reached here.

However, energy savings are not the only consideration. The continuous dimming controls produce a higher quality visual environment than either the step or on/off controls. Also, cost effectiveness is important. Compared to the Proposed Standard Case building, daylighting with step controls produces a 23% annual energy savings with a payback of four years. Daylighting with continuous dimming controls produced a 17% energy savings with a payback of 5.6 years. If "high-performance" glazings are used to reduce the solar heat gain but allow more visible light into the building, then the energy savings from daylighting are even greater.

Daylighting Benefits Using the "Good Practice" Building

In the Good Practice building it is very difficult to save energy by daylighting because the building's installed lighting power of 13 W/m^2 is a small installed lighting power base from which to obtain benefits. Only the continuous dimming controls were analyzed for the Good Practice building. With a lower initial lighting level, the payback period is longer. Continuous dimming controls produce a 16% annual energy savings (from a smaller base of installed lighting power than the Proposed Standard building) with a payback of eight years.

Impact of Overhangs with Daylighting

The use of external shading devices is common in Malaysian buildings. The effect of window overhangs on the performance of daylighting systems was examined. Two sizes of overhangs were modeled: 25% (1.9 m) and 100% (7.5 m) of the window height.

At low levels of effective aperture, overhangs are of negligible benefit. In fact, the building with larger overhangs uses 3-4% more energy than a building with none. Above EA = 0.10, overhangs show an increasing benefit up to 5% at the maximum effective aperture of 0.30. The larger overhang produces greater savings than the smaller one, but only by a few percentage points. Though producing only modest energy savings, overhangs, with their relatively flat performance curves (see Figure 18), allow the designer more flexibility in fenestration options.

Ventilating and A/C (VAC) Equipment Sizing Issues Related to Daylighting

In the above analyses, daylighting energy savings were credited in the sizing of the air-distribution system and the chiller. In these simulations, daylighting always resulted in smaller equipment sizes than otherwise (see Table 10). Some designers, though, are reluctant to reduce air-system and chiller sizes based on daylighting savings, since daylighting systems can potentially be deactivated simply by turning on the lights. To investigate the effect of VAC system sizing on the daylighting energy savings, the daylighting benefit was calculated when the VAC system size was fixed to meet the full artificial lighting load under all conditions. The results of this investigation show that the energy consumption change is negligible (see Figure 18). There is, however, a penalty in the form of higher initial investment costs for the larger capacity equipment. Note that the payback periods cited above for daylighting systems are conservative in that *no* economic credit was taken for down-sizing of the VAC equipment.

Another equipment sizing issue is raised by the window management strategy embedded in the daylighting simulations. Windows are assumed to be equipped with Venetian blinds which are pulled whenever the incident solar radiation exceeds 126 W/m^2 or when the glare index goes beyond 22. Then, each hour following a reduction of the triggering environmental phenomenon below the threshold, there is a probability of 0.7 that the blinds will be re-opened. This strategy is intended to approximate human behavior. When this strategy was deactivated (i.e., the blinds were left open), it resulted in a 7% increase in the required fan capacity.

SUMMARY

IMPLICATIONS FOR POLICY

The proposed energy standard is for new commercial building construction. In 1985, electricity use in Malaysian commercial buildings was approximately 4230 GWh. Commercial building energy use has increased by an average of approximately 8%/yr between 1981 and 1985. Assuming that this increase is due solely to new building construction, we can project future energy savings from implementation of the proposed standards.

If the standards are fully implemented in 1988, and if commercial sector floor space continues to increase 8%/yr, Table 1 shows the expected annual energy savings for the commercial sector and the energy cost savings to commercial customers. Commercial sector energy use in 1993 will be reduced by 424 GWh (5.4%) compared to projected energy use without energy standards. The cumulative energy cost savings to the consumer are $M 85 million over a six-year period. Additional savings result from avoided new power plant construction. In 1993, the projected reduction in power demand is 141 MW.[17] At a cost of $M 2,000/kW, the avoided cost of construction is $M 280 million.

The magnitude of the savings possible from daylighting presents a challenge for Malaysian policy. Currently, daylighting is not being implemented in new commercial buildings, nor is it being promoted. Eliminating import barriers (where they exist) for lighting controls and low-emittance coated glazings would help in countering the natural conservatism towards new technologies. The introduction of daylighting into Malaysian buildings can also be facilitated greatly by one or more daylighting demonstration projects.

It is highly likely that the building energy standards proposal for Malaysia will be used as a resource for energy standards in other ASEAN countries.

FUTURE TECHNICAL WORK NEEDED

The analysis and results reported in this paper have their limitations, many of which can be overcome by further technical work. The following list of needed technical work, in different subject areas, is by no means exhaustive but is simply intended to highlight further areas of work that would be fruitful for attaining additional energy conservation in Malaysia.

Data on Malaysian Building Energy Use

As indicated in this paper, data on Malaysian buildings are limited. Few buildings have been analyzed in detail. The accumulation of data about Malaysian building characteristics and their energy use will be of great assistance to Malaysian policymakers. This could be accomplished by the collection of *detailed* data for a statistically meaningful sample of buildings in the key building types, including building physical characteristics, operations data, and energy use data.

Climate Data

Insufficient data exist on Malaysian solar and daylight availability. Several projects would be helpful:

- Establish a solar data monitoring station in Kuala Lumpur and collect *at least* one year's solar data.
- Examine existing solar data for Penang. Correct, if in error; or collect additional data.

---

[17] Two assumptions lead to this result: 1) commercial buildings operate 3,000 hours per year with a flat daily (and seasonal) demand curve, and 2) the power system peak occurs at the time of building operation.

- Establish a daylighting data monitoring station in Kuala Lumpur and collect *at least* one year's data. Coordinate these data with similar data being collected in Singapore.

The solar data upon which all computations were based are for one year (instead of several) in nearby Singapore (instead of Kuala Lumpur). Available information suggests that year to year fluctuations in solar radiation are small in this region. However, actual monitored and audited data are necessary to confirm DOE-2 predictions.

Potential for Additional Research on Envelope Criteria

This study has resulted in some refinements and improvements of envelope energy criteria for general ASEAN climate conditions. However, a number of additional analyses may lead to further future refinements and improvements. These could include:

- Complete parametric analyses for roofs: This could be especially useful for roofs containing skylights, atria, and combinations of advanced technologies.
- Combined wall and roof expression: It may prove desirable to explore the benefits of developing a combined wall/roof OTTV expression, especially for buildings with large atria.
- Consideration of internal load on OTTV criteria: Proper envelope design includes consideration of thermal balances within a building. Internal loads, especially the heat from lights, make an important contribution to this balance. This factor is included in the latest ASHRAE 90.1P envelope formulations. It has not been included in the current version of the Malaysian OTTV equation for simplicity's sake. However, it might be considered for inclusion in future versions to improve accuracy.
- Adding a daylighting term directly into OTTV equation: Because daylighting is such a new technology in Malaysia, daylighting credits are provided independent of the OTTV calculation, as a change in OTTV criteria. If daylighting becomes more prevalent, it may be desirable to include a daylighting term within the OTTV equation. This is the case in the current proposed ASHRAE wall formulation in 90.1P.

All of the analyses suggested above could lead to refinements in calculations and improved accuracy that might be appropriate for some future version of envelope energy criteria for Malaysian buildings.

Potential for Additional Daylighting Research

Given the large benefits from daylighting projected by DOE-2.1C simulations, and the absence of daylighting use in Malaysia, this seems a fruitful area of work. The potential benefits are large, if the promise is realized. Several projects can be accomplished. However, foremost is the establishment of several demonstration projects, which could use different lighting control techniques, coupled with various envelope configurations. These demonstrations could assess the applicability of daylighting controls to Malaysian construction practices and building operating procedures.

Potentials for Additional HVAC Research

This paper has addressed only the most fundamental criteria for HVAC systems. Analysis is needed to determine not only which additional energy criteria would be appropriate for HVAC systems in Malaysia but also what the appropriate levels would be for such criteria.

Implications for the ASEAN Region

The implications of this study for the ASEAN region are several-fold. In particular, this study has identified factors that were not completely treated in the prior studies of OTTV standards for Singapore. First, it is likely that the accuracy of the OTTV standard would be enhanced by taking account of exterior wall color. Second, improved experimental design of the computer simulation parametric runs may result in altered values for the coefficients and their significance in the equation. Finally, due to the above considerations, the earlier recommendation to rely on a one-term OTTV equation may no longer be valid.

Future Revisions to the Standard

Several years' experience with this standard will provide a solid basis for two additional activities in the future: 1) a revision of the new building standard so that it will be more comprehensive and more energy conserving; and 2) the development of energy standards for existing buildings. For example, energy requirements for fans, pumps, electric motors, and water-heating are not contained in the current new building standard but could be considered for inclusion in the revision. The revision could also include tighter standards for lighting and air conditioning and additional incentives for daylighting.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Agency for International Development through the U.S. Department of Energy, under Contract No. DE-AC03-76SF0098. We also wish to acknowledge the editorial assistance of Karen H. Olson and Nan Wishner.

REFERENCES

1. Ministry of Energy (MOE), Telecommunications, and Posts, Malaysia, September, 1986, "National Energy Balances, Malaysia, 1978-1985", plus information supplied to the Analysis Team by MOE in September, 1986.
2. Dangroup International and J & A Associates, September 1985, "Energy Consumption in Buildings Study, Final Report".
3. Gas and Fuel Corporation of Victoria (G&FC), Energy Management Centre, August 1984, "Energy Conservation - Improved Techniques and Practices. Stage 2. Asian Region, Malaysia", Victoria, Australia.
4. A.D. Little, 1976, "Analysis of the Impacts of the ASHRAE 90-75".
5. AIA Research Corporation, 1980, "Analysis of ASHRAE 90-75R".
6. D. Crawley, and R. Briggs, 1986, "Energy Impacts of Proposed ASHRAE 90.1P", *ASHRAE Journal*, 1986.
7. The Development and Building Control Division (PWD), Singapore, 1979, "Singapore Standard CP 24, Code of Practice for Energy Conservation in Building Services".
8. The Development and Building Control Division, (PWD), Singapore, 1983, "Handbook on Energy Conservation in Buildings and Building Services".
9. Universiti Teknologi Malaysia (UTM), Unit Penyelidikan Dan Peeundingan, November, 1986, "Guidelines for Energy Conservation, Final Report".
10. ASHRAE Standing Standard Project Committee 90.1, 1986, Draft Standard 90.1P, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings," September 15, 1986 draft version.
11. I. Turiel, R. Curtis, and M. Levine, 1984, "Parametric Energy Analysis in Support of Singapore Energy Conservation Standards for Commercial Buildings", *Proceedings of the ASEAN Conference on Energy Conservation in Buildings*, May 29-31, 1984.
12. Building Energy Simulation Group (BESG), Lawrence Berkeley Laboratory, 1985, "Overview of the DOE-2 Building Energy Analysis Program", LBL-19735.
13. Los Alamos National Laboratory, (LANL), 1981, "DOE-2 Verification Project, Phase I, Interim Report", LA-8295-MS.
14. S.C. Diamond *et al.*, 1985, "User-Effect Validation Tests of the DOE-2 Building Energy Analysis Program", *ASHRAE Transactions 1985*, Vol. 91, Part Two.
15. B. Birdsall, 1985, "A Comparison of DOE-2.1C Prediction with Thermal Mass Test Cell Measurements", LBL-19881.

16. I. Turiel and Prof. K.R. Rao, 1986, memoranda on the Calculation of Window Thermal Transmission Value (WTTV) from DOE-2 Simulations.

Table 1.

Estimated Savings From
New Building Energy Standards in Malaysia

Year	Energy Use (GWh) No. Standards	Cumulative Energy Savings (GWh) From Standards	Cumulative Consumer Savings (Millions dollars)
1988	5,329	58	11.6
1989	5,755	120	24.0
1990	6,215	187	37.4
1991	6,712	260	52.0
1992	7,249	339	67.8
1993	7,829	424	84.8

Table 2.

Characteristics of the Malaysian Base Case Building

Building Type:	10-storey office building; 5200 m^2 conditioned floor area; 1000 m^2 unconditioned core.
Walls:	opaque wall U-value = 2.43 W/m^2-^oC; solar absorptivity = 0.45; mass = 250 kg/m^2; brick and lath construction.
Roof:	roof U-value = 0.60 W/m^2-^oC; solar absorptivity = 0.50; mass = 356 kg/m^2; built-up roofing.
Windows:	window to wall ratio = 0.4; shading coefficient = 0.69; glass U-value = 5.79 W/m^2; no window setback or external shading.
Lighting:	lighting power = 21 W/m^2; luminence = 500 lux.
Space Conditions:	outside ventilation air = 3.3 lit/sec/person; infiltration = 1.0 ach (when fans are off); cooling setpoint = 24 ^oC; night setback = 37 ^oC.

VAC Equipment:	VAV system;
	fan type = forward curved;
	fan air flow control = inlet vane;
	centrifugal chiller COP = 4.1;
	no economizer cycle.

Table 3.

Parameter Ranges for Wall OTTV Variables

Parameter	Units	Range	
Solar Absorptance	-	0.2	0.8
Window/Wall Ratio	-	0.1	0.66
U-Value Opaque Wall	$(W/m^2\text{-}^\circ C)$	0.42	2.18
Shading Coefficient	-	0.2	0.8
U-Value Glass	$(W/m^2\text{-}^\circ C)$	1.59	5.79

Table 4.

Solar Factor (W/m^2) Data for Penang, Malaysia

Orientation	Direct Vertical	Diffuse Vertical	Total Vertical
South	58	152.7	210.7
SE	114	152.7	267.7
E	139	152.7	291.7
NE	91	152.7	243.7
N	30	152.7	182.7
NW	30	152.7	182.6
W	48	152.7	200.7
SW	46	152.7	198.7

Table 5

Annual Energy and Peak Load Results for the Parametric Runs

		PEAK DEMAND			ANNUAL ENERGY CONSUMPTION				
		Fan Size (cfm)	Chiller Size (KW)	Total Peak (KW)	Cooling Energy (KWH /1000)	HVAC Aux. (KWH /1000)	Lights (KWH /1000)	Misc. Equip. (KWH /1000)	Total Energy (KWH /1000)
PARAMETRICS:	WORST CASE TO BASE CASE								
Worst Case	w/CV	84690	701.3	453.6	430.55	336.62	410.75	71.60	1249.52
Worst Case	w/VAV	84690	696.9	441.3	423.91	218.74	410.75	71.60	1125.00
VAV	w/static from 5.0 to 3.0 (inches)	84690	659.1	401.1	404.41	209.99	410.75	71.60	1096.75
VAV	w/ltg from 27 to 21 (w/m^2)	82370	640.9	369.2	387.79	204.22	328.58	71.60	992.19
Base Case	Combined	69400	562.1	332.6	348.03	115.69	328.58	71.60	863.90
PARAMETRICS:	BASE CASE TO STANDARD								
Base Case	ltg = 21 EIR = 0.244 SC = .69	69400	562.1	332.6	348.03	115.69	328.58	71.60	863.90
	w/EIR from 0.244 to 0.222	69400	562.1	321.1	323.01	115.69	328.58	71.60	838.87
	w/ltg from 21 to 17 (w/m^2)	67400	543.6	305.3	334.06	110.33	262.87	71.60	778.86
	w/SC from 0.69 to 0.53	67400	545.7	315.0	314.56	111.91	328.58	71.60	826.65
	w/DBT from 24 to 25 (°C)	69090	539.2	307.7	308.99	105.21	328.58	71.60	814.37
Standard Case	Combined	62180	491.8	270.7	277.56	93.11	262.87	71.60	705.15
PARAMETRICS:	WORST CASE TO STANDARD								
Worst Case	w/CV	84690	701.3	453.6	430.55	336.62	410.75	71.60	1249.52
Worst Case	w/VAV	84690	696.9	441.3	423.91	218.74	410.75	71.60	1125.00
VAV	w/static from 5.0 to 3.0 (inches)	84690	659.1	401.1	404.41	209.99	410.75	71.60	1096.75
VAV	w/ltg from 27 to 21 (W/m^2)	82370	640.9	369.2	387.79	204.22	328.58	71.60	992.19
Base Case	ltg = 21 EIR = 0.244 SC = .69	69400	562.1	332.6	348.03	115.69	328.58	71.60	863.90
	w/EIR from .244 to .22	69400	562.1	321.1	323.01	115.69	328.58	71.60	838.87
	w/ltg from 21 to 17 (W/m^2)	67400	543.6	305.3	334.06	110.33	262.87	71.60	778.86
	w/SC from .69 to .53	67400	545.7	315.0	314.56	111.91	328.58	71.60	826.65
	w/DBT from 24 to 25 (°C)	69090	539.2	307.7	308.99	105.21	328.58	71.60	814.37
Standard Case	Combined	62180	491.8	270.7	277.56	93.11	262.87	71.60	705.15
PARAMETRICS:	STANDARD TO GOOD PRACTICE								
Standard Case		62180	491.8	270.7	277.56	93.11	262.87	71.60	705.15
	w/ltg from 17 to 13 (W/m^2)	61000	479.5	251.4	268.13	90.16	213.57	71.60	643.46
	w/EIR from .222 to .185	62180	491.8	255.5	245.41	93.11	262.87	71.60	673.00
Good Practice		53270	421.7	212.4	209.56	56.61	171.84	71.60	509.61
PARAMETRICS:	GOOD PRACTICE BUILDING, PLUS DAYLIGHTING								
Good Practice		53270	421.7	212.4	209.56	56.61	171.84	71.60	509.61
	w/Daylighting	50750	396.2	186.1	197.89	52.00	105.26	71.60	426.75

Table 5 — Continued

Results of the Economic Analysis for the Parametric Runs

		ANNUAL ENERGY				ANNUAL PEAK						
		Total Energy (kWh /m^2)	Total Savings (kWh /m^2)	Energy Percent Savings	Energy Dollars Savings ($M) /$m^2$	Peak (kW)	Peak Savings (kW)	Peak Percent Savings	Peak Dollars Savings ($M/$m^2$)	Total Annual Savings ($M/$m^2$)	Change in Bldg Cost ($M/$m^2$)	Simple Payback Period (Yrs)
PARAMETRICS:	WORST CASE TO BASE CASE											
Worst Case	w/CV	240				453.6						
Worst Case	w/VAV	216	23.9	(9.98)	4.55	441.3	12.31	(2.71)	0.03	4.58	18.23	4.0
VAV	w/static from 5.0 to 3.0 (inches)	211	29.4	(12.24)	5.58	401.1	52.45	(11.56)	0.12	5.70	0.00	
VAV	w/ltg from 27 to 21 (W/m^2)	191	49.5	(20.61)	9.40	369.2	84.38	(18.60)	0.19	9.59	3.68	
Base Case	Combined	166	74.1	(30.89)	14.09	332.6	121.01	(26.68)	0.28	14.37	14.54	1.0
PARAMETRICS:	BASE CASE TO STANDARD											
Base Case	ltg = 21 EIR = 0.244 SC = .69	166				332.6						
	w/EIR from 0.244 to 0.222	161	4.8	(2.90)	0.91	321.1	11.42	(3.43)	0.03	0.94	2.20	2.3
	w/ltg from 21 to 17 (w/m^2)	150	16.3	(9.85)	3.11	305.3	27.25	(8.19)	0.06	3.17	0.33	
	w/SC from 0.69 to 0.53	159	7.2	(4.31)	1.36	315.0	17.58	(5.29)	0.04	1.40	6.94	4.9
	w/DBT from 24 to 25 (°C)	157	9.5	(5.74)	1.81	307.7	24.9	(7.49)	0.06	1.87	0.00	
Standard Case	Combined	136	30.5	(18.39)	5.80	270.7	61.82	(18.59)	0.14	5.94	9.46	1.6
PARAMETRICS:	WORST CASE TO STANDARD											
Worst Case	w/CV	240				453.6						
Worst Case	w/VAV	216	23.9	(9.98)	4.55	441.3	12.31	(2.71)	0.03	4.58	18.23	4.0
VAV	w/static from 5.0 to 3.0 (inches)	211	29.4	(12.24)	5.58	401.1	52.45	(11.56)	0.12	5.70	0.00	
VAV	w/ltg from 27 to 21 (W/m^2)	191	49.5	(20.61)	9.40	369.2	84.38	(18.60)	0.19	9.59	-3.68	
Base Case	ltg = 21 EIR = 0.244 SC = .69	166	74.1	(30.89)	14.09	332.6	121.01	(26.68)	0.28	14.37	0.00	
	w/EIR from .244 to .22	161	4.8	(2.00)	0.91	321.1	11.42	(2.52)	0.03	0.94	2.20	2.3
	w/ltg from 21 to 17	150	16.3	(6.81)	3.11	305.3	27.25	(6.01)	0.06	3.17	0.33	
	w/SC from .69 to .53	159	7.2	(2.98)	1.36	315.0	17.58	(3.88)	0.04	1.40	6.94	4.9
	w/DBT from 24 to 25 (°C)	157	9.5	(3.97)	1.81	307.7	24.9	(5.49)	0.06	1.87	0.00	
Standard Case	Combined	136	30.5	(12.72)	19.89	270.7	61.82	(13.63)	0.42	20.31	24.01	1.2
PARAMETRICS:	STANDARD TO GOOD PRACTICE											
Standard Case	136					270.7						
	w/ltg from 17 to 13 (W/m^2)	124	11.9	(8.72)	2.25	251.4	19.34	(7.14)	0.04	2.30	-0.96	----
	w/EIR from .222 to .185	129	6.2	(4.54)	1.17	255.5	15.24	(5.63)	0.04	1.21	0.38	0.3
Good Practice	98					212.4						
PARAMETRICS:	GOOD PRACTICE BUILDING, PLUS DAYLIGHTING											
Good Practice		98				212.4						
	w/Daylighting	82	15.9	(16.25)	3.03	186.1	26.37	(12.42)	0.00	3.03	1.58	0.5

Table 6.

FORMS OF THE OTTV EQUATION

	Independent Variables						
	X_{11} α (1-WWR)U_w (ΔT_{eq})	X_{12} (1-WWR)U_w (ΔT_{eq})	X_{13} $\sqrt{\alpha}$ (1-WWR)U_w (ΔT_{eq})	X_{14} α^2 (1-WWR)U_w (ΔT_{eq})	X_2 (WWR)U_f (ΔT)	X_8 (WWR)SC (SF)	Constant Term
Form #1:							
Coefficient	11.999				0.884	114.715	83.829
T-score	13.194				2.613	47.241	104.89
Physical Value	20.292				1.495	194	
$R^2 = 0.990$							
Form #2:							
Coefficient	11.598					117.681	84.667
T-score	11.839					50.162	105.836
Physical Value	19.120					194	
$R^2 = 0.987$							
Form #3:							
Coefficient						110.225	90.696
T-score						20.818	62.736
Physical Value						194	
$R^2 = 0.933$							
Form #4:							
Coefficient		5.424			0.811	114.239	84.479
T-score		3.041			1.108	21.767	41.592
Physical Value		9.211			1.377	194	
$R^2 = 0.952$							
Form #5:							
Coefficient			10.366		1.003	115.506	82.748
T-score			9.352		2.229	35.792	70.965
Physical Value			17.410		1.685	194	
$R^2 = 0.982$							
Form #6:							
Coefficient				13.974	0.728	113.677	85.254
T-score				12.995	2.137	46.416	114.495
Physical Value				23.848	1.242	194	
$R^2 = 0.989$							

Note: In all cases 33 observations were fitted.

Table 7.

Comparison of Predicted vs. Actual Chiller Loads

Computer Run	OTTV w/ 3 Terms (W/m^2)	% Diff. from Actual	OTTV w/ 2 Terms (W/m^2)	% Diff. from Actual	OTTV w/ 1 Term (W/m^2)	% Diff. from Actual	Actual (W/m^2)
1	91.35	0.7	91.58	0.9	92.90	2.4	90.74
2	98.24	0.1	98.64	0.3	99.51	1.2	98.34
3	104.13	0.2	101.92	1.9	105.25	1.2	103.95
4	149.56	1.7	148.52	1.0	148.89	1.3	147.04
5	105.50	0.3	105.26	0.6	92.90	12.2	105.86
6	112.39	1.2	112.32	1.3	99.51	12.5	113.77
7	109.48	0.0	107.09	2.1	105.25	3.8	109.44
8	154.91	1.5	153.69	0.7	148.89	2.4	152.60
9	87.54	0.3	87.89	0.7	92.90	6.4	87.32
10	94.42	2.1	94.95	1.6	99.51	3.1	96.49
11	102.69	0.7	100.53	2.8	105.25	1.7	103.45
12	148.12	1.5	147.13	2.2	148.89	1.0	150.41
13	90.24	0.8	90.51	0.5	92.90	2.2	90.93
14	97.13	2.9	97.57	2.4	99.51	0.5	100.01
15	103.71	0.8	101.52	2.9	105.25	0.7	104.54
16	149.14	1.4	148.12	2.1	148.89	1.6	151.29
17	90.98	1.3	91.58	1.9	92.90	3.4	89.85
18	97.86	0.7	98.64	1.5	99.51	2.4	97.21
19	101.68	4.5	101.92	4.7	105.25	8.1	97.32
20	147.11	2.3	148.52	3.3	148.89	3.5	143.81
21	105.13	0.1	105.26	0.2	92.90	11.5	105.00
22	112.01	0.8	112.32	0.5	99.51	11.9	112.93
23	107.02	3.3	107.09	3.4	105.25	1.6	103.57
24	152.45	1.6	153.69	2.4	148.89	0.8	150.05
25	87.17	1.2	87.89	2.1	92.90	7.9	86.12
26	94.05	1.5	94.95	0.6	99.51	4.2	95.48
27	100.24	3.5	100.53	3.8	105.25	8.7	96.86
28	145.66	2.0	147.13	1.1	148.89	0.1	148.70
29	89.87	0.0	90.51	0.7	92.90	3.3	89.89
30	96.75	2.4	97.57	1.6	99.51	0.4	99.17
31	101.26	3.2	101.52	3.5	105.25	7.3	98.10
32	146.69	2.1	148.12	1.2	148.89	0.7	149.90
33	109.57	3.8	109.55	3.8	111.64	2.0	113.92
AVG. DIFF.		1.5		1.8		4.0	
STD. DEV. DIFF.		1.2		1.8		3.8	

Table 8

Impact of Changing Wall Absorptance

Wall Absorp.	Glazing Type	Base Case Chiller Load (MBtu)	Malaysian OTTV Equation		Singapore OTTV Equation		ASHRAE OTTV Equation	
			Base Case	Std. Case	Base Case	Std. Case	Base Case	Std. Case
0.20	Single	3999	59	47	62	54	73	65
0.45	Single	4139	66	54	62	54	73	65
0.80	Single	4338	76	63	62	54	73	65

Table 9

Impact of Changing Glazing Conductance

Wall Absorp.	Glazing Type	Base Case Chiller Load (MBtu)	Malaysian OTTV Equation		Singapore OTTV Equation		ASHRAE OTTV Equation	
			Base Case	Std. Case	Base Case	Std. Case	Base Case	Std. Case
0.45	Single	4417	66	54	62	54	73	65
0.45	Double	4331	66	54	56	48	66	51

NOTE 1:

The analyses of absorptance changes were made using chiller loads from the Base Case building as reported in this report. The analyses of glazing conductance were made using chiller loads from an earlier version of the Base Case building. Thus the two sets of chiller loads are not directly comparable, but serve to demonstrate the relative magnitude of impacts of the changes under study.

NOTE 2:

In the parametric runs for the OTTV analysis, the chiller loads were calculated for various combinations of parameters. The change from single to double glazing affected the chiller load by 2 percent. However, changing the absorptance of the exterior opaque walls from an absorptance of 0.2 to 0.8 affected the chiller load by 9 percent. The largest effect occurred when the walls were uninsulated and the windows were small.

Table 10.

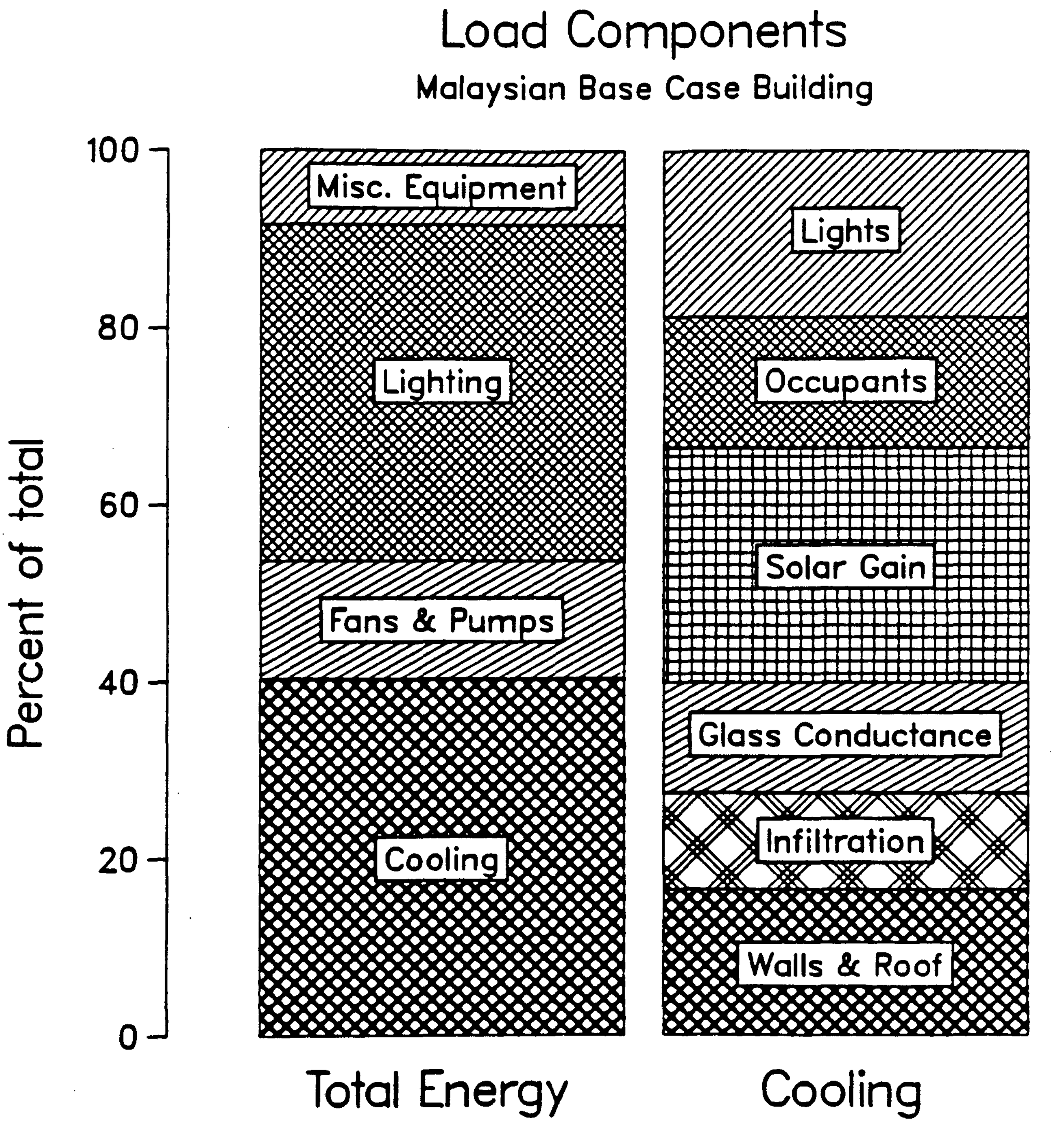
Savings from Daylighting in Malaysia

Run	Sizing		Energy				
	Fans (m^3/sec)	Chiller (kW)	Cooling (kWh/m^2)	Fans & Pumps (kWh/m^2)	Lights (kWh/m^2)	Total (kWh/m^2)	Peak (kW)
Proposed Standard Case	29.3	491.7	53.4	17.9	50.6	135.6	270.7
Stepped Control (0-50-100%):							
WWR=.1 SC=.5	28%	20%	17%	24%	4%	11%	13%
WWR=.2 SC=.5	24%	18%	16%	22%	27%	19%	14%
WWR=.3 SC=.5	19%	14%	14%	18%	43%	24%	13%
WWR=.4 SC=.625	4%	5%	6%	6%	53%	23%	12%
WWR=.56 SC=.625	-12%	-5%	-2%	-8%	55%	19%	8%
WWR=.56 SC=.8	-26%	-16%	-12%	-21%	57%	14%	5%
Stepped Control w/ Tvis=1.25*SC:							
WWR=.1 SC=.5	31%	23%	20%	28%	22%	20%	17%
WWR=.2 SC=.5	27%	21%	20%	26%	47%	29%	16%
WWR=.3 SC=.5	21%	16%	16%	20%	54%	29%	17%
WWR=.4 SC=.625	5%	6%	7%	6%	57%	25%	16%
WWR=.56 SC=.625	-12%	-4%	-2%	-8%	58%	20%	11%
WWR=.56 SC=.8	-25%	-16%	-12%	-21%	59%	15%	6%
Continuous Dimming:							
WWR=.1 SC=.5	30%	22%	20%	26%	17%	18%	19%
WWR=.2 SC=.5	25%	19%	17%	23%	32%	22%	19%
WWR=.3 SC=.5	17%	14%	13%	17%	37%	21%	19%
WWR=.4 SC=.625	1%	3%	3%	3%	40%	17%	15%
WWR=.56 SC=.625	-15%	-7%	-5%	-11%	41%	12%	10%
WWR=.56 SC=.8	-28%	-18%	-15%	-24%	41%	6%	3%
Continuous w/ Min. Power=0:							
WWR=.2 SC.5	27%	21%	20%	25%	46%	28%	21%
WWR=.56 SC.8	-26%	-16%	-12%	-21%	59%	14%	9%
Continuous w/ Fixed Sizing:							
WWR=.1 SC=.5	27%	19%	19%	25%	17%	17%	18%
WWR=.56 SC=.8	-34%	-26%	-16%	-27%	41%	5%	3%

Table 10. — continued

Savings from Daylighting in Malaysia

Run	Sizing		Energy				
	Fans (m^3/sec)	Chiller (kW)	Cooling (kWh/m^2)	Fans & Pumps (kWh/m^2)	Lights (kWh/m^2)	Total (kWh/m^2)	Peak (kW)
Continuous w/ Overhang=1.9 m:							
WWR=.1 SC=.5	32%	24%	21%	28%	15%	17%	19%
WWR=.2 SC=.5	28%	21%	19%	25%	30%	22%	20%
WWR=.3 SC=.5	22%	17%	15%	21%	36%	22%	20%
WWR=.4 SC=.6	8%	8%	7%	9%	39%	18%	16%
WWR=.56 SC=.6	-8%	-2%	-1%	-4%	40%	14%	13%
WWR=.56 SC=.8	-23%	-14%	-11%	-18%	41%	9%	6%
Continuous w/ Overhang=7.5 m:							
WWR=.1 SC=.5	32%	25%	21%	29%	9%	15%	19%
WWR=.2 SC=.5	31%	22%	19%	26%	19%	18%	18%
WWR=.3 SC=.5	26%	20%	17%	23%	28%	20%	18%
WWR=.4 SC=.6	13%	12%	10%	14%	36%	19%	17%
WWR=.56 SC=.6	-3%	1%	3%	1%	38%	16%	14%
WWR=.56 SC=.8	-17%	-12%	-6%	-11%	40%	11%	8%
Continuous w/ Tvis=1.25*SC:							
WWR=.1 SC=.5	32%	24%	22%	29%	30%	23%	21%
WWR=.2 SC=.5	26%	20%	18%	24%	38%	25%	21%
WWR=.3 SC=.5	18%	14%	14%	17%	40%	23%	21%
WWR=.4 SC=.625	2%	3%	4%	3%	41%	17%	17%
WWR=.56 SC=.625	-14%	-7%	-5%	-10%	42%	12%	11%
WWR=.56 SC=.8	-27%	-18%	-15%	-23%	42%	7%	3%
On/Off Control:							
WWR=.1 SC=.5	27%	19%	16%	23%	0%	9%	12%
WWR=.2 SC=.5	21%	15%	13%	18%	12%	12%	9%
WWR=.3 SC=.5	17%	12%	13%	16%	34%	20%	12%
WWR=.4 SC=.625	4%	5%	5%	5%	49%	21%	9%
WWR=.56 SC=.625	-12%	-5%	-3%	-8%	53%	18%	7%
WWR=.56 SC=.8	-26%	-16%	-12%	-21%	55%	13%	-1%
AVERAGE SAVINGS:	7%	6%	7%	7%	37%	18%	13%



XCG 873-6856

Figure 1. Total energy and cooling loads breakdown for the Malaysian Base Case building. Note that the cooling load components do *not* include ventilation air.

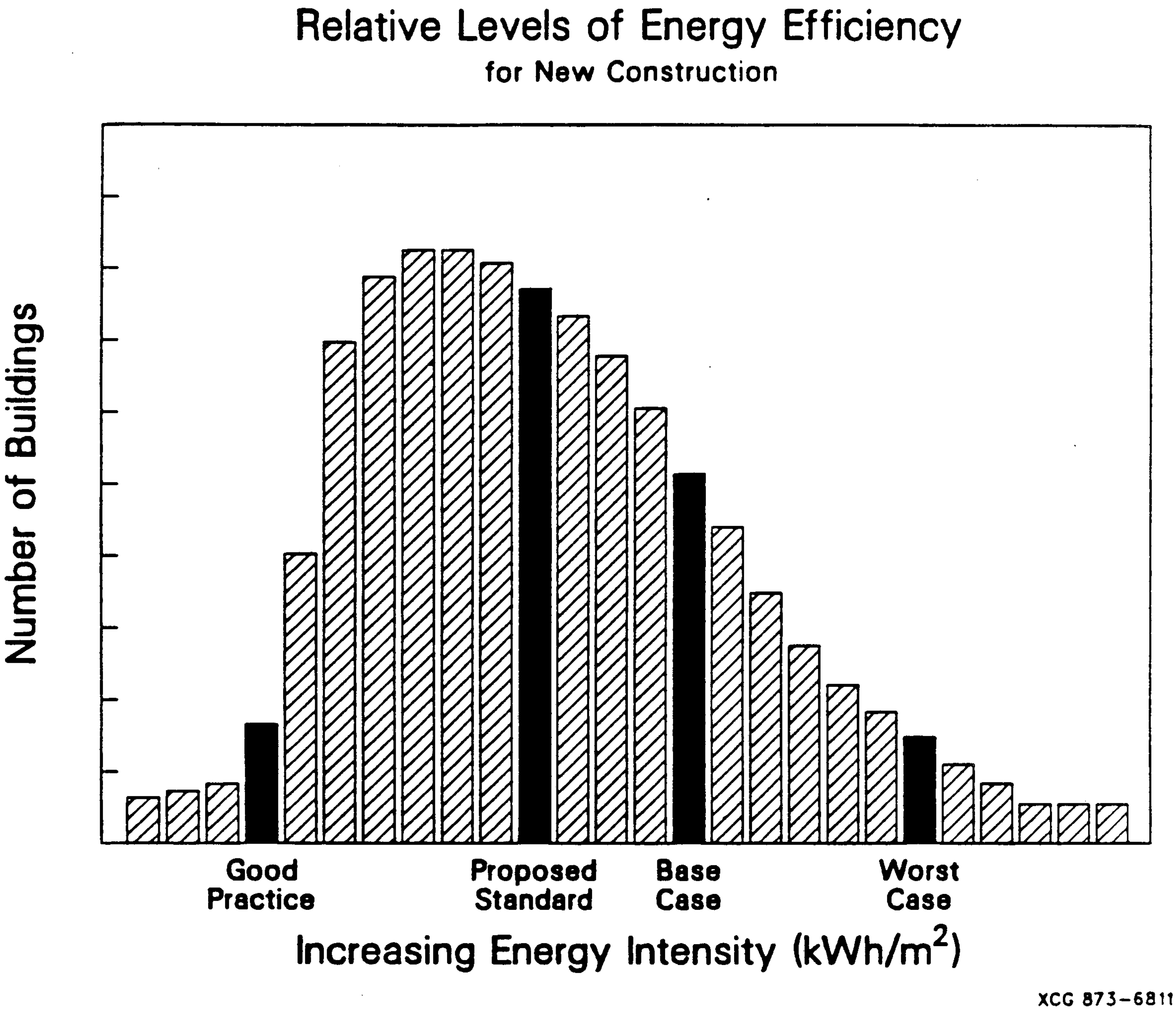


Figure 2. A schematic of the relative levels of energy efficiency for four commercial building cases in Malaysia.

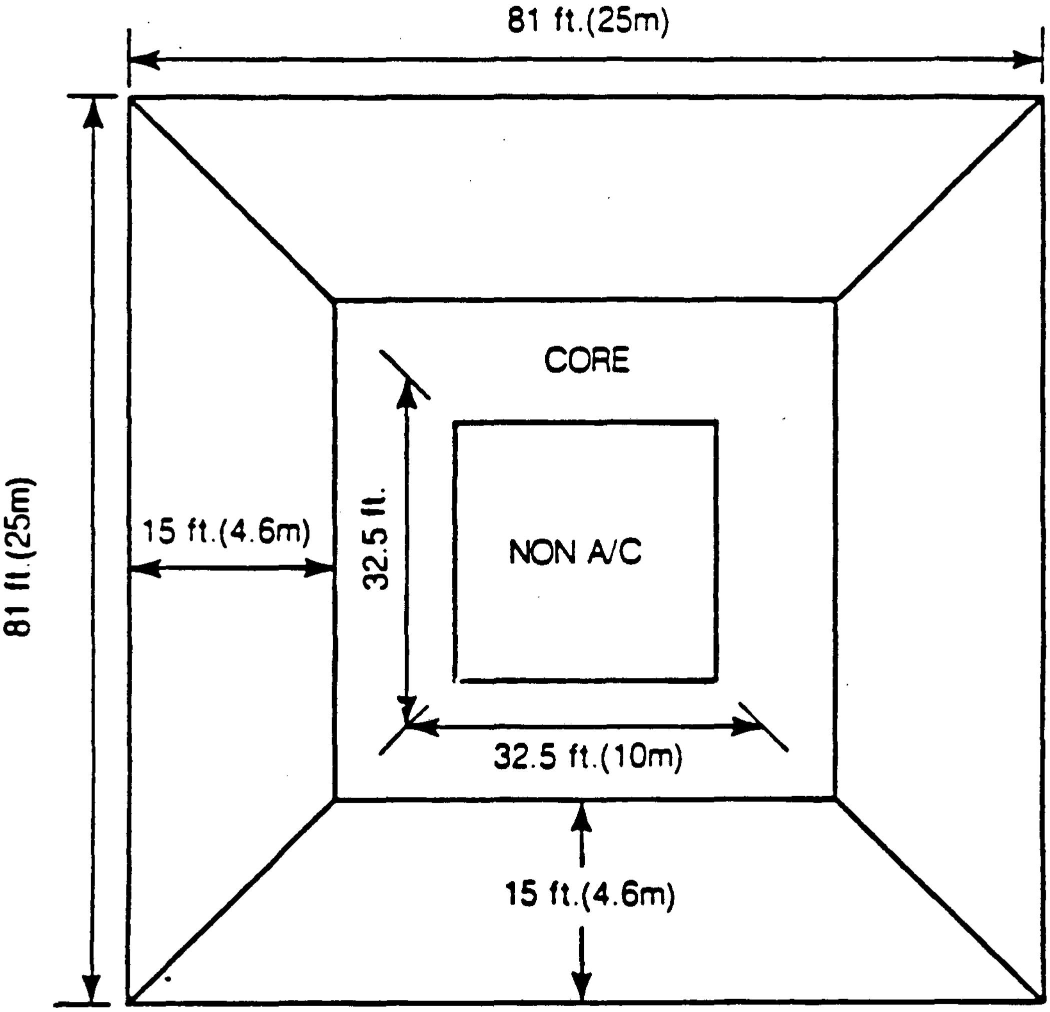
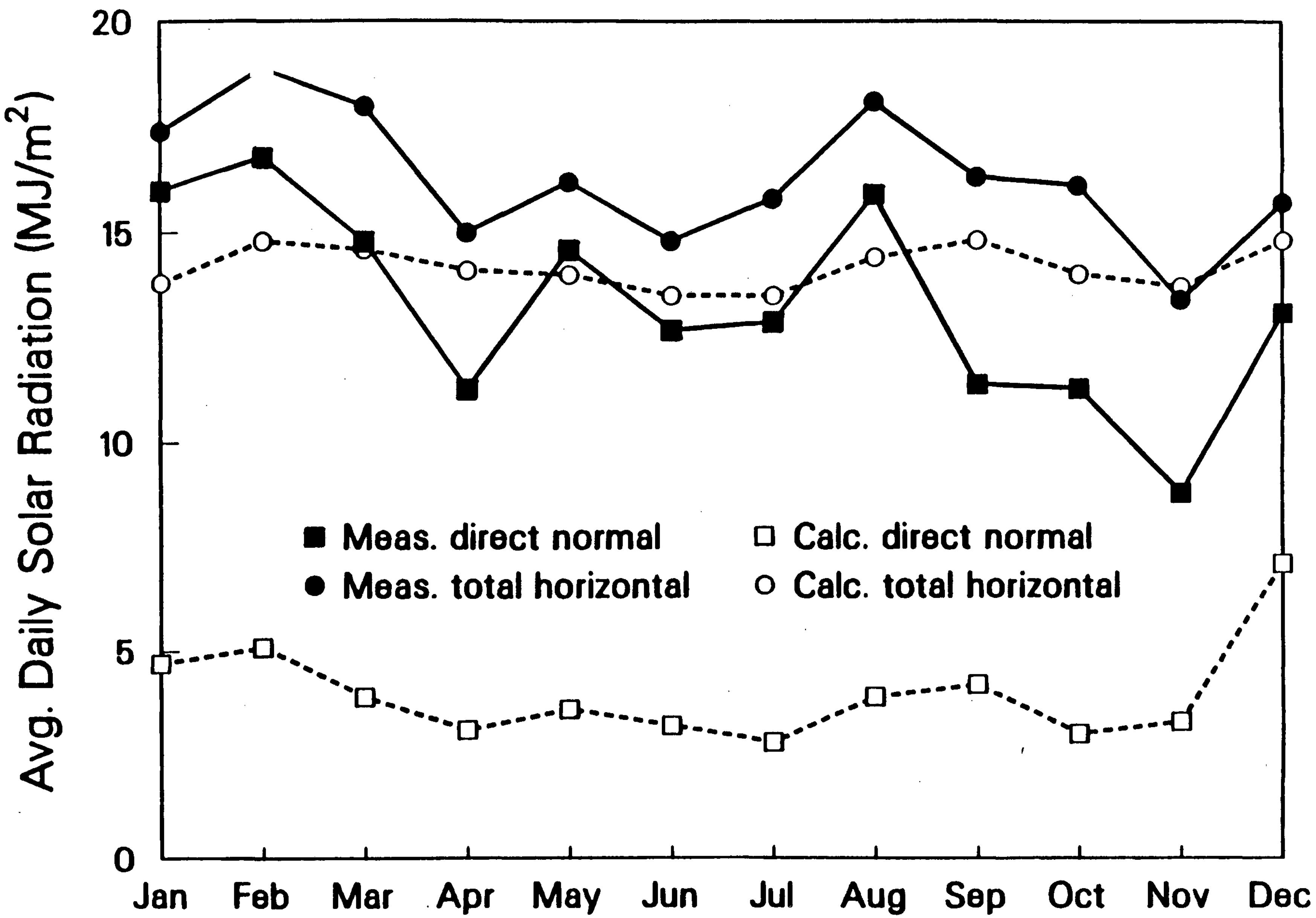


Figure 3. Plan of the Malaysian Base Case building with 10 floors and 5200 m^2 of total conditioned floor space.



XCG 873-6787

Figure 4. Calculated vs. measured solar radiation data for Singapore.

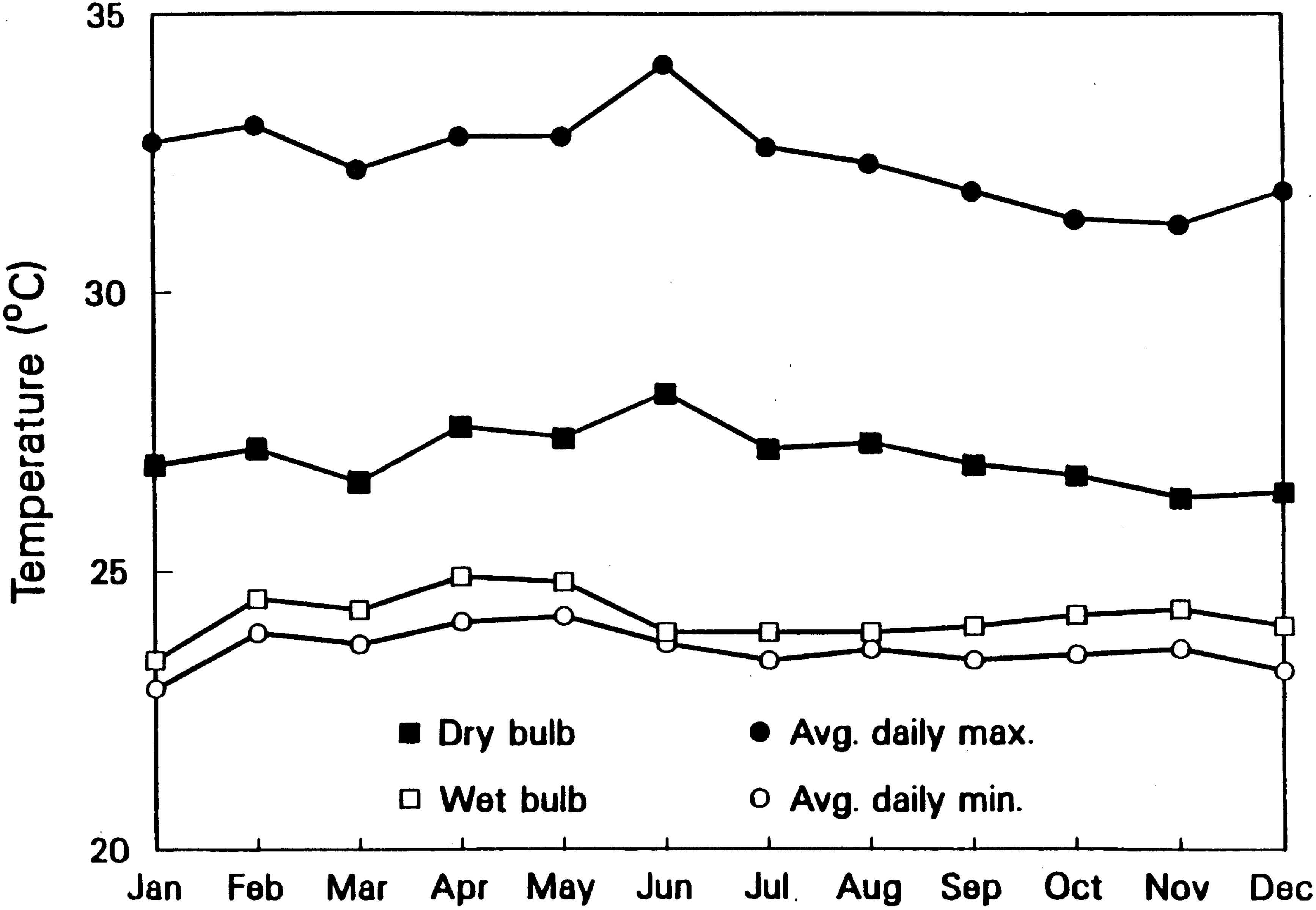
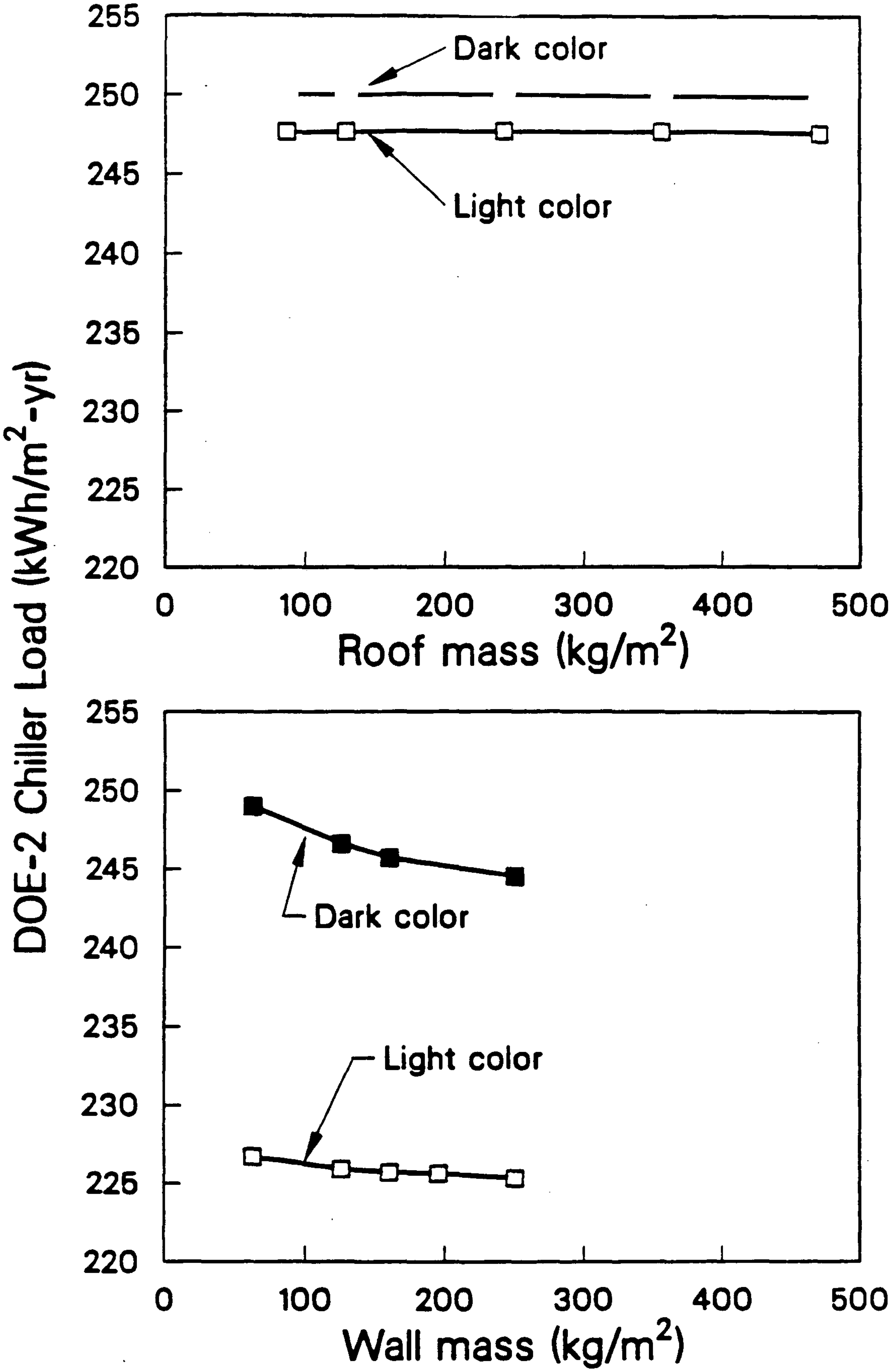


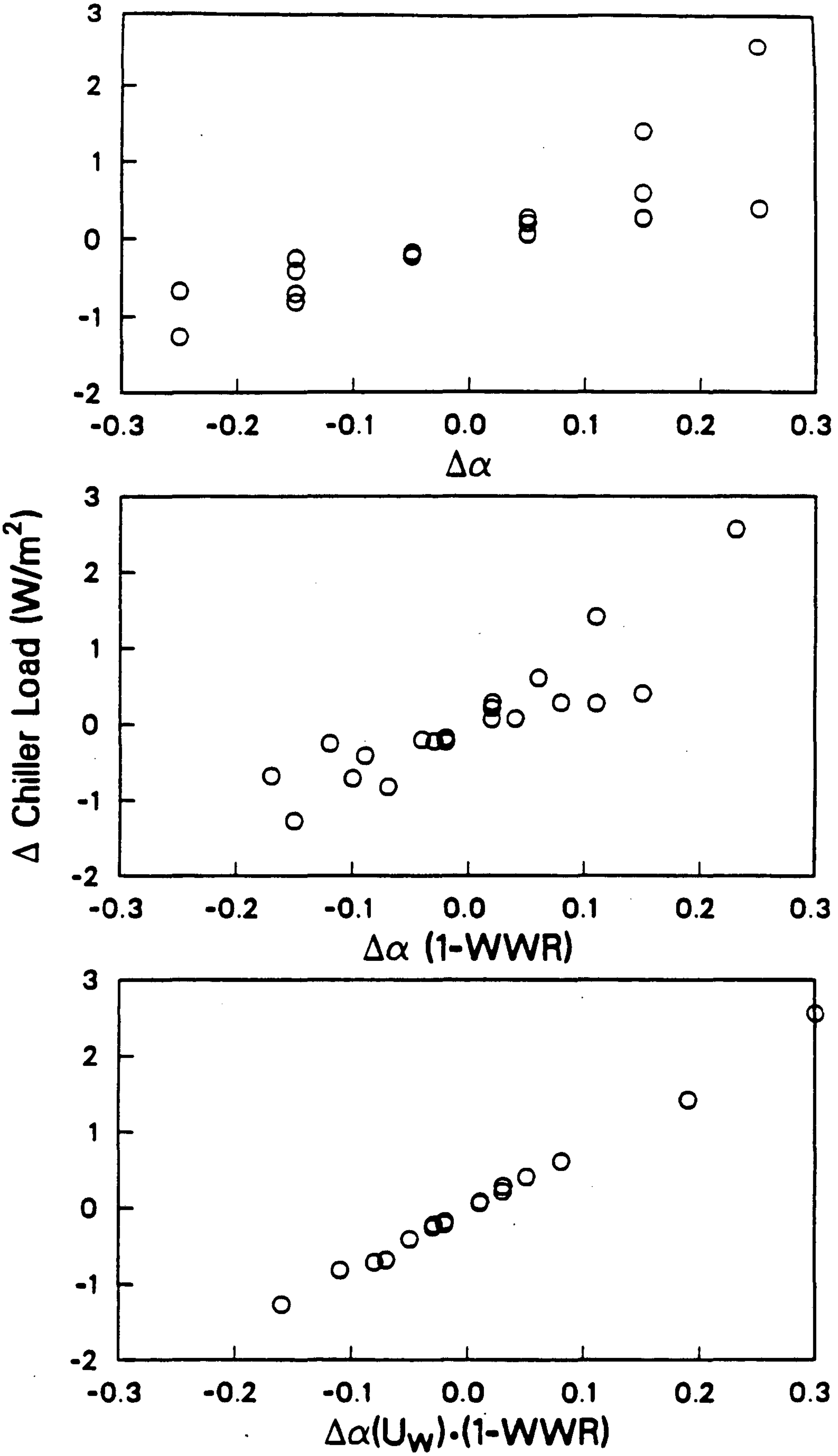
Figure 5. Measured temperature data for Kuala Lumpur in 1985.

XCG 873-6786



XCG 873-6788

Figures 6 and 7. The effect of thermal mass and exterior surface color on chiller loads for roof (5) and walls (6).



Figures 8-10. The relationship between chiller load and solar absorptance (α) of the exterior wall. Two sets of DOE-2.1C runs, identical except for α, provide the Δ chiller load values for comparing different ways of accounting for the effect of α.

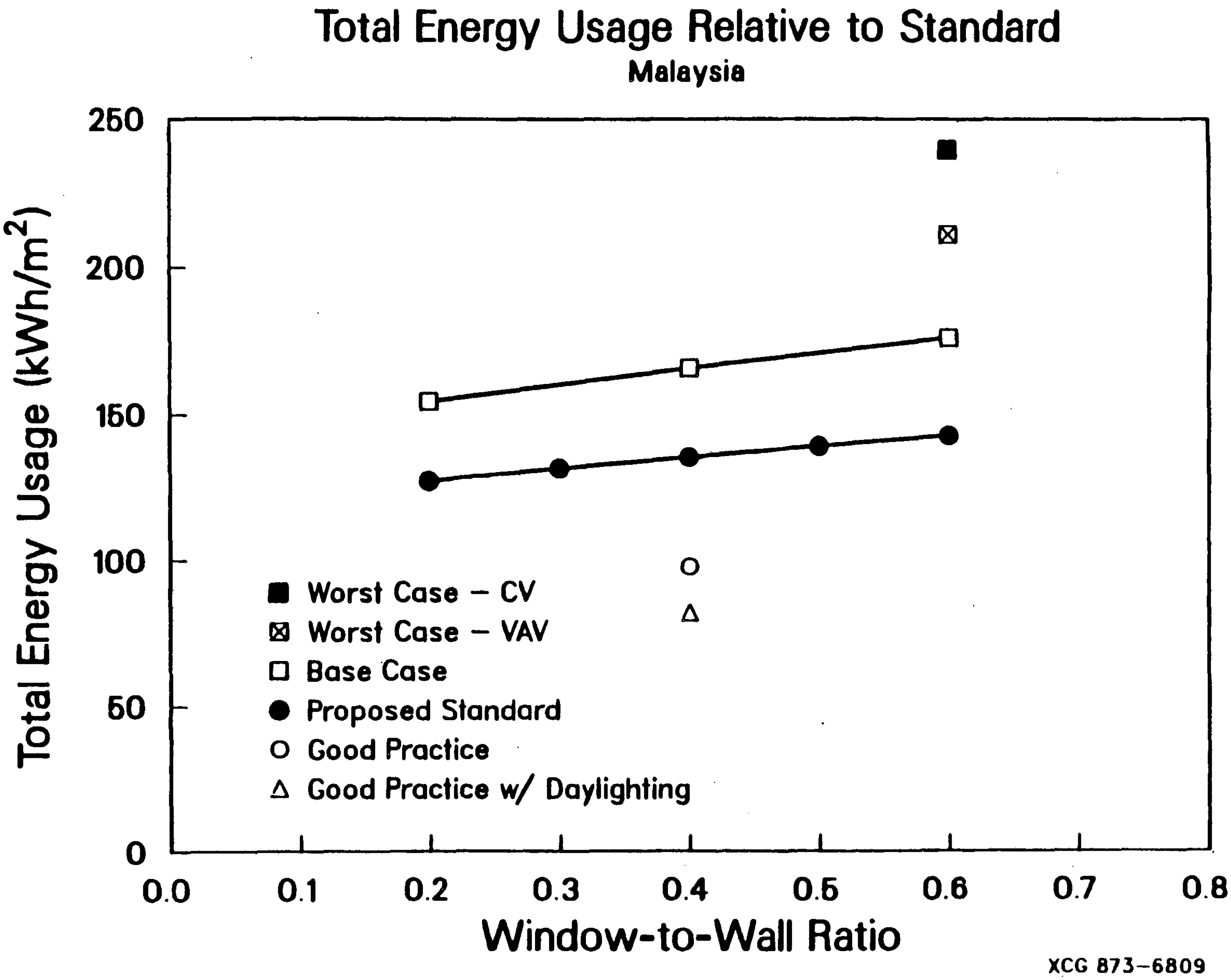
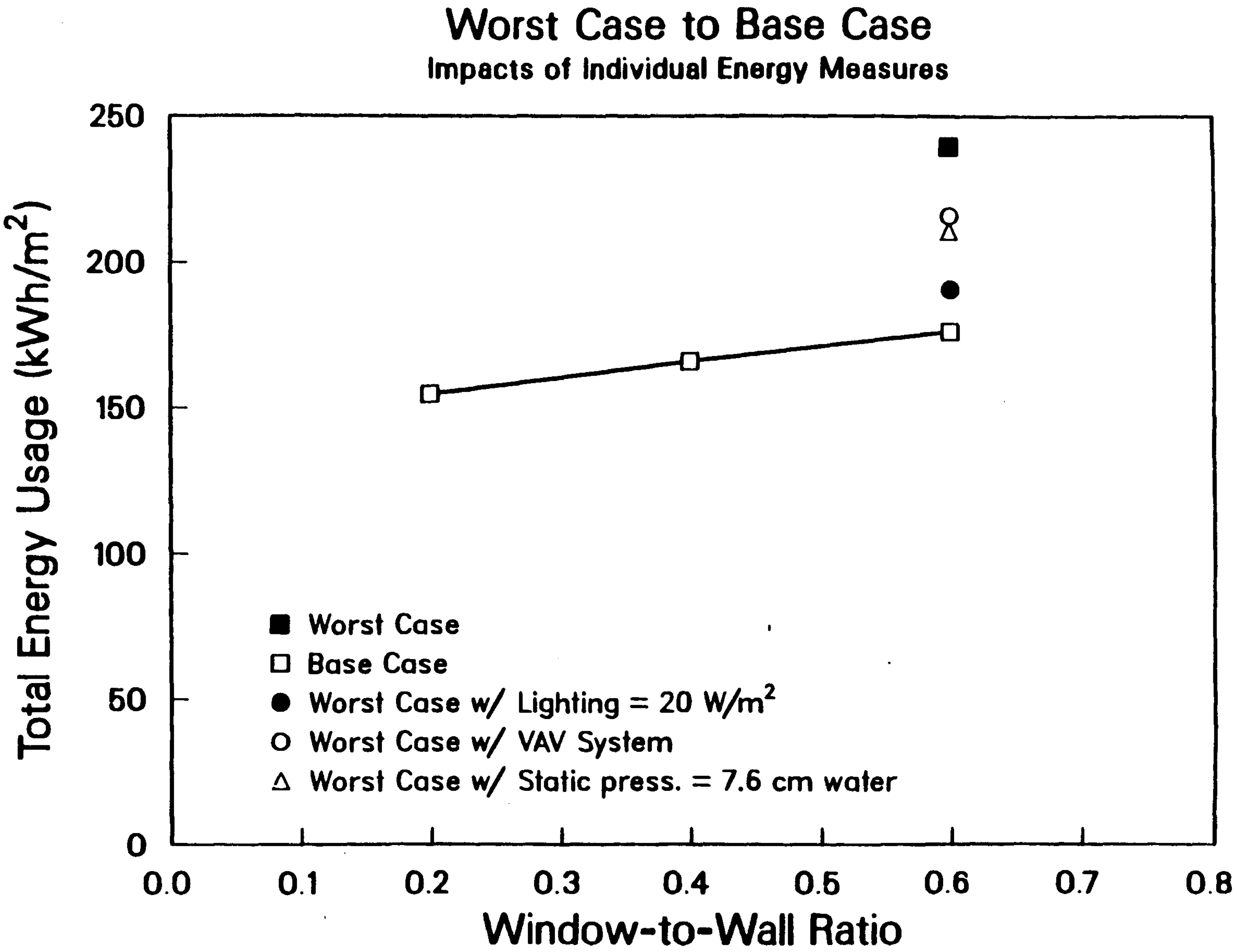
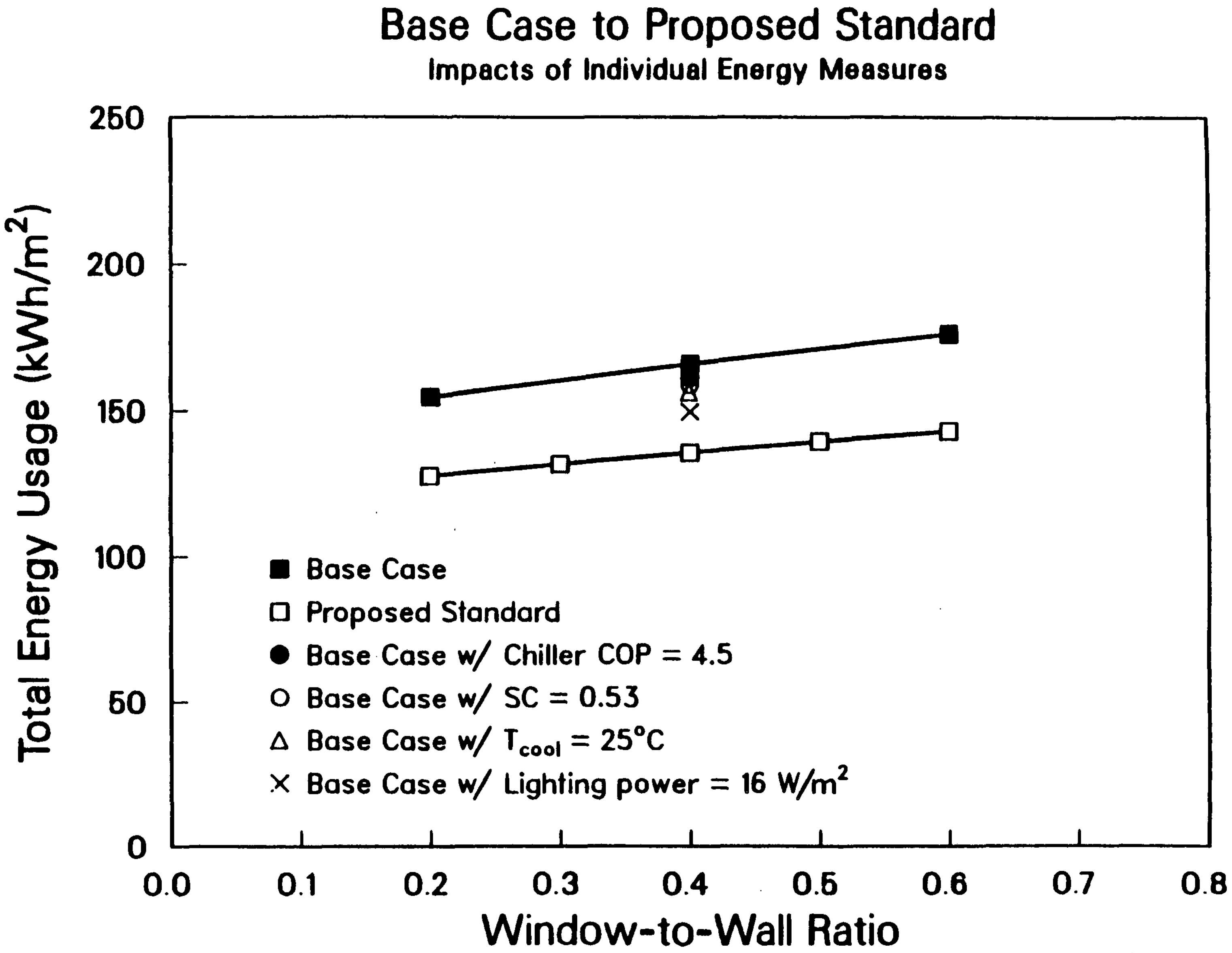


Figure 11. Comparison of the total energy consumption of the different cases relative to the proposed Malaysian commercial building energy standard.



XCG 873-6810

Figure 12. Impacts of individual measures in improving the energy efficiency from the Worst Case to the Base Case.



XCG 873-6807

Figure 13. Impacts of individual measures in improving the energy efficiency from the Base Case to the Proposed Standard Case.

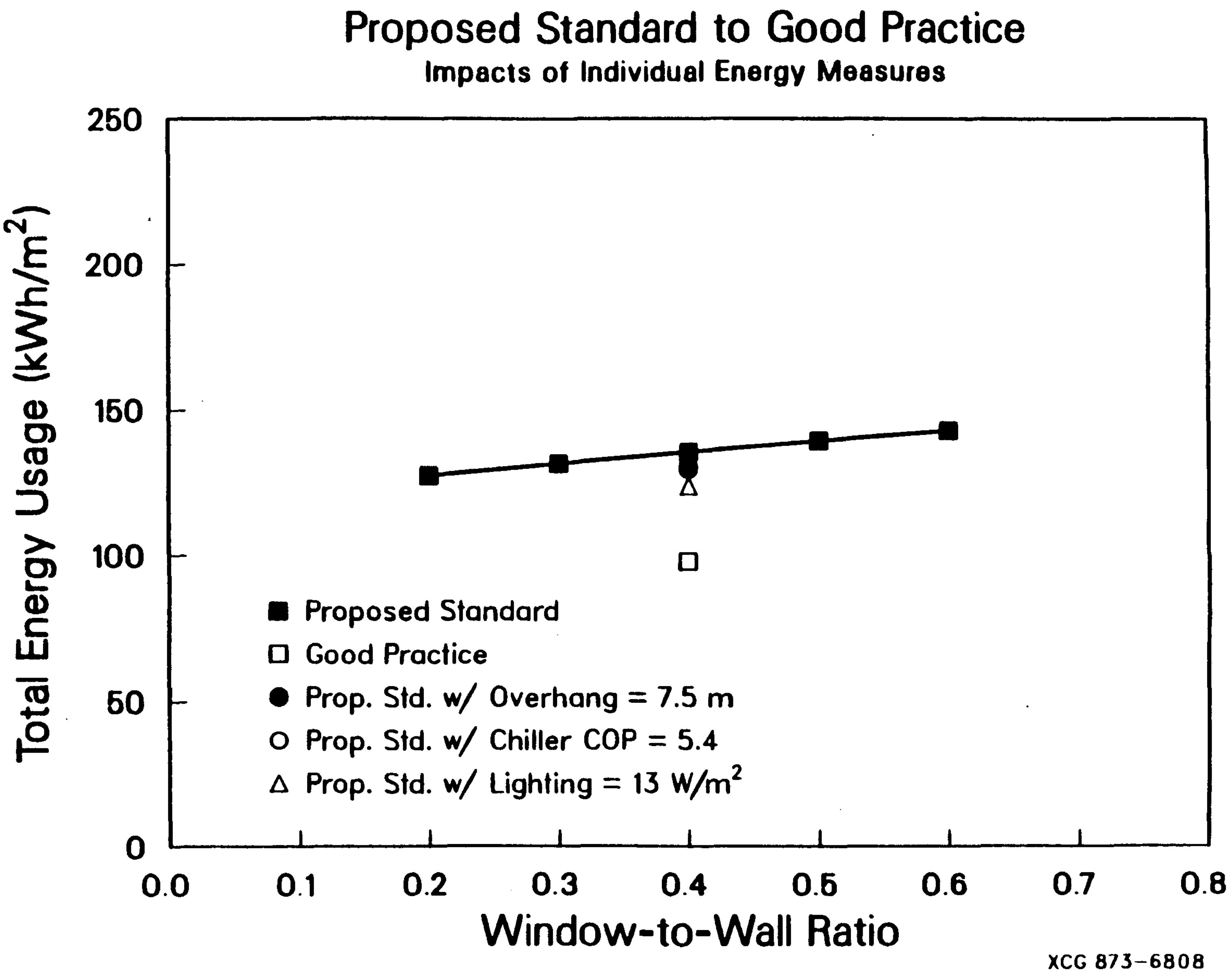
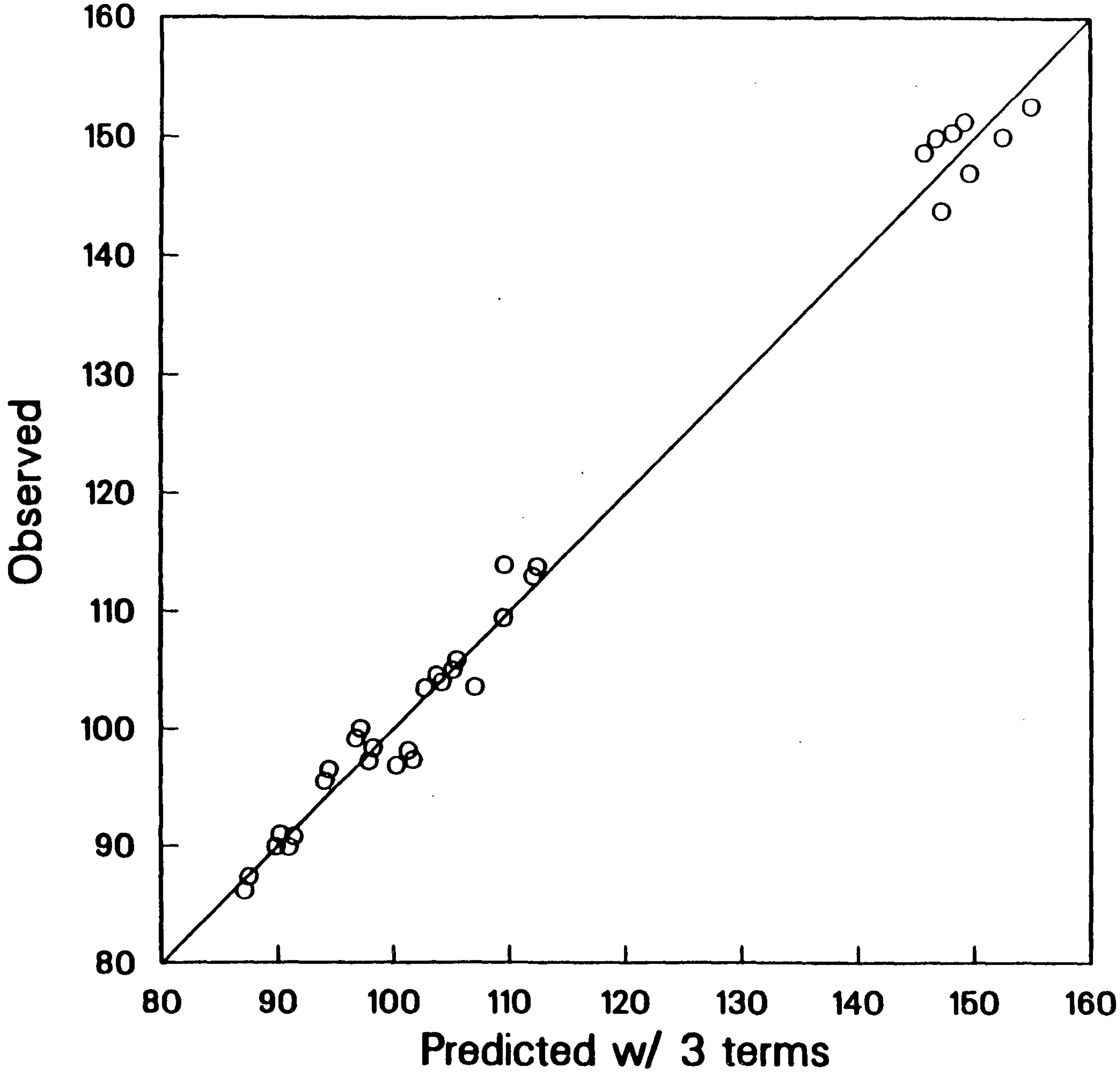
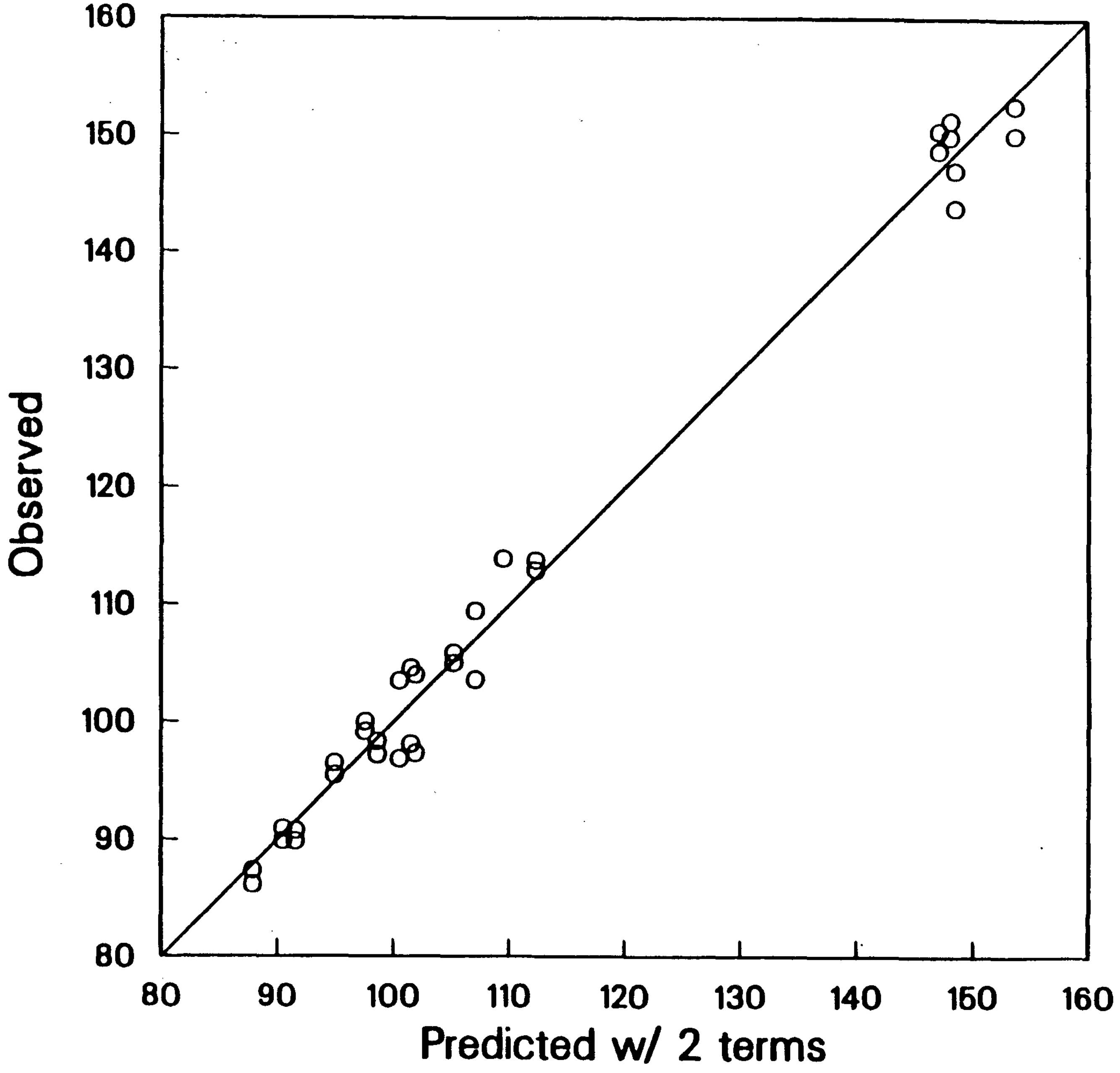


Figure 14. Impacts of individual measures in improving the energy efficiency from the Proposed Standard Case to the Good Practice Case.



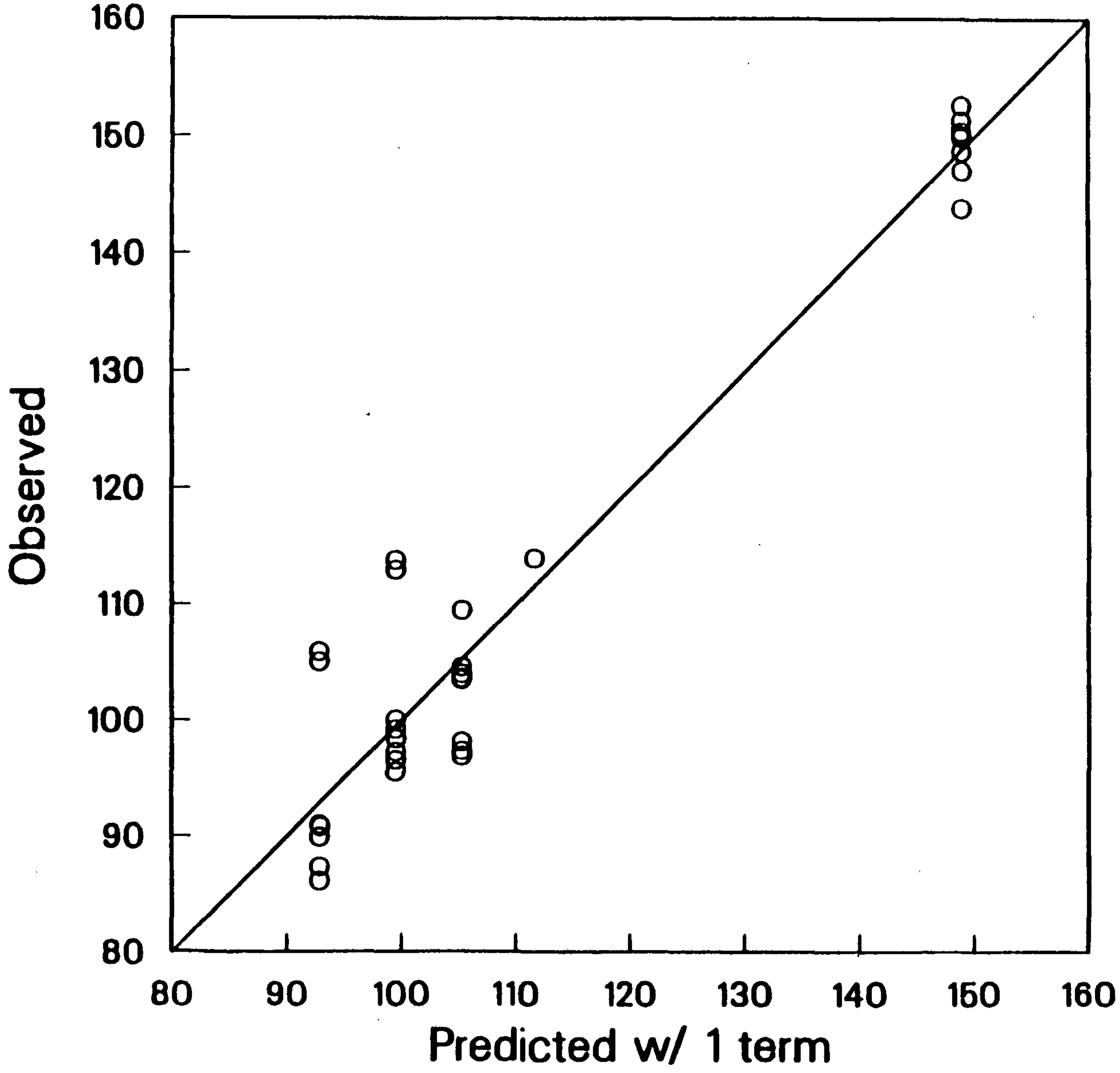
XCG 873-6823

Figure 15. Observed (DOE-2) vs. predicted chiller loads using the 3 term OTTV equation.



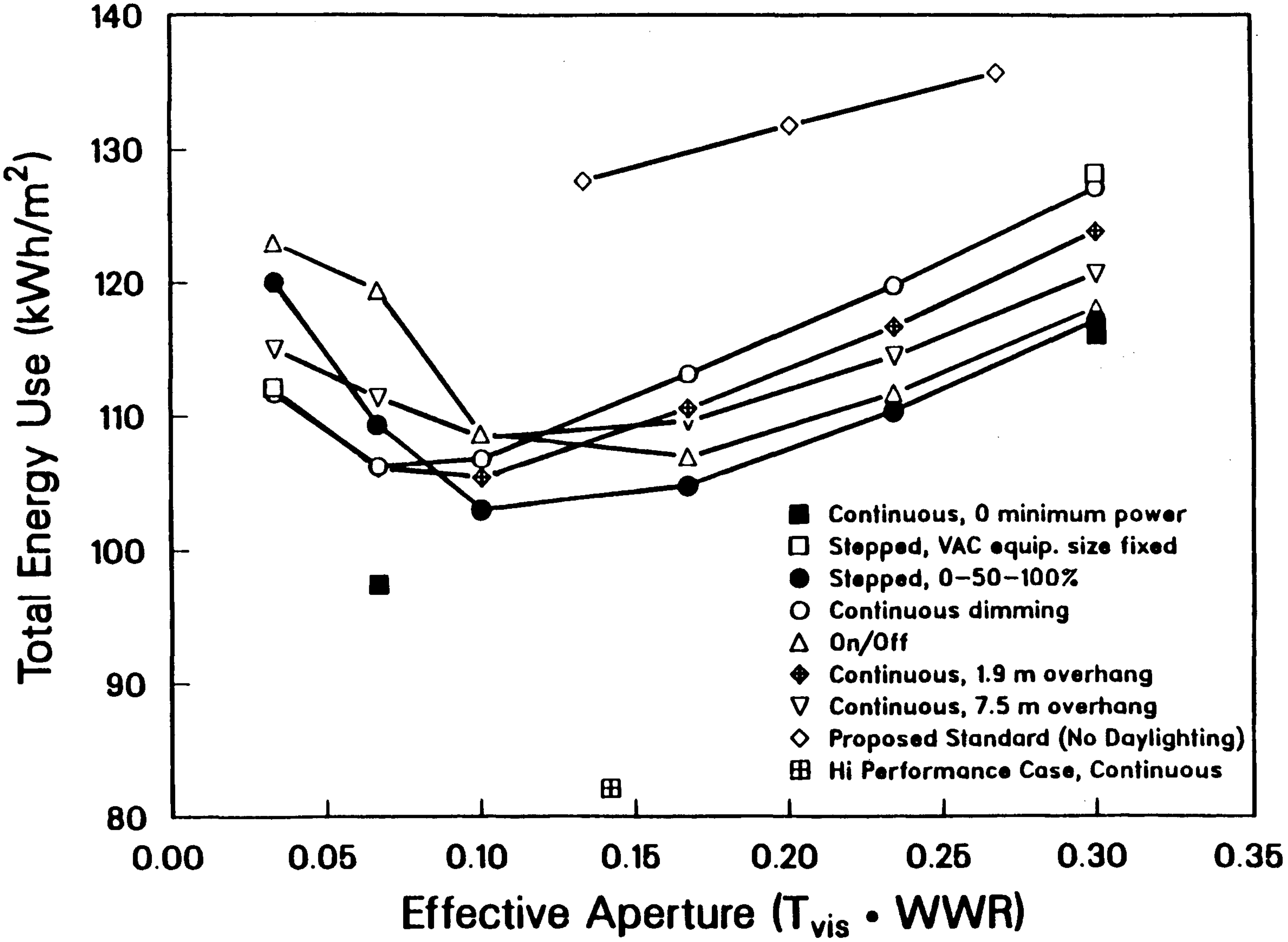
XCG 873-6822

Figure 16. Observed (DOE-2) vs. predicted chiller loads using the 2 term OTTV equation.



XCG 873-6821

Figure 17. Observed (DOE-2) vs. predicted chiller loads using the 1 term OTTV equation.



XCG 873–6785 A

Figure 18. Performance of daylighting in Malaysia as a function of effective aperature over a range of lighting control and fenestration systems.

APPENDIX A

MODIFICATIONS TO THE SINGAPORE BASE CASE BUILDING

The Malaysian Base Case building model was developed by modifying the model used for Singapore. The changes can be categorized into three types: 1) physical changes to the building, 2) changes to the A/C equipment, and 3) changes to the building and equipment operation strategies. In all, 17 changes were made.

Eight changes to the physical building were required:

1. The window setback as a proxy for external shading devices was not used. Instead, external overhangs and fins (where applicable) were simulated directly.
2. The level of infiltration was increased to 1.0 ach from 0.6 ach, in order to reflect the relative leakiness of Malaysian buildings.
3. The lighting power level was increased to 2.0 from 1.9.
4. The window glazing type was changed to single from double, to better reflect typical Malaysian building practice.
5. The window-to-wall surface area ratio was reduced to 0.40 from 0.44.
6. The shading coefficient for the glazing was increased to 0.69 from 0.47, to better reflect a commonly used type of glass in Malaysia.
7. The absorptivity of the roof surface was increased to 0.5 from 0.3, to reflect typical absorptivity over time unless special surface treatments are used to resist mold and discoloration.
8. The thickness of the exterior walls was reduced to 4 inches from 9.75 inches.

The air conditioning (A/C) equipment was modified as follows:

1. The number of air handling units was increased to five from one.
2. The efficiency of the supply air fan was set to correspond to a forward-curved fan with inlet vanes.
3. The number of cooling towers was increased to two.
4. The COP of the chiller was changed to 4.1 from 4.5.

The building and equipment operation was modified as follows:

1. The design cool temperature (in LOADS) was reduced to 74 °F from 78 °F.
2. The cooling set point was reduced to 75.2 °F from 77 °F.
3. The flow of ventilation (outside) air into the building was fixed. Economizers are not generally used in Malaysia.
4. The air-flow rate was controlled by inlet vanes rather than by variable speed motors.

APPENDIX B

LISTING OF THE DOE-2 INPUT DATA FOR THE MALAYSIAN BASE CASE BUILDING

```
 TITLE LINE-1 * MALAYSIA BLDG. ENERGY STANDARDS STUDY *
       LINE-2 * SINGAPORE BUILDING MODULE *
       LINE-3 * VAV HVAC SYSTEM *
       LINE-4 * BASE CASE *  ..
 INPUT LOADS ..
 RUN-PERIOD  JAN 1 1985 THRU DEC 31 1985 ..
 BUILDING-LOCATION
    LATITUDE=3.12
    LONGITUDE=-101.6
    TIME-ZONE= -7
    ALTITUDE= 10
    DAYLIGHT-SAVINGS=NO
    ATM-M=(1.3,1.3,1.3,1.3,1.3,1.3,1.3,1.3,1.3,1.3,1.3,1.3)
    C-N=(.67,.67,.67,.67,.67,.67,.67,.67,.67,.67,.67,.67)
    AZIMUTH   0  ..
 DIAGNOSTIC WARNINGS  ..
 ABORT ERRORS ..
 LOADS-REPORT  SUMMARY = (LS-A,LS-C,LS-D,LS-F)  ..
 $
 $ ----------------------------------------------------$
 $           LOADS PARAMETERS                          $
 $ ----------------------------------------------------$
   PARAMETER
        R-WALL = .01   $  R VALUE OF INSULATION ONLY FOR  $
        R-ROOF = 5     $  R VALUE FOR ROOF INSULATION     $
 $
        W-ABSORP = .45   $  SOLAR ABSORPTIVITY FOR WALLS    $
        R-ABSORP = .50   $  SOLAR ABSORPTIVITY FOR ROOFS    $
 $
        INFIL = 1.0      $  INFILTRATION IN AIR CHANGES PER $
                         $  HOUR FOR ALL EXTERIOR SPACES,   $
                         $  WITH WIN CORRECTION CALC.       $
 $
        GRND-R = .20     $  GROUND REFLECTANCE              $
 $
        WWR =  .40     $  WINDOW TO WALL RATIO            $
 $
        SCNS = .69  $  SHADING COEF - NORTH/SOUTH WINDOWS  $
        SCEW = .69  $  SHADING COEF - EAST/WEST WINDOWS    $
$
        SETBAK = 0     $  WINDOW SETBACK FOR SHADING AS $
                       $  FRACTION OF WINDOW HEIGHT     $
$
        SFF = .5   $ SKY FORM FACTOR FOR VERTICAL WALL $
$
        INF4=1 INF5=1 INF6=1 INF7=0 INF8=0
 $
        GLASS-CON = 1.47  $ GLASS CONDUCTANCE, NOT U-VALUE      $
 $
        ORIENT = 0     $  BUILDING ORIENTATION.     $
 $
        MASS = 0      $  FLOOR WEIGHT FOR ASHRAE WEIGHTING  $
                      $  FACTORS CALC.                      $
$
        BRICKTH = .37  $ THICKNESS OF BRICK IN EXTWALL3 $
        RCBEAMTH = .33  $ THICKNESS OF RC BEAM IN EXTWALL4 $
```

```
 $
       EQUIP    =  .5  $  EQUIPMENT, IN W/SQFT  $
 $
       LITP = 2.0 LITC = 2.0  $ LIGHTING WATTS PER SQ.FT. $
 $
       SPACE-LITE = 1.0   $  HEAT GAIN TO SPACE FROM LIGHTS     $
$
       LOADS-T = 73       $  LOADS TEMP FOR SPACE CONDITIONS    $
                          $  SHOULD BE HALFWAY BETWEEN SYSTEMS  $
                          $  HEATING AND COOLING SETPOINTS      $
                          $  OF DESIGN-HEAT-T AND COOL-T        $
 $
       FM = 8   $   NUMBER OF TYPICAL FLOORS  $
$
       LT-CTRL = CONTINUOUS  $ ARTIFICIAL LIGHT CONTROLS FOR DAYLT $
$
       NR-STEPS = 1  $ FOR STEPPED LT-CTRL $
$
       DAYLT = NO   $ DAYLIGHTING $
$
       FTCAND = 50  $ FOOTCANDLES $
$
       OVRHNG-A = 4.13  $ OVERHANG OFFSET FROM UPPER LEFT CORNER   $
                        $ OF WINDOW, RESET WITH WWR SINCE OVERHANG $
                        $ RUNS THE LENGTH OF WALL SECTION OR $
                        $ (20.25 - (WWR X 29.97))/2 $
       OVRHNG-D = 0  $ OVRHNG DIMENSION OUT FROM WALL $
$
       LFD = 0  RFD = 0  $ FACADE FINS DIMENSION OUT FROM WALL $
                              ..
$============================================================$
                  $ BUILDING OPERATING SCHEDULES $
                            $ OCCUPANCY $
$============================================================$
PEOP-OFFC-WD=DAY-SCHEDULE
             (1,6)(0) (7,8)(.1,.2) (9,12)(.95) (13)(.50)
             (14,17)(.95) (18)(.30) (19,22)(.10) (23,24)(.05) ..
PEOP-OFFC-SAT=DAY-SCHEDULE
              (1,6)(0) (7,8)(.1) (9,12)(.9) (13,17)(.1)
              (18,19)(.05) (20,24)(0) ..
PEOP-OFFC-SUN=DAY-SCHEDULE
              (1,6)(0) (7,18)(.05) (19,24)(0) ..
PEOP-OFFC-WK=WEEK-SCHEDULE
             (SUN) PEOP-OFFC-SUN (WD) PEOP-OFFC-WD
             (SAT) PEOP-OFFC-SAT (HOL) PEOP-OFFC-SUN ..
PEOP-OFFC=SCHEDULE  THRU DEC 31 PEOP-OFFC-WK ..
$==========================================$
                 $ LIGHTING $
$==========================================$
LITE-OFFC-WD=DAY-SCHEDULE
             (1,5)(.05) (6,7)(.10) (8)(.3) (9,12)(.9) (13)(.8)
             (14,17)(.9) (18)(.5) (19,20)(.3) (21,22)(.2)
             (23)(.1) (24)(.05) ..
LITE-OFFC-SAT=DAY-SCHEDULE
              (1,6)(.05) (7,8)(.1) (9,12)(.9) (13,17)(.15)
              (18,24)(.05) ..
```

```
LITE-OFFC-SUN=DAY-SCHEDULE
              (1,24)(.05) ..
LITE-OFFC-WK=WEEK-SCHEDULE
             (SUN) LITE-OFFC-SUN  (WD) LITE-OFFC-WD
             (SAT) LITE-OFFC-SAT (HOL) LITE-OFFC-SUN  ..
LITE-OFFC=SCHEDULE THRU DEC 31 LITE-OFFC-WK ..
$=============================================================$
                     $ INFILTRATION SCHEDULE $
$=============================================================$
INFILTWD=DAY-SCHEDULE
       (1,3)(1) (4,8)(INF4,INF5,INF6,INF7,INF8) (9,17)(0) (18,24)(1) ..
INFILTSAT=DAY-SCHEDULE
       (1,3)(1) (4,8)(INF4,INF5,INF6,INF7,INF8) (9,12)(0) (13,24)(1) ..
INFILTWEH=DAY-SCHEDULE
       (1,24)(1)  ..
INFILTWK=WEEK-SCHEDULE
         (SAT) INFILTSAT (HOL) INFILTWEH
         (WD) INFILTWD (SUN) INFILTWEH  ..
INFILTSCH1=SCHEDULE THRU DEC 31 INFILTWK ..
$============================================================ $
                 $ WINDOW MANAGEMENT SCHEDULE $
$============================================================ $
SHADE-MULT=SCHEDULE  THRU DEC 31  (ALL)  (1,24)  (.75)  ..
TRANS-MULT=SCHEDULE  THRU DEC 31  (ALL)  (1,24)  (.35)  ..
CLOSE-SHADE=SCHEDULE  THRU DEC 31  (ALL) (1,24)  (40)  ..
REOPEN-PROB=SCHEDULE  THRU DEC 31  (ALL) (1,24)  (.5)  ..
$
$============================================================ $
                                  $ MATERIALS $
$============================================================ $
                      $ INSULATION IS POLYSTYRENE $
$
WALLINS=MATERIAL
        CONDUCTIVITY=.02
        DENSITY=1.80
        SPECIFIC-HEAT=0.29
        THICKNESS=R-WALL TIMES .02  ..
                      $ FOR POLYSTYRENE THE THICKNESS OF $
                      $ THE INSULATION EQUALS            $
                      $ ITS "R" VALUE TIMES 0.02         $
ROOFINS=MATERIAL
        LIKE WALLINS
        THICKNESS=R-ROOF TIMES .02 ..
                      $ REINFORCED CONCRETE (RC) BEAM  $
RCBEAM=MATERIAL
        CONDUCTIVITY=0.84
        DENSITY=154.0
        SPECIFIC-HEAT=0.2
        THICKNESS=RCBEAMTH   ..
                             $ 140 LB/CF CONCRETE $
GLASS=MATERIAL
      CONDUCTIVITY=0.614
      DENSITY=161.0
      SPECIFIC-HEAT=0.19
      THICKNESS=.026     ..
BRICK=MATERIAL
```

```
      CONDUCTIVITY=0.470
      DENSITY=112.8
      SPECIFIC-HEAT=0.20
      THICKNESS=BRICKTH  ..
PLASTER=MATERIAL
        CONDUCTIVITY=0.31
        DENSITY=100.5
        SPECIFIC-HEAT=0.20
        THICKNESS=.039    ..
TILE=MATERIAL
     CONDUCTIVITY =0.757
     DENSITY =162.0
     SPECIFIC-HEAT=0.21
     THICKNESS=0.039     ..
$============================================================$
                       $ CONSTRUCTION $
$============================================================$
                       $ GROUND FLOOR SOUTH & EAST FACADE $
                       $ TWO TILE CONSTRUCTIONS NOT $
                       $ USED IN BASE CASE BLDG. $

TILERCPLAS1=LAYERS
            MATERIAL=(TILE,AL11,RCBEAM)
                     I-F-R=0.68          ..
                       $ GROUND FLOOR NORTH FACADE $
TILERCPLAS2=LAYERS
            MATERIAL=(TILE,AL11,RCBEAM)
                     I-F-R=0.68          ..
                       $ UPPER FLOORS $
                       $ SOUTH & EAST FACADES $
GLASSRC=LAYERS
        MATERIAL=(GLASS,AL11,WALLINS,RCBEAM)
                 I-F-R=0.68              ..
GLASSBRICK=LAYERS
           MATERIAL=(GLASS,AL11,PLASTER,BRICK,WALLINS,PLASTER)
                    I-F-R=0.68           ..
ROOF1=LAYERS
     MATERIAL=(BR01,                          $ BUILT UP ROOFING $
               ROOFINS,                       $ INSULATION $
               CC04,                          $ 6 INCH CONCRETE $
               AL33,                          $ AIR LAYER $
               AC02)                          $ ACOUSTIC TILE $
               I-F-R=0.68             ..
FLRMAT-GND=LAYERS
       MATERIAL=(CC04,CP01)
                 I-F-R=0.68   ..
                                 $ GROUND FLOORS ONLY
FLRMAT  -  LAYERS
       MATERIAL=(CC04)
                I-F-R=0.68 ..
                                 $ FLRMAT IS USED FOR BOTH CEILING
                                 $ FLOOR WHERE THERE IS AN ADJACENT
                                 $ ZONE.  IT MODELS HALF OF THE 4 INCH
                                 $ THICK FLOOR AND THUS AVOIDS DOUBLE
                                 $ COUNTING (SINCE EACH ZONE HAS BOTH
                                 $ A FLOOR AND A CEILING.)
```

```
PARTMAT=LAYERS
        MATERIAL=(GP02,          $ 5/8 INCH GYPSUM BOARD $
                  AL31,GP02)
                 I-F-R=0.68   ..
                                 $ MARBLE TILE WALL (THICK) $
EXTWALL1=CONSTRUCTION
         ABS=0.58
         ROUGHNESS = 5
         LAYERS=TILERCPLAS1   ..
                                 $ MARBLE TILE WALL (THIN) $
EXTWALL2=CONSTRUCTION
         ABS=0.58
         ROUGHNESS= 5
         LAYERS=TILERCPLAS2  ..
                                 $ GLASS WALL WITH CONCRETE $
EXTWALL4=CONSTRUCTION
         ABS=W-ABSORP
         ROUGHNESS=6
         LAYERS=GLASSRC      ..
                                 $ GLASS WALL WITH BRICK $
EXTWALL3=CONSTRUCTION
         ABS=W-ABSORP
         ROUGHNESS=6
         LAYERS=GLASSBRICK   ..
ROOFCON=CONSTRUCTION
        ABS = R-ABSORP
        LAYERS = ROOF1   ..
UFLOORS = CONSTRUCTION
       LAYERS = FLRMAT-GND    ..
PARTITION = CONSTRUCTION
          LAYERS = PARTMAT   ..
HALFLOOR = CONSTRUCTION
       LAYERS = FLRMAT    ..
$-------------------------------------------------------------$
                           $ GLAZING $
$-------------------------------------------------------------$
GLASS-EW=GLASS-TYPE
        SHADING-COEF=SCEW
        VIS-TRANS = SCEW TIMES .67
        GLASS-CONDUCTANCE=GLASS-CON    ..
GLASS-NS=GLASS-TYPE
        S-C=SCNS
        VIS-TRANS = SCNS TIMES .67
        G-C=GLASS-CON    ..
$=============================================================$
                     $ SET DEFAULTS FOR EXTERIOR-WALL $
$=============================================================$
SET-DEFAULT FOR EXTERIOR-WALL
     HEIGHT = 7.5
     WIDTH = 81
     AZIMUTH = 180
     Z = 3.6
     CONSTRUCTION = EXTWALL3
              ..
$=============================================================$
                     $ SET DEFAULTS FOR WINDOW $
```

```
$=============================================================$
SET-DEFAULT FOR WINDOW
     WIDTH        = WWR TIMES 29.97  $ 29.97 = WALL AREA/WINDOW HEIGHT $
                                     $ OR (11.1 X 20.25)/7.5) $
$ 29.6=(TOT. WALL HT.)/(WALL2 HT.) X (WALL WIDTH) OR@ 11.1/7.5 X 20.25
     HEIGHT       = 7.5
     SETBACK      = SETBAK TIMES 7.5
     GLASS-TYPE   = GLASS-NS
     S-F-F        = SFF
     G-F-F        = .5
     MAX-SOLAR-SCH = CLOSE-SHADE
     WIN-SHADE-TYPE = MOVABLE-INTERIOR
     SHADING-SCHEDULE = SHADE-MULT
     VIS-TRANS-SCH = TRANS-MULT
     OPEN-SHADE-SCH = REOPEN-PROB
     SUN-CTRL-PROB=.7
     OVERHANG-A = OVRHNG-A
     OVERHANG-D = OVRHNG-D
     OVERHANG-W = 20.25
     LEFT-FIN-H = 7.5
     LEFT-FIN-D = LFD
     RIGHT-FIN-H = 7.5
     RIGHT-FIN-D = RFD
                 ..
$=============================================================$
               $ SET DEFAULT FOR SPACE CONDITIONS $
$=============================================================$
SET-DEFAULT FOR SPACE
    TEMPERATURE=(LOADS-T)
      INF-METHOD=AIR-CHANGE
      INF-SCHEDULE=INFILTSCH1
      AIR-CHANGES/HR=INFIL
    FLOOR-WEIGHT=MASS
      LIGHTING-W/SQFT=LITC   $ BASE LIGHTING LEVEL  $
      LIGHT-TO-SPACE=SPACE-LITE
      LIGHTING-TYPE=SUS-FLUOR
      LIGHTING-SCHEDULE=LITE-OFFC
    EQUIPMENT-W/SQFT    =    EQUIP
    EQUIP-SCHEDULE      =    PEOP-OFFC
      PEOPLE-SCHEDULE=PEOP-OFFC
    ZONE-TYPE=CONDITIONED
      PEOPLE-HG-SENS=230
    PEOPLE-HG-LAT=190
    DAYLIGHTING = DAYLT
    LIGHT-REF-POINT1 =  (10,10,2.5)
    LIGHT-CTRL-TYPE1 = LT-CTRL
    LIGHT-CTRL-STEPS = NR-STEPS
    MAX-GLARE = 22
    LIGHT-SET-POINT1 = FTCAND
             ..
$=============================================================$
                      $ SPACE DESCRIPTIONS $
$=============================================================$
$
                                 $ TYPICAL MIDDLE FLOORS $
SPACE-NORTH-MID=SPACE
```

```
                  X = 81   Y = 81   AZ = 180
                  LIGHTING-W/SQFT = LITP
                  AREA=994
                  VOLUME=10934
                  N-O-P=10
                  FLOOR-MULTIPLIER=FM  ..
    EXTWL-NORTH-MID1=EXTERIOR-WALL
                   HEIGHT=3.6
                   Z = 0
                   CONSTRUCTION=EXTWALL4   ..
    EXTWL-NORTH-MID2=EXTERIOR-WALL  ..
       WDW-NORTH=WINDOW   X = 0  ..
       WI  LIKE WDW-NORTH  X = 20  ..
       WI  LIKE WDW-NORTH  X = 40  ..
       WI  LIKE WDW-NORTH  X = 60  ..
       INTWL1-NORTH=INTERIOR-WALL INT-WALL-TYPE=STANDARD
             AREA=233
             CONSTRUCTION=PARTITION
             NEXT-TO SPACE-EAST-MID  ..
       INTWL2-NORTH=INTERIOR-WALL INT-WALL-TYPE=STANDARD
             AREA=233
             CONSTRUCTION=PARTITION
             NEXT-TO SPACE-WEST-MID  ..
       CEIL-NORTH=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
             AREA=994
             TILT=0
             CONSTRUCTION=HALFLOOR ..
       FLR-NORTH=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
            AREA=994
            TILT=180
            CONSTRUCTION=HALFLOOR  ..
$
 SPACE-EAST-MID=SPACE
                 X = 81   Y =  0  AZ = -90
                 LIGHTING-W/SQFT = LITP
                 AREA=994
                 VOLUME=10934
                 N-O-P=10
                 FLOOR-MULTIPLIER=FM ..
   EXTWL-EAST-MID=EXTERIOR-WALL
                 HEIGHT=3.6
                 Z = 0
                 CONSTRUCTION=EXTWALL4  ..
   EXTWL-EAST-MID2=EXTERIOR-WALL  ..
         WDW-EAST=WINDOW  X = 0
               GLASS-TYPE = GLASS-EW  ..
         WI  LIKE WDW-EAST  X= 20  ..
         WI  LIKE WDW-EAST  X= 40  ..
         WI  LIKE WDW-EAST  X= 60  ..
      INTWL3-EAST=INTERIOR-WALL INT-WALL-TYPE=STANDARD
            AREA=233
            CONSTRUCTION = PARTITION
            NEXT-TO   SPACE-SOUTH-MID    ..
      CEIL-EAST=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
           AREA=994
           TILT=0
```

```
           CONSTRUCTION=HALFLOOR  ..
      FLR-EAST=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
          AREA=994
          TILT=180
          CONSTRUCTION=HALFLOOR  ..
$
 SPACE-SOUTH-MID=SPACE
                 X = 0  Y = 0  AZ = 0
                 LIGHTING-W/SQFT = LITP
                 AREA=994
                 VOLUME=10934
                 N-O-P=10
                 FLOOR-MULTIPLIER=FM ..
   EXTWL-SOUTH-MID1=EXTERIOR-WALL
                  HEIGHT=3.6
                  Z = 0
                  CONSTRUCTION=EXTWALL4  ..
   EXTWL-SOUTH-MID2=EXTERIOR-WALL  ..
         WDW-SOUTH=WINDOW  X=0  ..
         WI  LIKE WDW-SOUTH  X=20  ..
         WI  LIKE WDW-SOUTH  X=40  ..
         WI  LIKE WDW-SOUTH  X=60  ..
      INTWL5-SOUTH=INTERIOR-WALL INT-WALL-TYPE=STANDARD
              AREA=233
              CONSTRUCTION=PARTITION
              NEXT-TO SPACE-WEST-MID  ..
      CEIL-SOUTH=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
            AREA=994
            TILT=0
            CONSTRUCTION=HALFLOOR   ..
      FLR-SOUTH=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
           AREA=994
           TILT=180
           CONSTRUCTION=HALFLOOR  ..
$
 SPACE-WEST-MID=SPACE
                X = 0  Y = 81  AZ = 90
                LIGHTING-W/SQFT = LITP
                AREA=994
                VOLUME=10934
                N-O-P=10
                FLOOR-MULTIPLIER=FM  ..
   EXTWL-WEST-MID1=EXTERIOR-WALL
                 HEIGHT=3.6
                  Z = 0
                 CONSTRUCTION=EXTWALL4   ..
   EXTWL-WEST-MID2=EXTERIOR-WALL  ..
         WDW-WEST=WINDOW  X = 0
               GLASS-TYPE = GLASS-EW  ..
         WI  LIKE WDW-WEST  X = 20  ..
         WI  LIKE WDW-WEST  X = 40  ..
         WI  LIKE WDW-WEST  X = 60  ..
      CEIL-WEST=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
           AREA=944
           CONSTRUCTION=HALFLOOR
           TILT=0  ..
```

```
      FLR-WEST=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
          AREA=994
          CONSTRUCTION=HALFLOOR
          TILT=180              ..
$
 SPACE-CORE=SPACE
            DAYLIGHTING = NO
            AREA=1570
            VOLUME=17427
            N-O-P=16
            FLOOR-MULTIPLIER=FM  ..
      INTWL-CORE-NORTH=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                  AREA=566
                  CONSTRUCTION=PARTITION
                  NEXT-TO SPACE-NORTH-MID  ..
      INTWL-CORE-EAST=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-EAST-MID  ..
      INTWL-CORE-SOUTH=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                  AREA=566
                  CONSTRUCTION=PARTITION
                  NEXT-TO SPACE-SOUTH-MID  ..
      INTWL-CORE-WEST=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-WEST-MID   ..
      CEIL-CORE=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
           TILT=0
           AREA=1570
           CONSTRUCTION=HALFLOOR    ..
      FLR-CORE=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
          TILT=180
          AREA=1570
          CONSTRUCTION=HALFLOOR   ..

                                  $ TOP FLOOR $
$
 SPACE-NORTH-TOP=SPACE
                 X = 81  Y = 81  AZ = 180
                 LIGHTING-W/SQFT = LITP
                 AREA=994
                 VOLUME=10934
                 N-O-P=10 ..
   EXTWL-NORTH-TOP1=EXTERIOR-WALL
                  HEIGHT=3.6
                  Z = 0
                  CONSTRUCTION=EXTWALL4  ..
   EXTWL-NORTH-TOP2=EXTERIOR-WALL  ..
         WDW-NORTH-TOP=WINDOW  X = 0  ..
         WI  LIKE WDW-NORTH-TOP  X = 20  ..
         WI  LIKE WDW-NORTH-TOP  X = 40  ..
         WI  LIKE WDW-NORTH-TOP  X = 60  ..
 ROOF-TOP=EXTERIOR-WALL
          TILT=0
          CONSTRUCTION=ROOFCON
```

```
          HEIGHT=20
          WIDTH=50  ..
      INTWL-NORTH-TOP=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=233
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-EAST-TOP ..
      INTWL-NORTH-TOP2=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                  AREA=233
                  CONSTRUCTION=PARTITION
                  NEXT-TO SPACE-WEST-TOP ..
      FLR-NORTH-TOP=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
              TILT=180
              AREA=994
              CONSTRUCTION=HALFLOOR ..
$
 SPACE-EAST-TOP=SPACE
                X = 81  Y = 0  AZ = -90
                LIGHTING-W/SQFT = LITP
                AREA=944
                VOLUME=10934
                N-O-P=10  ..
   EXTWL-EAST-TOP1=EXTERIOR-WALL
                 HEIGHT=3.6
                  Z = 0
                 CONSTRUCTION=EXTWALL4  ..
   EXTWL-EAST-TOP2=EXTERIOR-WALL  ..
         WDW-EAST-TOP=WINDOW  X = 0
                   GLASS-TYPE = GLASS-EW ..
         WI  LIKE WDW-EAST-TOP  X = 20  ..
         WI  LIKE WDW-EAST-TOP  X = 40  ..
         WI  LIKE WDW-EAST-TOP  X = 60  ..
 ROOF-EAST-TOP=EXTERIOR-WALL
               TILT=0
               CONSTRUCTION=ROOFCON
               HEIGHT=20
               WIDTH=50  ..
      INTWL-EAST-TOP=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                AREA=233
                CONSTRUCTION=PARTITION
                NEXT-TO SPACE-SOUTH-TOP  ..
      FLR-EAST-TOP=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
             TILT=180
             AREA=994
             CONSTRUCTION=HALFLOOR ..
$
 SPACE-SOUTH-TOP=SPACE
                 X = 0  Y = 0  AZ = 0
                 LIGHTING-W/SQFT = LITP
                 AREA=994
                 VOLUME=10934
                 N-O-P=10  ..
   EXTWL-SOUTH-TOP1=EXTERIOR-WALL
                  HEIGHT=3.6
                  Z = 0
                  CONSTRUCTION=EXTWALL4  ..
   EXTWL-SOUTH-TOP2=EXTERIOR-WALL  ..
```

```
         WDW-SOUTH-TOP=WINDOW   X = 0  ..
         WI  LIKE WDW-SOUTH-TOP  X = 20  ..
         WI  LIKE WDW-SOUTH-TOP  X = 40  ..
         WI  LIKE WDW-SOUTH-TOP  X = 60  ..
 ROOF-TOP-SOUTH=EXTERIOR-WALL
                TILT=0
                HEIGHT=20
                WIDTH=50
                CONSTRUCTION=ROOFCON  ..
      INTWL-SOUTH-TOP=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=233
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-WEST-TOP  ..
      FLR-SOUTH-TOP=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
              TILT=180
              AREA=994
              CONSTRUCTION=HALFLOOR  ..
$
 SPACE-WEST-TOP=SPACE
                X = 0  Y = 81  AZ = 90
                LIGHTING-W/SQFT = LITP
                AREA=994
                VOLUME=10934
                N-O-P=10  ..
   EXTWL-WEST-TOP1=EXTERIOR-WALL
                 HEIGHT=3.6
                 CONSTRUCTION=EXTWALL4
                 Z = 0  ..
   EXTWL-WEST-TOP2=EXTERIOR-WALL  ..
         WDW-WEST-TOP=WINDOW  X = 0
               GLASS-TYPE = GLASS-EW ..
         WI  LIKE WDW-WEST-TOP  X = 20  ..
         WI  LIKE WDW-WEST-TOP  X = 40  ..
         WI  LIKE WDW-WEST-TOP  X = 60  ..
 ROOF-TOP-WEST=EXTERIOR-WALL
               TILT=0
               CONSTRUCTION=ROOFCON
               HEIGHT=20
               WIDTH=50  ..
      FLR-WEST-TOP=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
             TILT=180
             AREA=994
             CONSTRUCTION=HALFLOOR ..
$
 SPACE-CORE-TOP=SPACE
                DAYLIGHTING = NO
                AREA=1570
                VOLUME=17427
                N-O-P=16 ..
 ROOF-CORE-TOP=EXTERIOR-WALL
               TILT=0
               CONSTRUCTION=ROOFCON
               HEIGHT=40
               WIDTH=50  ..
      INTWL-CORE-NTOP=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
```

```
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-NORTH-TOP  ..
      INTWL-CORE-ETOP=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-EAST-TOP  ..
      INTWL-CORE-STOP=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-SOUTH-TOP  ..
      INTWL-CORE-WTOP=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-WEST-TOP ..
      FLR-CORE-TOP=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
             AREA=2000
             TILT=180
             CONSTRUCTION=HALFLOOR ..
                                   $ GROUND FLOOR $
$
 SPACE-NORTH-GND=SPACE
                 X= 81  Y= 81  AZ = 180
                 LIGHTING-W/SQFT = LITP
                 AREA=994
                 VOLUME=10934
                 N-O-P=10 ..
   EXTWL-NORTH-GND=EXTERIOR-WALL
                 HEIGHT=3.6
                 Z = 0
                 CONSTRUCTION=EXTWALL4  ..
   EXTWL-NORTH-GND2=EXTERIOR-WALL  ..
         WDW-NORTH-GND=WINDOW  X = 0  ..
         WI  LIKE WDW-NORTH-GND  X = 20  ..
         WI  LIKE WDW-NORTH-GND  X = 40  ..
         WI  LIKE WDW-NORTH-GND  X = 60  ..
      FLR-NORTH-GND=UNDERGROUND-FLOOR
               TILT=180
               U-EFFECTIVE=.028
               CONSTRUCTION=UFLOORS
               AREA=994 ..
      CEIL-NORTH-GND=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
               TILT=0
               CONSTRUCTION=HALFLOOR
               AREA=994 ..
      INTWL-NORTH-GND=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=233
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-EAST-GND ..
      INTWL-NORTH-GND2=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                  AREA=233
                  CONSTRUCTION=PARTITION
                  NEXT-TO SPACE-WEST-GND  ..
$
 SPACE-EAST-GND=SPACE
                X = 81  Y = 0  AZ = -90
                LIGHTING-W/SQFT = LITP
```

```
                 AREA=994
                 VOLUME=10934
                 N-O-P=10 ..
   EXTWL-EAST-GND=EXTERIOR-WALL
                 HEIGHT=3.6
                 Z = 0
                 CONSTRUCTION=EXTWALL4 ..
   EXTWL-EAST-GND2=EXTERIOR-WALL  ..
           WDW-EAST-GND=WINDOW  X = 0
               GLASS-TYPE = GLASS-EW ..
           WI  LIKE WDW-EAST-GND  X = 20  ..
           WI  LIKE WDW-EAST-GND  X = 40  ..
           WI  LIKE WDW-EAST-GND  X = 60  ..
 FLOOR-EAST-GND=UNDERGROUND-FLOOR
                 TILT=180
                 U-EFFECTIVE=.028
                 AREA=994
                 CONSTRUCTION=UFLOORS ..
      CEIL-EAST-GND=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
              TILT=0
              AREA=994
              CONSTRUCTION=HALFLOOR ..
      INTWL-EAST-GND=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=233
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-SOUTH-GND ..
$
 SPACE-SOUTH-GND=SPACE
                  X = 0  Y = 0  AZ = 0
                  LIGHTING-W/SQFT = LITP
                  AREA=994
                  VOLUME=10934
                 N-O-P=10 ..
   EXTWL-SOUTH-GND=EXTERIOR-WALL
                  HEIGHT=3.6
                  Z = 0
                  CONSTRUCTION=EXTWALL4  ..
   EXTWL-SOUTH-GND2=EXTERIOR-WALL  ..
           WDW-SOUTH-GND=WINDOW  X = 0  ..
           WI  LIKE WDW-SOUTH-GND  X = 20  ..
           WI  LIKE WDW-SOUTH-GND  X = 40  ..
           WI  LIKE WDW-SOUTH-GND  X = 60  ..
 FLOOR-GND-SOUTH=UNDERGROUND-FLOOR
                  CONSTRUCTION=UFLOORS
                  U-EFFECTIVE=.028
                  TILT=180
                  AREA=994 ..
      CEIL-SOUTH-GND=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
                TILT=0
                AREA=994
                CONSTRUCTION=HALFLOOR ..
      INTWL-SOUTH-GND=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                  AREA=233
                  CONSTRUCTION=PARTITION
                  NEXT-TO SPACE-WEST-GND ..
$
```

```
 SPACE-WEST-GND=SPACE
                 X = 0  Y = 81  AZ = 90
                 LIGHTING-W/SQFT = LITP
                AREA=994
                VOLUME=10934
                N-O-P=10 ..
   EXTWL-WEST-GND=EXTERIOR-WALL
                HEIGHT=3.6
                Z = 0
                CONSTRUCTION=EXTWALL4  ..
EXTWALL-WEST-GND2=EXTERIOR-WALL  ..
         WDW-WEST-GND=WINDOW  X = 0
              GLASS-TYPE = GLASS-EW ..
         WI  LIKE WDW-WEST-GND  X = 20  ..
         WI  LIKE WDW-WEST-GND  X = 40  ..
         WI  LIKE WDW-WEST-GND  X = 60  ..
 FLOOR-WEST-GND=UNDERGROUND-FLOOR
                TILT=180
                U-EFFECTIVE=.028
                AREA=994
                CONSTRUCTION=UFLOORS ..
      CEIL-WEST-GND=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
              TILT=0
              AREA=994
              CONSTRUCTION=HALFLOOR ..
$
 SPACE-CORE-GND=SPACE
                DAYLIGHTING = NO
                AREA=1570
                VOLUME=17427
                N-O-P=16 ..
 FLOOR-INT-GND=UNDERGROUND-FLOOR
               TILT=180
               CONSTRUCTION=UFLOORS
               U-EFFECTIVE=.02
               AREA=1570 ..
      CEIL-CORE-GND=INTERIOR-WALL INT-WALL-TYPE=ADIABATIC
              TILT=0
              AREA=1570
              CONSTRUCTION=HALFLOOR ..
      INTWL-CORE-GND1=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-NORTH-GND ..
      INTWL-CORE-GND2=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-EAST-GND ..
      INTWL-CORE-GNDS=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-SOUTH-GND ..
 INTWL-CORE-GNDW=INTERIOR-WALL INT-WALL-TYPE=STANDARD
                 AREA=566
                 CONSTRUCTION=PARTITION
                 NEXT-TO SPACE-WEST-GND ..
```

```
$
 END                    ..
 COMPUTE LOADS                ..
 $  ==========================================  $
 $
 $                      SYSTEMS
 $
 $  ==========================================  $
 $
 INPUT SYSTEMS   ..
 SYSTEMS-REPORT  VERIFICATION = (SV-A)
                 SUMMARY = (SS-A,SS-H,SS-I,SS-J,SS-M,SS-N,SS-O)
                ..
 $
 $  ============  SYSTEMS PARAMETERS  =============  $
 $
    PARAMETER
        MINAIRSB = -999.
$ HOURLY SCHEDULE TEMPERATURES  $
        T4 = 99
        T5 = 99
        T6 = 99
        T7 = 77
        T8 = 77
$  HOURLY FAN SCHEDULE RATIOS  $
        F4 = 0
        F5 = 0
        F6 = 0
        CDECK = 55
        CC = WARMEST
        T-COOL = 75.2
        T-COOL-SETBAK = 99
        OA-RATE = 7
        OA-CONT = FIXED  $ NO ECONOMIZER $
        NCC = STAY-OFF
        MINCFM = .5
        FC = INLET
        FANEFF = .49  $ FORWARD-CURVED W/ INLET VANE CONTROL $
                ..
$  ===============================================  $
    FS-1 = DAY-SCHEDULE
            (1,6)   (0,0,0,F4,F5,F6)
            (7,17)  (1)
            (18,24) (0)     ..
 $
        FS-2 = DAY-SCHEDULE
                (1,24)  (0)       ..
        FS-3=DAY-SCHEDULE
              (1,6) (0) (7,12) (1) (13,24)(0) ..
 $
 $
        FW-1 = WEEK-SCHEDULE
                (WD)    FS-1
               (SAT) FS-3
               (HOL) FS-2
                (SUN)   FS-2      ..
```

```
 $
 $
        FAN-1 = SCHEDULE
                THRU DEC 31   FW-1   ..
 $
        HEAT-1 = SCHEDULE
                 THRU DEC 31     (ALL)
                    (1,24)       (0)     ..
 $
        COOL-1 = SCHEDULE
                 THRU DEC 31     (ALL)
                     (1,24)      (1)     ..
$
   MINAIR-1    = SCHEDULE
                 THRU DEC 31     (ALL)
                 (1,6) (0)   (7,8) (MINAIRSB)
                 (9,17)      (-999.)
                 (18,24)     (0)      ..
 $
 $  ---------------    TEMPERATURE SCHEDULE    ---------------  \$
 $
        OFC-SCH-C = SCHEDULE
                    THRU DEC 31
                    (MON,FRI)   (1,3)   (T-COOL-SETBAK)
                                (4,8)   (T4,T5,T6,T7,T8)
                                (9,17)  (T-COOL)
                                (18,24) (T-COOL-SETBAK)
                    (SAT)       (1,6)   (T-COOL-SETBAK)
                                (7,12)  (T-COOL)
                                (13,24) (T-COOL-SETBAK)
                    (SUN,HOL)   (1,24)  (T-COOL-SETBAK)    ..
 $  ---------------    SYSTEM DESCRIPTION     ---------------  $
 $
 $  ----    VAV SYSTEM ALTERED TO BE CONSTANT VOLUME    ----  $
 $
    SET-DEFAULT FOR ZONE
        OA-CFM/PER = OA-RATE
        CFM/SQFT=0.75  ..
 $
    ZCONTROL-1 = ZONE-CONTROL
            DESIGN-HEAT-T       =   72
            DESIGN-COOL-T       =   74
            COOL-TEMP-SCH       =   OFC-SCH-C
            T-TYPE              =   PROPORTIONAL
            THROTTLING-RANGE    =   2
                        ..
 $
    SPACE-NORTH-MID = ZONE
            ZONE-TYPE       =   CONDITIONED
            ZONE-CONTROL    =   ZCONTROL-1
                   ..
    SPACE-EAST-MID = ZONE
            ZONE-TYPE       =   CONDITIONED
            ZONE-CONTROL    =   ZCONTROL-1
                   ..
    SPACE-WEST-MID = ZONE
```

```
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-SOUTH-MID = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-CORE = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
$
   SPACE-NORTH-TOP = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-EAST-TOP = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-WEST-TOP = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-SOUTH-TOP = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-CORE-TOP = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
$
   SPACE-NORTH-GND = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-EAST-GND = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-WEST-GND = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-SOUTH-GND = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
   SPACE-CORE-GND = ZONE
           ZONE-TYPE       =   CONDITIONED
           ZONE-CONTROL    =   ZCONTROL-1
                   ..
$  --------------   SYSTEM CONTROLS   ------------------  \$
$
   SCONTROL-1 = SYSTEM-CONTROL
```

```
        MIN-SUPPLY-T          =   CDECK
        COOL-CONTROL          =   CC
        HEATING-SCHEDULE      =   HEAT-1
        COOLING-SCHEDULE      =   COOL-1
                    ..
$
    SFANS-1 = SYSTEM-FANS
        FAN-SCHEDULE          =   FAN-1
        FAN-CONTROL           =   FC
        N-C-C                 =   NCC
                    ..
$
    VAV1 = SYSTEM
        SYSTEM-TYPE           =   VAVS
        SYSTEM-CONTROL        =   SCONTROL-1
        SYSTEM-FANS           =   SFANS-1
        MIN-AIR-SCH           =   MINAIR-1
        OA-CONTROL            =   OA-CONT
        SUPPLY-STATIC         =   3.0
        SUPPLY-EFF            =   FANEFF
        SUPPLY-DELTA-T        =   2
        SIZING-RATIO          =   1.0
        SIZING-OPTION         =   NON-COINCIDENT
        MIN-CFM-RATIO         =   MINCFM
        RETURN-AIR-PATH       =   DUCT
        ZONE-NAMES            =   (SPACE-NORTH-TOP,
                                  SPACE-NORTH-MID,
                                  SPACE-NORTH-GND)
           ..
   VAV2 = SYSTEM
          LIKE VAV1
          ZONE-NAMES          =   (SPACE-EAST-MID,
                                  SPACE-EAST-TOP,
                                  SPACE-EAST-GND)
           ..
   VAV3 = SYSTEM
          LIKE VAV1
          ZONE-NAMES          =   (SPACE-SOUTH-MID,
                                  SPACE-SOUTH-TOP,
                                  SPACE-SOUTH-GND)
           ..
   VAV4 = SYSTEM
          LIKE VAV1
          ZONE-NAMES           =  (SPACE-WEST-MID,
                                  SPACE-WEST-TOP,
                                  SPACE-WEST-GND)
           ..
   VAV5 = SYSTEM
          LIKE VAV1
          ZONE-NAMES           =  (SPACE-CORE,
                                  SPACE-CORE-TOP,
                                  SPACE-CORE-GND)
                    ..
$
    PL1 = PLANT-ASSIGNMENT
            SYSTEM-NAMES      =   (VAV1,VAV2,VAV3,VAV4,VAV5)   ..
```

```
 $
 END                ..
 COMPUTE SYSTEMS    ..
 $
 $
 $  ---------------------------------------------------------  \$
 $
 $                   PLANT SIMULATION
 $
 $  ---------------------------------------------------------  \$
 $
            INPUT PLANT         ..
 $
    PLANT-REPORT        SUMMARY = (ALL-SUMMARY)   ..
 $
    PL1 = PLANT-ASSIGNMENT           ..
 $
 $  ------------  PLANT PARAMETERS  ----------------------  $
 $
    PARAMETER
               IN      =   1
               CTYPE   =   HERM-CENT-CHLR
               EIR     =   .24
                ..
 $  ------------   PLANT DESCRIPTION   ------------------  \$
 $
    CHILLER = PLANT-EQUIPMENT
        TYPE    =   CTYPE
        SIZE    =   -999
        I-N     =   IN
        M-N-A   =   IN
                ..
 $
   PART-LOAD-RATIO
        TYPE    =   CTYPE
        E-I-R   =   EIR
               ..
$
   PLANT-PARAMETERS
        TWR-DESIGN-WETBULB = 82
                ..
 END            ..
 LIST NO-ECHO  ..
 COMPUTE PLANT  ..
 STOP           ..
^EOR
```

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720