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Asean-Usaid Buildings Energy Conservation Project Final Report Volume I: Energy Standards

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Publication Date

1992-06-01

ASEAN-USAID

Buildings Energy Conservation Project

FINAL REPORT

VOLUME I: ENERGY STANDARDS

Series Editors: M.D. Levine and J.F. Busch
Principal Authors: J.J. Deringer and J.F. Busch
Energy Analysis Program
Energy and Environment Division

June 1992

Association of
South East Asian Nations

Lawrence Berkeley
Laboratory

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LBL-32380
Vol. I
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Association of
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Secretariat:
Jakarta, Indonesia

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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.

ACKNOWLEDGMENTS

Joe Deringer and John Busch are the principal authors of this volume. Mark D. Levine and John Busch, serving as series editors, participated in the organization and review of the entire volume. Karen H. Olson provided valuable editorial assistance. The following individuals contributed written material to individual chapters, as identified:

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PREFACE

THE ASEAN-USAID BUILDINGS ENERGY CONSERVATION PROJECT

Energy Standards is the first in a series of three volumes that culminate an eight-year effort to promote building energy efficiency in five of the six members of the Association of Southeast Asian Nations (ASEAN). The Buildings Energy Conservation Project was one of three energy-related sub-projects sponsored by the United States Agency for International Development (USAID) as a result of the Fourth ASEAN-US Dialogue on Development Cooperation in March 1982. It was conceived as a broad and integrated approach to the problem of bringing about cost-effective energy conservation in Indonesia, Malaysia, the Philippines, Singapore, and Thailand (Brunei was the one ASEAN member nation that did not participate).

This volume summarizes intensive efforts that have resulted in new commercial building standard proposals for four ASEAN countries and revision of the existing Singapore standard. Further findings of the ASEAN-USAID Project are collected in the remaining two volumes of this series, which cover the following topics in depth:

- Volume II - *Technology* is a compilation of papers that report on specific energy efficiency technologies in the ASEAN environment.
- Volume III - *Audits* presents the results of audits that were performed on a large sample of ASEAN commercial buildings. This information was used to create an ASEAN-wide energy use database. The research was largely conducted by ASEAN analysts and professionals in local universities and government institutions.

PROJECT PHILOSOPHY AND CONTEXT

Underlying every aspect of the ASEAN-USAID Buildings Energy Conservation Project was a recognition that there were significant social, economic, and environmental benefits to be gained through enhanced energy efficiency. For the ASEAN nations, as for developing countries all over the world, the processes of modernization and industrialization have been accompanied by rapid growth in energy consumption. In the ASEAN region, commercial energy consumption grew from 27 to 85 million tons of oil equivalent (Mtoe), a factor of 3.15, during the period from 1970 to 1987. Electricity consumption increased from 20 to 101 billion kilowatt hours (kWh), or by a factor of five. Both growth rates were substantially in excess of the growth of economic productivity in the region; gross domestic product (GDP) increased by a factor of 2.5 during the same period.

While energy consumption has traditionally been regarded, and encouraged, as a vital input and stimulant of economic growth, the experiences of many of the industrialized nations recently have demonstrated the potential for decoupling economic growth rates from energy consumption growth rates. The benefits of this decoupling in an era of expensive energy sources, limited financial and natural resources, and critical global and local environmental stresses are also increasingly recognized. By supporting efforts toward improved energy efficiency through the ASEAN-USAID Project, the larger hope was to realize the potential for:

- Reduced growth of electricity demand to free capital for other uses, while avoiding the environmental externalities associated with power generation,
- Lower oil imports for many ASEAN countries to reduce balance of payments problems, and
- Money saved on electricity bills to be put to more productive uses.

The ASEAN-USAID Project targeted energy conservation in buildings because growth of electricity consumption in this sector has been particularly rapid throughout the region. In 1970, residential buildings in ASEAN consumed approximately 3.5 billion kWh and commercial buildings, 4.3 billion kWh. By 1987, these figures had grown to 22 billion kWh and 23 billion kWh, respectively. Thus, buildings in ASEAN—residential and commercial—currently make up 45% of the demand for electricity in the region. Their consumption has grown almost six-fold during this 17-year period, or at an annual rate of 10.9%.*

One of the immediate implications of increasing energy consumption is financial expense. The total annual cost of electricity for buildings in ASEAN (45 billion kWh) is about $4 billion (U.S.), and if industrial buildings, self-generation, and "public consumption" are counted, the total annual bill may be as high as $5 billion (U.S.). Since electricity consumption in buildings has grown rapidly and is likely to continue to do so, utility costs in the sector are likely to increase markedly over time. Because buildings represent such a significant fraction of electricity consumption in the region, they represent an important target sector for national efforts aimed at reaping the economic and environmental benefits of increased energy efficiency.

The ASEAN-USAID Project focussed on commercial buildings because of the magnitude of potential savings in this energy use sector. As described in greater detail elsewhere in this series, the potential for electricity savings in commercial buildings is significant:

- 10% savings achievable in the near term,
- 20% savings achievable in the intermediate term (5 to 10 years), and
- 40% or more savings achievable in the longer term.

A 10% reduction in commercial building energy use in ASEAN represents $200 million (U.S.) savings in fuel bills per year. Deducting the costs of investments needed to achieve these savings yields net annual savings to ASEAN of $100 to $150 million (U.S.).

A BRIEF HISTORY OF THE ASEAN-USAID BUILDINGS ENERGY CONSERVATION PROJECT

The first phase of the Project was initiated in 1982 with a collaboration by U.S. researchers at Lawrence Berkeley Laboratory (LBL) and the Singapore government. This first effort had several purposes, namely:

- to transfer to Singapore a computer code (DOE-2) to analyze the energy performance of buildings,
- to analyze measures to increase the energy efficiency of buildings in Singapore,
- to use the analysis results to extend and enhance Singapore's standards on energy efficiency in buildings, and
- to establish a process whereby the other ASEAN members can benefit from the experience in Singapore, including the use of DOE-2, the analysis to support energy standards, and the process of adapting and implementing building energy standards.

Detailed results of this first phase were presented at a conference in Singapore in May 1984. The proceedings from this conference are available in a separately bound volume. They include technical studies supporting recommended overall thermal transfer value (OTTV) refinements as well as energy performance simulation results, descriptions of existing energy conservation activities within ASEAN, and papers on several topics related to energy conservation in commercial buildings.

With the initiation of a second phase in 1985, the focus of the ASEAN-USAID Project was expanded to include the other participating ASEAN nations. Its purpose remained to promote the development and implementation of policies to improve the energy efficiency of commercial buildings. In pursuit of this goal, the Project funded 22 different research sub-projects within the five

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* Indeed, these consumption estimates underestimate the actual electricity demand attributable to buildings for at least three reasons: (1) a sizeable portion of industrial electricity consumption is for building services, (2) electricity generated on site, either as backup power or for normal use, is counted as self-production even if it is used in buildings, and (3) the category "public electricity consumption" may include considerable use of electricity in buildings. Thus, it is likely that buildings in ASEAN account for considerably more than 45% of total electricity demand—probably in the range of 55 to 60%.

participating ASEAN countries. The current series represents a compilation and synthesis of several of the many research papers that grew out of the overall Project.

Since its inception, the ASEAN-USAID Project has provided training to ASEAN participants, supported research projects throughout ASEAN, conducted research at LBL, and engaged U.S. consultants to work with ASEAN governments and private sector participants to design programs and policies. Within the Project, a key policy focus has been the application of technical tools to the development and assessment of efficiency standards and guidelines. The Project has stressed training (especially in computer simulation of building energy use and energy auditing) and the enhancement of research and development capabilities in ASEAN. Much of the data gathering, analysis, and research activity conducted under Project auspices was directed toward the eventual implementation of energy efficiency standards for ASEAN commercial buildings.

CHAPTER 1: ASEAN STANDARDS: AN OVERVIEW

INTRODUCTION

Mandatory or voluntary energy-efficiency standards for new or existing buildings can play an important role in a national program aimed at promoting energy conservation. Building codes and standards can provide a degree of control over design and building practices throughout the construction process, and encourage awareness of energy-conscious design. Studies in developed countries indicate that efficiency standards can produce energy reductions on the order of 20 to 40% or more [1, 2, 3]. Within ASEAN, analyses of the savings potential from the proposed standards suggest that if implemented, these standards would produce savings over current new design practice of 19% to 24%*.

In this volume we provide an overview of the ASEAN-USAID project aimed at promulgating standards for energy efficiency in commercial buildings. The process of developing and implementing energy-efficiency standards for buildings can be subdivided into two key components: policy development; and technical and economic analysis. Each of these involves a number of steps and processes, as outlined in Figure 1-1.

This volume describes the technical and economic analyses used to develop the proposed energy-efficiency standards for four countries (Malaysia, Thailand, the Philippines, and Indonesia), and to refine an energy standard existing in Singapore since 1979. Though oriented toward the ASEAN region, the analysis methods described here are applicable in a range of settings, provided appropriate modifications are made for local building construction, climatic, economic, and political conditions. (See Appendix A for further discussion of the policy development component.) Implementation issues are not specifically addressed here; rather this volume is oriented towards the analytical work needed to establish or revise an energy standard for buildings.

TECHNICAL AND ECONOMIC ANALYSIS

Analyses for the development of viable and cost-effective energy standards must accurately estimate the energy and economic impacts of various efficiency measures, relative to current construction practices. Typical products of such analyses include:

1) Parametric studies of key conservation measures, such as window shading or roof insulation that affects the envelope overall thermal transmission value (OTTV) criteria, increased air-conditioning and air-handling efficiency, more efficient lights, etc.;

2) Estimates of energy savings that will occur from implementing the standards; and

3) Estimates of the cost-effectiveness of the requirements in the standards.

One approach used widely in both the United States and ASEAN is to perform such assessments using computer-based simulations. To conduct the various analyses with sufficient accuracy, three fundamental elements must be in place:

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* Tighter standards, established to ensure the application of all widely applicable and cost-effective efficiency measures could reduce energy in new buildings in ASEAN by as much as 50%. However, no ASEAN country has yet chosen to pursue such a stringent standard or guideline at present. Experience with very energy-efficient buildings is a prerequisite for increasing the stringency of energy standards.

- An accurate energy-simulation tool;
- Hourly local weather data over a period of at least one year; and
- "Typical" building descriptions that represent current construction practices.

The following three chapters describe how each of these three analysis elements was developed for the various ASEAN standards analyses. The choice of energy analysis tool defines the type and detail of information needed for both weather data and for typical buildings.

Weather Data

A good, recent set of weather data is needed to properly assess building energy use. Current state-of-the art energy-simulation programs use hourly data for temperature, humidity, wind speed and direction, and direct and diffuse solar radiation intensity. Frequently, most of the basic data exist, but are in a format that cannot be used by the simulation tools.* Thus, a first analysis task in four of the ASEAN countries was to assemble the existing data and to convert them into a format compatible with the selected energy-simulation program.

Other times, the necessary data did not exist at all and approximations were made. In Kuala Lumpur, Malaysia, for example, lack of local solar radiation intensity data led to the use of solar data from nearby Singapore to supplement existing Malaysian data for temperature, humidity, and wind. In other cases, primary weather data were collected with sophisticated weather-sensing equipment. Solar data for Jakarta and Bandung, Indonesia, were obtained in this way.

Building Descriptions

Typical building descriptions are required for use with the energy-simulation programs. Because there are so little detailed data about building characteristics, most typical building descriptions are generated using professional judgment. Such judgment is either used to generate prototypes or reference buildings, or to select one or more actual buildings as reasonably typical. If possible, the typical buildings should be based on a review of data for sample buildings obtained from energy surveys and audits. The sample could include buildings from categories with large construction volumes, such as office buildings, hotels, shopping complexes, and hospitals.

Energy and Economic Analyses

Energy simulations can be performed using the typical building descriptions and a set of building operating conditions. Because data describing operating conditions are generally not available, expert judgement is needed for this set of inputs as well. The results of the simulations should be compared with utility bills to check for accuracy and completeness.

Costs and economic impacts, in addition to strictly energy-related data are important considerations in the standards development process. It is necessary to calculate the energy costs for buildings with different combinations of energy conservation measures. The relative construction costs of each building case can then be compared to the changes in energy costs to determine relative cost-effectiveness.

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* Hourly measurements of diffuse solar radiation are often not available. Such data are important for assessing the possible contribution of daylighting.

Feedback to Standards Development

The intent of the energy and economic analysis is to provide an solid basis for policy decisions. Needed information includes energy impacts of various energy measures on the current building stock and the energy and cost-effectiveness of the proposed energy standards.

STATUS OF STANDARDS DEVELOPMENT IN ASEAN

At the inception of the ASEAN-USAID Buildings Energy Conservation Project, Singapore was the only ASEAN country that had implemented a building energy standard. Partly because of the success of such standards in Singapore, and elsewhere, energy standards development was identified as a major energy-conservation policy initiative for the project. Currently, Singapore is well into the process of revising its standard; the other four countries have made major progress towards implementing a first building energy standard. The status of the various ASEAN countries in the standards development process is summarized in Table 1-1 and described below.

Standards Policy Development

All countries have formed policy/review committees, which have developed country-specific draft energy standards. Major inputs to these proposals came from the Singapore standard and a draft model standard prepared by the LBL team. This draft model was based on the latest ASHRAE materials from the 1986 draft of 90.1P, tailored specifically to ASEAN conditions.

Standards Analysis

All countries have developed sufficient weather data and typical building descriptions. These were then used, in conjunction with the criteria contained in the draft standards, to generate energy simulations. Thailand accomplished its analyses with in-country skills and focused on analysis of building envelope performance (OTTV). Malaysia, the Philippines, and Indonesia executed energy analyses in collaboration with LBL analysts. These analyses focused primarily on large office buildings, although the Philippines analysis also examined large hotel buildings. The Philippines used the extensive 50+ building database developed in the course of this project to provide a solid statistical basis for describing a typical office building and hotel. The other countries relied on a combination of data and professional judgment for typical building descriptions needed to perform the energy simulations. Cost and economic analyses have been performed as part of the Malaysian analysis, and were partly accomplished for the Indonesian analysis.

At the time of this writing, the standards development committees in the various countries are presently either in the process of reviewing draft standards or in the process of adopting them.

CONCLUSION

This volume describes the process by which energy-efficiency standards for commercial buildings have been developed in ASEAN. Chapters 2, 3, and 4 cover methodological issues related to gathering and processing data. Chapter 5 describes the potential impact standards can have in the ASEAN region. Chapter 6 reviews the energy conservation provisions included in ASEAN standards to date, including lighting, air-conditioning, and electric power and distribution. Chapters 7 and 8 take a much more detailed look at provisions addressing the energy performance of the building envelope, i.e., requirements for Overall Thermal Transfer Value, on which the most work has been done in the project. These technical chapters review the original formulation of the OTTV standards in ASHRAE and in Singapore, the subsequent modifications of those standards, and the rationale behind the changes.

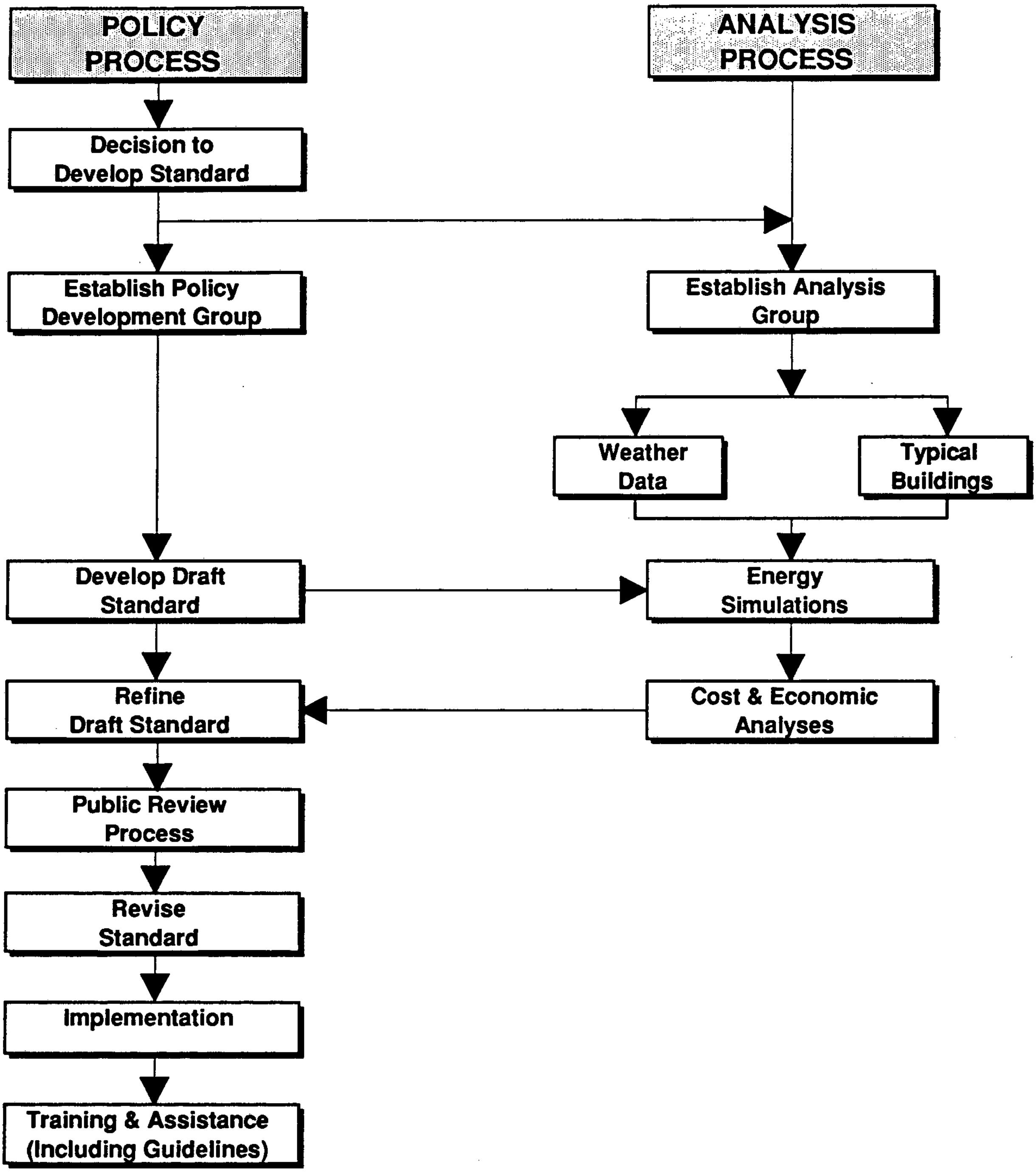

FIGURE 1-1. DEVELOPMENT PROCESS FOR BUILDING ENERGY STANDARDS

TABLE 1-1. COMMERCIAL BUILDING ENERGY EFFICIENCY STANDARDS - DEVELOPMENT STATUS (as of 1992)

Region & Country		Scope			Development Status					
		New	Existing	Type	Draft Standard	Energy Analysis	Estimated Reduction (%)	Economic Analysis	Adopted	Imple- mented
USA	**USA**	90-75					35%-40%	Ref. [1]	1975	Late 70s
	USA	90.1					15%-30%	Ref. [3]		1990
S.E. ASIA	**Singapore**	Yes	Yes	Mandatory		1984	~20%	Ref. [8]		1979
	Malaysia	Yes		Voluntary		1987	18%	Ref. [13]	1989	Pending
	Thailand	Yes		Voluntary	Yes	1990	23%		1992	Pending
	Philippines	Yes		Voluntary	Yes	1989	21%	Planned	Pending	Pending
	Indonesia	Yes		Voluntary	Yes	1989	24%	Ongoing	Pending	Pending

CHAPTER 2: ENERGY SIMULATION TOOL

INTRODUCTION

To assess the potential energy and cost savings of energy standards for buildings, researchers need to accurately estimate the energy impacts of building designs prior to construction or retrofit. A number of computer-based energy-simulation tools can provide such estimates. This chapter describes one such tool in particular: the DOE-2 building energy simulation program [4], which estimates the total and component energy consumption associated with a particular building design. This program is widely respected for its accuracy, extensive features, and availability as a "public domain"* tool.

WHAT IS ENERGY SIMULATION?

A building's thermodynamics involves nonlinear flows of heat through and among all of its surfaces and enclosed volumes. These flows are driven by a variety of heat sources and time variations (e.g., the sun, the lights, the occupants, and various types of equipment). A computer simulation program, like DOE-2, simulates a building's thermodynamic behavior with mathematical equations that represent both complex boundary and initial conditions.

The simulation process in DOE-2 is performed through four sequential programs. The first program (called LOADS) uses weather data, building envelope characteristics, and the occupancy schedule to calculate the heating addition and/or cooling extraction rates that occur in 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, and other uses to maintain temperature and humidity set points. In addition, control equipment, heating, ventilating, and air-conditioning (HVAC) auxiliary equipment, and energy-recovery equipment are also evaluated within the SYSTEMS program. The third program (PLANT) simulates the behavior of the primary HVAC systems (boilers, chillers, cooling towers, etc.) in meeting these demands calculated by the SYSTEMS program. The final program (ECONOMICS) simulates the energy costs incurred through consumption of electricity and other fuels, with the capability of modeling complex tariff structures.

The program's features have been expanded over time and new versions have been released and used. Several versions of the program have been used on the ASEAN project. Early analysis work for Singapore in 1982-1983 used version DOE-2.1B; the Malaysian and Thailand standards analyses in 1986-1988 used version DOE-2.1C. The Philippine and Indonesian standards analyses conducted in 1989 used the most recent version, DOE-2.1D.

All of these versions of DOE-2 have been verified against manual calculations and field measurements on existing buildings [5,6]. These studies all show that DOE-2 predictions agree with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' (ASHRAE) calculation methods, manufacturers' data, and measured annual building energy consumption. DOE-2 results also agree with predictions of other building energy analysis computer programs (e.g., BLAST, NBSLD). Extensive testing and validation studies have made DOE-2 a program that, within the limits of its design, can simulate the performances of a wide variety of building types and HVAC systems.

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* The source code for DOE-2 is available, thus allowing close inspection or substitution of its algorithms.

DOE-2 is considered accurate over a wide range of energy features, and its computer code is "in the public domain," that is, open for inspection and modification. Because of these features, DOE-2 is considered a "benchmark" for other energy-simulation tools and has been used widely for similar energy-policy analyses in the United States and elsewhere. For example, DOE-2 has been used extensively both in the development and impact assessment of the new version of the U.S. ASHRAE standard for commercial buildings, and for the proposed U.S. ASHRAE standard for residences. It has been used to provide analysis support for state energy standards for California, New Mexico, a group of states in New England, and the several-state region served by the Bonneville Power Administration in the northwestern United States.

DOE-2's drawbacks relate either to its structure or to its user interface. Currently, DOE-2 LOADS output is for a fixed-zone temperature, a feature used to shorten calculation time. SYSTEMS outputs, on the other hand, include the impacts of hourly changes in zone temperature throughout the year. Thus, SYSTEMS outputs may be considered more accurate, but they also include system-specific characteristics that influence the hourly coil loads reports in the DOE-2.1D. Thus, care must be taken in evaluating both the LOADS and SYSTEMS outputs to ensure that complete and appropriate loads factors are included [7].

DOE-2's user interface was conceived and designed over a decade ago. Consequently, even with some recent enhancements to its interface, it is awkward and difficult to use and provides many opportunities for an unwary user to make significant errors. The DOE-2 program does not include extensive error-checking routines, so the user must be careful to verify inputs. Other tools are available that are much easier to use than DOE-2. Unfortunately, such tools also lack key energy simulation features available in DOE-2.

First-time users (who are already experienced energy analysts) should plan at least two months of full-time effort simply to become reasonably competent in the use of DOE-2. If DOE-2 (or a similarly complex analysis tool) is being used to support policy-related decision making, the analysts should consult experienced users on a review and consultation basis.

CHAPTER 3: WEATHER DATA

INTRODUCTION

When the ASEAN-USAID Buildings Energy Conservation Project began, there were no sets of weather data that could readily be used with the selected energy simulation program. In some instances, sufficient data existed in disparate locations and forms, and only needed to be compiled. In other cases, fundamental weather data collection efforts were necessary. Early in the first phase of the project in 1982, a full year of hourly weather data for Singapore was assembled and put into DOE-2 format. During Phase 2 of the project, considerable additional effort went into generating at least one set of weather data for each participating ASEAN country that could be used with DOE-2 analyses. Today, new DOE-2 weather files exist for Bangkok (1985), Kuala Lumpur (1985), Manila (1983), Jakarta (1987), and Singapore (1979 and 1988).* See Appendix B for summary weather statistics of the weather data files.

This chapter describes the weather data sources and procedures used to generate the appropriate weather files for each ASEAN country. The chapter ends with a discussion of the impacts of ASEAN regional weather conditions on energy conservation potentials, strategies, and priorities.

WEATHER DATA OBTAINED FOR ASEAN LOCATIONS

The weather variables used by DOE-2 include those for temperature, humidity, wind, and solar, as follows:

- Temperature: Dry-bulb temperature, wet-bulb temperature, and ground temperature.
- Wind: Speed and direction.
- Humidity: Humidity ratio, density of air, and specific enthalpy.
- Solar: Total** horizontal solar and total direct normal solar radiation, cloud type, cloud amount, clearness number, and atmospheric turbidity.

Hourly values for the variables are needed, since DOE-2 performs a sequential hourly analysis for each of the 8760 hours in a year. For the temperature, humidity, and wind variables, local data are usually available for major cities from data collected at airports, etc. Sometimes such data are available only for 3-hour intervals. In such cases, DOE-2's weather processor will "fill in" the missing values.

Obtaining sufficiently accurate solar data from existing sources is often problematic. Solar radiation is important to building energy use in ASEAN. In the absence of measured solar data, DOE-2 is equipped with a model that estimates the global and direct solar radiation from cloud cover observations. Yet, the existing cloud cover model was not considered sufficiently accurate for ASEAN conditions as it was developed for continental U.S. conditions, based upon temperate conditions in the northwestern United States. Because the ASEAN climate and sky conditions are very humid and have a higher level of diffuse radiation, more precise measures of solar radiation are needed, as are more precise local solar data. If this information is not readily available from existing sources of weather data, as is usually the case, monitoring with appropriate instruments may be necessary.

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[*] Copies of the ASEAN weather files for DOE-2 are available at LBL, as well as from analysts in each ASEAN country.

[**] "Total" and "global" are used interchangeably throughout this volume.

A variety of sources and procedures were used in generating the various weather files for ASEAN locations. We briefly describe below the weather data sources for in each country and the data acquisition and processing procedures.

Status of Weather Data for Building Energy Simulation in ASEAN

Singapore:

In 1982, LBL and Singapore collaborated in transferring a copy of the DOE-2.1 computer code to mainframe computers at both the National University of Singapore (NUS) and the Singapore Public Works Department. As part of this effort, a DOE-2 weather file was generated for Singapore for 1979. Hourly solar insolation data had been collected for the 1979 period at a weather monitoring station installed at NUS. These data, which included data for both the global and diffuse radiation components, were merged with hourly 1979 weather data for the other required variables, which were obtained from the U.S. National Climatic Data Center.

These 1979 data were used for various analyses for Singapore during most of the project. Later in the project, data for 1988 were assembled, including global and diffuse solar data collected at NUS for the 1988 period. The 1988 data set has fewer missing solar data values than the 1979 data set and has been used for analyses conducted since late 1989.

Indonesia:

Existing weather data for Jakarta and Bandung in Indonesia had been collected and tabulated by the Institute of Technology in Bandung (ITB). Hourly weather data were obtained for Jakarta and Bandung from the Meteorological Institute of Jakarta. These data included temperature, wind speed, relative humidity, and global and diffuse solar radiation. Hourly global direct solar data were available for both Jakarta and Bandung from another Indonesian source (LAPAN). However, diffuse solar data were available only for Bandung. To obtain estimates of diffuse solar radiation for Jakarta within the time-frame needed for the standards analysis, the ITB team correlated the global radiation component to the diffuse radiation component based on the available existing Bandung data. They then applied this correlation to the Jakarta global solar data to generate a related set of diffuse solar data estimates for Jakarta. (see Volume II, Chapter 5).

In addition, through this project the ITB team set up a weather monitoring station (first tested in Bandung) in Jakarta to collect current weather information. This monitoring equipment measures all the variables needed for the annual energy simulations of buildings on an hourly basis. The monitoring equipment began operating in Jakarta in October, 1988. Due to some early equipment problems, a complete year of monitored weather data was not developed until mid-1990. The monitored weather data provide a sound basis for building energy analysis in Jakarta because they contain both global and diffuse solar radiation data measured directly in Jakarta.

Malaysia:

All weather data used in the DOE-2.1C computer runs for the various Malaysian analyses are actual hourly data recorded at Kuala Lumpur in 1985, except hourly solar data which were not available. Measured 1979 solar data from nearby Singapore were merged with the other weather data from Kuala Lumpur to create a composite weather file for DOE-2.

The Philippines:

In April 1989, a DOE-2 weather file was developed for Manila using data for the year 1983. The hourly tabulations of climate variables needed for DOE-2 (with the exception of solar data) were obtained from the U.S. National Oceanographic and Atmospheric Administration (NOAA). These data had been compiled at a military airport near Manila. Solar radiation data (both global and diffuse) collected in a suburb of Manila for the 1983 period were also available from the Philippine National Radiation Center.

Thailand:

Hour-by-hour standard meteorological data, including global solar radiation, are available for major Thai cities. These data date back at least five years for solar radiation, and longer for other data. To date, however, weather data for DOE-2 have been prepared only for Bangkok. This is partly because total and diffuse solar radiation data are available only for Bangkok.

All weather data used in the Overall Thermal Transmittance Value (OTTV) formulation and the subsequent DOE-2 simulation are based on hourly weather records for Bangkok. Development of hourly weather data for the other major cities of Thailand should not be difficult, since most weather data are already available, and only the diffuse component of the solar radiation needs be obtained. This could be done using standard correlation techniques using the global radiation and the sunshine hour records already available for major cities.

Processing of the Collected Weather Data

Once obtained, the data were put into the appropriate formats for use by the DOE-2 program, and the resulting weather files were reviewed for accuracy and reasonableness. This process required considerable attention to detail. Missing or problematic data and unexpected format problems seem to be the norm when generating weather data, rather than the exception. Thus, future project plans for developing new weather files should allocate reasonable time and resources for resolving such problems. For example, both the Philippine and Indonesian weather data required multiple iterations to achieve final data sets.

ASEAN WEATHER CHARACTERISTICS

The typical ASEAN year-round hot and humid climate causes the energy consumption profiles of buildings to be significantly different from the profiles of buildings located in temperate or cold climates. Considered by itself, space cooling is the single largest consumer of energy in a typical ASEAN office building. Solar heat gain is one of the two largest sources of heat gain to the building; the second is from lighting fixtures. Another large heat gain is the combined sensible and latent load from ventilation air brought into the building by warm moist outside air. The combined effect of these sources of heat gain account for the preponderance of the cooling load, which accounts for about 60% of the energy use in a typical ASEAN office building.

Temperature and humidity

The measured average daily dry bulb temperatures for five ASEAN cities is presented in Figure 3-1. The patterns of daily average temperature are fairly constant over the year. Also, temperatures are similar for all of the five locations examined, with Bangkok's temperatures being highest early in the year, and Jakarta's temperatures being somewhat higher during the later part of the year, reflecting the monsoon weather patterns in the region.

Figure 3-2 shows monthly average relative humidity (RH) values for all five locations at both 4 am and 4 pm. Coupled with the previous temperature figure, this figure illustrates the high latent cooling-load conditions prevailing throughout the region. Again, the cities show similar patterns, especially for early morning RH, but some variations within the region are also noticeable. The daytime RH is more variable, but generally is in the 60–70% range. Of the five locations, Singapore has the highest daytime RH, while Jakarta tends to have the lowest.

Solar

Measured solar data for energy analysis is necessary because calculation routines for generating solar data from available summary weather (e.g., percentage possible sunshine or cloud cover information) were derived for temperate locations in the United States and were known to give inaccurate results for the ASEAN region. For example, calculated solar radiation data was compared with measured solar radiation data in Singapore, and they were found to be markedly different. This result was found for ASEAN other locations as well.

Figure 3-3 shows measured average daily solar radiation data for four ASEAN locations, depicting both total horizontal (TH) and direct normal (DN)* figures by month.

For energy use of tall commercial buildings, the most relevant solar statistic is the solar radiation impinging on vertical surfaces. Figures 3-4a through 3-4d present average daily solar radiation on vertical surfaces for the four cardinal orientations for four ASEAN cities. For Singapore (3-4c), the average daily total vertical solar radiation is about 600 Btu/ft^2 for north and south orientations and about 30% more (800 Btu/ft^2) for east and west. On an annual basis, there tends to be little difference in the annual totals falling on north or south walls because these cities reside close to the equator. For example, Singapore and Jakarta are located at 1.3° north latitude and 6.2° south latitude, respectively, while Manila and Bangkok are slightly further away at 14.5° and 13.7° north latitude, respectively. However, in the region the 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 the region, diffuse light makes up about two-thirds of total solar radiation. This is apparent in Figure 3-5, which compares diffuse radiation as a percent of total radiation for vertical surfaces for the four ASEAN cities.

These variations in diffuse light amounts throughout the region are of interest. Singapore consistently has the highest proportion of diffuse light—in the 70% to 80% range. By contrast, both Bangkok and Manila have diffuse light in the 55 to 65% range for several key orientations. Jakarta experiences a very high percentage of diffuse light in the mornings, but a lower portion in the afternoons. This is because Jakarta is quite hazy in the morning but clears in the afternoon.

DETERMINING THE SOLAR FACTOR FOR ASEAN LOCATIONS

Calculating an appropriate Solar Factor (SF) for vertical surfaces in each ASEAN location was an important consideration in determining requirements for the building envelope (i.e., the exterior walls and roof) portion of the energy standards for buildings and for establishing a compliance procedure for meeting the building envelope requirements.

The solar factor is the rate, averaged over a defined period of time in the day, at which solar radiation, including both direct and diffuse radiation, is transmitted through clear, single-pane, vertical glass

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* Direct normal solar radiation is that which impinges on a plane perpendicular to the incident direct beam rays.

(expressed in W/m^2). The average should be over all hours during the year that the cooling system is operating in order to best correlate with the load on the building (and thus the cooling energy requirements of the building).

Using the hourly solar data available for each of four ASEAN locations (Kuala Lumpur used the solar data from Penang which was not available in hourly intervals), standard procedures were used to compute the solar factor averaged over different hours of the year.

Energy standards use the solar factor in combination with the shading coefficient of the building's windows to calculate the radiative contribution to overall heat transfer through the building envelope. The shading coefficient is defined as the fraction of solar radiation that passes through the windows relative to that transmitted by clear 0.32 cm (1/8 inch) thick, single-pane, double-strength sheet glass. Higher shading coefficients produce greater heat gains and increased cooling energy use. When the shading coefficient is specified in the DOE-2.1 input, the program first calculates the solar heat gain using transmission coefficients for clear, 0.32 cm thick, single-pane sheet glass. This solar heat gain is multiplied by the value of the shading coefficient to determine the resultant solar heat gain. We used a typical value of 0.87 for the fraction of incident solar radiation transmitted through such glazing to adjust the incident solar radiation in determining the solar factor.

Figure 3-6 shows the solar factor determined by orientation for the daily period of 0800 to 1800 hours for Bangkok, Jakarta, Manila, and Singapore. Bangkok and Manila show very similar magnitudes and patterns of solar factor by orientation, as they did for percent of diffuse radiation (Figure 3-5). Singapore, which had the highest percent of diffuse radiation, has generally the lowest solar factor. Jakarta has an even lower solar factor for the East-facing orientations, but a much higher solar factor for the North and West orientations, again corroborating the typical daily patterns observed in Figure 3-4b.

Figures 3-7a and 3-7b show the change in the solar factor when computed over five different time periods for Bangkok and Jakarta, respectively. Over the time periods studied, there is about a 20% variation in magnitude in Bangkok and a 15% variation in magnitude in Jakarta.

The solar factors thus determined were used in various studies to develop envelope thermal performance criteria. This is discussed in further detail in Chapters 7 and 8, which describe the development of building envelope thermal performance criteria.

Figure 3-1. Temperatures in ASEAN Cities

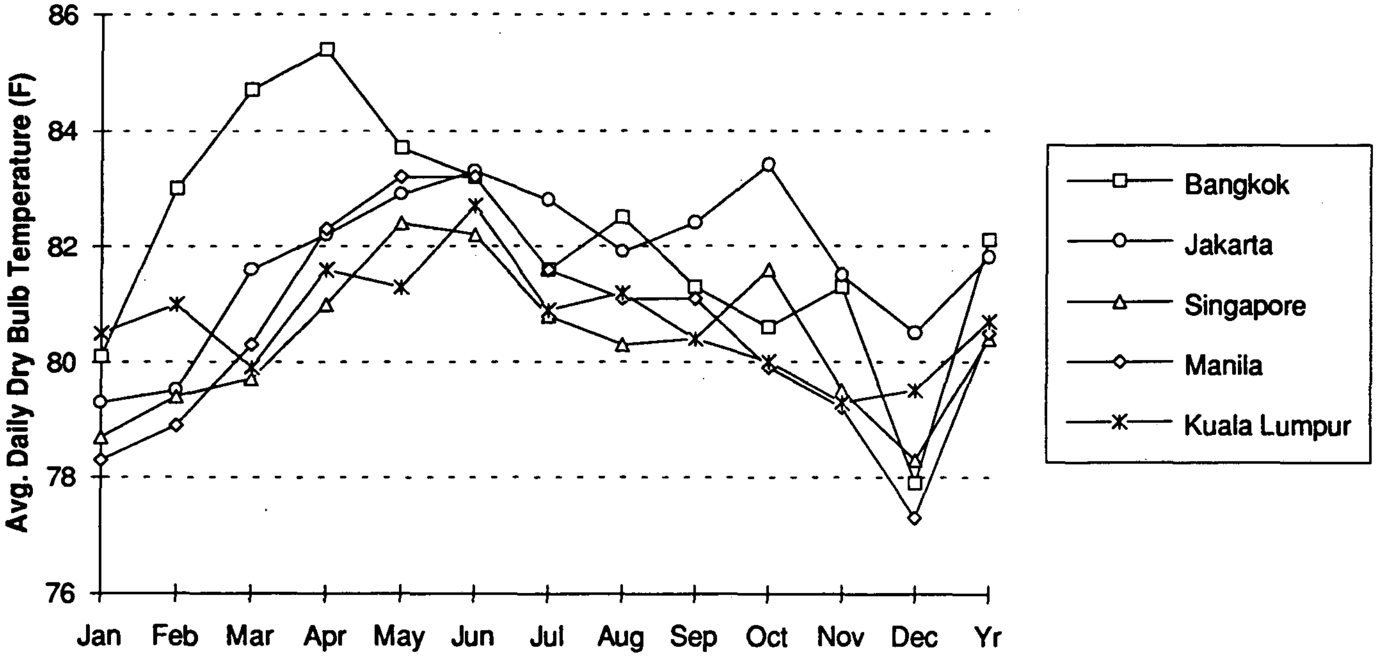


Figure 3-2. Relative Humidities in ASEAN Cities

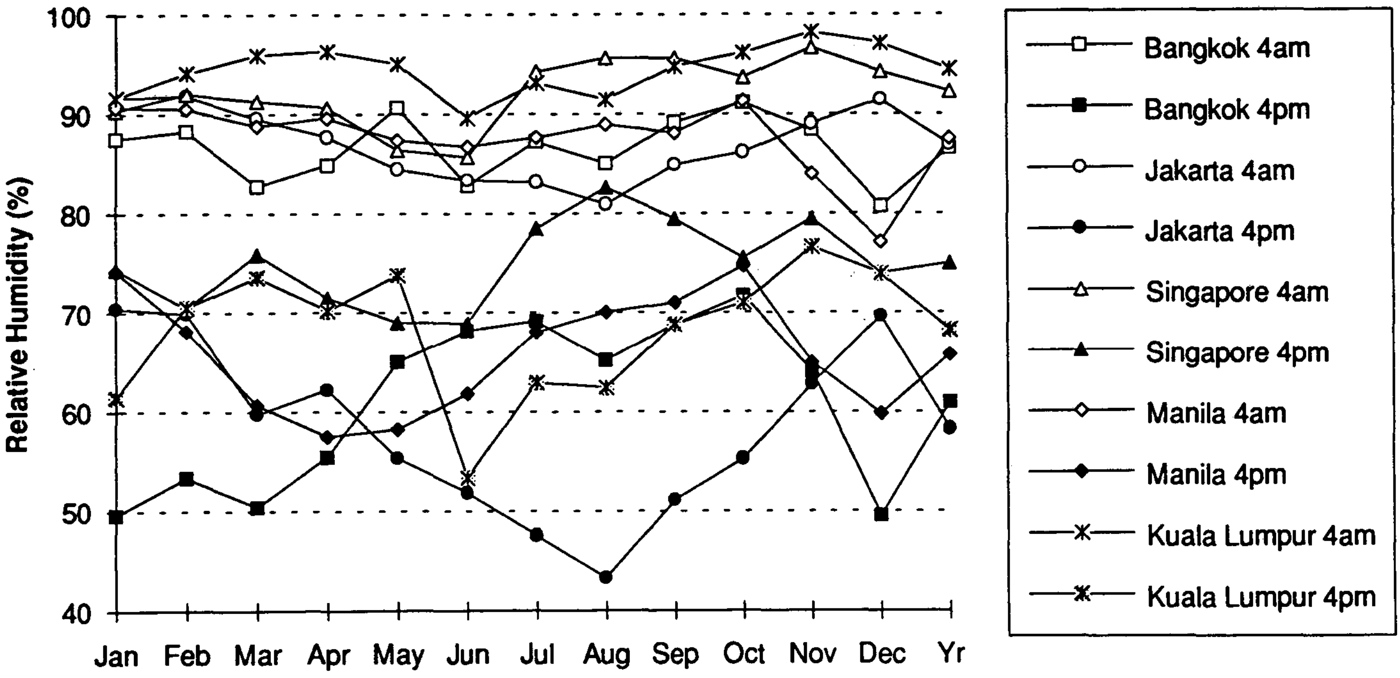


Figure 3-3. Measured Solar Radiation in ASEAN Cities

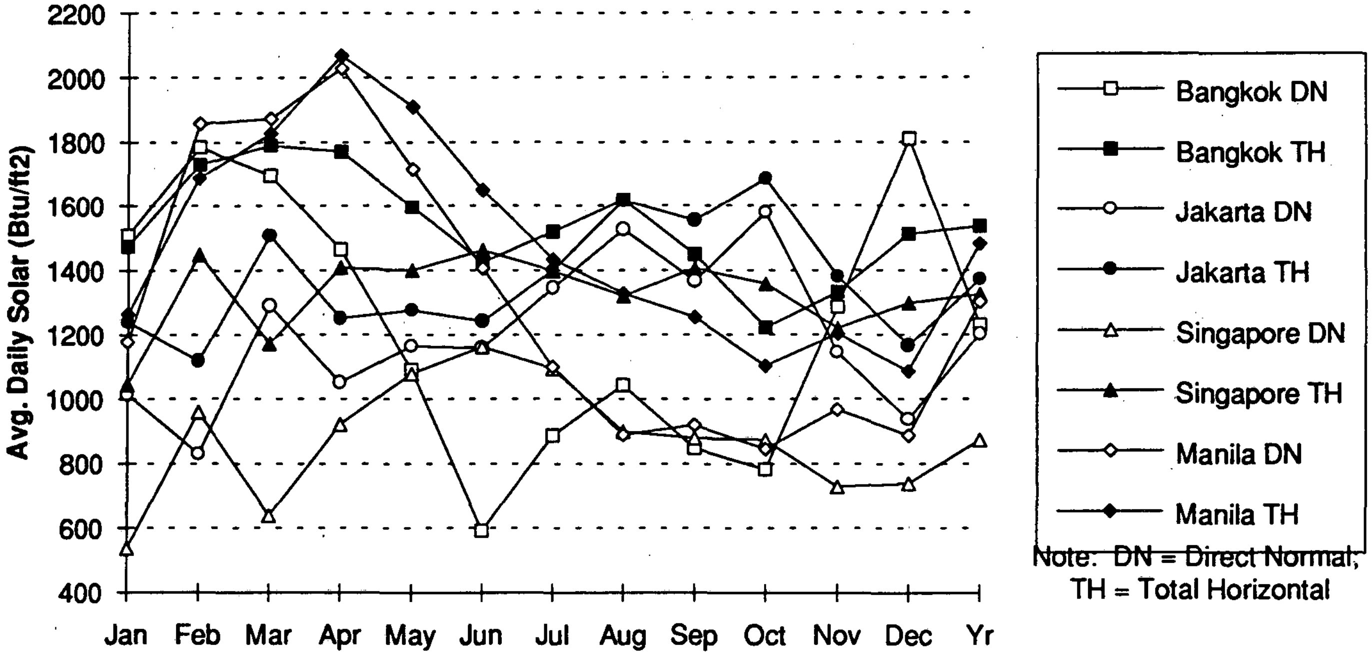


Figure 3-4a. Solar Radiation on Vertical Surfaces in Bangkok

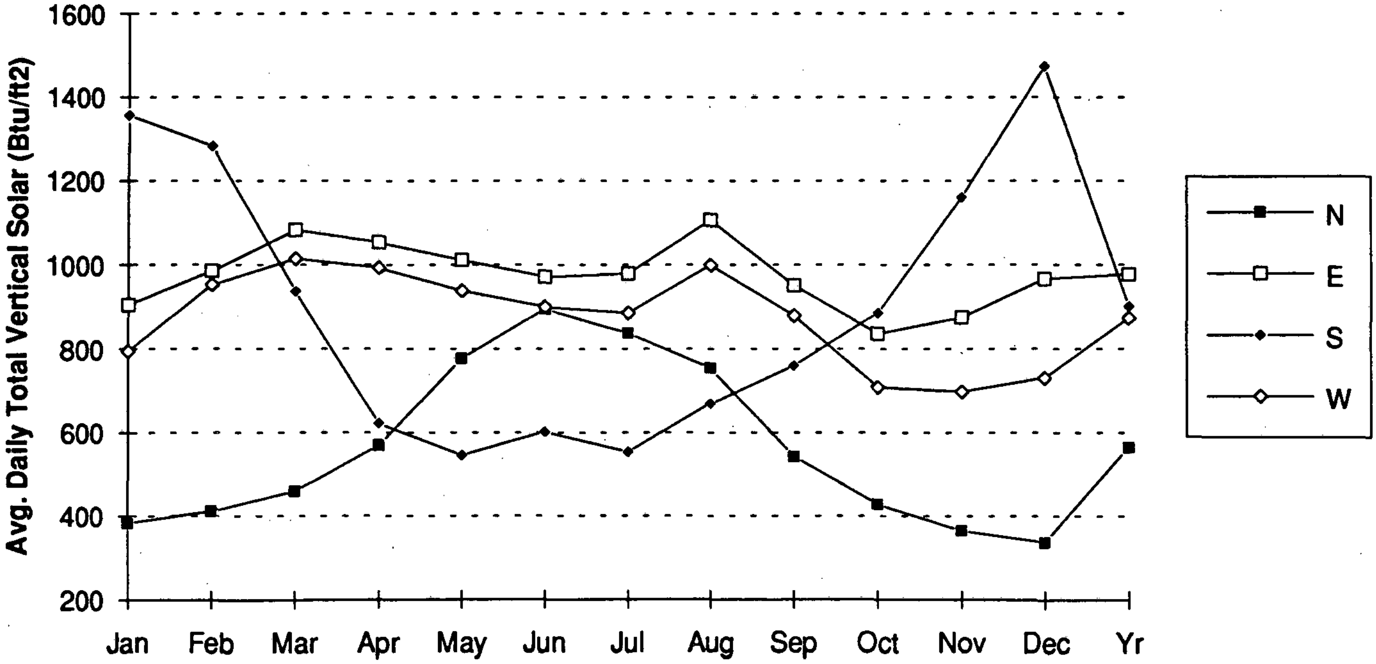


Figure 3-4b. Solar Radiation on Vertical Surfaces in Jakarta

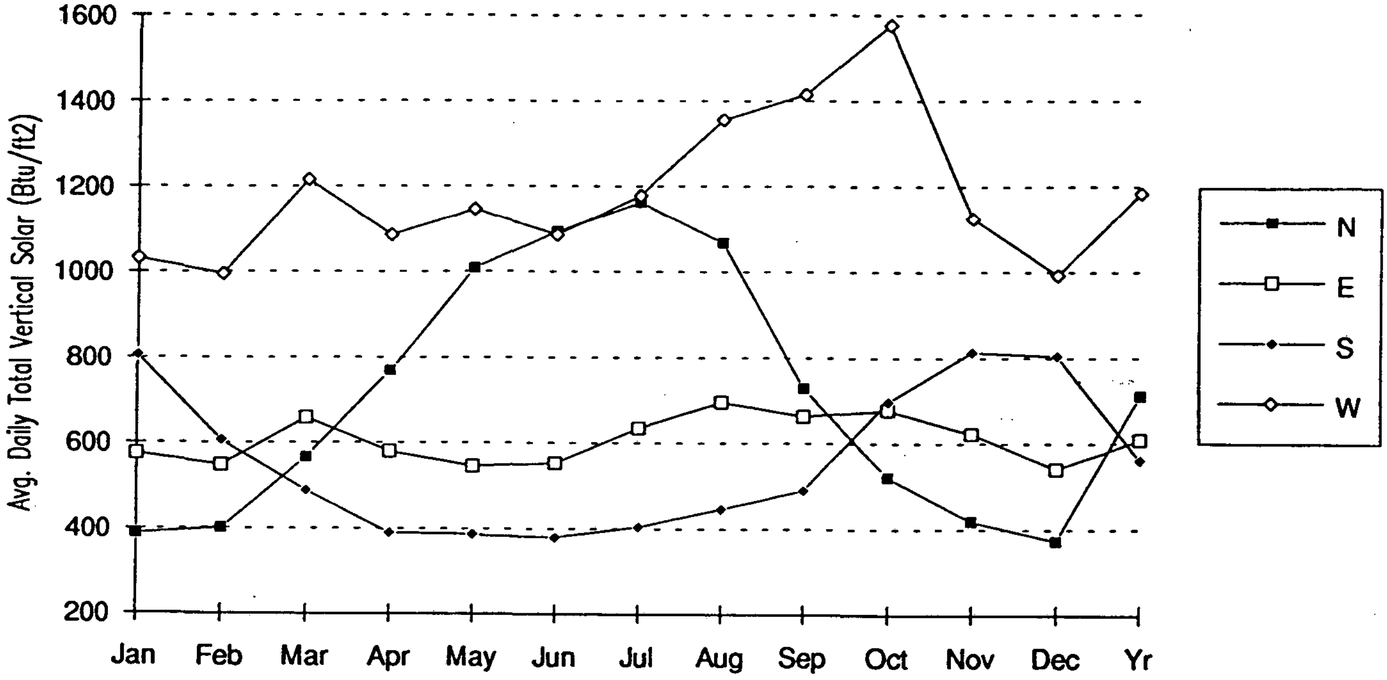


Figure 3-4c. Solar Radiation on Vertical Surfaces in Singapore

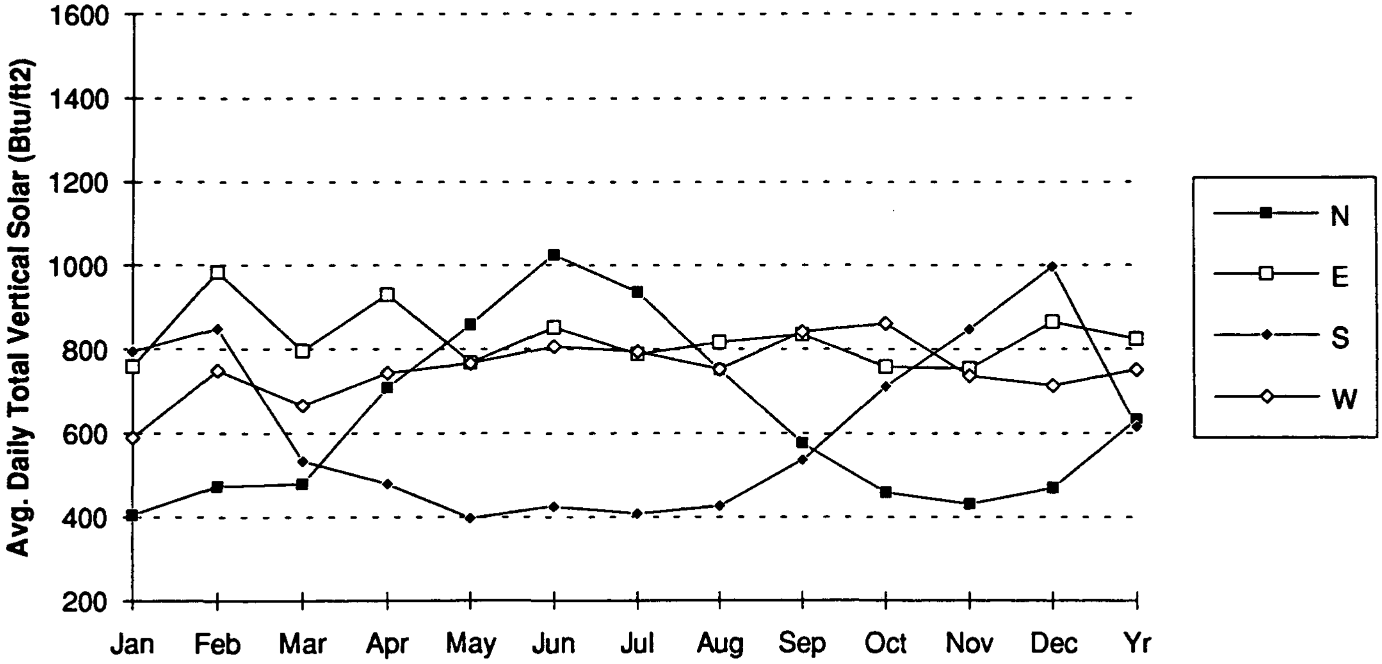


Figure 3-4d. Solar Radiation on Vertical Surfaces in Manila

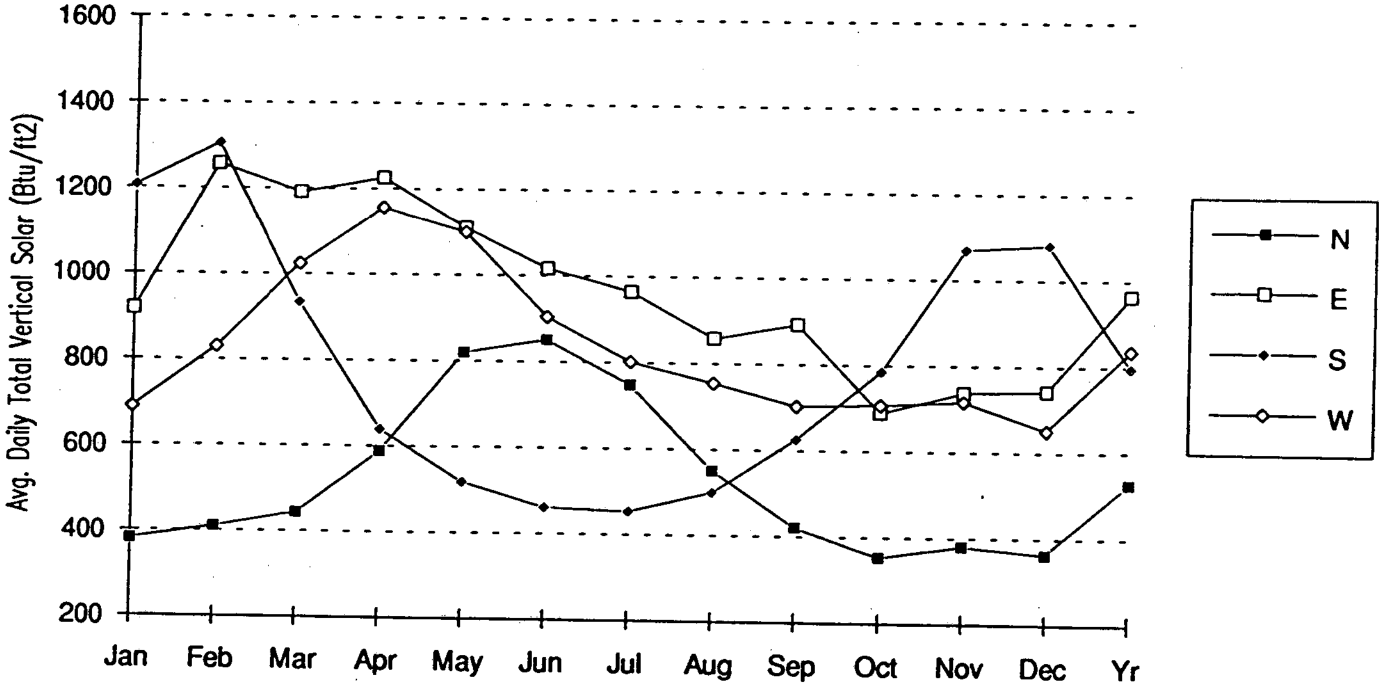


Figure 3-5. Diffuse Solar Radiation as Percent of Total for Vertical Surfaces (0800-1800 hours)

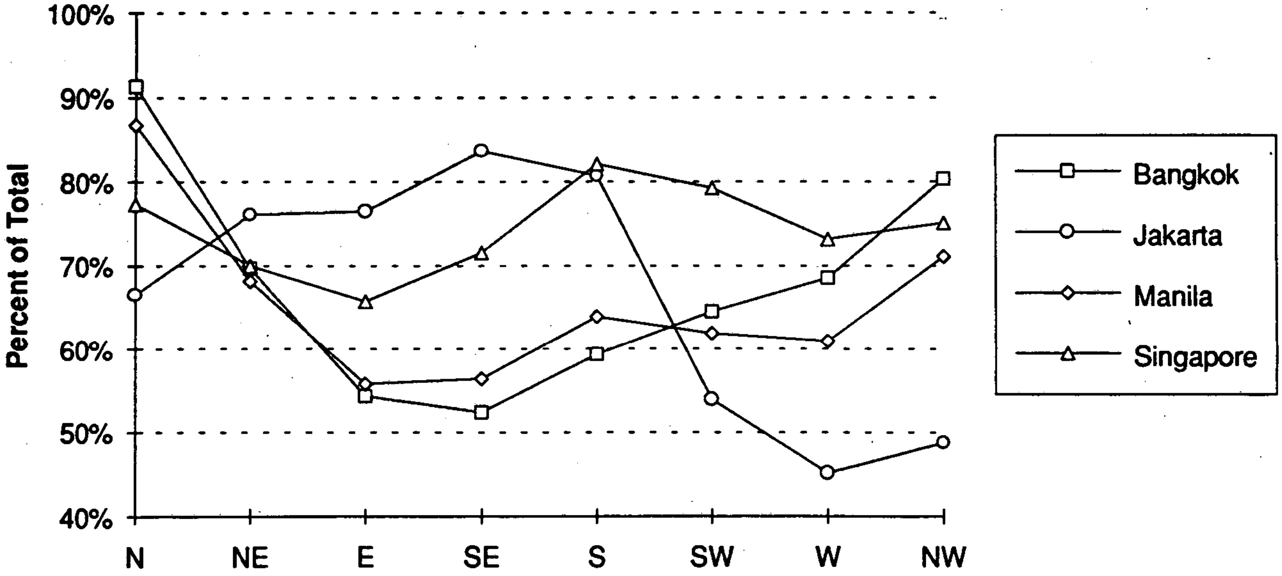


Figure 3-6. Solar Factors for Vertical Surfaces (0800-1800 hrs)

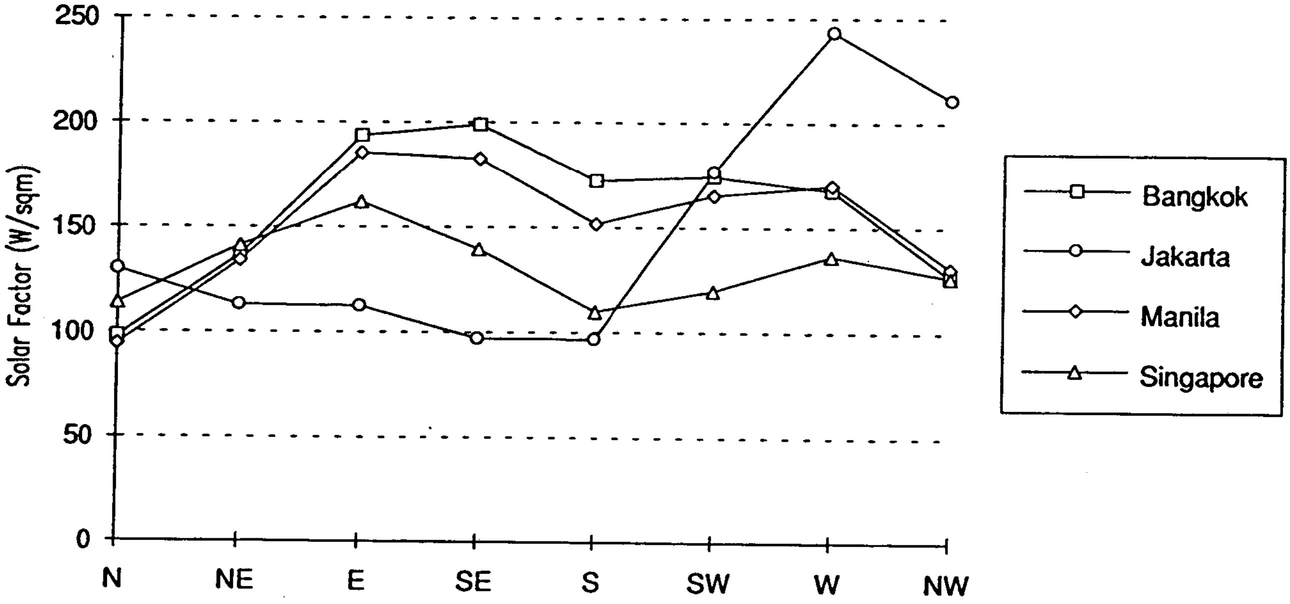


Figure 3-7a. Bangkok Solar Factor by Averaging Hours

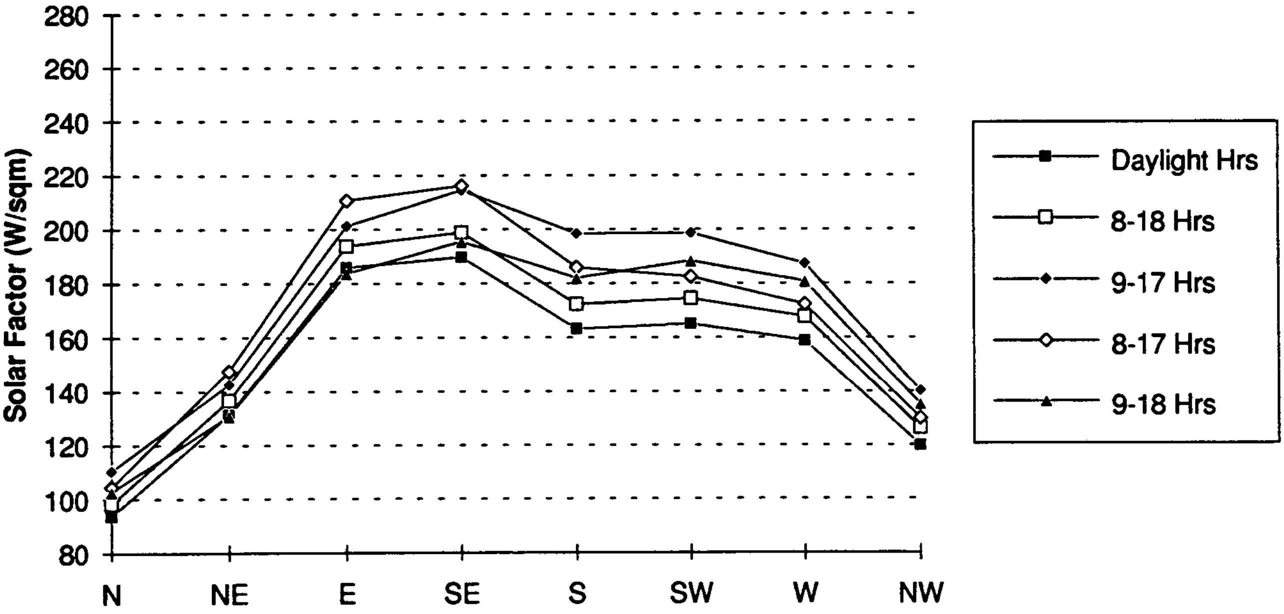
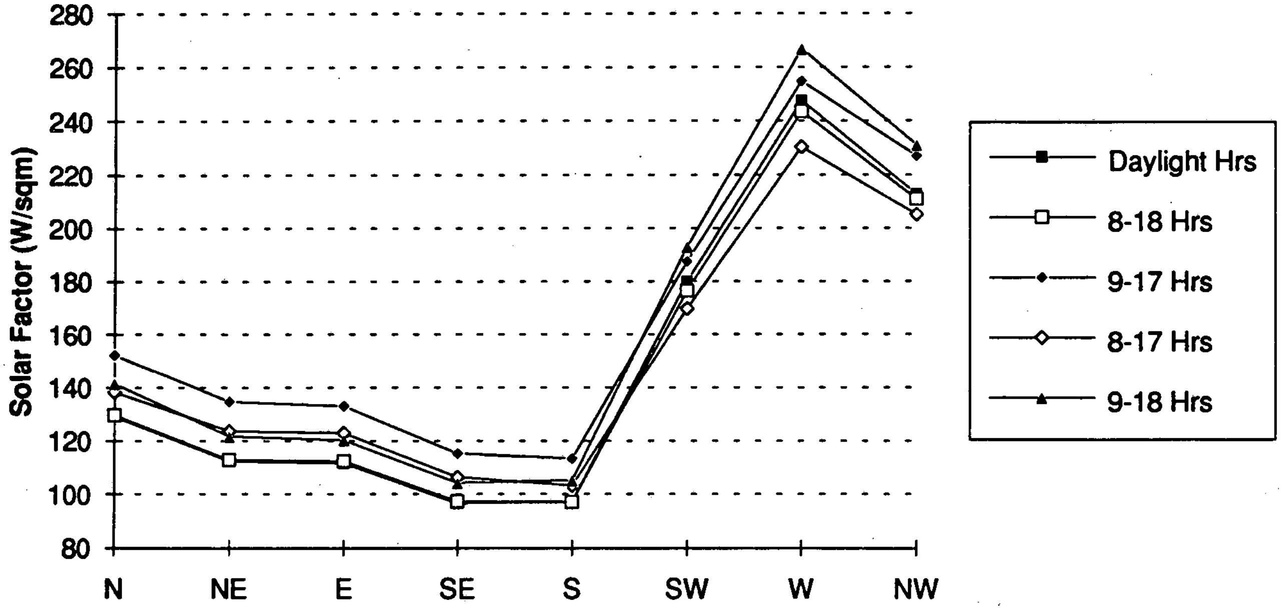


Figure 3-7b. Jakarta Solar Factors by Averaging Hours



CHAPTER 4: TYPICAL BUILDINGS

INTRODUCTION

The development of building descriptions that reasonably represent the energy-related features of the building stock is critical to producing an appropriate energy standard. During Phase 2 of the ASEAN-USAID project, detailed descriptions of typical buildings were produced for the purpose of developing criteria for, and analyzing the energy and economic impacts of, energy standards for buildings in Malaysia, the Philippines, and Indonesia. We describe below the procedures used by each ASEAN country to define typical buildings for later analysis using computer simulation of the buildings' energy performance.

In ASEAN, the four predominant energy-using commercial building types are offices, hotels, retail stores, and hospitals. Large office buildings, which have the highest construction volume, are considered the principal energy-using building category among the four, and analyses for energy standards in all five participating ASEAN countries focused primarily on them. The Philippines and Indonesia, however, expanded their analyses to include hotels as well.

Ideally, these typical building descriptions* should be developed directly from data accumulated through actual, detailed surveys and audits. Partial data may exist from previous surveys, but usually such data is inconsistent or incomplete for energy standards analysis needs. The benefits of using actual building data are strong enough that, time and resources permitting, a special effort to survey a sample of buildings is desirable.

In the sections that follow, we describe the prototypical buildings and how they were developed. They are presented in chronological order since, to some degree, building prototypes developed later were refinements of earlier ones.

SINGAPORE - TYPICAL LARGE OFFICE BUILDING (1984)

The first reference building description developed in the ASEAN region was for Singapore. During Phase 1 of the ASEAN-US AID project, a Base Case large office building description was developed. The description was developed at LBL, using input from a group of knowledgeable Singaporean building professionals [8]. The building has 10 stories and a square floor plan. Basic data about the physical parameters of this building prototype is given in Table 4-1.

The base case reference building was used in a parametric analysis of energy use conducted in 1983-1984. Furthermore, this same base case building description has been used for analyses by various analysts since 1984 [9,10].

MALAYSIA - TYPICAL LARGE OFFICE BUILDING (1987)

The "base case" building was intended to reflect a typical range of construction and energy use features prevalent in Malaysian new commercial office building construction. In 1986, when the standards analysis work began for Malaysia, substantial data bases of Malaysian building characteristics and energy use did not exist. Some data existed in a report summarizing the results of energy audits for 15 Malaysian

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*Here "typical", "prototypical", "reference" or "base case" are all used interchangeably.

buildings [11]. Unfortunately, the level of detail presented in that document was not sufficient to create a detailed building description needed for the analyses conducted here. Another report based on energy audits of four buildings gave sufficient detail, but constituted a small data set [12].

This lack of data restricted the scope of the effort to develop prototypical buildings for Malaysia. In the absence of such data bases, a "reference" building approach was used that relied primarily on professional judgment. One key resource for this was the Singapore reference building [8]. Since it was assumed that construction practices in Kuala Lumpur were similar to those in nearby Singapore, the Singapore reference building was used as a starting point for the development of the Malaysian reference building. Modifications were made to the building description to reflect contemporary construction practices in Malaysia. A complete description of the changes to derive a Malaysian reference building from the Singapore reference building is reported elsewhere [13]. The Malaysian reference building has the same 10 stories, floor size and square floor plan as the Singapore reference building. Basic data about the physical parameters is given in the second column of Table 4-1.

Standards Case

Once the Malaysian base case building was defined, modifications were made so that the building would comply with the requirements of the proposed Malaysian energy efficiency standards. The base case, modified to meet the standard, is called the "standards case" building. The improvement in energy efficiency over the base case represents the overall impact of the proposed energy standard on large office buildings.

Energy-Intensive and Energy-Efficient Cases

Estimated values for building characteristics were also developed using professional judgment for the energy-intensive and energy-efficient Malaysian cases. Together, these were thought to provide an estimate of variation in energy use of the base case. They were not intended to represent the full range of variation at the extremes, but rather some reasonable intermediate levels of poor and good energy design.

Cost Estimates

Construction cost estimates were developed for key building parameters that changed from the above illustrative cases. As with the building characteristics, these cost data were based on professional judgment drawn from conversations with Malaysian building design professionals [13]. The construction cost data was used in conjunction with electricity costs to estimate the cost-effectiveness of the proposed energy standard relative to the base case and other cases (see Chapter 5).

THE PHILIPPINES - TYPICAL BUILDINGS (1989)

The process of developing a typical base case large office building description for the Philippines departed from the earlier Singaporean and Malaysian efforts. The Philippines effort benefitted from the existence of a detailed database of building characteristics and energy use. This permitted the use of statistical procedures to produce not only the base case building characteristics, but also the energy-intensive and energy-efficient illustrative cases.

As part of the ASEAN-USAID Buildings Energy Conservation Project, the Philippine project team had just completed energy surveys for 52 existing Philippine commercial buildings: 26 office buildings, 9 hotels, 8 shopping complexes, and 9 hospitals. In the surveys, information was obtained first from utility bills and building "as-built" plans. Interviews with building personnel and visual inspection of the building facilities were then made to become familiar with building operations and to note if there were differences between the existing conditions and "as-built" plans. Survey forms were developed and used by the team to facilitate data gathering.

In a few of the surveyed buildings, detailed energy audits were conducted in which tests, measurements, and evaluations were made to determine the amount of energy used by each energy-consuming system in the building. The auditors were equipped with portable measuring and monitoring instruments, which they used to assess the energy efficiencies of the major energy-consuming equipment.

Philippine Typical Large Office Building

The detailed data on 26 Philippine office buildings provided a reasonable sample of the Philippine office building stock. To develop the base case office building description, statistical analyses were done for each key energy-related building variable.* Specifically, both the average and the standard deviation values were calculated. For each variable, the statistical mean was used as the value for the base case building, and the standard deviation was used to set the values for the energy-intensive and the energy-efficient cases. Since one standard deviation unit on either side of the mean encompasses about 2/3rds of the population of a normally-distributed sample, this procedure allowed the determination of a reasonable range of variation in building variables relative to the sample buildings.

Thus, the Philippine analysis constitutes a major refinement of the Malaysian procedure, which used the energy-intensive and energy-efficient building cases to estimate the dispersion of building energy uses in the building stock. The Malaysian building descriptions had been developed on a professional judgment basis, in the absence of an extensive and detailed database.

The Philippine large office differs from the Singapore and Malaysia reference buildings in several key areas, for example:

- Shape: Rectangular, compared with square shape.
- Floor size: 1565 m^2 per floor, compared with 625 m^2.
- External shading: Overhangs of 1 m depth, compared with none.
- Lighting Power: 17.2 W/m^2, versus with 20 W/m^2.

It was not known at the beginning of this process if the illustrative building cases, defined using the means and standard deviations of the major energy-related building characteristics, would produce building cases with corresponding energy use dispersion. In fact, a comparison of annual energy results for these cases simulated using DOE-2 with the distribution of annual energy consumption drawn from utility bills for the sample of 26 Philippine office buildings confirmed that this approach was appropriate (at least for this sample). This comparison is shown in Figure 4-1. The DOE-2-based energy results for the Base Case office building with average building characteristics also has a simulated annual energy use that is very close to the average of actual utility bills. Likewise, the energy results for the intensive and efficient cases fall close to the standard deviation of energy use determined from utility bills for the sample of buildings.

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* Statistics were calculated following the removal of any "outliers" from the sample. There was not sufficient time or resources to determine whether the outlawries were due to actual unusual circumstances of the building, or simply errors. In any case, for a given variable, there were typically only one or two outlawries eliminated.

Philippine Typical Large Hotel

In developing the prototypical Philippine hotel building description, a typical Thai hotel building description [15] was adapted using the detailed data available from the survey of 9 Philippine hotels. The procedures used to develop values for each building variable are the same as those described above for the Philippine large office building.

INDONESIA - TYPICAL BUILDINGS (1989)

In the absence of a database on building energy use characteristics like the Philippines, Indonesia developed its typical building descriptions using a variety of information sources, both from within Indonesia as well as from ASEAN. From Indonesia, a database of nine commercial buildings surveyed in Jakarta and Surabaya provided some useful, concrete, information on general building characteristics. A set of approximately 100 photographs of building facades gathered in an informal survey in Jakarta was helpful in defining typical building envelope characteristics. Finally, a number of Indonesian building design professionals provided input on the key characteristics of building envelope, lighting, and air-conditioning sub-systems.

From ASEAN, by the time that the typical Indonesian building descriptions were being developed, information from audits of 117 commercial buildings throughout ASEAN had been collected into a database [16]. Coupled with the aforementioned information sources, these data were used to fill out the profiles of typical Indonesian buildings.

In all, four typical building descriptions were created: a large and small office, and a large and small hotel. Small offices and hotels were deemed to be important energy-using building types in the Indonesian building stock. The descriptions were prepared in sufficient detail to permit the generation of DOE-2 input files for all four building types. However, DOE-2 input files were created only for the large and small offices. Figure 4-2 depicts the simulated energy performance of the resultant four illustrative cases for large Indonesian offices amongst the available sample of electricity bills from such buildings throughout ASEAN.

Costs Estimates

For large office buildings in Indonesia, construction cost estimates were developed for some of the key building components. For example, construction cost estimates were developed for various typical office building lighting system configurations, which showed that a strategy to achieve installed lighting power reductions of close to 50% would not appreciably increase first cost, thereby paying itself back within a few weeks. The lighting system configurations analyzed and their respective costs are shown in Table 4-2.

THAILAND - TYPICAL LARGE OFFICE BUILDINGS (1989)

Typical building descriptions of Thai commercial buildings were developed by Thai analysts using professional judgement guided by data from recent surveys of buildings in that country. By late 1989, energy audits had been conducted in over Thai 50 commercial buildings. Although not all the audit data were available, nor their accuracy verified, some of the available information was sufficiently complete and accurate to be used in the creation of typical building descriptions and the definition of requirements for the proposed Thai energy standard.

For the standards-related assessments in Thailand, a single typical office building case was developed [17]* This typical 15-story building description was used primarily to perform building envelope parametric analyses. While the building was developed to be representative of current Thai construction practices, it incorporates several key values that are in compliance with the proposed Thai energy standard. Variations to represent either higher or lower levels of energy consumption were not undertaken.

In the development of the Thai envelope standard, two envelope configurations were applied to the typical office building. One envelope design resembles traditional Thai design using overhangs for sun shading. The other employs a curtain wall design, reflecting a trend in current design practice in Thailand. Both envelope designs can be used to exhibit not only the processes associated with an OTTV evaluation and envelope performance, but also the benefits of management options such as daylighting or use of thermal energy storage. The following characteristics of the Thai typical office are noteworthily, in addition to those listed in Table 4-1:

Air-conditioning:

Accounts for the most significant proportion of total electricity consumption, at between 50-60%. The average power required for air-conditioning ranges from 25 to 45 W/m^2. In large buildings, centrifugal chillers are almost always used, with typical operational COPs of 3.5. Based on this information, the reference building uses a constant air volume, constant water volume system. Interior temperatures for most office buildings are in the range of 24-26°C. For hospitals, temperatures are in a similar range, but in hotels, the temperatures are usually set at 21-22°C.

Lighting:

Ranks second in total building electricity consumption, at 10-30%. The average power required for lighting ranges from 7.5 to 15 W/m^2. As a rule, fluorescent bulbs are used for illumination in offices and in hospitals. Compact fluorescents are beginning to be used instead of incandescent in many hotels. Interior illumination levels for most office buildings are about 400 lux.

Building Envelope:

Local Thai architectural practice tends to use shading devices and takes advantage of daylight for areas close to windows. But a high percentage of buildings, either just occupied or now under construction, feature a curtain wall design on at least part of the building. Typical wall construction is (concrete) plastered brickwork, but concrete blocks are more often used in new buildings. Single window glazing is typical.

Electrical and Miscellaneous Equipment:

Little is used in offices, typically averaging below 2 W/m^2.

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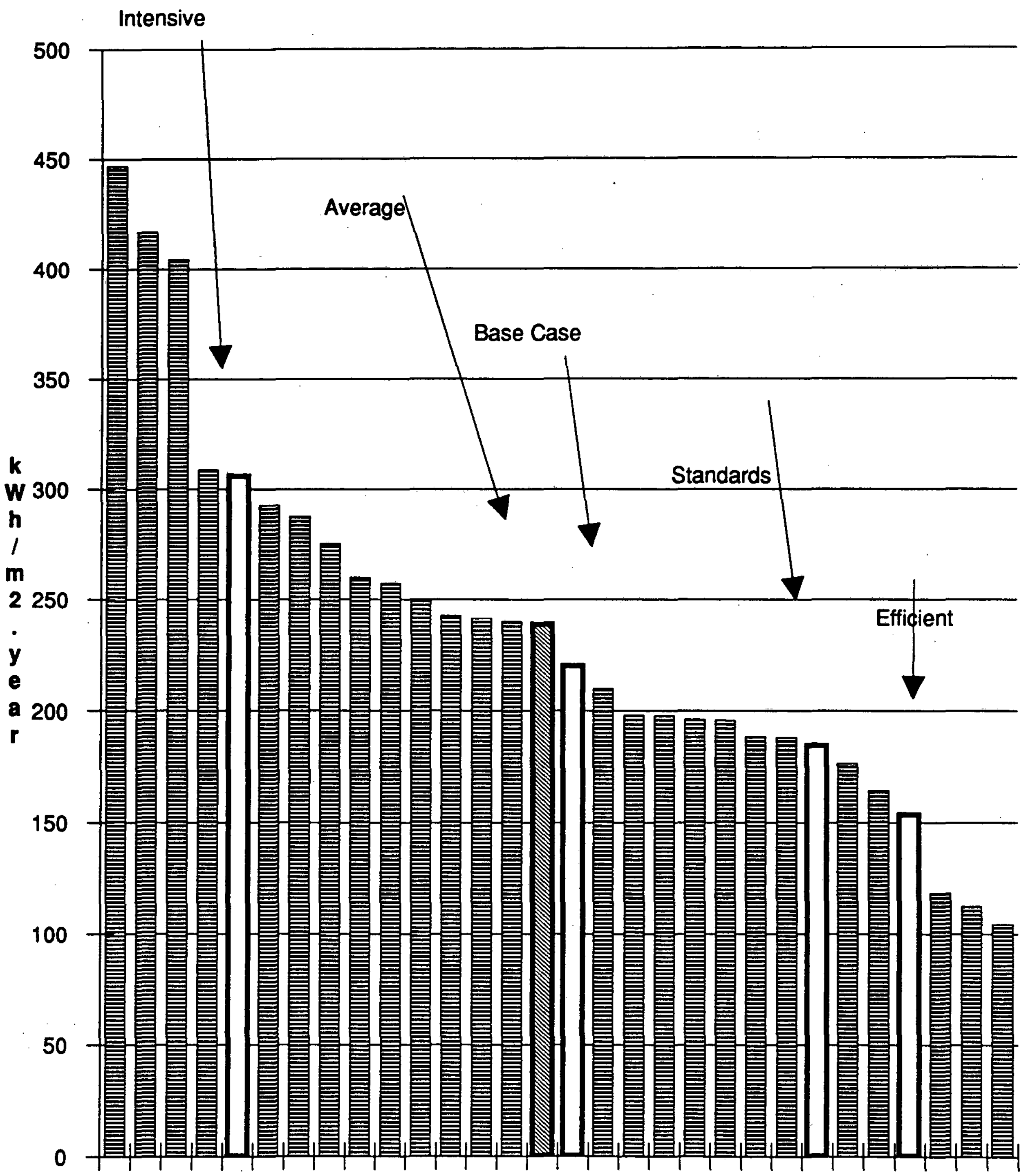
* Three other prototypical Thai building descriptions, for large offices, hotels, and retail buildings, were developed independently [15]. While these typical building descriptions were not used as part of the analyses in support of the Thai energy standards, they provide a valuable additional information source, especially the extensive parametric analyses conducted on these buildings. See Chapter 6 in Volume II.

Medium-speed Elevators:

Are commonly used. Capacity ranges from 8 to 14 persons/car. All buildings have a water storage tank on top for storage of piped water, which is pumped from the supply main.

The construction and the other physical characteristics of the reference building follow those prevalent in the buildings in Bangkok. The lighting power takes on the values recommended in the standards. Building equipment and air-conditioning system descriptions emulate typical buildings in Bangkok. The schedules follow those for an office building, being used only in the daytime, 5+ days a week, with Saturday schedules taken from the morning schedule of a normal weekday.

Figure 4-1. Comparison of Large Office Illustrative Cases with Office Building Survey Sample in Philippines



25 sample buildings (shaded), average (shaded) & 4 simulated cases (white)

Figure 4-2. Comparison of Indonesian Large Office Illustrative Cases with ASEAN Offices

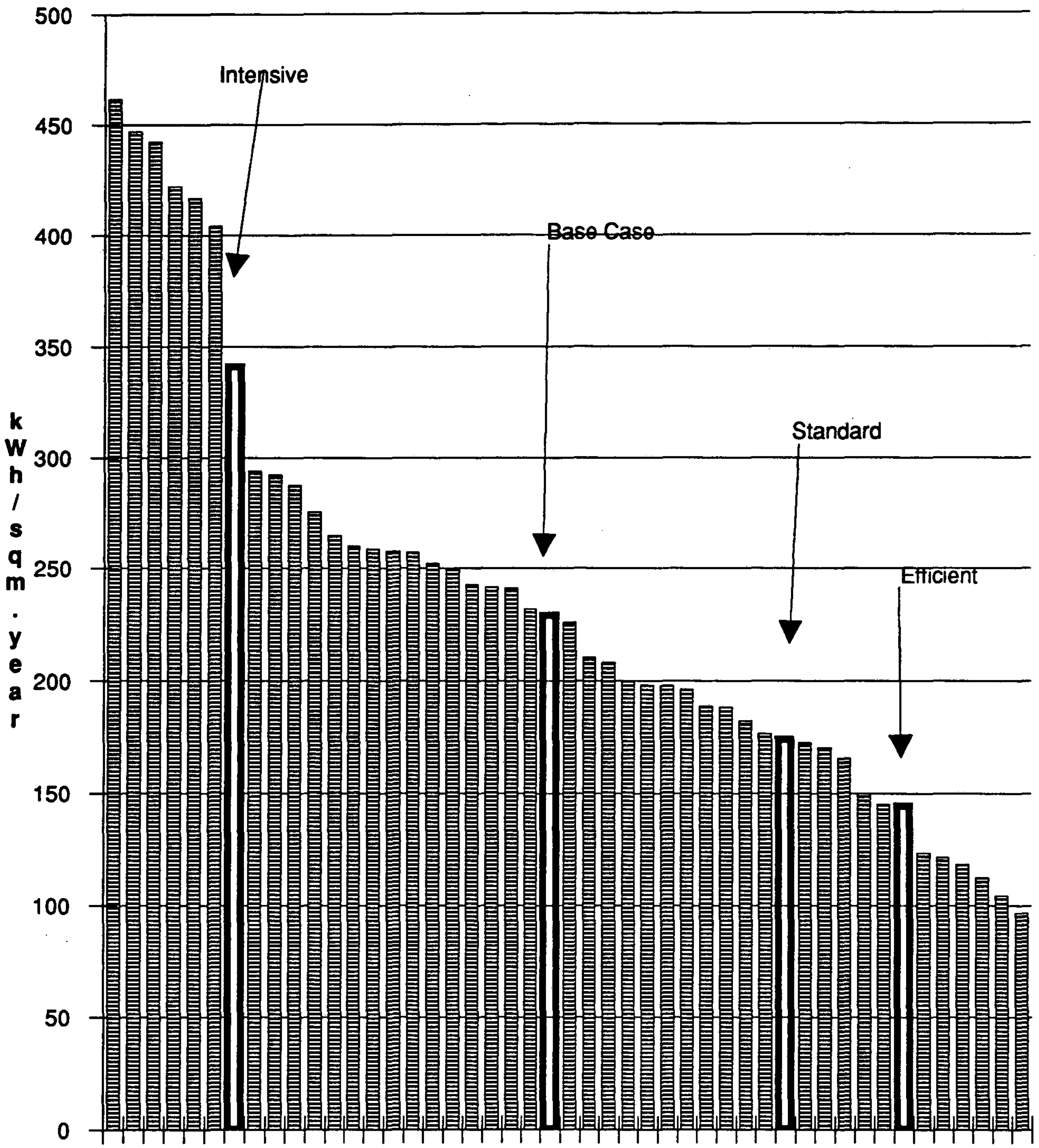


TABLE 4-1. ASEAN LARGE OFFICE REFERENCE BUILDINGS CHARACTERISTICS

				BASE CASE LARGE OFFICE BUILDINGS			
			Singapore [1983]	Malaysia [1986]	Philippine [1989]	Indonesia [1989]	Thailand [1989]
SOURCE OF DATA			Judgment	Judgment	Data Base	Judgment	A Building
Building Type	No Floors		10.0	10.0	10.0	10.0	15.0
	Net Cond: Spec		5200	5200	11350	11350	20160
	Gr Area		6200	6200	15650	15650	
	Pct Cond		83.9	83.9	72.5	72.5	
	M2/Flr: Cond.		520	520	1135	1135	
	M2/Flr: Gross		620	620	1565	1565	
	Shape		Square	Square	Rectangular	Rectangular	Rectangular
	Aspect Ratio		1 to 1	1 to 1	2 to 1	2 to 1	2.5 to 1 @
	Orientation		N-E-S-W	N-E-S-W	Long side E-W	Long side E-W	Long side N-S
Walls	U-Value	W/sq.m.-deg C	2.13	2.43	2.15	2.15	2.88
	Solar Abs		0.45	0.45	0.65	0.65	0.30
	Mass	kg/sq.m.		250	247	247	
	Constr		CHB	Brick & lath	CHB	Brick	Conc. & brick
Roof	U-Value	W/sq.m.-deg C	0.62	0.60	1.05	1.05	0.31
	Solar Abs		0.30	0.50	0.65	0.65	0.70
	Mass	kg/sq.m.		356	364	364	
	Constr		Built-up	Built-up	Conc Deck	Conc Deck	Conc.,alum. fbr
Windows	WWR		0.44	0.40	0.49	0.50	Tower @ 0.4
	SC		0.47	0.69	0.88	0.69	0.63
	Glass Type		2-pane, tint	1-pane, tint	1-pane, clear	1-pane, clear	1-pane, tinted
	U-Value	W/sq.m.-deg C	3.20	5.79	4.59	4.59	5.81
	Ext Shdg		None	None	Overhang	Overhang	Overhang
	Horizontal	depth, meters			1.00	1.00	1.20
	Vertical	depth, meters					
Occup. (No Sun. Operat'n)	Density	sq.m./person	12.4	12.4	12.4	10.0	
	MF-Start	people [fans]	800 [600]	800 [600]	730 [600]	730	800
	MF-Stop	people [fans]	1700 [1700]	1700 [1700]	1700 [1700]	1700	1700
	Sat-Start	people [fans]	800 [600]	800 [600]	800 [600]	800	
	Sat-Stop	people [fans]	1200 [1200]	1200 [1200]	1300 [1200]	1300	
Lighting	Installed Power	W/sq.m.	20.0	21.0	17.2	15.9	18.4
	Illuminance	lux, design		500		500	400
Space Conditions	Outside Air	cfm	7.00	7.00	20.00	20.00	
	Infiltration	air change/ hour	0.60	1.00	1.00	1.0	
	SPT	deg C	23.3	24.0	23.3	24.0	25.0
VAC Equipment	Syst Type		VAV	VAV	CV/SZ	CV/Sz	CV/Sz
	Plant		CCh	CCh	CCh	CCh	CCh
	COP		4.50	4.10	3.80	3.80	4.50
	Capacity	tons	Auto-sized	Auto-sized	Auto-sized	Auto-sized	Auto-sized
	Cond type		Clg Twr	Clg Twr	Clg Twr	Air-Cooled	Clg Twr
	Static Pressure		4.5	4.5	4.5	4.5	
	Fan Type			Forward curved			
	Min Air Flow Rate		0.5				
	Fan Air Flow Control			Inlet vane			

TABLE 4-2:
INDONESIAN OFFICE LIGHTING SYSTEM CALCULATIONS

SPECIFICATIONS: OPTIONS

LAMPS

	Watts	Color/ Type	UNIT COST
1	40	Color # 54/ RS	4.000
	36	Color # 54	3.200
	36	Color # 80	11.000
2	32	Color # 80/ HF	14.000
3	40	Color # 80	3.500

DIFFUSER

	FLoor Area per Fixture	Diffuser Type	UNIT COST
1	5.76 m2, OR 2.4M X 2.4M	PRISMATIC	105.000
2	7.68 m2	Mirror Optic M1	129.500
3	7.68 m2	Mirror Optic M5	151.500

BALLAST

			UNIT COST
1	10 W	STANDARD ballast	4.250
2	5 W	ENERGY EFFICIENT ballast	8.500
3	3.5 W	VERY ENERGY EFFICIENT ballast	50.000

CALCULATIONS

	BASE CASE	ENERGY INTENSIVE	STANDARDS CASE	STANDARDS ALT	ENERGY EFFICIENT
LAMP (W)	36	40	36	36	32
TYPE	# 54	# 54	# 80	# 54	# 80
No. Lamps	2	3	2	2	2
DIFFUSER	Prismatic	Prismatic	M1	Prismatic	M1
Area/Fixture	5.76	7.68	7.68	5.76	7.68
BALLAST	10	10	5	5	3.5
No. Ballasts	2	3	2	2	2
W/m2	15.9	19.5	10.6	14.2	9.2
Unit Cost/ Sq.M.	25.000	24.000	25.000	27.000	36.000

Note: Data provided by Ir. Herman Endro, 1989.

CHAPTER 5: ENERGY AND ECONOMIC ANALYSIS OF STANDARDS

INTRODUCTION

Energy analyses in support of building energy standards development were conducted by each participating country in the ASEAN-USAID project. Formal economic cost-effectiveness analyses have also been undertaken in two countries and were begun for a third country. In this chapter, we summarize both the methods used and the results obtained from these analyses.

Energy standards developed for commercial buildings in ASEAN emphasized the potential for energy savings over other possible objectives such as peak electrical demand savings, or cost-effectiveness. As such, energy analyses were used to assess the energy impact of measures that would be covered in the standard, which in turn aided in establishing target minimum compliance levels for the standards. Economic analyses were used to verify that compliance with the standard was cost-effective. Information gathered in the course of conducting energy and economic analysis provides valuable material for inclusion in guidebooks for standards compliance or for other types of programs aimed at increasing energy efficiency in buildings. Finally, the results of energy analyses could help to focus future research and development.

Energy analyses reported on here focus on specific issues and technologies related to the development of standards in ASEAN, particularly for the building envelope. This emphasis on the building envelope stems from a combination of technical and historical reasons, including Singapore's early emphasis on a building envelope overall thermal transmittance value (OTTV). We shall see in subsequent chapters of this volume that, within the various ASEAN standards efforts, considerable attention has been paid to the format and stringency of building envelope requirements for standards. This is partly because proper requirements are dependent upon an analysis using local weather data, and such data had only recently become available. Comparable analyses using local weather data could have been used to develop requirements for either lighting or air-conditioning, but were not even though these systems can, independently, produce cost-effective energy reductions of greater magnitude than those of the building envelope. More intensive technical and economic analyses outside of this scope are presented in Volumes II and III of this series.

TECHNICAL ANALYSIS

Establishing the basis for analysis, in terms of energy simulation tools, climate data, and typical buildings, has been discussed in the preceding chapters. Once these elements have been established, conducting the energy and economic analyses is relatively straightforward. The key steps are as follows:

Energy analysis:

- Prepare DOE-2 input files
- Prepare annual energy simulations
- Check for errors and reasonableness
- Perform special parametric analyses, such as on key building envelope or air-conditioning systems

Economic analysis:

- Estimate construction costs of parameter changes
- Calculate energy cost impact of parameter changes
- Assess economic cost-effectiveness

In the previous chapter, we discussed the use of illustrative cases (i.e., base, standards, energy-intensive, and energy efficient cases) to present a reasonable spectrum of energy use characteristics of a country's building stock. Comparing the base case with the standards case provides an estimate of the energy impact of the standard. This comparison is shown in Table 5-1, along with the energy savings comparing some of the other illustrative cases with each other.* All savings are estimates based on energy simulation, rather than measured savings.

As the table indicates, energy standards can save both energy and the need for substantially increased electricity-generating capacity to serve buildings. This can enable existing electrical generating capacity to absorb future growth in demand and thus allow for some of the "freed" development capital to flow to other productive sectors.

To assess economic cost-effectiveness, the construction cost changes were compared with the changes in energy costs. An economic analysis was conducted for most energy strategies examined in the analysis for the Malaysian standard [13]. The overall simple payback was 1.6 years for changing from the base case efficiency level to that of the proposed standard.

EXTENSIONS OF ENERGY AND ECONOMIC ANALYSIS FOR STANDARDS

Energy and economic analysis in support of standards for buildings can be extended beyond the applications cited here. More detailed parametric analysis can be done of the key requirements in each section of the proposed standard (plus additional measures that might be under consideration). The results obtained for individual buildings could be transformed to the sectoral level, allowing energy savings for the entire building stock to be estimated, based upon building type mix, growth rates, etc. Crude estimates of these sectoral impacts from proposed ASEAN standards are presented in Table 5-2. These estimates could be improved by disaggregating the savings by building type, by using more precise floor space growth estimates (also distinguished by building type), and by accounting for the effectiveness of obtaining compliance with the energy standard. With the ability to analyze sectoral level impacts, one could analyze the overall savings from applying the standard in different ways. For instance, the impacts from applying the standard to new and/or existing buildings could be compared. One could also assess whether best to promulgate the standard as voluntary, mandatory, by offering financial incentives, or some combination.

Given that energy standards would likely have impacts (beneficial or otherwise) on different entities in society, economic analysis could be conducted for a variety of perspectives beyond that of the building owner presented here. Such analyses might investigate the economic impact on the electric utilities or other major energy providers to the building sector, or on society as a whole. In fact, energy standards could be formulated to maximize cost-effectiveness from one of more of these perspectives, depending on how standards fit into the overall energy conservation policy context.

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* Singapore and Thailand did not produce illustrative cases such as "energy-intensive" or "energy-efficient" in their analyses of the energy impact of standards. Hence, these comparisons do not appear in Table 5-1.

Such information would further improve the information base needed for sound decision-making on improving energy efficiency for buildings.

TABLE 5-1. Relative Energy Savings of Illustrative Office Building Cases

Case	Singapore	Malaysia	Philippines	Thailand	Indonesia
From Intensive to Base:		31%	28%		33%
From Base to Standards:	~20%	18%	21%	23%*	24%
From Intensive to Standards:		43%	43%		51%
From Standards to Efficient:		28%	13%		17%
From Intensive to Efficient:		59%	51%		58%

* Note that savings from compliance with the proposed standard in Thailand were estimated for hotels and shopping centers to be 35% and 42%, respectively.

TABLE 5-2. BUILDING ENERGY EFFICIENCY STANDARDS - IMPACTS ON DEMAND FOR ELECTRIC POWER

Region & Country	SCOPE		IMPACTS, IF STANDARD FULLY IMPLEMENTED							
	New	Existing	Estimated Reduction (%)	Comm'l Elect. Consump. 1987 (% of Tot.)	Est. Future Comm'l Elect. Growth Rate	Comm'l Elect. Consump. 1987 (TWh)	Comm'l Elect. Consump. by 2000 (TWh)	Savings From Std. 1992 - 2000.0 (TWh)	Savings From Std. (%)	Avoided New Elect Gen. Capac. By 2000 (MW)
USA										
USA	90-75		35%-40%							
USA	90.1		15%-30%							
S.E. ASIA										
Singapore	Yes	Yes								
Malaysia	Yes		18%	36%	8.0%	4.9	13.3	1.1	23%	98
Thailand	Yes		23%	29%	8.0%	7.3	19.9	2.1	29%	186
Philippines	Yes		21%	33%	9.5%	5.0	16.3	1.8	35%	156
Indonesia	Yes		24%	18%	10.0%	3.1	10.7	1.4	45%	123

Note: Avoided electricity generating capacity calculation assumes a 60% load factor, a 90% customer class coincidence factor with the system peak, reserve margin savings of 25%, and transmission loss savings of 15%.

CHAPTER 6: CONTENT OF ASEAN ENERGY STANDARDS

INTRODUCTION

As described in the previous chapter, for a number of historical and technical reasons the ASEAN standards development efforts have concentrated on improved methods and criteria for the building envelope. However, the building envelope is just one aspect of building energy efficiency standards. Indeed, in a large ASEAN office building, the envelope by itself accounts for perhaps only 15% of total building energy use. Treatment of the building envelope is discussed in detail in subsequent chapters.

In this chapter we summarize the requirements for the key energy-related building systems that have been included in the ASEAN efficiency standards. The standards for the various ASEAN countries all contain similar provisions, with some variation in both format and stringency. In general, the Malaysian standard (1986) is the shortest and simplest. The Thai, Philippine, and Indonesian standards are all quite similar to one another, with differences mainly in stringency levels, and minor ones in format. The Philippine standard probably has more detail in the air-conditioning systems and equipment sections than the other ASEAN standards.

To a large extent, all of the energy standards developed in Phase 2 of the ASEAN-USAID project stem from the Draft Energy Standard for Thailand prepared in 1987. We will use the Thai standard as the basis for most discussion in this chapter. The following are the major building elements for which requirements are listed in that standard:

- Building Envelope
- Electric Power and Distribution
- Lighting
- Air-conditioning Systems and Equipment

There is considerable potential for energy conservation in each of these components. Moreover, there is further conservation potential from downsizing air-conditioning equipment in response to reduced air-conditioning loads as a result of improved energy efficiency of the building envelope and the lighting. Each of these latter three elements of the ASEAN energy standards is discussed in turn below.

ELECTRIC POWER AND DISTRIBUTION

This is a relatively new section in building energy efficiency standards in general, for none of the requirements cited here appear in the first two generations of ASHRAE standards, for example. There are three important types of requirements in this section:

- Check metering
- Transformer efficiency
- Electric motor efficiency and sizing

Check Metering

This is defined as measurement instrumentation for the supplementary monitoring of energy consumption to isolate various categories of energy use to permit conservation and control. Check metering is in addition to the revenue metering furnished by the utility. The general requirement is that for larger buildings (electric service over 250 KVA), the *capability* for check metering be included in the building design, and that the feeders contain the capability for either portable or permanent sub-metering. The meters do not need to be installed, but the capability to install them in the future must be provided. This is considered an important provision. It is very low cost because the equipment does not need to be installed immediately; the criteria simply requires thoughtful design of the system. However, it will greatly facilitate the future assessment of a building's energy performance. A key provision of this requirement in the Thai standard is that the electrical feeders be subdivided to permit separate metering of 1) lighting and receptacle loads, and 2) air-conditioning systems and equipment. This is somewhat simpler than the most recent ASHRAE requirements, which also call for a third category that includes service water heating, elevators, and other special occupant equipment.

Transformers

The requirement here is simple and somewhat limited. For larger transformer capacities (combined larger than 300 KVA), a calculation of transformer efficiency must be made. The intent of this requirement is simply to encourage evaluation of transformer efficiencies (which are often simply not assessed). However, there is no requirement that any action be taken as a result of the calculation (although one might expect such a requirement in later generations of the standard).

Motors

There are two separate motor requirements: 1) minimum motor efficiencies are specified, and 2) motor oversizing is limited to 125% of the calculated load.

Specified motor efficiencies for three ASEAN countries are listed in Table 6-1: the Philippines, Thailand, and Indonesia. The Thai and Indonesian requirements are quite similar, while the Philippine requirements are more stringent for smaller motors. Early drafts of the ASHRAE/IES 90.1-1989 requirements were the source for the various ASEAN requirements, and Table 6-1 permits a comparison. As can be seen in Table 6-1, the presentation of motor efficiency requirements in the various ASEAN standards is somewhat simplistic compared with the presentation in ASHRAE/IES 90.1-1989. In these latter versions, a future more stringent set of efficiency levels is set for 1992, and there is discussion of recommended (but not required) higher efficiency levels reflecting the economics of increased hours of use per day.

In all cases, the minimum requirements appear to be conservative, for they have been selected assuming about 3 hours of motor operation per day — a low number. Since hours of operation is an important factor in assessing cost-effectiveness, higher efficiencies become relatively more cost-effective as hours of operation increase, as can be seen from the efficiencies listed in the right-most column of Table 6-1.

LIGHTING

Lighting is an important energy end use in commercial buildings. For example, in office buildings, lighting may account for about 20% of total energy use, but the impact of the heat from lighting on air-conditioning loads is significant, so that total energy from lighting is about 30% of total. In large retail facilities, lighting energy use combined with its impact on cooling can represent the largest building energy load. There are two important types of lighting requirements specified in the various ASEAN standards:

- Lighting power
- Lighting controls

In general, the various ASEAN efficiency standards emphasize power requirements much more than lighting controls. This was probably appropriate when the standards were first drafted. However, lighting controls are one of the most rapidly evolving technologies for buildings, due to the rapid advances in microprocessing electronics. By the early 1990s, lighting controls represent an increasingly important and cost-effective means of attaining considerable energy conservation, with little or no compromise in lighting quality. Indeed, lighting quality may improve. For example, a recent study for a utility in California indicated that the installation of a combination of four types of lighting controls (daylight, lumen maintenance, occupancy sensors, timers) resulted in a 50% to 70% reduction in lighting energy usage, with a two-year payback. The main barrier to their widespread use is that they are a new technology without a long track record.

Lighting Power

Most lighting requirements place a limit on the amount of installed lighting capacity that can be used. For the building interior spaces, this is usually expressed in terms of a limit on the watts of lighting installed per unit of floor area.

In the late 1980s in ASEAN, lighting installed capacity for large offices was in the range of 20 to 25 watts per square meter. For retail facilities, the wattage could get as high as 60 or more watts per square meter for lighting power alone. In contrast, the draft Thailand standard recommends 16 watts per square meter for offices and 22 to 23 watts per square meter for retail.

Table 6-2 compares the lighting power limits for various space functions from several ASEAN standards and also for the prescriptive requirements of ASHRAE/IES 90.1-1989. The recommended values for lighting power vary from country to country largely as a result of the technical review process in each country. For example, the initial value in Malaysia for offices was 18 watts/m^2, but this value was later adjusted upward to 20 watts/m^2 by the Malaysian review committee. In 1989, the values recommended in the Philippines and Indonesia were 18 watts/m^2 and 15 watts/m^2, respectively.

The lighting power requirements used in the various ASEAN standards were developed largely by professional judgment based upon general knowledge of current lighting design practice. A survey of installed lighting power was conducted for several hundred buildings in Singapore (see Volume III, Appendix H), confirming that the requirements selected for the standards were reasonably representative of current practice in Singapore.

In general, recent lighting practice in the ASEAN region has been more energy-efficient (i.e., lower installed power) than that in the US. This has not been so much because more efficient equipment is used, but rather because lower illumination levels are typically specified in ASEAN than in the US. Lighting practice in the ASEAN region stems more from English practice than from US practice, and the English did not raise illumination criteria as much as the US when fluorescents came into widespread use.

The lower watts/m^2 are in general attained by the use of combinations of more efficient lamps (say 32-watt or 36-watt instead of 40-watt lamps), more efficient ballasts (2-watt electronic or 5-watt efficient core ballasts instead of 10-watt standard core ballasts), and more efficient fixtures. In some cases, the combinations produce more efficient lighting systems at a lower cost than the less efficient systems.

For office spaces, the requirements set in the standard are relatively easy to attain at a design illuminance of, say 500 lux, and the premium in first cost for the more efficient lighting system can be small or even negative. If credit is taken for the reduction in air-conditioning capacity due to the reduced waste heat given off from the more efficient lighting system, then the cost premium is further decreased.

Lighting Controls

Once reasonably stringent lighting power requirements are in effect, then the most promising area for reductions in lighting energy are controls, which can substantially reduce the amount that the installed capacity is used over time. For example, a combination of daylighting, lumen maintenance, and occupancy sensor controls can easily eliminate the use of over 1/2 of the installed power. That means that an installed power of 15 watt/m^2 could effectively be 7.5 watts/m^2 or less.

The lighting controls requirements are limited to a short list, including specification of a minimum number of controls, basic controls for exterior lighting, requirements for hotel room master switches, and a general requirement for daylighting controls when daylighting is available. Very little credit is given for the use of more advanced controls.

Like electric distribution system requirements, the lighting control requirements are new to commercial building standards. This is because many lighting controls have only recently become highly cost-effective as a result of rapid advances in microprocessors. The lighting control requirements specified in the ASEAN standards are quite conservative and could be easily strengthened. This is especially true given the continued rapid advances in electronic circuitry and the parallel lowering of lighting control costs.

A compelling case can be made for an integrated requirement combining lighting power and controls together, thus offering flexible tradeoffs among a number of power and control options. Even more advantageous would be the development of a comprehensive lighting system performance energy requirement that includes both lighting power, and its use over time.

AIR-CONDITIONING

In the tropics, energy use for air-conditioning can be the most significant end use for a large building. To address this important energy use, two types of requirements are found in the ASEAN standards:

- Ventilating and Air-conditioning (VAC) systems
- Air-conditioning equipment

VAC Systems

The selection of proper VAC system and components is extremely important, yet the multitude of design factors and options make system design a complex undertaking. For this reason, it has proven difficult to write comprehensive energy efficiency requirements for VAC systems. Indeed, it is widely felt that this is one of the weakest sections of the ASHRAE-based standards. This section of the ASEAN standards includes provisions for load calculations, system sizing, fan and pumping system design criteria, various control requirements, and duct and pipe insulation. Overall, these criteria could impact total building energy use by 30% or more.

This area is one that provides for much potential improvement in future updates to standards in ASEAN. The specification of criteria for cooling only systems is easier than the similar task facing ASHRAE in the US, which includes cooling and heating combined. There is more room for clear delineation of requirements such as fan efficiency requirements. The current requirements impact only the most energy intensive systems. More focused requirements would specify variable requirements for differing systems and conditions.

Two examples help to illustrate the magnitude of effect. First, analyses indicate that the use of Variable Air Volume (VAV) systems instead of constant volume systems in large offices can reduce **total** building energy use by about 10%, assuming the VAV system is properly balanced and operated. Yet the energy standards are rather weak in terms of requiring, or even strongly encouraging the use of VAV systems. As of the late 1980s, VAV systems tended to be used in large offices in Singapore and in Malaysia, but not in the rest of ASEAN. Thus, a major opportunity for energy conservation in the ASEAN climate is being overlooked.

Second, if VAV systems are used, then for larger systems (fan Kw > 60) the fan motor must demand no more than 50% design wattage at 50% design load. This requirement effectively eliminates the discharge damper for fan control, and requires either inlet fan or variable speed drive control. Studies show that these control types can improve total building energy performance in the range of 6% to 10%. This, together with the use of VAV and proper fan control, can impact total building energy use as much as eliminating the entire building envelope load. Yet the requirements to do this within in the various ASEAN standards are quite weak. The ASEAN standards simply reflect a similar weakness in this area within the ASHRAE standards. It is an area in which improved delineation of requirements can induce significant energy conservation.

Unfortunately, requirements alone will not solve the overall problem relative to VAV. Substantial training in balancing and maintaining VAV systems will certainly be needed. For example, there were only two VAV systems installed in large buildings in all of Java, and only one in Thailand by the late 1980s. This was because there were so many problems in attempting to get the early systems balanced and working properly that subsequent systems were not specified or installed.

Space temperature set point levels are another critical determinant of energy use in air-conditioned buildings. One rule of thumb is the each degree celsius reduction in temperature causes an increase in energy use of 10% for air-conditioning. Thus, part of the load calculation requirements in the standards is the specification of space temperature set point levels. Table 6-3 shows an example of such requirements extracted from the Philippine energy standard.

Air-conditioning Equipment

The air-conditioning equipment requirements have been kept quite simple in comparison to those in the ASHRAE standard. This partly reflects the realities of initiating the first generation of standards in ASEAN, whereas ASHRAE standards are now into their third generation. It also reflects the fact that fewer types of equipment tend to be used in the hot and humid tropics than in the diverse range of climates experienced in the US. Table 6-4 compares the various ASEAN requirements. In each case, the ASEAN data has been extracted from a single table. By comparison, the ASHRAE/IES 90.1-1989 requirements are much more detailed and require a total of 10 tables to display.

TABLE 6-1. Minimum Acceptable Full Load Motor Efficiency (%)

TYPICAL ASEAN REQUIREMENT*				ASHRAE/IES 90.1-1989 REQUIREMENTS			
	Minimum Required Efficiency (%)				Minimum Required Efficiency (%)		Recommend High Eff.
Motor Size (hp)	Thailand	Philippines	Indonesia	Motor Size (hp)	1990	1992	High Efficiency**
0.4	72.0	77.0	72.0	---	---	---	---
0.8	78.0	82.5	78.0	---	---	---	---
4.0	83.0	84.0	83.0	1-4	77.0	78.5	---
8.0	85.0	87.5	85.0	5-9	82.5	84.0	89.5
---	---	---	---	10-19	84.0	85.5	91.0
40.0	90.0	89.5	90.5	20-49	87.5	88.5	---
80.0	91.5	91.0	91.5	50-99	89.5	90.2	94.1
100+	92.0	91.7	92.0	100-124	91.0	91.7	---
---	---	---	---	125+	91.7	92.4	---
---	---	---	---	200+	---	---	96.2

* Minimum motor efficiency requirements were not specified for the Singapore 1979 standard or the Malaysian standard

** Motors operating more than 750 hours per year are likely to be cost-effective with efficiencies greater than those listed under minimum requirements for either 1990 or 1992. The more efficient motors are classified by most manufacturers as "High-Efficiency," and are presently available for common applications with typical nominal efficiencies listed in the far right column. Guidance for evaluating the cost effectiveness of high-efficiency motor applications is given in NEMA MG 1-01983

TABLE 6-2. Unit Lighting Power Allowances (ULPA)

Building Type/Space	Recommended Illuminance Levels (lux)[*]	Maximum Lighting Power Allowed (ULPA) (W/m²) Singapore 1979	Malaysia 1986	Thai Draft 1987	Philippines 1989	Indonesia 1989	ASHRAE 90.1[**] 1989
Service Station/Auto Repair	300[***]	---	---	---	---	---	---
Apartments & Condos (Public Spaces)	300	---	---	---	---	---	---
Banks	300-500	---	---	---	18	---	---
Barber Shops/Beauty Parlors	750	---	---	---	---	---	---
Churches/Auditoriums	150-300	---	---	---	8	25	---
Parking Garages	20-100	5	---	2	---	2	2-3
Lobbies, Corridors	10	---	---	---	---	---	---
Stairs	---	10	---	---	---	---	---
Hotels/Motels							
Guest Rooms & Corridors	50[***]	17	15	12	17	---	---
Public Areas	50-200	---	20	17	17	20	---
Banquet & Exhibit	300-500	---	20	20	20	---	---
Nursing Homes (Hosp patient rooms)	18	16	15	---	---	---	---
Office & Office Buildings	300-500	20	18	16	18	15	16-20
Restaurant/Food Service							
Fast Food/Cafeteria	50-100	25[****]	---	14	14	10	14-16
Leisure Dining/Bar/Lounge	50-100 25[****]	25	---	15	15	---	15-24
Retail							
General Merchandising, Food, and Display	500	30[****]	23	22	22	---	23-36
Fine Merchandising	---	30[****]	26	23	23	---	---
Supermarket	---	30[****]	---	---	---	20	---
Mall Concourse at Multi-Store Shopping Ctr	150	---	15	15	---	15-17	---
Service Establishment	---	---	---	---	---	---	18-29
School							
Pre/Elementary	300-500	20[*****]	---	16	17	15	16-19
High School/Technical/University	300-500	20[*****]	---	18	18	15	---
Warehouse Storage	50-100	---	---	5	4	5	4-9
General Storage Areas	50-100	---	---	5	2	5	---

[*] Supplemental lighting for task areas may be desirable.

[**] In the ASHRAE 90.1-1989 prescriptive path referenced here, the ULPA allowance increases as building size decreases, and the range listed shows the extremes, converted to metric units.

[***] Applies to all lighting, including accent and display lighting.

[****] Singapore (1979) has no separate requirements for subtypes in this building type.

[*****] Singapore (1979) requirement is for "Classrooms"

TABLE 6-3. Indoor and Outdoor Design Conditions

Indoor Design Conditions in an Air-Conditioned Space shall be:

1.	Design Dry Bulb Temperature	25 Deg C
2.	Design Relative Humidity	55 %
3.	Maximum Dry Bulb Temperature	27 Deg C
4.	Minimum Dry Bulb Temperature	23 Deg C
5.	Maximum Relative Humidity	60 %
6.	Minimum Relative Humidity	50 %

Outdoor Design Conditions shall be:

1.	Design Dry Bulb Temperature	33 Deg C
2.	Design Wet Bulb Temperature	27 Deg C

TABLE 6-4. Air Conditioning Equipment Efficiency Requirements

Type of A/C Unit	Malaysia Draft 1986	Thai Draft 1987	Indonesian 1989	Philippine 1989
Centrifugal Chiller	0.22	0.22	---	---
Water Cooled	---	---	0.20	---
Air Cooled	---	---	0.37	---
Water Cooled <=800 kWr	---	---	---	0.25
Air Cooled <=800 kWr	---	---	---	0.44
Water Cooled > 800 kWr	---	---	---	0.22
Air Cooled > 800 kWr	---	---	---	0.37
Reciprocating Chiller	0.26	0.26	---	---
Water Cooled	---	---	0.26	---
Air Cooled	---	---	0.38	---
Water Cooled <=120 kWr	---	---	---	0.26
Air Cooled <=120 kWr	---	---	---	0.39
Water Cooled > 120 kWr	---	---	---	0.28
Air Cooled >120 kWr	---	---	---	0.36
Water Cooled Package Unit	0.25	0.25	0.31	---
Air Cooled Package Unit	0.37	0.37	0.38	---
Unitary A/C Units				
Up to 20 kWr Capacity	---	---	---	0.56
21 to 60 kWr Capacity	---	---	---	0.53
61 to 120 kwr Capacity	---	---	---	0.50
Over 120 kWr Capacity	---	---	---	0.48

CHAPTER 7: OTTV ANALYSIS FOR WALLS: ORIGINAL ASHRAE AND SINGAPORE DEVELOPMENT

INTRODUCTION

Within the ASEAN-USAID project, an Overall Thermal Transfer Value (OTTV) concept was used to develop appropriate criteria for the wall system within the building envelope system. This approach was first used in the 1975 ASHRAE Standard 90-75 [18] and was refined in 1979 for the Singapore standard [19].

The $OTTV_w$ formulation is a performance-based criteria for the thermal effectiveness of the wall system. The $OTTV_w$ concept takes into account the three basic heat gains through the external walls of a building:

- Heat conduction through opaque walls
- Heat conduction through glass windows
- Solar radiation through glass windows

A major benefit of the $OTTV_w$ wall system performance approach is that it allows a building designer to vary important wall characteristics to meet design objectives and still comply with the 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 for the building is not greater than that specified by the $OTTV_w$ requirement.

Each of the participating ASEAN countries conducted an $OTTV_w$ analysis. Because Singapore already had an $OTTV_w$ requirement and wanted to refine it, several studies were performed to examine possible improvements. Other countries performed analyses to develop an $OTTV_w$ adapted to the local climate and building practices. Each of these countries used methodologies that would have resulted in improvements over the original 1979 Singapore method.

Concentration on refining the OTTV for walls is warranted by the importance of walls and fenestration to the cooling loads of high-rise buildings in relation to roofs. For tall buildings, roof area is small relative to wall area. Roof thermal performance is, however, important for low-rise buildings. Because of our emphasis on the energy performance of large commercial buildings, we focussed on analysis of criteria for walls. However, the fundamental principals and approach would be similar when applied to roofs.

This work had two primary objectives. First, there has been a concerted effort to improve the accuracy of the OTTV expression as it applies to the buildings and climate conditions within the ASEAN region. Based on experience, the original OTTV equation [18,19] was thought to overemphasize the thermal impact of the opaque wall, and to underemphasize the thermal impact of fenestration. Thus, a major thrust of the various ASEAN analyses has been to determine the magnitude of thermal impacts of various wall elements.

Second, several studies were made in the effort to reduce the complexity involved in using the OTTV equations for compliance with code requirements. In particular, the computation of U-values for the opaque portion of the wall consumes most of the compliance calculation time. This effort might be appropriate in cold climates, but becomes a burden in ASEAN, where opaque wall thermal conduction is a secondary effect at best.

THE ORIGINAL 1975 ASHRAE $OTTV_w$ EQUATION

The original form of the wall $OTTV_w$ equation, as developed for ASHRAE Standard 90-75 [18] and also used in the 1980 revision [19]

$$OTTV_w = [(U_w \times A_w \times TD_{eq}) + (A_f \times SF \times SC) + (U_f \times A_f \times DT)]/A_o \qquad \text{(Eq. 7-1)}$$

where:

$OTTV_w$ = Overall Thermal Transfer Value - Walls
U_w = Thermal transmittance of all elements of opaque wall area, W/m^2-°C (Btu/ft^2-h-F)
A_w = Opaque wall area, m^2 (ft^2)
U_f = The thermal transmittance of the fenestration area, W/m^2-°C (Btu/ft^2-h-F)
A_f = Fenestration area, m^2 (ft^2)
TD_{eq} = Equivalent indoor-outdoor SOL-AIR temperature difference for the opaque wall, °C (°F)
SC = Shading coefficient of the fenestration
DT = Temperature difference between exterior and interior design conditions, °C (°F)
SF = Solar factor value given W/m^2 (Btu/h-ft^2)
A_o = Gross area of exterior wall, $A_w + A_f$, m^2 (ft^2).[*]

An alternate form of the $OTTV_w$ equation replaces the area terms (A_w, A_f, and A_o) with a Window-to-Wall Ratio (WWR) term. The WWR form, shown in Equation 7-2 below, is functionally equivalent to Equation 7-1 above. Because it is simpler to calculate, this form is used in many examples in the text below and is also used as the basic format for the $OTTV_w$ expressions for Malaysia, the Philippines, Indonesia, and Thailand. This form is:

$$OTTV = [U_w \times (1\text{-}WWR) \times TD_{eq}] + [WWR \times SF \times SC] + [U_f \times (WWR) \times DT] \qquad \text{(Eq. 7-2)}$$

where:

WWR = Window-to-wall ratio.

Compliance With the Original ASHRAE OTTV

The ASHRAE $OTTV_w$ requirement applies to all buildings that are mechanically cooled, except Type A buildings (one- and two-family residences, and hotels and motels not exceeding three stories above grade). The stringency of the $OTTV_w$ requirement in ASHRAE 90-75 and 90A-1980 is a function of latitude. If applied to locations within ASEAN, the $OTTV_w$ is required to not exceed 90.1 W/m^2 (27.8 Btu/h-ft^2) [19].

To determine if a building meets this $OTTV_w$ requirement, information is needed both on building features and on climate data for the location. From the building features, one can calculate directly the values of U_w, A_w, U_f, A_f, and SC. The value of TD_{eq} can be determined from a figure as a function of kg/m^2 (lbs/ft^2) [19] which is independent of climate or location. The Solar Factor (SF) is given as a function of latitude. For all major ASEAN cities, with latitudes less than 20°, SF is set to 361 W/m^2 (115 Btu/h-ft^2) [19].

Calculation of OTTV for compliance with ASHRAE 90-75 [18] is demonstrated for an example building in Singapore, with the following characteristics:

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[*] The equation also contained a note permitting the expansion of any element of the wall if more than one type of construction is present.

U_w = 2.13
A_w = 1904
U_f = 6.53
A_f = 1496
TD_{eq} = 17.5 (for wall mass of 247 kg/m^2)
SC = 0.47
A_o = 3400 m^2 (25 m width x 3.4 m height x 4 sides x 10 floors)

The climate variables for Singapore are:

DT = 8.8 (32.8 °C -24.0 °C)
SF = 361

Solving for these inputs, Equation 7-1 yields:

$$
\begin{aligned}
OTTV_w &= (2.13 \times 1904 \times 17.5)/3400 + (1496 \times 361 \times 0.47)/3400 + (6.53 \times 1496 \times 8.8)/3400 \\
&= 20.87 + 74.65 + 25.28 \\
&= 120.8 \text{ W/m}^2
\end{aligned}
$$

Thus, the building design does not comply with the requirement of 90.1 W/m^2.

Comments on the Original ASHRAE $OTTV_w$

Orientation:

The original ASHRAE formulation did not explicitly consider the variation in solar radiation by orientation, for it used a weighted average for all building facades. The benefit of this approach was simplicity; compliance required calculation of only a single equation. The disadvantage was inaccuracy, for the substantial differences in solar radiation impinging on vertical surfaces facing in different directions were not considered.

Stringency:

The ASHRAE $OTTV_w$ requirement was intended as a cooling requirement, the stringency of which was dependent on latitude. The $OTTV_w$ was more stringent in lower latitudes, but did not change for latitudes less than 20°.

Recent Refinements:

The $OTTV_w$ requirement was that recommended by ASHRAE in the US from 1975 until 1990. However, during the 1980s, substantial analysis was conducted on ways to improve the envelope requirements. The methodologies used have much in common with those used concurrently in the ASEAN studies, and the resulting refinements have also been similar.

The newly published ASHRAE Standard 90.1-1989 provides a more comprehensive and stringent set of cooling requirements [20]. Like the newly proposed $OTTV_w$ expressions in ASEAN, the 90.1 envelope requirements are based upon parametric computer simulations using DOE-2 that are used to generate regression equations. The US analyses included two sources of added complexity. First, the regressions included changes in climate variables across a wide range of climate conditions. Second, the regressions involved the integration of both heating and cooling impacts.

THE 1979 SINGAPORE $OTTV_w$ EQUATION

Singapore had for many years recognized the importance of reducing energy use in commercial buildings. In 1979, the Singapore government established energy conservation standards for both new and existing commercial buildings and provided for strong enforcement requirements. The standards consisted of maximum allowable lighting loads and maximum allowable OTTV of the building envelope and roof. The Singapore OTTV standard for walls and roof was estimated to reduce energy use by 6% for all buildings meeting the standard. This estimate is based on an assumed reduction in OTTV from 70 W/m^2 prior to the introduction of the standard to the 45 W/m^2 (of envelope area) after the standard.

Since its implementation in Singapore, the OTTV has been used to ensure that building envelopes are adequately designed to reduce external heat gains. Owners of existing buildings could write off in one year the cost of conversion work to conform to the prescribed OTTV. Consumers of electricity in buildings that had not achieved the prescribed standard as of January 1, 1982 were required to pay a surcharge of 20% tax on electricity bills.

The wall $OTTV_w$ requirement was developed by Singapore in 1979, four years after the original ASHRAE expression. It used the same $OTTV_w$ equation as the original ASHRAE formulation shown in Equation 7-1, above. However, the Singapore version [21] included several changes intended to make the requirements more appropriate to the hot humid ASEAN conditions. These substantially altered the numerical values produced by the equation, the relative importance of each of the terms in the equation, the stringency of the $OTTV_w$ requirements, and the complexity of the compliance procedures. The three changes are:

- Wall thermal mass: The credit for wall thermal mass was reduced by over 30% for all but the most heavy wall constructions.
- Solar Factor: A Solar Factor (SF) value was developed, based on local Singapore climate data. The Singapore SF value of 130 W/m^2 was substantially lower than the ASHRAE SF value of 360 W/m^2 for the same location.
- Wall Orientation: A Correction Factor (CF) that allowed assessment of the impacts of the orientation of glass was added to the Solar Factor (SF) term.

As a result of these changes, the Singapore $OTTV_w$ requirement of 45 W/m^2 is slightly less than half of the ASHRAE requirement for the Singapore location of 91 W/m^2. However, even though the Singapore requirement is numerically smaller at 45 W/m^2, it is actually less stringent than the earlier ASHRAE requirement of 91 W/m^2 for the Singapore location. This is shown in Table 7-1 where the ASHRAE 90-75 and Singapore 1979 OTTV results are compared for identical buildings in Singapore. The OTTV calculations are depicted for three hypothetical buildings: a square building, a rectangular building with aspect ratio of 4:1 and long axis oriented east-west, and the latter building oriented with the long axis north-south. The table indicates that a building wall system meeting the Singapore requirement will fail the ASHRAE requirement by a slight amount.

Because the Singapore $OTTV_w$ equation accounts for the variation in the amount of solar radiation received by vertical wall surfaces of different orientations, the OTTV procedure involves two steps. First, the $OTTV_i$ of each wall is computed. Then, the composite OTTV for the whole building envelope is computed by taking the weighted average of these individual values. Thus, to calculate the OTTV for the envelope of a building having 'n' walls, the following formula is used:

$$OTTV = \{A_1 \times OTTV_1 + A_2 + OTTV_2 + \ldots + A_n \times OTTV_n\}/\{A_1 + A_2 \ldots + A_n\} \quad \text{(Eq. 7-3)}$$

Also, Singapore did considerable work in developing explicit credits for effective shading coefficients of external shading devices, both to facilitate compliance with the $OTTV_w$, and to emphasize the importance of using external shading devices as a compliance strategy. As part of this effort, a refinement was made to the delineation of the SC term of the equation. The SC term was expanded to include an effective shading coefficient for external shading devices, as follows:

$$SC = SC_1 + SC_2 \qquad \text{(Eq. 7-4)}$$

where

SC_1 = Shading coefficient of the glass.
SC_2 = Effective shading coefficient of an external shading device.

The Singapore government developed and published a handbook to aid in compliance with their 1979 energy code [21]. A series of tables in a handbook provides explicit numerical credits for a wide set of external shading devices and dimensions.

ASHRAE 90-75 and Singapore 1979 in Context

The two $OTTV_w$ formulations just discussed provide the starting points and context for the extensive work on envelope performance criteria accomplished within the ASEAN-USAID Project since 1982. The efforts have indeed resulted in major improvements to the earlier ASHRAE and Singapore products. The final chapter of this volume discusses each of the major analyses conducted, the methods used, and the results obtained.

Table 7-1. Comparison of ASHRAE and Singapore OTTV Equation

		Units	ASHRAE 90-75	SINGAPORE 1979 N	E	S	W	ALL
WEATHER DATA								
Equiv. Temp. Diff.	(TDeq)	Deg. C	17.6					10.0
Temperature Diff.	(deltaT)	Deg. C	8.8					8.8
Degrees N. Latitude		Deg. C	5.0					5.0
Solar Factor	(SF)	W/m2	360.0					130.0
Orientation Correction	(CF)	-	N/A	0.72	1.25	1.02	1.25	
BUILDING DESIGN INPUTS								
Wall U-value	(Uw)	W/m2-C	2.13					2.13
Weight		kg/m2	247.0					247.0
Wall Area	(Aw)	m2	2138.6	535	535	535	535	2139
Fenestration U-value	(Uf)	W/m2-C	3.20					3.20
Fenestration Area	(Af)	m2	1261.4	315	315	315	315	1261
Shading Coefficient	(SC)	-	0.42					0.42
Window-to-Wall Ratio	(WWR)	-	0.37	0.37	0.37	0.37	0.37	0.37

COMPARISON FOR A SQUARE BUILDING

	Units	ASHRAE 90-75	N	E	S	W	ALL
Building Aspect Ratio: 1 to 1			0.25	0.25	0.25	0.25	1.0
Opaque Wall Conduction	W/m2	23.6					13.4
Glass Solar Radiation	W/m2	56.1	3.65	6.33	5.17	6.33	21.5
Glass Conduction	W/m2	10.4					10.4
OTTVw (Building Design)	W/m2	**90.1**					**45.3**
OTTVw Requirement	W/m2	**90.1**					**45.0**

COMPARISON FOR A RECTANGULAR BUILDING (Long sides E-W)

	Units	ASHRAE 90-75	N	E	S	W	ALL
Building Aspect Ratio: 4 to 1			0.1	0.4	0.1	0.4	1.0
Opaque Wall Conduction	W/m2	23.6					13.4
Glass Solar Radiation	W/m2	56.1	1.46	10.13	2.07	10.13	23.8
Glass Conduction	W/m2	10.4					10.4
OTTVw (Building Design)	W/m2	**90.1**					**47.6**
OTTVw Requirement	W/m2	**90.1**					**45.0**

COMPARISON FOR A RECTANGULAR BUILDING (Long sides N-S)

	Units	ASHRAE 90-75	N	E	S	W	ALL
Building Aspect Ratio: 4 to 1			0.4	0.1	0.4	0.1	1.0
Opaque Wall Conduction	W/m2	23.6					13.4
Glass Solar Radiation	W/m2	56.1	5.83	2.53	8.26	2.53	19.2
Glass Conduction	W/m2	10.4					10.4
OTTVw (Building Design)	W/m2	**90.1**					**43.0**
OTTVw Requirement	W/m2	**90.1**					**45.0**

CHAPTER 8: CRITERIA FOR ENERGY PERFORMANCE OF WALLS OF LARGE OFFICE BUILDINGS IN ASEAN

INTRODUCTION

In an effort to improve on the accuracy of the original ASHRAE and Singapore $OTTV_w$ equations and to simplify compliance procedures, seven separate studies have been conducted in the ASEAN region since the early 1980s. Virtually all of these studies have used variations of the same analysis methodology, which involves conducting parametric computer simulations of the annual energy impacts of changes in envelope features. The main features of this methodology, and the options available, are described in Appendix D of this volume, as a context for the descriptions of the various ASEAN studies described in this chapter.

These studies have resulted in a number of modifications to the original ASHRAE and Singapore equations discussed in the previous chapter. These modifications reflect refinements, local climate conditions, and attempts to simplify compliance. Table 8-1 compares the overall format and content of the OTTV equations resulting from each of the various ASEAN studies. Most ASEAN studies have added a term for solar absorptivity to the opaque wall conduction term. One study proposed eliminating the opaque wall conduction term entirely in order to simplify compliance. Three studies proposed elimination of the fenestration conduction term. The proposed OTTV criteria for Malaysia and Indonesia exclude this term (which has the smallest impact of the three terms). All ASEAN studies follow the original Singapore OTTV equation in considering orientation an integral part of the OTTV. Table 8-2 compares compliance among the various forms of OTTV equation proposed or adopted in ASEAN *for the same building envelope characteristics.*

A word of caution seems appropriate here about both the methodology and the results. Parametric energy simulations and regression analyses of the parametric results are powerful new tools being applied to building energy studies in general, and more specifically to energy standards and $OTTV_w$ analyses. These tools can easily be misused, however. Improperly conceived or executed studies can produce results that make statistical sense but do not reflect reality. To avoid such pitfalls, each step in the process needs to be reviewed and checked very carefully.

Figure 8-1 shows the general nine-step process that is discussed in Appendix D for developing or refining the $OTTV_w$ equation, given the starting requirements of a simulation tool, climate data, and reference building. In each of the nine steps, equally valid and reasonable choices among options are available; the selection among these choices will influence the nature and type of results obtained from the analyses. As we shall see, both the approaches taken and the results of the analyses have been richly varied in this project.

EARLY REFINEMENTS TO THE 1979 SINGAPORE $OTTV_W$ CRITERIA (1984)

Phase I of the ASEAN-USAID project focused on analysis related to Singapore because of its prior experience and its desire to improve on the energy standard already in place. USAID arranged for the Lawrence Berkeley Laboratory (LBL) to undertake the project in close consultation with the Development & Building Control Division, Public Works Department of Singapore. The overall objectives of the project were:

- To transfer to Singapore a computer code (DOE-2) to analyze the energy performance of buildings

- To analyze measures to increase the energy efficiency of buildings in Singapore
- To use the analysis results to extend and enhance Singapore's standards on energy efficiency in buildings
- To establish a process whereby the other ASEAN members can benefit from the experience in Singapore, including the use of DOE-2, the analysis to support energy standards, and the process of adapting and implementing building energy standards.

The Phase 1 effort was largely successful in attaining these objectives. For example, the DOE-2 computer code was installed on several mainframe computers in Singapore, training courses were conducted, and a number of Singaporean analysts became proficient in the use of DOE-2. These analysts both assisted in training other ASEAN analysts in the use of DOE-2, and used DOE-2 in a number of studies undertaken during Phase 2 of the ASEAN-USAID Energy Conservation in Buildings Project. Two such studies are described later in this chapter and a third is described in Appendix B, Volume III of this series of final project reports.

The Phase 1 study by [8] conducted extensive analyses to assess the effectiveness of the 1979 Singapore standards for office buildings, and recommended revisions to the standards as a result. The overall methodology used in this study involved a nine-step process:

1. Design of a hypothetical reference office building: A summary of the characteristics of this building have been discussed above in Chapter 4 and are shown in Table 4-1.
2. Choice of a computer code to estimate energy use: The version of DOE-2 available at the time, DOE-2.1B, was used.
3. Weather data: Hourly weather data for 1979 was used for the DOE-2 simulations, including solar radiation data derived from measurements taken in Singapore.
4. Single parametric runs: To assess the conservation potential of individual measures, selected envelope, lighting, and systems features were varied individually, while all other parameters were kept constant.
5. Combinations of measures: An energy efficient building design was simulated by combining several of the most promising individual measures.
6. Analysis of present Singapore standards: The 1979 Singapore lighting and envelope OTTV standards were analyzed to estimate the energy savings achieved through the standards and to assess ways to improve the standards.
7. Development of preliminary recommendations: The results from steps 4, 5, and 6 were presented to the Singapore government as a basis for more detailed evaluations of selected conservation measures.
8. Detailed study of key measures: The measures chosen for careful study included (1) lighting, (2) daylighting and (3) air-conditioning and other equipment maintenance strategies.
9. Policy recommendations: Final recommendations were made to the Singapore government on short-term and long-term revisions to the 1979 standards.

The remainder of this section summarizes the results of the analyses in steps 6 and 7 above to refine the OTTV_w wall criteria of the 1979 Singapore energy standard.

Investigating the Functional Form of OTTV_w

A building envelope thermal standard involves considering insolation, glass conductance and wall conductance simultaneously. The Singapore expression for the wall criteria of the standard was described in the previous chapter and presented in Equations 7-1 and 7-2. For a building with a square floor plan and identical wall configurations, and assuming a wall mass of greater than 195 kg/m^2 typical of office buildings in Singapore, the OTTV_w criteria can be simplified to the following,

$$\mathrm{OTTV}_w = 10\,(1\text{-WWR})\,U_w + 5\,(\mathrm{WWR})\,U_f + 130\,(\mathrm{WWR})\,(\mathrm{SC}) \qquad \text{(Eq. 8-1)}$$

By varying the four envelope design variables of Equation 8-1 — WWR, U_w, U_f, and SC — in a series of DOE-2 simulations, the energy use impact of constructing office buildings with different OTTV was studied. Using the reference office building described in Chapter 4, a series of 11 DOE-2 simulations were run. The cooling energy use results are plotted as a function of OTTV in Figure 8-2.* For reference, two points are shown on the OTTV scale: the minimum threshold for compliance with the 1979 standard and an estimate of pre-1979 construction practice in Singapore.

In general, energy use increases with increased OTTV. Total cooling energy use, however, can vary by as much as 35% for different simulations with the same total OTTV. For example, at an OTTV of 45, total cooling energy use may vary from 1850 to 2545 Mbtu. In order to better understand the scatter observed in Figure 8-2, the solar radiation fraction of OTTV (defined as "a" below) for each point were placed next to each point on the graph.

$$a = \{130\,(\mathrm{WWR})\,(\mathrm{SC})\} / \mathrm{OTTV}_w \qquad \text{(Eq. 8-2)}$$

Two conclusions can be made by examining the data in Figure 8-2. One is that for roughly equal "a", energy use increases with increasing OTTV. Thus, it appears that if "a" remains constant, then OTTV can be used as a measure of cooling energy use. An exception is when "a" = 0.75 at very low OTTV (20 W/m^2). In this case, the cooling energy use is much lower than expected. Lowering OTTV from 70 W/m^2 to 45 W/m^2 at "a" = 0.60, reduces total cooling energy use by 400 Mbtu or 16%. This results in a 10% reduction in total energy use for the base case reference building.

The second conclusion is that if OTTV is held constant and "a" is varied, large energy use changes can occur. Changing "a" from 0.87 to 0.46 at an OTTV of around 45 W/m^2 results in a cooling energy use reduction of approximately 700 Mbtu or 27%. Thus, OTTV alone is not an adequate indicator of cooling energy use in office buildings.

In order to further test the hypothesis that cooling energy use is linearly related to OTTV, a series of 200 simulations were conducted at four different values of "a", 0.4, 0.6, 0.7, and 0.8. The load (in Mbtu) that must be satisfied by the chiller is plotted as a function of OTTV in Figure 8-3. Desegregating the simulations according to the value of "a" results in four distinct straight lines. This figure corroborates the hypothesis that cooling energy use is linear with OTTV at constant "a".

Further investigation of this relationship, in which the last term in the OTTV expression was modified to increase the importance of solar gain relative to conductive heat transfer across the windows and opaque walls, led to the following interesting result.

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* A constant volume, constant temperature HVAC system was used in these simulations in order to isolate the energy use impact of cooling load changes from HVAC system effects.

It was found that the greater the relative importance of the last term in the OTTV equation, the better the correlation between cooling energy use and OTTV. The logical extension of this was to drop the wall and window conduction terms altogether and determine the effect of the solar radiation term alone on cooling energy use. A linear regression of chiller load as a function of WWR x SC was performed for the previous set of 20 DOE-2 simulations and plotted in Figure 8-4. The R^2 of the fit is 0.986.

When a linear regression analysis was carried out using the original Singapore $OTTV_w$ formulation, the R^2 of the fit was 0.899. The implication of this analysis is that the last term of the OTTV equation is sufficient to explain 98.6% of the variation of cooling energy use, whereas the original OTTV equation (with 3 terms) explains only 90% of the variation of cooling energy use. Therefore, including the first two terms in the $OTTV_w$ equation worsens the ultimate prediction of cooling energy use by OTTV.

Correcting the Solar Factor for Singapore

Given the importance of the radiation term in the $OTTV_w$ equation, and uncertainty about the value used for the solar factor in the 1979 Singapore code, two independent assessments were conducted to establish the true solar factor. The first assessment analyzed the 1979 hourly weather data used in the DOE-2 simulations for Singapore (see Chapter 3). The incident solar radiation on vertical surfaces averaged over all orientations and over all seasons of the year between the hours of 8 am and 5 pm (the typical hours of occupancy in Singaporean offices) was between 210 and 230 W/m², depending on assumptions regarding the angular dependence of diffuse solar radiation.* Thus, the average value of 220 W/m² is substantially higher than the 130 W/m² used in the standard.

The second assessment of Singapore's solar factor started with the regression equation obtained earlier from considering the chiller load a linear function of WWR x SC, as displayed in Figure 8-4.

$$\text{Chiller Load} = L_o + B \times WWR \times SC \qquad \text{(Eq. 8-3)}$$

where

B = 1034 Mbtu/yr
L_o = 786 Mbtu/yr

L_o equals the chiller load from internal loads such as lights, people and equipment and conductive loads from windows, walls and roof. The latter three terms are quite small relative to the internal loads. Assuming that all of the solar gain results in a cooling load that the chiller must remove, then we can equate the variable term in the equation above to the heat gain from insolation.

$$1034 \times WWR \times SC = A_{walls} \times WWR \times SC \times SF$$

Treating SF as the unknown in the equation, assuming the chiller operates for 3050 hours annually**, and making appropriate unit conversions results in the following.

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* The former value for the solar factor assumes that diffuse radiation is isotropic (i.e., independent of orientation), while the latter value assumes that the diffuse radiation is anisotropic, using an algorithm developed for clear sky conditions. Since such conditions rarely exist in Singapore, it was felt that the actual angular dependence of the diffuse solar radiation is probably between the two assumptions.

** Assuming the chiller operates between the hours of 6 am and 5 pm Monday through Friday, and 6 am and noon on Saturdays.

$$SF = (1034 \text{ Mbtu/yr} \times 293 \text{ Kwh/Mbtu}) / (454.5 \text{ m}^2 \times 3050 \text{ h/yr})$$
$$= 218 \text{ W/m}^2$$

The estimated value for the solar factor of 218 W/m^2 is within 7% of the two values (based on isotropic and anisotropic diffuse solar radiation, respectively) calculated directly from the weather data. The close agreement between the results of these two approaches lends confidence in a markedly higher solar factor as compared to the original 130 W/m^2, and is consistent with the earlier finding of the larger relative influence on cooling energy use from the solar radiative term in the $OTTV_w$ equation.

Refining $OTTV_w$

As a final step in the OTTV analysis, a multi-variable linear regression analysis was conducted where the chiller load was the dependent variable and the coefficients of DT, TD_{eq}, and SF were treated as independent variables. The R^2 was slightly higher (0.994 versus 0.986) for this new formulation of OTTV. However, there was a great amount of uncertainty in TD_{eq} and a moderate amount in DT. Fixing SF at 220 W/m^2, results in DT equal to 1.35°C and TD_{eq} equal to 1.14°C. The 95% confidence intervals for TD_{eq} and DT turn out to be -1.85°C to 4.14°C and 0.76°C to 1.93°C, respectively.

Reducing the number of terms in the OTTV equation from three to two was tested, employing the solar radiation and window conduction terms whose coefficients (i.e., SF and DT) offer the greatest confidence. The R^2 for this formulation was identical as for a three term $OTTV_w$ equation. The confidence interval for DT is similar to the case above.

In conclusion, there was no apparent advantage to using the full three-term original OTTV formulation. The single solar radiation term is sufficient to determine cooling energy use with great accuracy. Thus the wall criteria for the Singapore energy standard were recommended for redefinition as,

$$OTTV_w = 220 \times WWR \times SC \qquad \text{(Eq. 8-4)}$$

Summary

This technical revision to the present OTTV standard could improve the ability of the code to represent energy use in commercial buildings in Singapore. These revisions would give greater importance to the effect of radiation through windows and less to window and wall conductance. The effect of this change in OTTV would be to encourage increased shading and/or reductions in window area (in the absence of daylighting) but to discourage the use of multiple glazings and wall insulation to meet the standard.

The analysis for Singapore resulted in major advances in the understanding of building external envelope impacts in the ASEAN region at the time it was conducted. These include identification of:

- Energy conservation impacts of various building envelope components for a large office in Singapore.
- The magnitude and nature of inaccuracies of the 1979 Singapore $OTTV_w$ formulation (and implicitly, some similar inaccuracies in the original ASHRAE $OTTV_w$ formulation).
- Methodologies that could be used to improve the accuracy of the OTTV formulation, specifically, using the results of parametric simulations of a detailed energy tool on a typical building to generate regression-based values for key OTTV equation parameters.

The study used a parametric analysis and regression equation approach to derive a proposed revision for the $OTTV_w$ equation that would both improve its accuracy and simplify compliance. However, two issues arose in reviewing the approach subsequent to the analysis.

First, some variables were not analyzed over the full range over variation experienced in practice, and thus their effect was distorted. Second, in the multi-regression analysis of chiller load versus OTTV, only a limited number of parametric energy analyses were done. This hindered the procedure's ability to accurately isolate the effects of the multiple terms. These limitations were addressed in the following study conducted for Malaysia.

$OTTV_w$ ANALYSIS FOR MALAYSIA (1987)

$OTTV_w$ wall thermal performance criteria were formulated for the building energy standard in Malaysia. This section summarizes the analyses used to develop the $OTTV_w$ described elsewhere [22]. The methodology involved evaluating the correlation between selected envelope parameters known to be important to energy use and the resulting changes in the load on the chiller of the base case building, building upon the Singapore experience. The analysis began with an exploration of possible additional variables to incorporate into the $OTTV_w$ formulation. It follows that with refinements in defining the set of parametric energy simulations used to calculate an $OTTV_w$ that best predicts cooling energy loads generated from heat gains through a building envelope in Malaysia.

Adding Variables to the OTTV Equation

In addition to the parameters used in the earlier Singapore analysis, both thermal mass and absorptivity of the opaque wall were hypothesized to have a significant impact on energy use in Malaysian buildings. Thermal mass impacts were embedded in the TD term of the original ASHRAE and Singapore equations. However, absorptivity was not included in either the original ASHRAE or Singapore wall OTTV equations. Therefore, analyses were conducted to determine how much an explicit incorporation of either thermal mass or the exterior wall solar absorptivity parameters (or both) would contribute to the accuracy of the OTTV equation for Malaysia. Energy simulations were performed by varying the wall mass and roof mass at solar absorptivities of 0.2 and 0.8, corresponding to light and dark colored surfaces, respectively.

The results of these separate simulations for thermal mass and absorptivity are shown in Figures 8-5a and 8-5b. The exterior wall thermal mass had relatively little effect on the chiller load, changing it only 1% to 2% over the range. This was not considered a large enough impact to increase the complexity of the $OTTV_w$ equation by adding a separate thermal mass term. Neither roof mass nor roof color had a significant impact on the chiller load, due to the relatively small roof area in the reference high-rise office building used.

However, changing opaque wall color, as indicated by varying the solar absorptivity over the range of $\alpha = 0.2$ to $\alpha = 0.8$, had an 8% to 9% effect on chiller load. This result confirmed the initial suspicion that wall color was an important design factor affecting building energy use in the type of climate in the ASEAN region. This is especially true because typical Malaysian construction practice uses little or no insulation in the walls.

Determining Best Way to Add Absorptivity Term to OTTV Equation.

A new form of the $OTTV_w$ equation was needed in order to properly incorporate the solar absorptivity term, α. To evaluate the best configuration, two sets of 20 DOE-2 simulations each were executed using various combinations of the key design variables. In one set, the solar absorptivity 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 that was attributable to the changing absorptivity. The computed variations in the chiller load were then compared to several different methods of incorporating the absorptivity term, shown in Figures 8-6a through 8-6c.

The first two of these figures show that neither the solar absorptivity nor solar absorptivity multiplied by a measure of the opaque wall area (1-WWR) have a discernable mathematical relationship to chiller load. The last figure, however, shows a strong linear relationship between chiller load and solar absorptivity 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 absorptivity term into the OTTV equation is to include it as a multiplicative constant in the opaque wall term. Thus, Equation 7-2 modified for the Malaysia study as follows:

$$OTTV_w = [\alpha \times U_w \times (1\text{-}WWR) \times TD_{eq}] + [WWR \times SF \times SC] + [U_f \times (WWR) \times DT] \quad \text{(Eq. 8-5)}$$

where

α = Solar absorptivity of the opaque wall.

The analysis that follows estimates the unknowns in the above equation for Malaysia, namely TD_{eq}, SF, and DT.

Solar Factor for Malaysia

The solar factor was derived from solar data collected in Penang, northwest of Kuala Lumpur. The vertical radiation is averaged over the time period 7:30 a.m. to 5:30 p.m. The average (over eight orientations) solar factor is equal to 222 W/m^2.

However, because 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 double-strength glass. The shading coefficient is defined as the fraction of solar radiation that passes through the windows relative to that transmitted by clear 0.32 cm (1/8 inch) thick, single pane, double-strength sheet glass. Higher shading coefficients produce greater heat gains and increased cooling energy use. When the shading coefficient is specified in the DOE-2.1 input, the program first calculates the solar heat gain using transmission coefficients for clear, 0.32 cm thick single pane sheet glass. This solar heat gain is multiplied by the value of the shading coefficient to determine the resultant solar heat gain. If we use 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 which TD_{eq} and DT were determined.

Refinements to Methodology for Determining $OTTV_w$

The initial analytic strategy was to follow the methodology for designing the DOE-2 parametric runs and conducting the multi-variate regressions as had been used in the 1984 Singapore study just discussed. The rationale was that the analysis would in all likelihood result in only a slight modification of the Singapore results because of the similarity between the climates and building types in the two places. Another consideration was to have a sufficient number of runs to define adequately the unknowns in the OTTV equation.

However, subsequent close examination of the Singapore analysis revealed that some of the input parameters were not varied throughout their range of likely occurrence, nor were they systematically combined into a coherent set of runs. The result was that the full impact of these parameters on cooling loads was either significantly under- or overestimated.

To eliminate these distortions, the design of the set of parametric energy simulation runs 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, plus 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 the variation of each parameter in combination with the others.

For instance, suppose one wants to solve a problem with two parameters, A and B, each with a plausible value range of 0 to 1. This would lead to $2^2 + 1 = 5$ cases to run, shown in Table 8-3. Every possible combination of factor extremes is given, along with the midpoint of both. In this way, problems with any number of parameters can be analyzed.

Reasonable minimum and maximum values for the key wall parameters were chosen, based on a combination of professional judgment and observed conditions in Malaysia. The range of each parameter used for the revised analysis is shown in Table 8-4.

Determining Form and Content of $OTTV_w$

The addition of the solar absorptivity 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 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:

$$\text{Chiller Load} = k_1 + k_2\,(OTTV_x) \qquad \text{(Eq. 8-6)}$$

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 DT and TD_{eq}.

The chiller load is taken from the DOE-2 systems or plant output report, depending upon system type. The value used is the total annual load on the chiller, in Kwh. Before this output can be used in conjunction with other terms in the $OTTV_x$ cited above, it must be put into consistent units of W/m^2 of external wall area. To do this, the DOE-2 output is divided by annual hours of chiller operation and by the total area of the external wall for the building, using:

$$\text{Chiller Load}_{OTTV}\ (W/m^2) = \text{Chiller Load}_{DOE\text{-}2}\ (Kwh) / (A_o\ (ft^2) \times H_{co}\ (hours)) \qquad \text{(Eq. 8-7)}$$

where

A_o = Gross area of exterior wall, $A_w + A_f$, m^2 (ft^2), as defined in Eq. (7-1), for all orientations combined.

H_{co} = Annual hours of chiller operation (hours), derived from the chiller schedule used in the DOE-2 simulation.

A regression analysis was performed to evaluate the proper format of the OTTV equation and the unknown terms in it (DT, TD_{eq}). In all, six alternate forms of the OTTV equation were evaluated and are shown in Table 8-5. For each configuration, selected regression statistics are compiled, such as the coefficients, their significance (student's t-score), and an estimate of the quality of the straight-line fit of the data to the equation (R^2).

The first form of the equation shown in Table 8-5, with all three terms as in the original Singapore equation, provided the best fit to the data. Almost all (99%) of the variation in chiller loads was accounted for by the functional relationships of the independent variables shown. In this equation, the solar absorptivity 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 terms are significant. The solar radiation term is by far the most significant term in the equation with a t-score of 47; the window conduction term is barely significant at 2.6.

Using Form #1 and the solar factor value of 194 W/m^2, the two unknowns are derived from the coefficients in regression equation, leading to TD_{eq} = 20.3°C and DT = 1.5°C. Thus, these values inserted into Equation 8-5 yield:

$$OTTV_w = [20.3 \times \alpha \times U_w \times (1\text{-}WWR)] + [194 \times WWR \times SC] + [1.5 \times U_f \times (WWR)] \quad \text{(Eq. 8-8)}$$

For reasons of expediency in compliance, a simpler 2 term equation was preferred for use in Malaysia. Ignoring the heat gain contribution from window conduction in the $OTTV_w$ equation (i.e., Form #2, Table 8-5) results in little loss of accuracy. Thus, the wall performance criteria for Malaysia became:

$$OTTV_w = [19.1 \times \alpha \times U_w \times (1\text{-}WWR)] + [194 \times WWR \times SC] \quad \text{(Eq. 8-9)}$$

$OTTV_w$ ANALYSIS FOR THE PHILIPPINE STANDARD (1989)

An analysis was conducted to derive a Philippine $OTTV_w$ wall criteria for the proposed energy standard for buildings [23]. The approach used and the wall characteristics analyzed closely followed the methodology used in the Malaysian study just described. Given the similarity of building types and climates, it was expected that the analysis would result in only a slight modification of these previous results,

A major refinement to the methodology in this Philippine study was in the development of the reference building descriptions from a survey of over 50 buildings conducted in Manila. The detailed features of both a reference office building and a reference hotel were generated via statistical analysis of the sample data for each key energy-related building feature. Because the reference Philippine office building is rectangular with a typical aspect ratio of 2:1, instead of the square prototypes established for Singapore and Malaysia, this permitted an examination of the sensitivity of the coefficients to building orientation. Here, we focus on the analysis in support of an $OTTV_w$ for office buildings. In a later section we discuss the companion analysis for Philippine hotels.

Results

As in the Malaysia study, a variety of alternate forms for the OTTV equation were evaluated. While all the regression fits in terms of R^2 value were relatively high (i.e., above 0.90), the $OTTV_w$ formulation shown in Equation 8-5 had the highest. Furthermore, the t-score for the coefficients indicated that all three of the terms were significant, hence, should all be considered in the final wall OTTV expression. The solar radiation term was by far the most significant term in the OTTV equation, with a t-score greater than 95.

The $OTTV_w$ coefficients were re-estimated for the base case building rotated 90° so that the long axis of the building was oriented north-south, instead of east-west. The resulting coefficients from the regressions for TD_{eq} and DT were within 10% of one another. Hence, for the purposes of the standard, the TD_{eq} and DT were averaged over the two orientations and adopted as constants for the wall and glass conduction terms in the $OTTV_w$ equation, respectively.

The rectangular Philippine reference building also afforded the opportunity to test the robustness of the regression procedure in estimating the solar factor. The solar factor values derived directly from analysis of the weather data, adjusted by the weighted average wall area by orientation, were in agreement with the regression estimates to within 10%. The SF is defined by orientation and hours of building operation as indicated in Table 8-6.

Proposed Philippine $OTTV_w$ Equation

Based on the database of office buildings in the Philippines, and the standards case building derived from it, the requirement proposed for the Philippine energy standard is that the $OTTV_w$ for the exterior walls of buildings not exceed 48 W/m^2. The following wall $OTTV_w$ equation was developed from the analysis for use in determining compliance with the requirement for each wall of a commercial building:

$$OTTV_w = 12.6\,\alpha\,(1\text{-}WWR)\,U_w + 3.4\,(WWR)U_f + SF\,(R)\,SC \qquad \text{(Eq. 8-10)}$$

INDONESIA ENERGY STANDARD (1989)

In terms of methodology used, the Indonesian analysis effort was very similar to the Philippine analysis. The major differences were in the climate data and the development of the reference building descriptions described earlier. For this reason, we do not report here separately on the Indonesian $OTTV_w$ development method, but note the resultant form of the equation in Table 8-1.

FURTHER ANALYSIS OF $OTTV_w$ FOR SINGAPORE (1989)

This section is adapted from an effort to upgrade Singapore's building energy conservation standards, and in particular, revision of the OTTV equations for the envelopes [9]. Earlier analyses suggesting improvements to the 1979 OTTV formulation (described previously) were never acted upon. Yet the inaccuracies of the original OTTV formulation remain, with up to a 15% discrepancies between the calculated OTTV and the resultant heat gains. The primary motivation for this study was to increase the accuracy of the envelope criteria.

What is described here is a slightly different methodological approach to define the OTTV than that taken previously in Singapore, as well as in Malaysia, Philippines, and Indonesia. The differences are important and result in a different $OTTV_w$ formulation for Singapore. The main distinction in the methodology used here is the use of heat gain through the building envelope as the dependent variable, whereas the others used the cooling load faced by the chiller. This is a subtle, but key distinction, having to do with the time delays between heat transmission through a building shell and its appearance as a load on the air-conditioning system. For buildings that do not operate continuously, such as office buildings, some of those heat gains can dissipate during the unoccupied (and unconditioned) period without ever placing a demand on the system. For buildings that operate on a continuous basis, such as hotels or hospitals, there may be no difference between heat gains and chiller loads.

One advantage of defining heat gain as the dependent variable in the analysis is that it permits a simpler approach to calculating the unknowns in the OTTV equation (e.g., TD, DT, and SF). By employing the standard reporting features of DOE-2 as shown below, the unknowns can be determined directly without conducting multi-variable regression analysis. However, in so doing, the ability to assess the significance of terms in the equation is lost.

Methodology

In this approach, OTTV is defined as the average heat transfer rate through the building envelope.

This is obtained by dividing the total annual heat gain through the envelope and dividing by the total operating hours of the air conditioning system and the envelope area, i.e.,

$$\text{OTTV}_w = \{\text{Total heat gain through envelope}\} / \{\text{Total operating hours x envelope area}\} \quad \text{(Eq. 8-11)}$$

Note that this has the effect of averaging the loads accumulated during non-operating hours over the operating hours for the air-conditioning system. This heat gain can be sub-divided into components, which account for conduction gain through walls, conduction gain through windows, and radiation gain through windows during operating and non-operating hours in the building. Retaining the functional form of OTTV_w as originally laid out for Singapore in Equation 7-2, these components can be described by the following set of relations.

$$TD_{eq} (U_w) (1 - WWR) / OTTV = \text{Wall heat conduction gain/total heat gain through the envelope} \quad \text{(Eq. 8-12)}$$

$$DT (U_f) (WWR) / OTTV = \text{Glass heat conduction/ total heat gain through the envelope} \quad \text{(Eq. 8-13)}$$

$$SF (SC) (WWR) / OTTV = \text{Solar radiation gain / total heat gain through the envelope} \quad \text{(Eq. 8-14)}$$

The building is simulated using DOE-2, from which the total heat gain and components are extracted directly from a LOADS summary report. Using these heat gains and the known parameters used as inputs to the simulation (i.e., U_w, U_f, WWR, SC), the unknown coefficients, TD_{eq}, DT, and SF can be derived from Equations 8-11 through 8-14. A single simulation is sufficient to provide an estimate of the coefficients. However, it is desirable to conduct a series of simulations in which the principal envelope parameters are varied, so that the individual coefficient estimates can be averaged.

Results

Following this approach, a series of 41 DOE-2 simulations on the Singapore reference office building were run. The envelope parameters were varied in combination* over the following ranges:

- Window-to-wall ratio (WWR, 0.20 to 0.95)
- Shading coefficient of fenestration (SC, 0.16 to 0.95)
- Window U-value (U_f, 0.20 to 4.21 $W/m^{2\circ}C$)
- Wall U-value (U_w, 1.49 to 2.44 $W/m^{2\circ}C$)

Surprisingly, there is little variation in the resultant values for the coefficients among the simulations. TD_{eq} varies between 10.7 and 11.1; SF varies between 228.9 and 230.4; and DT varies between 4.52 and 5.38. Taking the average values and rounding off results in the following revised OTTV_w equation for a square building in Singapore:

$$OTTV = 11 (U_w) (1 - WWR) + 4.8 (U_f) (WWR) + 230 (SC)(WWR) \quad \text{(Eq. 8-15)}$$

What is striking about Equation 8-15, is how close the first two coefficients are to the original Singapore OTTV_w. There is, however, a dramatic increase in the weight of the solar heat gain component

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* While it is possible that some systematic approach was followed in combining the parameters to form the set of simulations, this study did not follow the factorial analysis technique described for the Malaysian OTTV analysis.

relative to the conductive heat gain components across the windows and opaque walls. This results in an increase in the magnitude of the $OTTV_w$ results for a given building configuration of between 40% and 60% over that calculated by using the original equation. Obviously, the original $OTTV_w$ requirement of 45 W/m^2 would not be appropriate to use with Equation 8-15 and would need to be adjusted to the desired level of stringency. And, as discussed earlier, there is no way of knowing how significant the coefficients are when determined with this technique.

The robustness of the revised $OTTV_w$ equation was further tested by modifying the reference building from a square shape to a rectangular shape of different aspect ratios (4.1, 2.62, and 1.82, respectively), and by varying the thermal mass of the wall construction from 48.8 kg/m^2 to 341.7 kg/m^2. The results obtained from these sensitivity analyses demonstrated that the coefficients of the simplified OTTV equation remain relatively constant. Thus Equation 8-15 is capable of predicting envelope heat gains in Singapore office buildings over a wide range of envelope parameters.

ESTABLISHMENT OF $OTTV_w$ FOR THAILAND (1989)

As with the other ASEAN countries, Thailand's energy criteria for walls stems from the 1979 $OTTV_w$ established for Singapore. This section summarizes a study comparing two approaches to determining the coefficients for the $OTTV_w$ [17]. In a sense, this study incorporates the two different approaches to developing wall criteria embodied in the Malaysia, Philippine, Indonesia, and earliest Singapore revisions on the one hand, and the later Singapore revisions on the other. The coefficients for the wall criteria contained in the proposed energy standard for Thai commercial buildings were determined largely through analytical means, without the use of building energy simulation nor regression. We will first describe the development of this Thai OTTV equation, and follow with a comparison of the coefficients determined empirically from regression.

Analytical Derivation of the $OTTV_w$ Coefficients

Equation 7-2 was chosen as the functional form of the $OTTV_w$ proposed for Thailand. The coefficients, TD_{eq}, DT, and SF were determined analytically. TD_{eq} was derived to account for the effects of solar radiation absorbed by opaque exterior wall surfaces. The extent of this radiation absorption is dependent on the solar absorptivity of the surface, as is the size of the heat transfer through the opaque wall. This can be represented by employing the concept of sol-air temperature defined as follows.

$$T_s = T_o + (\alpha/h_o)I - (\varepsilon/h_o)I_r \qquad \text{(Eq. 8-16)}$$

where,

T_s = Sol-air temperature,
T_o = External ambient temperature,
α = Absorption coefficient for solar radiation,
h_o = The heat transfer coefficient of the external surface,
ε = Emission coefficient for thermal radiation,
I = Solar radiation incident on the wall, and
I_r = Thermal radiation emitted from the wall.

Sol-air temperature is a linear function of α. Because of the finite heat capacity of the wall, the heat transfer is not immediate but is delayed by the wall mass, the extent of which is modulated by the thermal resistance of the wall. Using a static heat transfer characterization, the sol-air temperature can be brought into the $OTTV_w$ framework through the following equation.

$(U_w)(TD_{eq})$ = Average instantaneous heat flux across the wall (Eq. 8-17)

where the right hand side of Equation 8-17 is a function of T_s-T_i. Since T_s is a linear function of α, from Equation 8-17 one can surmise that TD_{eq} is also a linear function of α. Thus, TD_{eq} can be evaluated by using the ASHRAE weighting factor method for wall materials of different specific densities and solar absorptivities. Table 8-7 shows the values for TD_{eq} determined in this way and compiled for use in the proposed standard, ranging from 9 to 18 °C depending on wall density and solar absorptance.

DT, the temperature difference across the glazing, is defined here as the difference in the outdoor temperature of the Bangkok location and the design internal temperature. For a Thai building operating only during the day, this is assumed to be 5°C. Finally, based on analysis of five years of solar data collected in Bangkok, the average solar factor over all orientations is 160 W/m². Thus, the proposed $OTTV_w$ equation for a Thai office building of medium construction (i.e., wall mass between 125 kg/m² and 195 kg/m²) and light exterior colored walls (i.e., α = 0.3) is the following.

$$OTTV_w = 12\,(1\text{-}WWR)(U_w) + 5(WWR)(U_f) + 160\,(WWR)(SC) \qquad \text{(Eq. 8-18)}$$

Thailand has set the OTTV compliance level at or below 45 W/m².

Comparison of Analytic and Empirical Approaches

In order to test the accuracy of $OTTV_w$ coefficients derived from the analytic approach, the coefficients were estimated in a similar manner to that used in the Malaysia, Philippines, Indonesia, and early Singapore approaches. A set of 12 simulations were performed using the DOE-2.1C model to simulate the energy performance of a prototypical Thai office building. The simulations were designed as three sets of four simulations in which for each set, two of three envelope parameters (U_w, U_f, and SC) were held fixed at their base values while the third parameter was varied about some range. The set of runs are shown in Table 8-8. Note that WWR and α were not varied in the parametric.

The results of these simulations were then used to derive the coefficients, TD_{eq}, DT, and SF. Multiple linear regression was performed, equating the annual cooling load from the simulations (as dependent variable) with the known parameters in the three terms of the $OTTV_w$ equation (see Equation 7-2). The resulting coefficients were TD_{eq} = 16.8°C, DT = 5.3°C, and SF = 165.7 W/m². All three coefficients were highly significant, with student's t-scores exceeding 12 in all cases.

The latter two coefficients derived through regression generally agree with their counterparts contained in the proposed Thai standard (which were derived analytically). For TD_{eq}, the regressed value is higher than the value in the standard. This could be interpreted to mean that the effect of the external ambient temperature and solar radiation on the opaque wall — the sol-air temperature — is higher than anticipated. More likely, however, is that the values differ due to inaccuracies introduced by the experimental design of the set of simulations. With some of the parameters held fixed and others not properly varied in combination as prescribed by the factorial analysis technique (as described for Malaysia), the factor space was not adequately covered. A further discrepancy between the analytic and empirical approaches is that the former related heat gain to $OTTV_w$ while the latter related cooling load to $OTTV_w$, an issue raised earlier in connection with the approach followed by Singapore in its later $OTTV_w$ revision. This would have the greatest effect on the estimate of TD_{eq}, though with the opposite outcome to that obtained here. In other words, use of cooling load, with the time delay of heat transfer from building thermal mass, should diminish the importance of the opaque wall conduction term (by estimating a smaller coefficient), not enhance it as resulted here. The difference probably stems from the experimental design.

$OTTV_w$ ANALYSIS FOR HOTELS IN THE PHILIPPINES (1989)

The objective of this effort was to determine if the $OTTV_w$ equation developed for a large hotel would be the similar to that for large office buildings. The typical Philippine hotel operates 24 hours per day, seven days per week (8760 hours per year), while the typical Philippine office building operates 10.5 hours per day on weekdays and 6 hours on Saturday (3042 hours per year). It is this distinction in operation that might necessitate separate wall criteria formula.

The hotel $OTTV_w$ parametric analysis used the same methodology and 1983 climate data as with the office building analysis. Also, the same set of wall characteristics, ranges, and sets of parametric runs were used, but the midpoints used in the parametric simulations were slightly different, corresponding to the averages for those envelope parameters determined for the typical hotel building. The five independent variables were: U_w, U_f, WRR, SC, and α. Solar factor estimates were developed both from the regression analysis and exogenously from direct analysis of the weather data.

The factorial-analysis experimental-design technique was used to determine the appropriate set of parametric runs. Regression analyses using the least squares method were made for each chiller load estimate from the parametric runs and the corresponding combination of the five envelope parameters. To test the effect of orientation on the estimated coefficients, two sets of ($2^5+1 = 33$) parametric runs were done for the reference building, which has a 3.5:1 aspect ratio. For these two sets of runs, the long axis of the reference hotel was oriented east-west and north-south, respectively, since these represent the extremes. Then two regressions were performed and compared.

Regression statistics (including coefficients, standard errors, t-scores and the R-squared values) were compiled for the two building orientations. The fits were highly significant, as were all three terms in the $OTTV_w$ equation.* The resulting values for TD_{eq}, DT, and SF derived from the regression runs are shown in Table 8-9.

The most striking aspect of these results is how small the coefficients are relative to their counterparts for offices: they are one-half to two-thirds smaller for the hotel. This is the effect of the 24-hour operating schedule for hotels. TD_{eq} and DT are smaller because the nighttime external temperatures are lower than daytime temperatures, narrowing the effective temperature differences. SF is smaller because the solar energy intensity is averaged over all hours, including nighttime hours. Changing the orientation of the building causes TD and DT estimates each to differ by about 10%, whereas SF differs by about 20% between orientations. While outdoor air temperatures would not be expected to vary according to orientation, the sol-air temperature phenomenon does cause TD_{eq} and DT to vary. Compared to a direct estimate of the SF for hotels from the weather data (shown in Table 8-6 for all 24 hours), the SF obtained through regression is 15% to 20% lower, depending on orientation. It is not clear why this discrepancy exists, since the same comparison conducted for the Philippine office building yielded a close agreement.

Philippine $OTTV_w$ Equation for Hotels

It was decided that the TD_{eq} and DT were reasonably close regardless of orientation such that the average of the TD_{eq} and DT values in both orientations could be used as the coefficients for the wall and glass conduction terms in the OTTV equation, respectively. However, SF would depend on orientation as usual, and would be drawn from Table 8-6. Thus, for a square hotel building, the wall criteria would be the following.

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* R^2 values were 0.997 for both orientations. The solar radiation term was by far the most significant term with a student's t-score of 87 for the east-west orientation and 79 for the north-south orientation.

$$\text{OTTV} = 5.4\,\alpha\,(1\text{-WWR})\,U_w + 1.1\,(\text{WWR})\,U_f + 73\,(\text{WWR})\,\text{SC} \qquad \text{(Eq. 8-19)}$$

SUMMARY OF OTTV$_w$ THROUGHOUT ASEAN

Table 8-1 compares the OTTV$_w$ equations prepared for office buildings in ASEAN. What is most striking is the overall similarity of the terms in spite of the variation in climate and construction throughout the region.

The implication of the results of the Philippine hotel OTTV$_w$ analysis is that changes in wall design parameters have about half the impact on energy efficiency for hotels than similar changes in offices and other buildings with daytime occupancies. This is indicated by the magnitudes of the coefficients for wall conductance and fenestration conductance, as well as the solar factor values. The hotel analysis did not address impacts on peak load relative to office buildings. The peak load differences between offices and hotels might well be substantially less than the energy differences indicated. Further analysis is needed in order to resolve this issue.

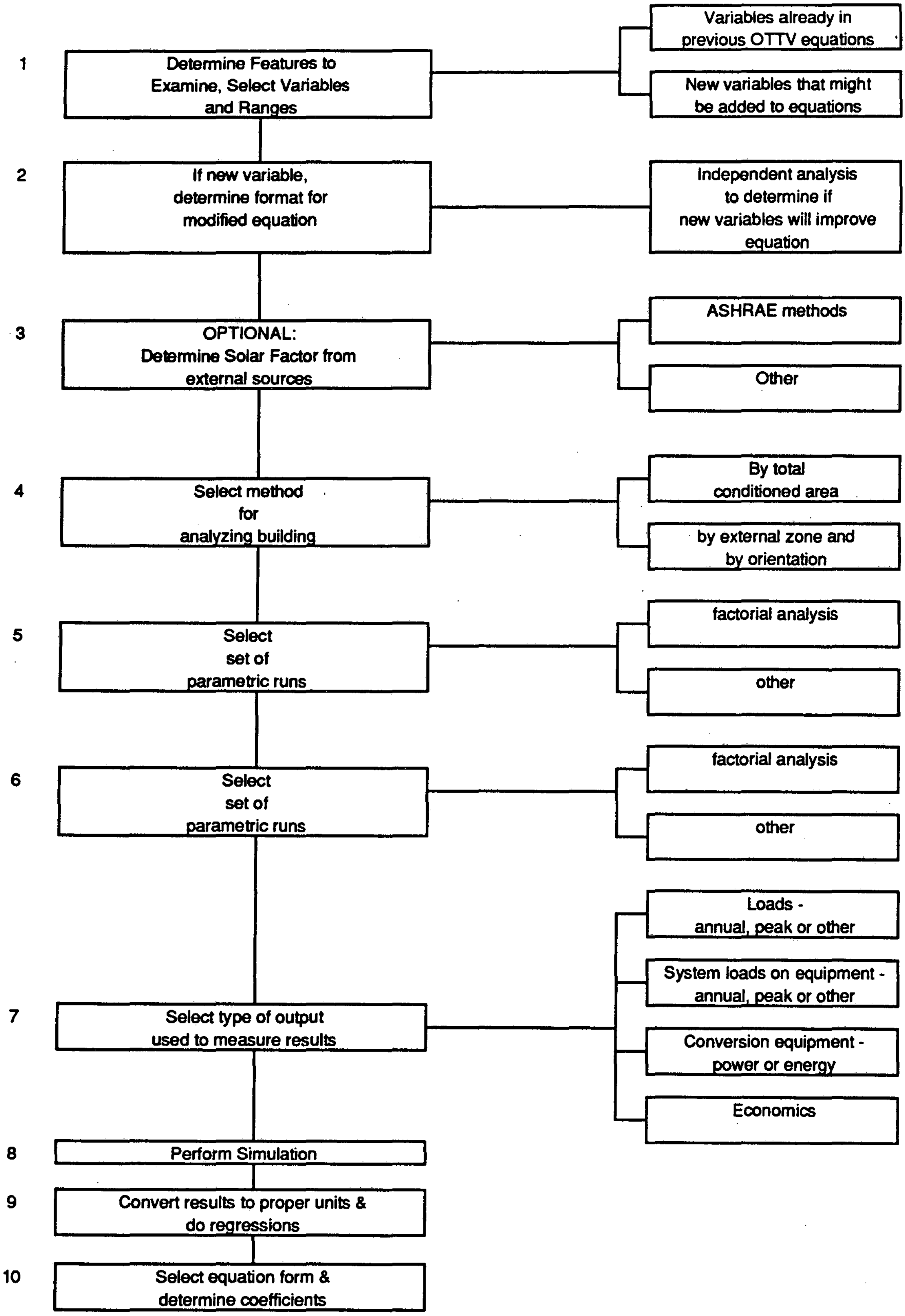


FIGURE 8-1. OTTV Analysis Procedure (for a single climate location)

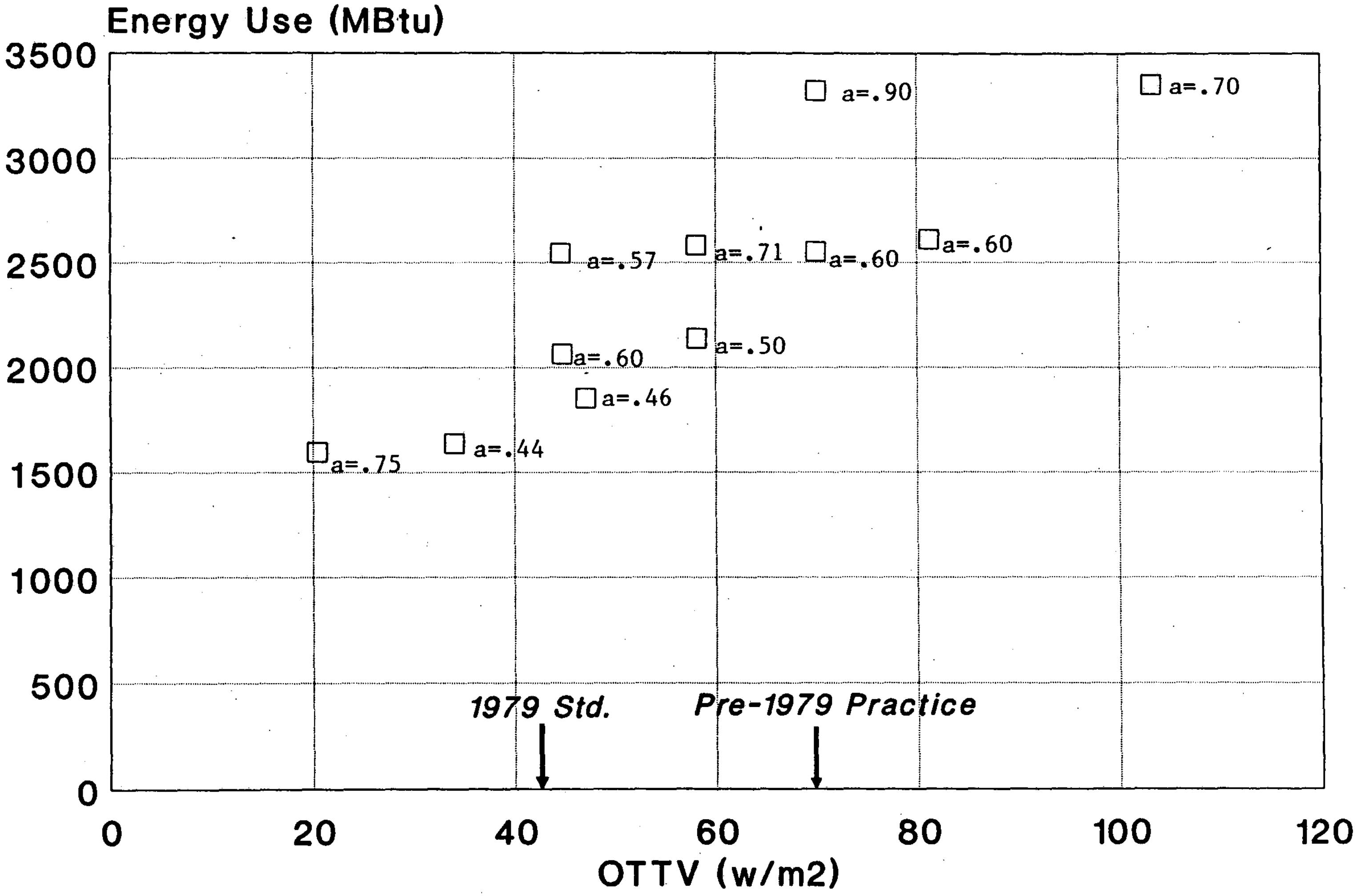


Figure 8-2. Cooling Energy Use vs. OTTV.

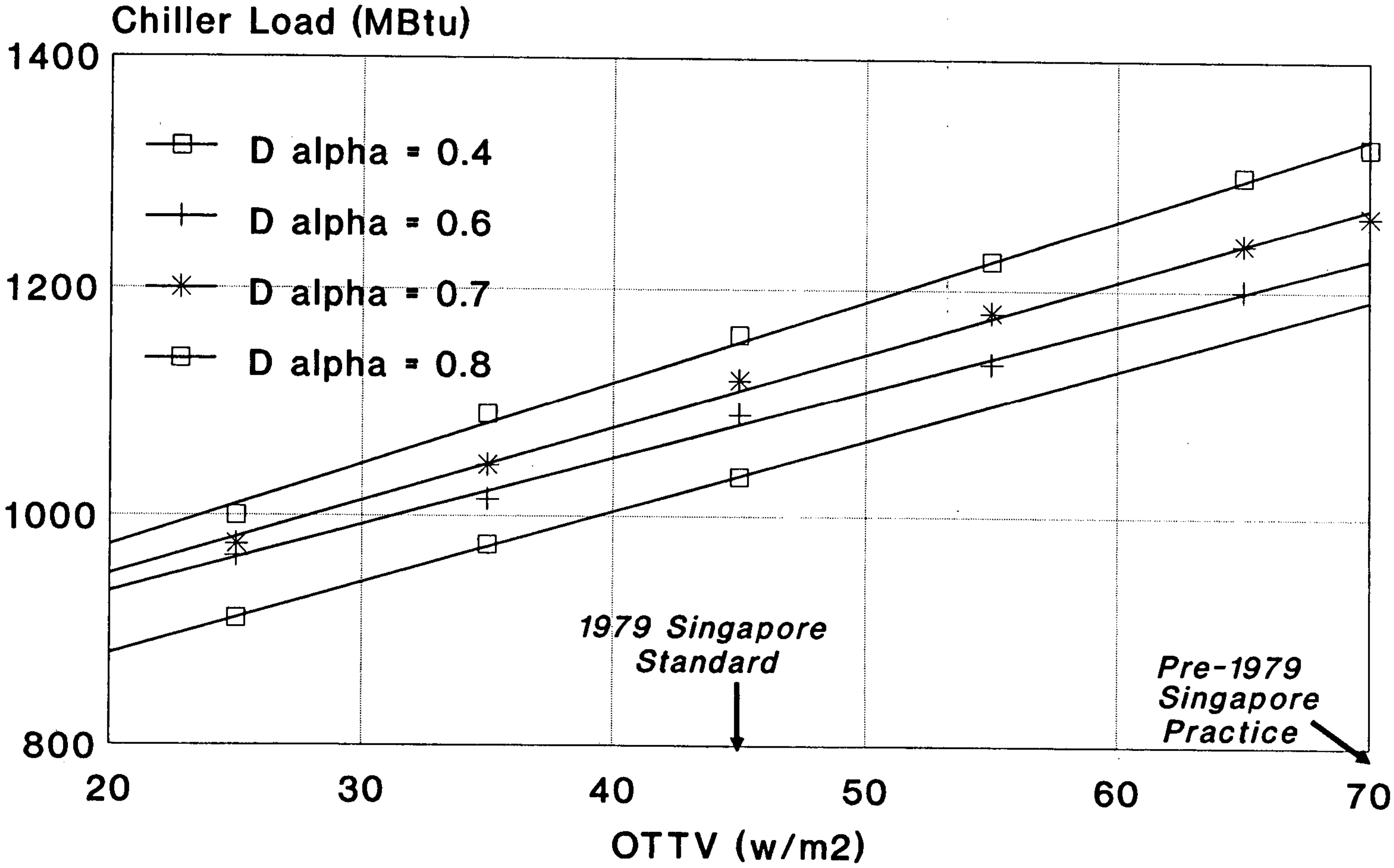


Figure 8-3. Chiller Load for Typical Floor vs. OTTV (No Overhang).

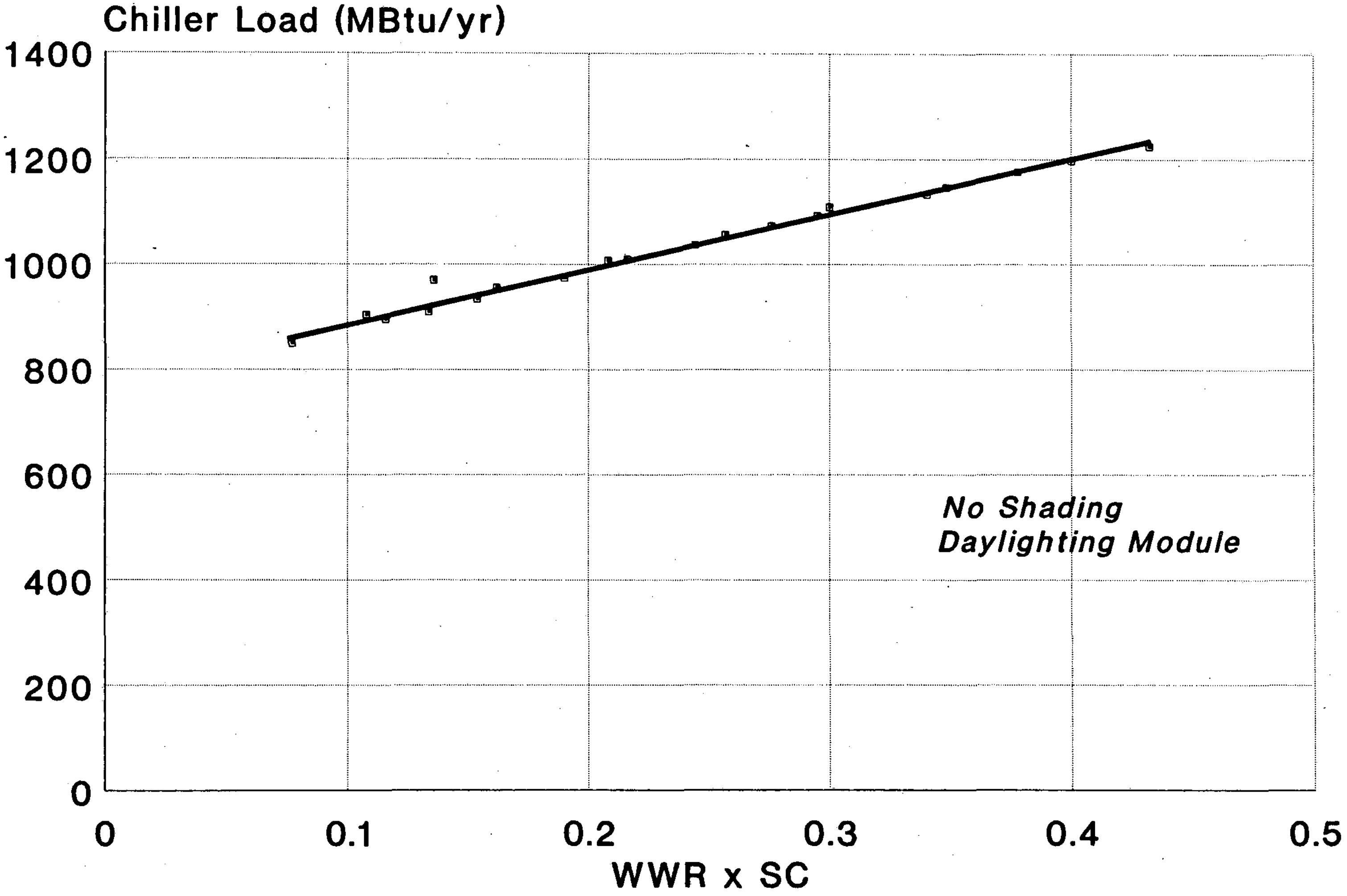
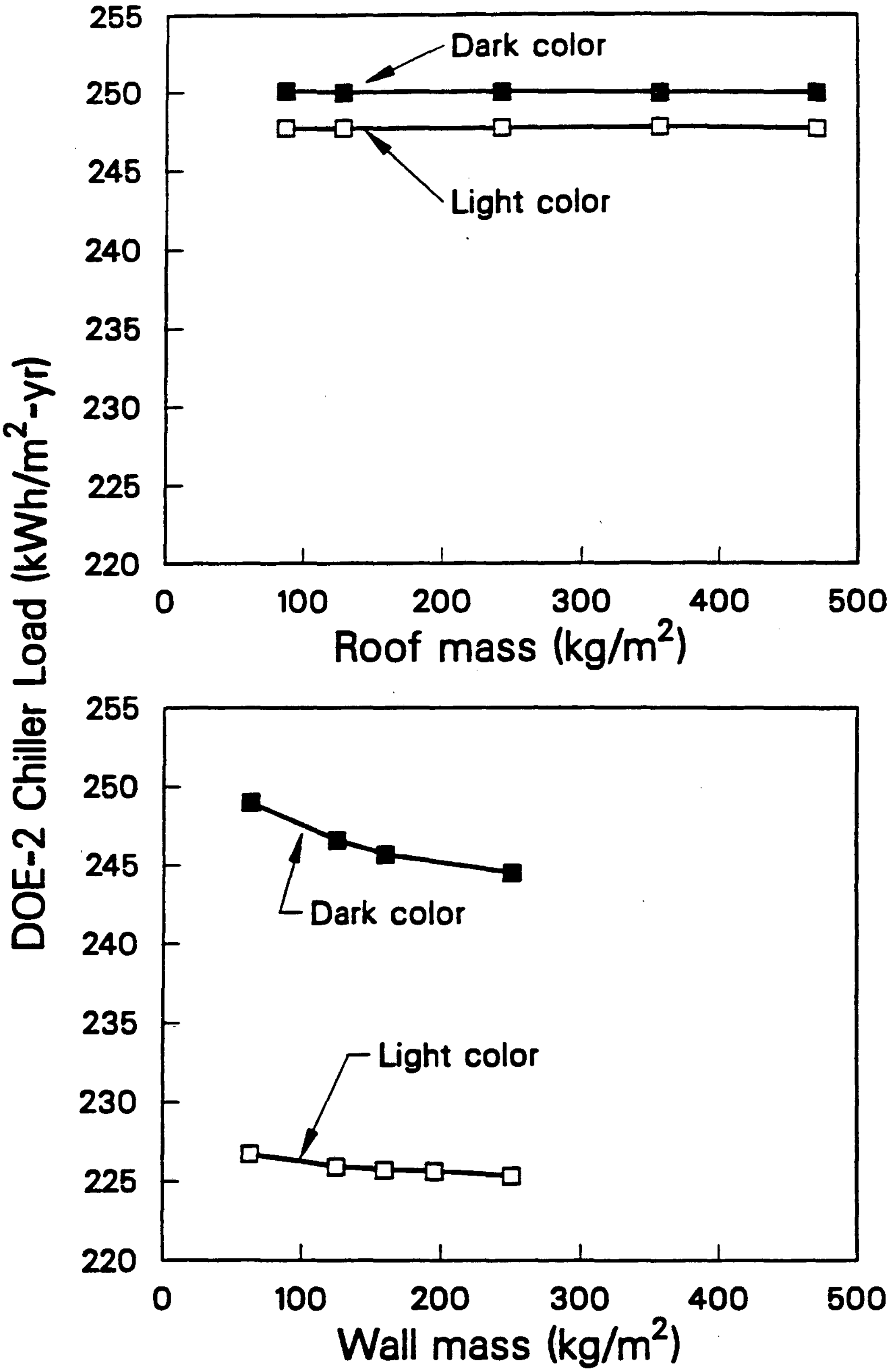


Figure 8-4. Chiller Load vs. WWR x SC.



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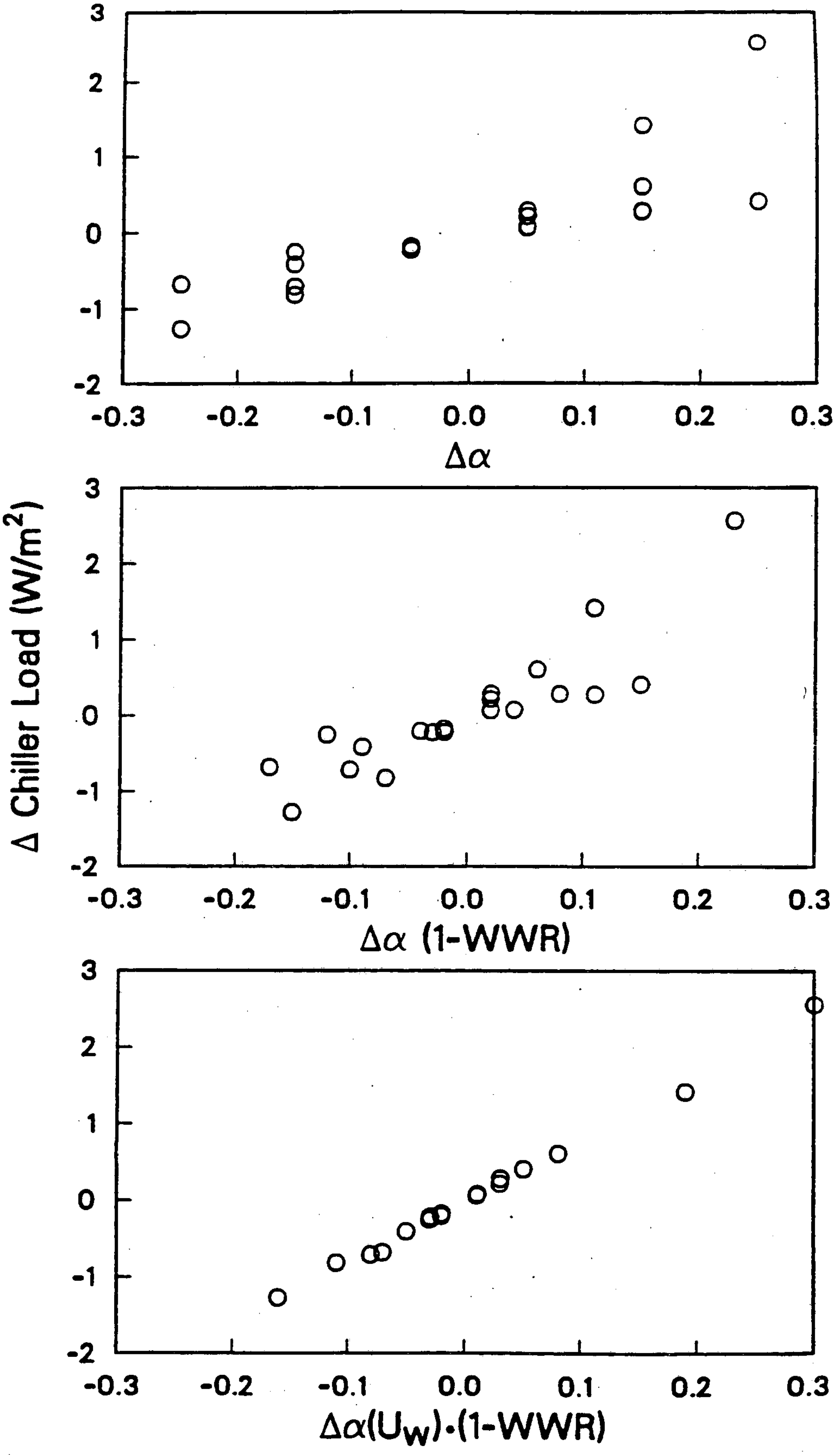
Figures 8-5a and 8-5b. The Effect of Thermal Mass and Exterior Surface Color on Chiller Loads for Roof (5a) and Walls (5b).



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Figures 8-6a - 8-6c. 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.

TABLE 8-1 OTTVw EQUATIONS IN ASEAN

Country and Date of Analysis	OTTVw Requirement	Opaque Wall Conduction Term				Fenestration Conduction Term			Fenestration Solar Term			
		TDeq (deg C)	alpha	Uw	(1-WWR)	DT (deg C)	Uf	WWR	Avg SF (W/sqm)	CF	SC	WWR
ASHRAE 90-75 (for Singapore)	91	8 to 27		Yes	Yes	8.8	Yes	Yes	361		Yes	Yes
Singapore (1979)	45	10 to 15		Yes	Yes	8.8	Yes	Yes	130	Yes	Yes	Yes
Singapore (1984)	n/a								220	Yes	Yes	Yes
Malaysia (1987)	45	19.1	Yes	Yes	Yes				194	Yes	Yes	Yes
Philippines (Offices) (1989)	48	12.6	Yes	Yes	Yes	3.4	Yes	Yes	162	Yes	Yes	Yes
Philippines (Hotels) (1989)	n/a	5.4	Yes	Yes	Yes	1.1	Yes	Yes	73	Yes	Yes	Yes
Indonesia (1989)	45	10 to 15	Yes	Yes	Yes				147	Yes	Yes	Yes
Singapore (1989)	68	11		Yes	Yes	4.8	Yes	Yes	230	Yes	Yes	Yes
Thailand (1989)	45	14 to 18	Yes	Yes	Yes	5.0	Yes	Yes	160	Yes	Yes	Yes

TABLE 8-2 OTTVw EQUATIONS COMPARISON - TYPICAL LARGE OFFICE

OTTV Eq. VERSION	OTTV Requirement	OTTVw Compliance				Opaque Wall Conduction Term				Fenestration Conduction			Fenestration Solar Term						NS Wall Fract. of Tot
		Total	Wall	Glass	Solar	TDeq (deg C)	a	Uw	(1-WWR)	DT (deg C)	Uf	WWR	SF N (W/sqm)	SF E	SF S	SF W	SC	WWR	
FOR A SQUARE BUILDING																			
ASHRAE 90-75 (for Singapore)	91	98.3	15.9	20.2	62.2	17.5		1.82	0.5	8.8	4.59	0.5	361	361	361	361	0.34	0.5	0.50
Singapore (1979)	45	51.5	9.1	20.2	22.2	10		1.82	0.5	8.8	4.59	0.5	94	163	96	163	0.34	0.5	0.50
Singapore (1984)	n/a	37.5			37.5								158	275	163	275	0.34	0.5	0.50
Malaysia (1987)	45	43.5	10.4		33.1	19.1	0.6	1.82	0.5				140	243	144	243	0.34	0.5	0.50
Philippines (Offices) (1989)	48	42.4	6.9	7.8	27.7	12.6	0.6	1.82	0.5	3.4	4.59	0.5	101	202	165	176	0.34	0.5	0.50
Indonesia (1989)	45	30.5	5.5		25.1	10	0.6	1.82	0.5				130	112	97	243	0.34	0.5	0.50
Singapore (1989)	68	60.2	10.0	11.0	39.2	11		1.82	0.5	4.8	4.59	0.5	166	288	170	288	0.34	0.5	0.50
Thailand (1989)	45	44.8	6.0	11.5	27.3	11	0.6	1.82	0.5	5.0	4.59	0.5	112	179	178	165	0.34	0.5	0.50
FOR A RECTANGULAR BUILDING, with 2:1 Aspect Ratio, Long Sides Facing E-W																			
ASHRAE 90-75 (for Singapore)	91	98.3	15.9	20.2	62.2	17.5		1.82	0.5	8.8	4.59	0.5	361	361	361	361	0.34	0.5	0.33
Singapore (1979)	45	53.4	9.1	20.2	24.1	10		1.82	0.5	8.8	4.59	0.5	94	163	96	163	0.34	0.5	0.33
Singapore (1984)	n/a	40.8			40.8								158	275	163	275	0.34	0.5	0.33
Malaysia (1987)	45	46.4	10.4		36.0	19.1	0.6	1.82	0.5				140	243	144	243	0.34	0.5	0.33
Philippines (Offices) (1989)	48	44.0	6.9	7.8	29.3	12.6	0.6	1.82	0.5	3.4	4.59	0.5	101	202	165	176	0.34	0.5	0.33
Indonesia (1989)	45	32.4	5.5		26.9	10	0.6	1.82	0.5				130	112	97	243	0.34	0.5	0.33
Singapore (1989)	68	63.7	10.0	11.0	42.7	11		1.82	0.5	4.8	4.59	0.5	166	288	170	288	0.34	0.5	0.33
Thailand (1989)	45	45.5	6.0	11.5	28.1	11	0.6	1.82	0.5	5.0	4.59	0.5	112	179	178	165	0.34	0.5	0.33
FOR A RECTANGULAR BUILDING, with 2:1 Aspect Ratio, Long Sides Facing N-S																			
ASHRAE 90-75 (for Singapore)	91	98.3	15.9	20.2	62.2	17.5		1.82	0.5	8.8	4.59	0.5	361	361	361	361	0.34	0.5	0.67
Singapore (1979)	45	49.5	9.1	20.2	20.2	10		1.82	0.5	8.8	4.59	0.5	94	163	96	163	0.34	0.5	0.67
Singapore (1984)	n/a	34.2			34.2								158	275	163	275	0.34	0.5	0.67
Malaysia (1987)	45	40.6	10.4		30.2	19.1	0.6	1.82	0.5				140	243	144	243	0.34	0.5	0.67
Philippines (Offices) (1989)	48	40.8	6.9	7.8	26.1	12.6	0.6	1.82	0.5	3.4	4.59	0.5	101	202	165	176	0.34	0.5	0.67
Indonesia (1989)	45	28.7	5.5		23.2	10	0.6	1.82	0.5				130	112	97	243	0.34	0.5	0.67
Singapore (1989)	68	56.8	10.0	11.0	35.8	11		1.82	0.5	4.8	4.59	0.5	166	288	170	288	0.34	0.5	0.67
Thailand (1989)	45	44.0	6.0	11.5	26.5	11	0.6	1.82	0.5	5.0	4.59	0.5	112	179	178	165	0.34	0.5	0.67

TABLE 8-3. Example of Factorial Analysis Parameter Problem

	Parameter	
Case	A	B
1	1	1
2	1	0
3	0	0
4	0	1
5	0.5	0.5

TABLE 8-4. Parameter Ranges for Wall OTTV Variables in Malaysia

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

TABLE 8-5. Forms of the OTTV$_w$ Equation Tested for Malaysia

	Independent Variables						
	X_{11} $\alpha(1 - WWR)$ (ΔT_{eq})	X_{12} $(1 - WWR)U_w$ (ΔT_{eq})	$\sqrt{\alpha}(1 - WWR)U_w$ (ΔT_{eq})	X_{14} $\alpha^2(1 - WWR)U_w$ (ΔT_{eq})	X_2 $(WWR)U_f$ (ΔT)	X_3 $(WWR)SC$ (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				13.084	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 8-6. Solar Factors for Manila

Orientation	Direct	Diffuse	Total	Total Transmitted
		All Daylight Hours (W/m^2)		
Horizontal	224.8	150.8	375.6	
North	17.2	101.1	118.3	88.2
East	107.4	121.0	228.4	184.3
South	65.5	116.3	181.8	138.9
West	74.4	118.6	193.0	154.5
NE	61.0	109.9	170.9	133.7
SW	71.9	118.9	190.8	150.1
SE	100.9	121.0	221.9	176.0
NW	43.4	108.5	151.9	119.1
8 Dir. AVERAGE	67.7	114.4	182.1	143.1
EW/NS: 2/1 AVG.				150.8
NS/EW: 2/1 AVG.				132.2
		Hours 8 to 18 (W/m^2)		
Horizontal	247.7	164.8	412.5	
North	16.7	109.5	126.2	94.4
East	102.2	128.9	231.1	185.4
South	71.5	126.8	198.3	151.7
West	83.0	129.7	212.7	170.2
NE	55.0	117.4	172.4	134.0
SW	80.1	130.1	210.2	165.3
SE	100.7	130.2	230.9	182.7
NW	48.4	118.5	166.9	130.7
8 Dir. AVERAGE	69.7	123.9	193.6	151.8
EW/NS: 2/1 AVG.				159.6
NS/EW: 2/1 AVG.				141.3
		All 24 Hours (W/M^2)		
Horizontal	114.9	77.0	191.9	
North	8.8	51.6	60.4	45.0
East	54.9	61.8	116.7	94.1
South	33.5	59.4	92.9	70.9
West	38.0	60.6	98.6	78.9
NE	31.2	56.1	87.3	68.3
SW	36.7	60.8	97.5	76.7
SE	51.5	61.8	113.3	89.9
NW	22.2	55.4	77.6	60.8
8 Dir. AVERAGE			93.0	73.1
EW/NS: 3.5/1 AVG.				80.2
NS/EW: 3.5/1 AVG.				64.3

TABLE 8-7. Values for Equivalent Temperature Difference (TDeq) in Thai Standard

Wall Density (kg/m^2)	Ranges of Solar Absorptivity (α)				
	0 - 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0
0 - 125	14	15	16	17	18
126 - 195	11	12	13	14	15
> 195	9	10	11	12	13

TABLE 8-8. Parameters in Simulations of Thai Office Prototype

Run	WWR	α	SC	U_w (W/m^2 - °C)	U_f (W/m^2 - °C)
1	0.488	0.3	0.63	3.1	7.0
2	0.488	0.3	0.63	0.948	7.0
3	0.488	0.3	0.63	2.8	7.0
4	0.488	0.3	0.63	2.0	7.0
5	0.488	0.3	0.63	3.0	8.5
6	0.488	0.3	0.63	3.0	6.81
7	0.488	0.3	0.63	3.0	11.35
8	0.488	0.3	0.63	3.0	9.65
9	0.488	0.3	0.63	3.0	7.0
10	0.488	0.3	0.9	3.0	7.0
11	0.488	0.3	0.4	3.0	7.0
12	0.488	0.3	0.2	3.0	7.0

TABLE 8-9. $OTTV_w$ Coefficients for Philippine Hotel of Aspect Ratio 3.5:1

	Orientation	
	North-South	East-West
TD_{eq}	5.1	5.6
DT	1.2	1.1
SF	55.7	66.4

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APPENDIX A

THE POLICY DEVELOPMENT PROCESS

This appendix describes each of the six steps identified for the policy procedures involved in developing a first-time energy standard. These steps also could apply to refinements to existing standards, with some modifications. The six steps are:

DECISION TO DEVELOP A STANDARD

The decision to develop an energy standard for buildings usually originates in government planning activities aimed at promoting the efficient use of energy nationally. The benefits of such a policy are discussed in greater depth in the body of this report, along with the rationale for using building codes as a vehicle for energy conservation. In some cases, however, the impetus may come from — or be prompted by — other sources, such as concerned building professional or management organizations. The specific actors and procedures involved in formalizing such a decision will depend on the political and bureaucratic structure of each country. Typically, one of two processes are used to develop building energy standards:

1. A government may have a standard developed, with review by representatives of affected groups; or

2. A private sector organization, such as an engineering society, may develop a standard, with review by representatives of affected groups and adoption by the government.

In either process, the involved groups remain the same, while their roles differ.

FORMATION OF A STANDARDS POLICY GROUP AND STANDARDS ANALYSIS GROUP

Within ASEAN, standards have been developed using two separate groups, a Policy Group and an Analysis Group. Generally, some overlap in the membership of the two groups occurs. Typical composition and functions of these groups is discussed below.

Policy Group

The standards policy group typically consists of senior, highly experienced professionals drawn from both the public and private sectors. Normally, individuals are identified from within their respective constituency group and serve on a voluntary (non-funded or partially funded) basis. Ideally, in addition to their technical expertise and experience, such individuals have excellent communication and collaboration skills, for they tend to serve as informal channels for information on standards development activities. Whether the standard itself is developed by the government or by a private sector organization, the following types of organizations are typically represented on the policy group.

1. Government
    - Administrators
    - Technical Advisors
2. Professional Societies and Building Industry Groups
    - Architects

  - Mechanical Engineers
  - Electrical Engineers
  - Illuminating Engineers/Lighting Designers
  - Builders/Contractors
  - Other Design Professionals

3. Building Owners and Managers

   - From the Private Sector
   - From the Public Sector

4. Utilities

5. Manufacturers

   - Energy-Related Building Materials (glazing, insulation, etc)
   - Energy-Using Equipment (chillers, fans, motors, lighting, etc)

The main function of the policy group is to exercise collective judgement, based on individual experience and expertise, in formulating the appropriate contents and implementation framework for an effective standard. Because a building energy standard involves a complex of issues, including political, economic, and social concerns, the standards policy group will typically need to be multi-disciplinary in its composition.

Analysis Group

The tasks of the standards analysis group are somewhat more narrowly technical in focus than the tasks of the policy group. Nonetheless, the analysis group also needs to have a multi-discipline character. Ideally, the minimum set of disciplines that should be represented on the analysis groups are architecture, lighting, and mechanical engineering. Input from the electrical engineering profession may also be needed for some analyses.

The main function of the analysis group is to provide technical and analytic support to the standards development process, a responsibility which typically involves:

1. Carrying out building energy surveys and audits to gather data on typical physical building characteristics;

2. Collecting and organizing weather data;

3. Performing computer simulation-based energy and economic analyses; and,

4. Reviewing proposed standards based on original research and/or standards used in other countries.

The standards analysis component is discussed in greater detail below.

The iterative nature of the standards development process and the linkages between the policy group and the analysis group are graphically illustrated in Figure 1-1. The work of both groups will be occurring simultaneously for much of the process and it is likely that the groups will share key members in common.

DEVELOP CONTENTS OF STANDARD

Today, most standards development work consists of review of existing standards, and the adaptation of the best part of these existing standards to local building practices and climate conditions. Within ASEAN, a draft "model" energy standard was developed in 1987 as part of the ASEAN-USAID Buildings Energy Conservation Project. This draft was based upon the latest standards development work in the US (in the form of early drafts of ASHRAE Standard 90.1-1989), as well as upon the Singapore and more recent Malaysia formats and standards.

The policy development group begins to make specific recommendations as to the content of the proposed standard, using an existing standard or standards as a "take off" point and incorporating local environmental conditions, indigenous design practices, results of building surveys and audits, and the existing regulatory and institutional framework. At the same time, decisions or recommendations must be made concerning the structure and organization of the standard (eg., in the Philippines, the standard was divided into two parts; one addressing building design and one addressing operation and maintenance), and the scope of the standard (eg., which buildings are to be covered by the code and which are not). These recommendations will be reviewed and refined throughout the standards development process.

The preparation of each section of code generally involves the following six steps:

1. Selection of applicable criteria/guidelines from other available building energy standards/codes. In ASEAN countries the following codes and standards have served as references:
    - ANSI/ASHRAE/IES Standard 90.1P - Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, Working Draft 88/3, July 22, 1988.
    - CIBS Building Energy Code, Part 1 - Guidance Towards Energy Conserving Design of Buildings and Services, 1977.
    - CIBS Building Energy Code, Part 3 - Guidance Towards Energy Conserving Operation of Buildings and Services, 1979.
    - Building Energy Efficiency Standards, 1988; ed., California Energy Commission.
    - Philippine Society of Mechanical Engineers Code.
    - ASHRAE Handbook of Fundamentals, 1988 ed.
    - ASHRAE Systems Handbook, 1984 ed.
    - ASHRAE Equipment Handbook, 1988 ed.
    - ASHRAE HVAC Systems and Applications Handbook, 1987 edition.
    - Handbook on Energy Conservation in Buildings and Building Services, Singapore.
    - Energy Conservation in New Buildings, Thailand, 1987.
2. Research into the rationale behind some of the applicable criteria/guidelines, especially those questioned by the policy analysis or other technical committees. This process may include

surveys of the literature and consultation with professionals in other countries.

3. Computation of the values to be incorporated into the standards. This step is likely to involve judgment calls and reasonable estimates as well as straightforward computation. The proposed values should be refined and supported by analyses utilizing local environmental and design conditions. Such analyses are typically performed with computer simulations, such as the DOE-2 program.

4. Writing the proposed draft of the section.

5. Technical review and discussion with the policy analysis group and other consultants (in the ASEAN case, Lawrence Berkeley Laboratory in the US has performed this role).

6. Revision and refinement.

PUBLIC REVIEW PROCESS

Once a draft standard has been developed, and the supporting analysis concluded, then the typical next step is to have the draft reviewed by the various parties that will use it or be impacted by it. This is typically done via a "public review" process.

Experience suggests that it is important to have this review process begin as soon as possible within the overall standards development process. The benefit of an early start for public review is that potentially affected parties can have input before the provisions of the standard appear "cast in stone." This can allow potentially affected parties to claim some "ownership" in the provisions of the standard.

One informal way to accomplish this is to have members of key potentially impacted groups participate as members of the policy development group that establishes the contents of the standard. Such members are then in a position to communicate informally with their peers about the proposed provisions of the standards.

IMPLEMENTATION

Once the public review process is completed, the standards can be promulgated and implemented. Energy standards may be implemented as voluntary or mandatory requirements. Voluntary standards may be disseminated and implemented through a variety of information channels, both public and private. For mandatory standards, two main implementation mechanisms can be used: building codes or utility hookup programs.

Mandatory Implementation through Building Codes

The building code route uses local building code inspection and permit enforcement mechanisms. Effective use of this implementation route requires that building code procedures and personnel are already in place; their role would be expanded to include the new energy efficiency requirements. This is the implementation means used in Singapore since 1979 and in all 50 states in the US, and it is the route currently being explored by the other ASEAN countries.

Implementation may involve enlisting existing agencies or authorities, and/or setting up new ones. Effective implementation will depend on effective enforcement and regulatory mechanisms and effective education of the design and construction industry (see below). A key factor in successful implementation is likely to be the availability of building inspectors and officials trained in performing energy audits and utilizing compliance tools such as computer simulation programs. The precise mechanisms that are mobilized to implement a standard will vary according to local resources, needs, and customary procedures.

Mandatory Implementation through Utility Hookup Programs

Standards can also be very effective in reducing the demand for peak electric power. Because of this, some new trends are occurring in the US, relative to implementation of energy standards. For example, enforcement of standards is beginning to occur by the utility at "hookup" time, before the completed building is occupied. A number of options are being explored, from energy-related hookup fees and rebates to a lower energy rates for buildings meeting the standard.

Such approaches might prove attractive in developing countries, where energy standards could help to reduce the amounts of new, and very costly, electricity-generating capacity required, or help to free existing generating capacity for other uses. However, utilities in developing countries have not expressed interest in this approach, and indeed may resist the implementation of such programs. One possible route may be to establish separate, utility-funded energy service companies as a condition of power plant construction loans. The service companies thus established would have authority to enforce energy hookup standards and responsibility for assuring the energy efficiency of buildings applying for hookups.

TRAINING AND ASSISTANCE (GUIDELINES)

The enforcement of building codes and standards typically occurs at the local level. Thus, the ASEAN countries that implement energy standards will need training programs for building code officials. Such training programs have been essential to the successful implementation of building energy codes and standards in the developed countries.

Training will also be needed for architects and engineers to ensure proper compliance with the new standards. The effort will require the publication of guidelines or manuals of recommended practice that can assist building designers and code officials to understand the implications of various energy strategies in specific building design situations. A trend in the US is to provide microcomputer programs to facilitate the task of code compliance.

Providing proper training and assistance is critical to effective use of the standard by all parties involved. Training mechanisms and tools can include:

- General introduction to the implementation and impacts of the standards (aimed at decision makers in the public and private sectors, including present and future building owners and administrators).
- Workshops for design professionals (both introductory and detailed).
- Workshops for building inspectors and officials.
- Manuals of acceptable practice and guidebooks.
- Case studies of appropriate applications.

A number of manuals and tools exist as a result of previous training activities in various countries, including Singapore and the US. These can provide resources for use in the development of local training and assistance courses and materials.

APPENDIX B

SUMMARY WEATHER DATA FOR MAJOR CITIES IN ASEAN

1985 BANGKOK W/SOLAR MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 13.70 LONGITUDE = -100.60 TIME ZONE = -7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
AVG. TEMP. (F) (DRYBULB)	80.1	83.0	84.7	85.4	83.7	83.2	81.6	82.5	81.3	80.6	81.3	77.9	82.1
AVG. TEMP. (F) (WETBULB)	72.5	75.7	76.2	77.6	77.9	76.7	75.7	76.3	76.3	75.9	75.2	69.2	75.4
AVG. DAILY MAX. TEMP.	90.0	91.5	94.0	94.7	91.5	89.2	88.1	89.0	88.2	87.2	88.2	87.6	89.9
AVG. DAILY MIN. TEMP.	72.2	76.6	77.6	78.7	77.7	78.9	76.6	77.4	76.5	75.9	75.7	69.5	76.1
HEATING DEG. DAYS (BASE 65)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. DAYS (BASE 80)	38.0	113.0	180.5	201.5	143.0	121.0	75.0	99.0	73.0	55.0	62.5	33.0	1194.5
(BASE 75)	189.5	253.0	335.5	351.5	298.0	271.0	229.0	254.0	220.5	204.0	208.5	124.0	2938.5
(BASE 70)	344.5	393.0	490.5	501.5	453.0	421.0	384.0	409.0	370.5	359.0	358.5	264.5	4749.0
(BASE 65)	499.5	533.0	645.5	651.5	608.0	571.0	539.0	564.0	520.5	514.0	508.5	419.0	6573.5
HEATING DEG. HRS./24 (BASE 65)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.4
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. HRS./24 (BASE 80)	84.9	104.5	159.9	173.4	130.8	102.3	78.8	96.7	69.8	60.8	74.4	63.1	1199.4
(BASE 75)	175.7	225.5	301.3	311.5	269.5	245.7	204.6	233.8	187.8	173.8	189.5	142.8	2661.5
(BASE 70)	311.8	363.4	455.1	461.5	424.5	395.7	359.5	388.7	337.6	328.3	337.7	259.2	4423.0
(BASE 65)	466.6	503.4	610.1	611.5	579.5	545.7	514.5	543.7	487.6	483.3	487.7	401.8	6235.4
MAXIMUM TEMP.	93	95	102	102	102	103	93	93	91	90	92	103	103
MINIMUM TEMP.	68	71	70	75	75	76	74	74	74	74	70	60	60
NO. DAYS MAX. 90 AND ABOVE	19	26	31	27	21	12	8	15	9	6	8	11	193
NO. DAYS MAX. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 0 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
AVG. WIND SPEED (MPH)	3.2	6.1	6.6	5.6	4.7	7.0	4.7	5.6	3.4	1.9	2.6	3.0	4.5
AVG. WIND SPEED (DAY)	4.9	7.5	7.5	6.1	5.9	8.5	5.8	7.5	4.2	2.8	3.6	4.0	5.7
AVG. WIND SPEED (NIGHT)	1.9	5.0	5.7	5.0	3.4	5.4	3.6	3.8	2.6	1.1	1.7	2.2	3.4
AVG. TEMP. (DAY)	84.5	87.0	88.7	88.8	86.5	85.4	84.1	85.4	84.0	83.2	84.2	81.9	85.3
AVG. TEMP. (NIGHT)	76.7	79.8	81.2	82.1	80.9	80.9	79.2	79.9	78.7	78.1	78.6	74.6	79.2
AVG. SKY COVER (DAY)	5.8	6.3	7.3	7.1	8.6	9.2	9.0	9.1	9.1	8.9	8.0	4.2	7.8
AVG. REL. HUM. AT 4AM	87.5	88.3	82.7	84.9	90.6	82.8	87.2	85.0	89.1	91.1	88.4	80.7	86.5
10AM	70.0	66.3	62.8	64.3	71.9	69.5	70.0	68.1	73.7	74.6	69.7	61.5	68.5
4PM	49.6	53.3	50.4	55.4	65.0	68.1	69.1	65.1	68.8	71.7	64.0	49.5	60.9
10PM	76.8	81.9	77.5	79.8	83.5	78.9	82.8	82.4	86.7	88.4	82.1	69.1	80.8

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1985 BANGKOK W/SOLAR  MONTHLY WEATHER DATA SUMMARY                                      DOE-2.1

                  LATITUDE =  13.70                    LONGITUDE = -100.60                    TIME ZONE =  -7


                                      JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR

AVG. DAILY DIRECT NORMAL  SOLAR    1506.5 1783.1 1696.4 1462.0 1090.6  590.5  886.9 1043.5  848.4  781.9 1284.6 1810.1 1229.5
AVG. DAILY TOTAL HORIZNTL SOLAR    1473.4 1730.5 1788.8 1769.3 1596.1 1423.5 1517.8 1617.7 1447.1 1221.5 1331.5 1511.1 1534.6

MAX. DAILY DIRECT NORMAL  SOLAR    2370.0 2581.0 2402.0 2762.0 2490.0 2153.0 2483.0 3471.0 1785.0 1746.0 2633.0 2374.0 3471.0
MAX. DAILY TOTAL HORIZNTL SOLAR    1893.0 2184.0 2163.0 2296.0 2298.0 2225.0 2278.0 2235.0 2102.0 1978.0 1907.0 1830.0 2298.0
MIN. DAILY DIRECT NORMAL  SOLAR     138.0   61.0  794.0    0.0   38.0    0.0   18.0  140.0   68.0    0.0  106.0  383.0    0.0
MIN. DAILY TOTAL HORIZNTL SOLAR     807.0  852.0  956.0  524.0  665.0  491.0  754.0    0.0  797.0  472.0  718.0  624.0    0.0

MAX. HRLY  DIRECT NORMAL  SOLAR     339.0  341.0  325.0  334.0  316.0  319.0  317.0  342.0  321.0  328.0  342.0  332.0  342.0
MAX. HRLY  TOTAL HORIZNTL SOLAR     291.0  300.0  326.0  361.0  317.0  308.0  317.0  326.0  326.0  317.0  300.0  255.0  361.0
AVG. MAX. HRLY DIRECT NORML SOLAR   248.9  264.4  261.8  226.6  195.1  152.7  171.9  207.3  197.6  185.2  243.5  302.8  221.3
AVG. MAX. HRLY TOTAL HRZNTL SOLAR   234.0  267.7  266.6  272.4  249.1  230.1  240.3  256.0  249.5  219.5  225.3  237.0  245.5




AVG. DAILY TOTAL VERTICAL SOLAR
                AZIMUTH
                   N                382.8  410.2  458.0  568.1  777.6  895.2  837.6  754.0  542.2  428.0  364.4  336.2  563.8
                   E                904.2  984.3 1082.5 1053.3 1011.7  971.2  978.5 1105.3  951.0  835.5  874.2  966.3  976.6
                   S               1356.9 1282.2  937.5  621.4  544.6  600.4  553.0  668.3  761.0  886.2 1160.4 1473.8  902.0
                   W                794.4  951.7 1014.7  992.8  938.4  900.1  886.1  998.6  878.9  709.3  698.5  731.4  874.0

MAX. DAILY TOTAL VERTICAL SOLAR
                AZIMUTH
                   N                604.9  604.8  567.6  773.7 1101.8 1062.9 1035.7  952.2  698.4  598.4  543.3  503.4 1101.8
                   E               1103.1 1211.1 1249.9 1297.8 1377.1 1377.7 1311.2 1443.2 1267.6 1187.8 1104.7 1119.7 1443.2
                   S               1679.6 1472.3 1208.2  849.6  783.6  778.9  732.3  843.2  953.8 1356.7 1692.8 1825.3 1825.3
                   W               1013.5 1466.1 1221.0 1180.7 1745.5 1295.8 1206.4 1415.7 1242.9 1082.3 1004.3 1076.1 1745.5

MAX. HRLY  TOTAL VERTICAL SOLAR
                AZIMUTH
                   N                102.9  104.5   92.9  105.3  146.2  157.7  149.1  153.3  122.4   89.2  102.9  122.7  157.7
                   E                271.7  246.6  266.7  261.6  279.0  252.1  249.2  285.0  258.7  256.6  241.4  222.6  285.0
                   S                242.3  195.6  176.1  118.2  109.8  128.8  118.4  131.4  157.3  207.6  235.7  223.9  242.3
                   W                205.0  368.2  318.4  310.2  372.1  274.3  257.0  479.6  262.6  248.2  254.2  240.0  479.6
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1985 BANGKOK W/SOLAR  MONTHLY WEATHER DATA SUMMARY                                          DOE-2.1


DESIGN TEMPERATURES -------------------------------- SUMMER ---------- WINTER

                                PER CENT        T(DRY)  T(WET)         T(DRY)
                                   1.0              91      80             65
                                   2.5              90      79             67
                                   5.0              89      79


MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

                     JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP     OCT     NOV     DEC    YEAR
        HOUR         ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----
          0          75.3    79.1    81.0    81.8    80.5    80.6    79.0    79.8    78.4    77.6    77.9    74.0    78.7
          1          74.5    78.8    80.5    81.3    80.0    80.4    78.3    79.5    78.1    77.5    77.8    72.6    78.3
          2          73.9    78.4    80.0    80.8    79.6    80.1    78.0    79.2    77.9    77.1    77.3    71.8    77.8
          3          73.7    77.9    79.5    80.3    79.3    79.8    77.8    78.7    77.5    77.1    76.9    71.1    77.4
          4          73.2    77.6    78.9    79.9    78.9    79.5    77.5    78.4    77.2    76.8    76.6    70.6    77.1
          5          72.8    77.0    78.1    79.4    78.4    79.3    77.3    78.2    77.0    76.5    76.0    69.9    76.6
          6          72.6    76.7    78.1    79.5    78.8    80.0    77.7    78.9    77.4    76.8    76.0    70.2    76.9
          7          73.6    78.2    80.5    82.2    81.5    82.1    80.2    81.5    79.6    79.4    78.2    71.5    79.0
          8          77.6    82.0    84.6    84.9    84.1    84.2    82.2    83.5    81.9    81.3    81.2    76.1    82.0
          9          81.7    85.5    87.3    87.9    86.4    85.8    84.1    85.5    83.8    83.2    83.6    79.2    84.5
         10          84.7    87.4    89.3    89.8    87.3    86.7    85.6    86.7    84.9    84.2    85.3    82.2    86.2
         11          86.7    89.3    90.9    91.3    88.5    87.2    86.3    87.5    85.8    85.4    86.3    84.4    87.5
         12          88.2    90.1    92.0    91.9    89.4    87.7    86.9    88.3    86.2    86.1    87.3    85.7    88.3
         13          89.1    90.7    92.6    93.0    89.9    87.6    86.9    88.2    86.7    85.5    87.5    86.3    88.6
         14          89.3    90.8    92.9    92.8    89.6    88.0    86.7    88.3    87.0    85.1    86.9    86.6    88.7
         15          89.1    90.6    92.4    92.7    89.5    87.0    84.9    87.2    86.2    84.2    86.3    86.4    88.0
         16          88.0    89.2    90.6    90.7    87.7    85.7    84.2    85.1    84.4    83.6    85.2    85.1    86.6
         17          84.8    86.1    87.8    88.2    86.0    84.0    83.1    82.6    82.6    82.4    83.4    83.1    84.5
         18          81.8    83.0    84.7    85.6    83.8    82.9    81.9    81.4    80.8    80.5    81.9    80.1    82.4
         19          80.2    81.6    83.3    84.3    82.8    82.2    80.9    80.5    80.0    79.7    81.0    78.7    81.3
         20          79.0    80.9    82.6    83.7    82.5    81.9    80.1    80.6    79.4    79.1    80.4    77.5    80.6
         21          78.2    80.5    82.2    82.8    81.9    81.6    79.8    80.5    79.4    78.7    79.7    76.7    80.2
         22          77.3    80.1    81.5    82.3    81.4    81.2    79.5    80.6    79.1    78.3    79.0    75.2    79.6
         23          76.0    79.8    81.0    82.0    81.0    80.9    79.3    80.2    78.8    77.9    78.4    75.0    79.2


GROUND TEMPERATURES  530.0   530.0   531.0   532.0   532.0   533.0   534.0   535.0   534.0   533.0   532.0   530.0
CLEARNESS NUMBERS     1.06    1.05    1.03    1.01    0.99    0.97    0.99    0.98    1.00    1.00    1.04    1.05
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1987 JAKARTA W/SOLAR  MONTHLY WEATHER DATA SUMMARY                                    DOE-2.1

                    LATITUDE =  -6.20                    LONGITUDE = -106.80                    TIME ZONE =  -7


                                     JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR

AVG. TEMP. (F) (DRYBULB)            79.3   79.5   81.6   82.2   82.9   83.3   82.8   81.9   82.4   83.4   81.5   80.5   81.8
AVG. TEMP. (F) (WETBULB)            74.8   75.0   75.1   75.7   74.8   74.7   73.4   71.4   73.7   75.0   75.2   75.4   74.5

AVG. DAILY MAX. TEMP.               84.6   84.9   89.6   89.6   91.1   91.5   91.4   90.8   90.7   90.9   89.1   86.8   89.3
AVG. DAILY MIN. TEMP.               75.0   74.9   75.8   76.7   77.0   77.1   75.9   74.5   75.5   76.9   76.1   75.3   75.9

HEATING DEG. DAYS (BASE 65)          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                  (BASE 60)          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                  (BASE 55)          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                  (BASE 50)          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0

COOLING DEG. DAYS (BASE 80)         13.0    9.0   85.0   94.5  125.5  129.5  112.5   82.0   93.5  120.5   80.5   49.0  994.5
                  (BASE 75)        149.5  137.5  239.0  244.5  280.5  279.5  267.5  236.5  243.0  275.5  228.0  191.0 2772.0
                  (BASE 70)        304.5  277.5  394.0  394.5  435.5  429.5  422.5  391.5  393.0  430.5  378.0  342.0 4593.0
                  (BASE 65)        459.5  417.5  549.0  544.5  590.5  579.5  577.5  546.5  543.0  585.5  528.0  497.0 6418.0

HEATING DEG. HRS./24 (BASE 65)       0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.5    0.5
                     (BASE 60)       0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.1    0.1
                     (BASE 55)       0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                     (BASE 50)       0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0

COOLING DEG. HRS./24 (BASE 80)      37.2   35.7   92.5   91.9  114.2  118.5  115.5  102.8  104.0  125.7   82.2   63.0 1083.2
                     (BASE 75)     133.4  128.0  207.0  216.3  245.7  250.3  241.6  216.7  223.0  260.4  196.1  172.2 2490.7
                     (BASE 70)     286.9  265.4  361.0  366.1  400.7  399.6  395.6  368.8  372.1  415.4  345.5  326.2 4303.2
                     (BASE 65)     441.9  405.4  516.0  516.1  555.7  549.6  550.6  523.7  522.1  570.4  495.5  480.5 6127.5

MAXIMUM TEMP.                         88     91     93     93     95     95     94     93     95     95     92     92     95
MINIMUM TEMP.                         73     72     73     74     75     73     73     69     70     75     69     58     58

NO. DAYS MAX. 90 AND ABOVE             0      1     18     16     22     25     30     23     17     27     15      8    202
NO. DAYS MAX. 32 AND BELOW             0      0      0      0      0      0      0      0      0      0      0      0      0

NO. DAYS MIN. 32 AND BELOW             0      0      0      0      0      0      0      0      0      0      0      0      0
NO. DAYS MIN.  0 AND BELOW             0      0      0      0      0      0      0      0      0      0      0      0      0

AVG. WIND SPEED (MPH)                5.0    4.3    4.6    4.3    4.7    4.8    5.2    4.9    5.0    4.2    3.4    4.5    4.6

AVG. WIND SPEED (DAY)                6.6    6.4    6.9    6.0    7.2    7.2    7.4    7.2    7.2    6.2    5.1    6.0    6.6
AVG. WIND SPEED (NIGHT)              3.2    2.1    2.4    2.5    2.1    2.4    3.1    2.7    2.6    1.8    1.4    2.7    2.5

AVG. TEMP. (DAY)                    80.7   81.2   84.4   84.5   85.7   86.0   85.6   84.7   85.1   85.9   83.7   82.5   84.2
AVG. TEMP. (NIGHT)                  77.7   77.8   78.9   79.9   80.2   80.7   80.0   79.1   79.5   80.6   78.9   78.3   79.3

AVG. SKY COVER (DAY)                 2.0    2.0    2.0    2.0    2.0    2.0    2.0    2.0    2.0    2.0    2.0    2.0    2.0

AVG. REL. HUM. AT  4AM              91.6   91.8   89.5   87.7   84.4   83.3   83.1   80.9   84.9   86.1   89.0   91.4   86.9
                  10AM              79.5   78.9   68.9   69.7   65.5   64.7   63.6   59.3   61.3   62.6   69.2   75.8   68.2
                   4PM              70.4   69.9   59.7   62.2   55.3   51.8   47.5   43.3   51.1   55.2   62.8   69.6   58.2
                  10PM              85.2   86.5   83.5   81.2   76.5   74.4   69.7   66.7   72.9   73.8   82.6   85.5   78.2
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1987 JAKARTA W/SOLAR  MONTHLY WEATHER DATA SUMMARY                                     DOE-2.1

                    LATITUDE =  -6.20                  LONGITUDE = -106.80                 TIME ZONE =  -7


                                           JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR

AVG. DAILY DIRECT NORMAL  SOLAR         1014.2  830.5 1288.7 1051.2 1163.5 1158.4 1344.2 1523.6 1364.7 1578.8 1143.8  936.7 1203.1
AVG. DAILY TOTAL HORIZNTL SOLAR         1239.9 1117.7 1506.1 1250.6 1275.8 1241.3 1399.0 1615.3 1552.4 1685.8 1380.0 1166.0 1371.4

MAX. DAILY DIRECT NORMAL  SOLAR         1919.0 1444.0 2120.0 1824.0 1791.0 1643.0 1903.0 1919.0 1902.0 2088.0 1877.0 2223.0 2223.0
MAX. DAILY TOTAL HORIZNTL SOLAR         1896.0 1583.0 2066.0 1805.0 1762.0 1573.0 1739.0 1864.0 1886.0 2072.0 1874.0 2082.0 2082.0
MIN. DAILY DIRECT NORMAL  SOLAR          284.0  231.0  318.0  419.0  372.0  354.0  472.0 1134.0  797.0  869.0  523.0  107.0  107.0
MIN. DAILY TOTAL HORIZNTL SOLAR          544.0  549.0  616.0  753.0  579.0  613.0  795.0 1216.0 1096.0 1160.0  829.0  225.0  225.0

MAX. HRLY  DIRECT NORMAL  SOLAR          342.0  318.0  337.0  324.0  316.0  297.0  296.0  322.0  322.0  330.0  321.0  342.0  342.0
MAX. HRLY  TOTAL HORIZNTL SOLAR          313.0  298.0  324.0  298.0  317.0  251.0  251.0  269.0  280.0  302.0  284.0  309.0  324.0
AVG. MAX. HRLY DIRECT NORML SOLAR        211.8  181.0  254.5  222.5  238.5  216.5  224.2  238.8  243.4  289.7  238.8  193.3  229.8
AVG. MAX. HRLY TOTAL HRZNTL SOLAR        225.2  208.1  265.4  225.8  219.5  206.8  219.8  236.7  230.8  257.5  244.4  198.2  228.4



AVG. DAILY TOTAL VERTICAL SOLAR
                AZIMUTH
                   N                     387.3  399.0  565.5  768.1 1006.3 1092.0 1161.8 1066.3  727.2  520.2  419.1  372.7  709.2
                   E                     574.5  547.0  658.2  578.4  543.5  551.5  633.7  695.0  661.3  676.8  621.4  539.3  607.2
                   S                     805.9  603.3  488.2  389.4  386.3  378.7  404.8  446.4  489.4  697.3  812.9  803.8  559.0
                   W                    1030.6  994.0 1215.7 1084.4 1145.5 1084.2 1178.7 1355.9 1415.3 1576.2 1125.2  992.1 1184.8

MAX. DAILY TOTAL VERTICAL SOLAR
                AZIMUTH
                   N                     501.8  483.3  843.9 1029.1 1358.6 1343.6 1379.3 1202.5  986.6  587.0  494.7  551.1 1379.3
                   E                     769.7  770.0  823.4  702.1  642.8  649.9  720.7  755.9  749.7  749.9  750.4  948.4  948.4
                   S                    1217.5  812.7  632.3  522.5  450.6  438.9  442.4  472.6  554.0  892.0 1034.0 1359.0 1359.0
                   W                    1713.4 1483.5 1761.9 1713.2 1523.1 1439.2 1414.1 1593.7 1701.7 1785.1 1704.6 1834.0 1834.0

MAX. HRLY  TOTAL VERTICAL SOLAR
                AZIMUTH
                   N                      78.3   71.3  110.1  167.1  193.8  194.0  184.1  160.3  126.7   96.1   81.8   75.5  194.0
                   E                     158.8  148.6  170.0  138.2  119.0  113.0  131.0  138.9  149.5  145.8  174.7  177.9  177.9
                   S                     169.9  106.9   94.1   76.0   65.9   61.6   67.5   71.5   88.0  111.5  143.6  181.3  181.3
                   W                     373.9  373.9  403.6  439.4  365.6  341.3  330.2  346.1  371.8  397.8  369.8  385.1  439.4
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 1987 JAKARTA W/SOLAR  MONTHLY WEATHER DATA SUMMARY                                                   DOE-2.1


DESIGN TEMPERATURES --------------------------------- SUMMER ---------- WINTER

                                        PER CENT        T(DRY)  T(WET)        T(DRY)
                                           1.0             91      80            73
                                           2.5             90      78            74
                                           5.0             88      78


MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

                             JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC    YEAR
          HOUR               ----   ----   ----   ----   ----   ----   ----   ----   ----   ----   ----   ----   ----
            0                77.3   77.6   78.2   79.4   79.3   79.9   79.4   78.4   79.1   79.7   78.4   77.7   78.7
            1                76.9   76.9   77.8   78.8   78.9   79.7   78.6   77.5   78.4   79.2   77.9   77.3   78.2
            2                76.6   76.1   77.3   78.5   78.5   79.0   78.0   76.9   77.5   78.6   77.3   76.8   77.6
            3                76.2   75.8   76.8   78.0   78.2   78.5   77.4   76.2   77.2   78.0   77.1   76.5   77.2
            4                75.7   75.5   76.6   77.7   77.7   78.1   76.7   75.5   76.4   77.5   76.9   75.9   76.7
            5                75.7   75.4   76.5   77.2   77.5   77.8   76.5   75.1   76.1   77.2   76.6   75.8   76.5
            6                75.4   75.5   76.7   77.1   77.6   77.7   76.1   74.9   76.0   77.1   76.7   75.7   76.4
            7                76.2   76.1   77.0   77.9   78.0   78.1   77.1   75.4   76.9   78.8   77.7   77.4   77.2
            8                77.8   78.3   80.0   80.6   80.5   80.6   79.9   78.3   80.4   82.6   80.9   80.2   80.0
            9                80.0   80.5   83.6   84.0   84.4   84.4   83.2   82.2   84.3   85.8   83.3   82.1   83.1
           10                80.9   81.9   86.1   86.0   86.9   86.7   86.5   85.8   86.8   88.0   85.1   83.9   85.4
           11                81.9   82.4   87.5   87.8   88.9   89.1   88.3   88.0   89.1   89.7   87.4   85.0   87.1
           12                82.7   82.9   88.3   88.5   89.8   90.3   89.5   89.5   89.4   89.9   88.1   85.6   87.9
           13                83.3   83.6   88.3   87.9   90.2   90.6   90.8   90.2   89.8   89.8   87.8   85.5   88.2
           14                83.6   84.1   88.1   87.3   90.0   90.3   90.7   89.6   89.1   89.6   87.2   85.1   87.9
           15                83.6   83.9   87.1   87.0   88.5   89.3   89.6   88.8   88.3   88.6   86.1   84.7   87.2
           16                82.6   83.4   86.0   85.9   87.8   88.3   88.4   87.5   87.2   87.7   84.9   84.3   86.2
           17                81.6   82.3   84.7   84.9   86.1   86.2   86.5   86.0   85.7   86.6   83.8   82.9   84.8
           18                80.5   80.9   82.9   83.6   84.6   84.8   84.9   84.5   84.2   85.4   82.6   81.8   83.4
           19                79.7   79.9   81.5   82.3   83.2   83.5   83.4   82.8   82.8   84.1   81.4   80.7   82.1
           20                79.0   79.4   80.5   81.4   82.1   82.6   82.4   81.9   81.9   83.1   80.8   79.9   81.2
           21                78.6   79.0   79.9   81.0   81.2   81.9   81.6   80.7   81.2   82.3   80.0   79.3   80.6
           22                78.4   78.4   79.3   80.4   80.5   81.4   80.7   80.1   80.4   81.5   79.4   78.9   80.0
           23                77.8   78.0   78.8   79.9   80.0   80.6   80.1   79.4   79.6   80.7   78.9   78.5   79.4


GROUND TEMPERATURES         530.0  530.0  531.0  532.0  532.0  533.0  534.0  535.0  534.0  533.0  532.0  530.0
CLEARNESS NUMBERS            1.06   1.05   1.03   1.01   0.99   0.97   0.99   0.98   1.00   1.00   1.04   1.05
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YEAR -999 OTHER MALAYSIA

MONTHLY WEATHER DATA SUMMARY

DOE-2.1

LATITUDE = 3.12

LONGITUDE = -101.60

TIME ZONE = -7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
AVG. TEMP. (F) (DRYBULB)	80.5	81.0	79.9	81.6	81.3	82.7	80.9	81.2	80.4	80.0	79.3	79.5	80.7
AVG. TEMP. (F) (WETBULB)	74.1	76.1	75.7	76.9	76.7	75.1	75.0	75.1	75.2	75.5	75.8	75.2	75.5
AVG. DAILY MAX. TEMP.	90.8	91.4	89.9	91.1	91.0	93.3	90.6	90.1	89.3	88.3	88.2	89.3	90.3
AVG. DAILY MIN. TEMP.	73.3	75.1	74.6	75.4	75.6	74.6	74.1	74.5	74.2	74.3	74.4	73.7	74.5
HEATING DEG. DAYS (BASE 65)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. DAYS (BASE 80)	67.5	92.5	70.5	97.0	102.5	118.0	78.0	77.5	54.0	46.5	42.5	51.0	897.5
(BASE 75)	218.0	232.0	225.5	247.0	257.5	268.0	228.0	227.0	202.5	195.5	190.0	202.0	2693.0
(BASE 70)	373.0	372.0	380.5	397.0	412.5	418.0	383.0	382.0	352.5	350.5	340.0	357.0	4518.0
(BASE 65)	528.0	512.0	535.5	547.0	567.5	568.0	538.0	537.0	502.5	505.5	490.0	512.0	6343.0
HEATING DEG. HRS./24 (BASE 65)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. HRS./24 (BASE 80)	88.1	81.6	69.4	91.8	88.4	127.8	89.3	94.8	71.8	63.9	49.0	66.8	982.6
(BASE 75)	182.1	171.4	154.9	199.7	195.5	236.3	188.2	197.1	166.2	157.8	132.3	147.8	2129.2
(BASE 70)	327.1	309.0	306.8	347.8	348.9	380.3	336.7	348.1	311.2	308.5	279.0	295.8	3899.2
(BASE 65)	482.0	449.0	461.8	497.8	503.9	530.3	491.7	503.1	461.2	463.5	429.0	450.8	5724.1
MAXIMUM TEMP.	94	95	93	94	95	97	95	94	92	92	93	94	97
MINIMUM TEMP.	69	73	73	73	73	71	71	72	71	72	72	71	69
NO. DAYS MAX. 90 AND ABOVE	23	22	20	26	23	29	24	21	16	10	8	18	240
NO. DAYS MAX. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 0 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
AVG. WIND SPEED (MPH)	2.6	2.1	2.7	3.0	2.4	2.3	2.4	2.5	2.2	2.1	2.5	1.9	2.4
AVG. WIND SPEED (DAY)	3.5	2.8	3.9	4.3	3.4	3.3	3.2	3.5	2.8	2.6	3.4	2.6	3.3
AVG. WIND SPEED (NIGHT)	1.8	1.5	1.6	1.9	1.5	1.4	1.7	1.6	1.6	1.5	1.6	1.4	1.6
AVG. TEMP. (DAY)	84.9	85.1	83.8	85.1	84.6	87.1	84.6	84.9	83.6	82.9	82.3	83.2	84.3
AVG. TEMP. (NIGHT)	76.8	77.6	76.5	78.3	78.0	78.4	77.4	77.9	77.3	77.0	76.4	76.2	77.3
AVG. SKY COVER (DAY)	7.5	8.8	8.8	8.8	8.8	7.8	8.5	9.0	9.0	9.0	9.0	9.0	8.7
AVG. REL. HUM. AT 4AM	91.6	94.1	95.9	96.3	95.0	89.6	93.1	91.4	94.7	96.1	98.2	97.1	94.4
10AM	63.5	74.0	72.2	72.3	72.0	66.0	69.1	68.6	69.3	72.0	73.9	69.4	70.2
4PM	61.4	70.5	73.6	70.2	73.8	53.3	62.9	62.4	68.8	71.0	76.6	73.9	68.2
10PM	84.0	89.6	93.0	88.8	89.2	79.4	84.4	83.9	87.7	90.0	94.7	91.6	[illegible]

OTHER MALAYSIA MONTHLY WEATHER DATA SUMMARY DOE-2.1

DESIGN TEMPERATURES -------------------------------- SUMMER ---------- WINTER

PER CENT	SUMMER T(DRY)	SUMMER T(WET)	WINTER T(DRY)
1.0	94	79	72
2.5	93	79	73
5.0	92	78	

MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	76.1	76.9	76.4	77.8	77.7	77.4	76.7	77.1	76.7	76.6	76.2	75.7	76.8
1	75.4	76.9	76.1	77.3	77.3	76.7	76.2	76.5	76.1	76.2	75.7	75.3	76.3
2	75.0	76.6	75.6	76.8	76.9	76.2	75.6	76.0	75.7	75.7	75.3	74.8	75.8
3	74.5	76.2	75.3	76.2	76.5	75.5	75.1	75.6	75.2	75.3	75.1	74.4	75.4
4	73.9	75.8	74.9	75.8	76.2	74.8	74.7	75.3	74.8	75.0	74.7	74.1	75.0
5	73.5	75.6	74.7	75.6	75.9	74.6	74.4	74.8	74.3	74.7	74.7	73.8	74.7
6	73.5	75.4	74.8	75.8	76.2	74.8	74.6	75.1	74.8	75.0	74.9	74.0	74.9
7	75.7	76.9	76.9	78.2	78.1	77.2	76.6	77.4	76.7	76.9	76.3	75.4	76.9
8	79.9	80.3	80.4	82.2	82.4	82.3	80.6	81.7	80.6	80.4	80.1	80.3	80.9
9	84.4	84.1	83.9	85.4	85.7	86.2	84.0	84.4	83.6	83.1	82.8	83.7	84.3
10	87.0	87.1	86.5	87.7	88.0	88.9	86.6	86.5	86.0	85.0	84.8	86.0	86.7
11	88.8	89.0	88.2	89.0	89.0	90.7	88.4	88.0	87.2	86.3	86.2	87.8	88.2
12	89.6	90.5	88.5	89.8	89.5	91.9	88.4	89.0	87.7	86.7	86.3	88.8	88.9
13	89.9	89.9	88.6	88.7	88.2	92.5	88.5	89.0	87.0	86.4	85.3	87.6	88.5
14	89.1	87.8	86.9	88.3	86.9	92.5	88.6	88.5	86.2	86.0	84.7	86.0	87.6
15	87.3	86.3	84.1	87.0	84.6	91.0	87.7	87.3	85.3	84.6	83.4	83.7	86.0
16	84.9	84.8	82.2	84.6	83.5	89.2	85.8	85.7	84.2	83.0	82.1	81.6	84.3
17	82.8	82.4	79.7	83.0	82.0	86.9	83.3	83.7	82.6	81.4	80.4	80.3	82.4
18	80.9	80.5	78.5	81.7	80.7	84.3	81.4	82.1	81.1	80.2	78.7	79.1	80.8
19	79.7	79.4	77.7	80.7	79.8	82.5	80.2	80.9	80.0	79.2	78.0	78.5	79.7
20	78.9	78.9	77.3	80.1	79.3	81.1	79.5	79.9	79.2	78.5	77.4	77.8	79.0
21	78.1	78.3	77.0	79.3	78.9	80.0	78.6	79.1	78.5	78.1	77.1	77.3	78.4
22	77.3	77.8	76.8	78.8	78.5	79.0	77.9	78.3	78.0	77.5	76.7	76.8	77.8
23	76.8	77.6	76.5	78.5	78.2	78.0	77.3	77.7	77.5	77.1	76.4	76.3	77.3

GROUND TEMPERATURES	540.4	540.2	540.1	540.3	540.7	541.2	541.6	541.8	541.9	541.7	541.3	540.8
CLEARNESS NUMBERS	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67

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1983 MANILA W/SOLAR   MONTHLY WEATHER DATA SUMMARY                                  DOE-2.1

                 LATITUDE =  14.50                  LONGITUDE = -121.00              TIME ZONE =  -8


                                        JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR

AVG. TEMP. (F) (DRYBULB)               78.3   78.9   80.3   82.3   83.2   83.2   81.6   81.1   81.1   79.9   79.2   77.3   80.5
AVG. TEMP. (F) (WETBULB)               73.6   73.8   74.1   74.9   75.8   76.0   75.7   75.5   75.7   75.6   72.8   69.6   74.4

AVG. DAILY MAX. TEMP.                  86.1   88.7   90.3   93.8   94.8   93.0   90.5   89.1   88.1   86.0   85.7   84.5   89.2
AVG. DAILY MIN. TEMP.                  70.2   68.6   71.0   72.3   73.1   73.9   73.9   73.0   74.9   75.1   73.8   71.9   72.7

HEATING DEG. DAYS (BASE 65)             0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                  (BASE 60)             0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                  (BASE 55)             0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                  (BASE 50)             0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0

COOLING DEG. DAYS (BASE 80)             1.0    0.0   24.5   93.0  123.0  103.5   79.0   43.0   55.0   29.5   19.5    3.5  574.5
                  (BASE 75)            97.5  102.5  175.5  241.5  278.0  252.5  222.5  187.0  194.5  172.5  143.5   99.5 2167.0
                  (BASE 70)           252.5  242.5  330.5  391.5  433.0  402.5  377.5  342.0  344.5  327.5  293.5  254.5 3992.0
                  (BASE 65)           407.5  382.5  485.5  541.5  588.0  552.5  532.5  497.0  494.5  482.5  443.5  409.5 5817.0

HEATING DEG. HRS./24 (BASE 65)          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                     (BASE 60)          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                     (BASE 55)          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                     (BASE 50)          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0

COOLING DEG. HRS./24 (BASE 80)         40.4   57.3   85.5  120.7  142.9  130.9   99.7   87.0   73.7   48.5   37.7   24.1  948.3
                     (BASE 75)        127.1  135.4  178.9  226.0  258.5  250.5  208.8  196.2  185.5  152.5  131.4   93.0 2143.8
                     (BASE 70)        259.5  251.0  317.9  367.9  407.8  397.5  360.8  345.6  333.8  307.1  275.5  228.2 3852.7
                     (BASE 65)        412.9  388.2  472.9  517.9  562.8  547.5  515.8  500.6  483.8  462.1  425.5  382.4 5672.3

MAXIMUM TEMP.                            90     91     93     95     99     97     95     93     91     90    102     88    102
MINIMUM TEMP.                            66     66     70     70     72     70     72     72     73     73     68     66     66

NO. DAYS MAX. 90 AND ABOVE                1     12     27     29     30     27     23     22     15      3      2      0    191
NO. DAYS MAX. 32 AND BELOW                0      0      0      0      0      0      0      0      0      0      0      0      0

NO. DAYS MIN. 32 AND BELOW                0      0      0      0      0      0      0      0      0      0      0      0      0
NO. DAYS MIN.  0 AND BELOW                0      0      0      0      0      0      0      0      0      0      0      0      0

AVG. WIND SPEED (MPH)                   4.6    6.0    7.0    8.5    6.7    6.2    5.7    5.1    2.7    2.5    2.9    3.9    5.1

AVG. WIND SPEED (DAY)                   7.0    8.5    9.3   10.7    8.7    8.4    8.0    7.6    3.8    3.8    4.7    5.9    7.2
AVG. WIND SPEED (NIGHT)                 2.5    3.8    4.8    6.2    4.5    3.6    3.1    2.5    1.5    1.1    1.0    2.0    3.0

AVG. TEMP. (DAY)                       81.5   83.0   84.7   86.5   87.3   86.6   84.8   84.1   83.7   82.0   81.6   80.3   83.9
AVG. TEMP. (NIGHT)                     75.6   75.2   76.0   77.7   78.3   79.3   78.0   78.0   78.4   77.7   76.8   74.6   77.1

AVG. SKY COVER (DAY)                    6.9    4.8    3.6    3.3    4.5    6.4    7.5    8.3    8.1    8.3    8.4    8.2    6.5

AVG. REL. HUM. AT  4AM                 90.6   90.5   88.8   89.6   87.4   86.7   87.6   88.9   88.1   91.3   84.0   77.1   87.5
                  10AM                 77.3   78.2   74.8   72.2   69.1   69.6   74.4   75.1   72.3   77.1   67.7   61.3   72.4
                   4PM                 74.2   68.1   60.6   57.5   58.2   61.8   68.0   70.0   71.0   74.7   64.9   59.8   65.7
                  10PM
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1983 MANILA W/SOLAR   MONTHLY WEATHER DATA SUMMARY                                          DOE-2.1

                  LATITUDE =  14.50                  LONGITUDE = -121.00                  TIME ZONE =  -8


                                    JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR

AVG. DAILY DIRECT NORMAL  SOLAR   1179.0 1856.7 1872.4 2027.8 1715.4 1405.2 1101.2  889.8  919.7  845.3  966.1  887.2 1300.7
AVG. DAILY TOTAL HORIZNTL SOLAR   1263.9 1686.9 1827.8 2068.2 1908.9 1649.5 1432.6 1327.4 1253.7 1102.0 1202.2 1086.1 1481.8

MAX. DAILY DIRECT NORMAL  SOLAR   2301.0 2746.0 2835.0 2711.0 2532.0 2444.0 2291.0 1945.0 1946.0 1902.0 2042.0 2267.0 2835.0
MAX. DAILY TOTAL HORIZNTL SOLAR   1864.0 2165.0 2284.0 2381.0 2333.0 2287.0 2391.0 2223.0 2052.0 1879.0 1836.0 1757.0 2391.0
MIN. DAILY DIRECT NORMAL  SOLAR    106.0  659.0  536.0  868.0  773.0  167.0  165.0   78.0  146.0  104.0  202.0  157.0   78.0
MIN. DAILY TOTAL HORIZNTL SOLAR    561.0 1089.0 1030.0 1308.0 1133.0  598.0  401.0  264.0  465.0  202.0  572.0  619.0  202.0

MAX. HRLY  DIRECT NORMAL  SOLAR    300.0  306.0  301.0  304.0  302.0  278.0  286.0  267.0  287.0  301.0  281.0  329.0  329.0
MAX. HRLY  TOTAL HORIZNTL SOLAR    306.0  343.0  343.0  335.0  339.0  332.0  354.0  335.0  335.0  332.0  295.0  350.0  354.0
AVG. MAX. HRLY DIRECT NORML SOLAR  212.6  254.0  241.3  249.7  226.9  208.7  184.2  159.7  167.9  170.5  183.9  176.1  202.5
AVG. MAX. HRLY TOTAL HRZNTL SOLAR  224.1  272.5  273.8  302.5  281.1  261.4  239.6  229.2  224.1  222.9  216.0  198.3  245.2



AVG. DAILY TOTAL VERTICAL SOLAR
                 AZIMUTH
                   N               380.9  410.0  443.2  587.6  819.1  850.3  747.1  550.1  420.0  353.8  379.5  362.0  525.9
                   E               917.1 1257.8 1191.3 1226.5 1110.1 1015.1  964.1  858.3  891.6  688.4  736.0  741.5  964.1
                   S              1206.9 1305.6  934.4  638.8  517.8  460.8  453.7  500.0  624.9  785.2 1070.1 1081.5  795.2
                   W               688.3  829.9 1024.0 1156.0 1099.9  903.6  800.3  752.8  702.4  707.4  716.5  650.4  835.6

MAX. DAILY TOTAL VERTICAL SOLAR
                 AZIMUTH
                   N               480.8  470.4  535.8  746.1  969.4 1078.7 1039.0  745.4  624.5  505.9  465.9  478.5 1078.7
                   E              1291.2 1514.7 1475.8 1485.8 1321.0 1281.5 1423.1 1391.6 1284.2 1116.9 1006.0 1257.6 1514.7
                   S              1726.7 1631.7 1288.6  815.2  625.8  585.1  561.2  740.6 1108.3 1241.7 1611.6 1788.2 1788.2
                   W              1086.4 1183.9 1259.9 1353.3 1335.3 1337.8 1355.7 1287.4 1273.3 1316.5 1169.1 1159.3 1355.7

MAX. HRLY  TOTAL VERTICAL SOLAR
                 AZIMUTH
                   N                76.5   80.4   73.2  104.1  104.1  136.2  121.5   95.9   95.3   88.0   82.4  122.8  136.2
                   E               251.6  293.5  282.6  259.1  250.2  250.7  253.6  276.1  263.9  218.8  214.0  471.5  471.5
                   S               265.0  231.4  185.9  126.2   92.2   92.4   87.9  124.9  159.3  209.3  240.0  370.2  370.2
                   W               222.3  217.8  252.3  264.1  248.3  265.3  238.0  270.8  289.9  281.4  289.1  241.0  289.9
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1983 MANILA W/SOLAR   MONTHLY WEATHER DATA SUMMARY                                     DOE-2.1


DESIGN TEMPERATURES -------------------------------- SUMMER ---------- WINTER

                              PER CENT         T(DRY)  T(WET)          T(DRY)
                                 1.0               95      82              68
                                 2.5               93      81              68
                                 5.0               91      80


MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

                  JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR
      HOUR        ----   ----   ----   ----   ----   ----   ----   ----   ----   ----   ----   ----   ----
        0         75.0   74.6   74.7   76.7   77.6   78.8   77.5   77.4   78.1   77.5   76.4   74.3   76.5
        1         73.7   73.6   74.4   75.9   76.5   77.9   76.7   76.8   77.5   76.9   76.0   74.1   75.8
        2         72.9   72.3   73.5   74.9   75.7   76.5   75.8   75.4   76.7   76.7   75.4   73.5   75.0
        3         72.0   71.1   72.7   73.5   74.5   75.0   74.7   74.4   76.1   76.5   75.0   73.3   74.1
        4         71.0   70.0   71.8   72.8   73.3   74.1   74.2   73.2   75.5   76.2   74.8   72.8   73.3
        5         70.3   69.3   71.3   72.7   73.4   74.9   74.5   73.5   75.8   75.5   74.2   72.3   73.2
        6         72.7   72.4   75.3   76.1   77.6   77.7   77.0   76.0   77.9   77.1   74.9   72.9   75.6
        7         75.5   75.6   78.4   80.3   81.2   81.2   79.7   79.3   80.1   79.5   77.7   75.1   78.7
        8         78.5   78.4   81.1   82.4   83.2   83.3   81.5   81.1   82.2   81.1   80.5   78.7   81.0
        9         80.3   80.7   82.9   84.1   85.4   85.5   83.6   82.7   83.9   82.8   82.1   80.8   82.9
       10         81.6   82.4   85.3   87.0   88.3   87.6   85.9   84.6   85.5   83.6   83.2   81.8   84.7
       11         82.9   84.1   86.9   89.1   90.0   88.9   87.1   86.3   86.4   83.9   83.5   82.7   86.0
       12         84.0   86.4   88.6   90.9   92.4   91.0   88.4   87.5   86.4   84.4   84.5   83.5   87.3
       13         85.3   88.0   90.0   93.4   94.7   92.4   89.6   88.2   86.4   83.9   83.5   83.4   88.2
       14         85.1   88.5   89.7   92.8   93.4   91.9   89.7   88.3   86.1   83.7   83.8   82.7   88.0
       15         83.9   87.1   88.5   90.4   91.9   90.1   88.1   87.3   85.0   83.1   83.4   81.6   86.7
       16         82.9   85.3   86.1   89.0   89.9   89.0   86.8   86.0   84.4   81.9   81.8   80.1   85.3
       17         81.7   83.3   83.6   86.6   87.5   86.9   85.1   84.5   83.1   80.3   80.6   78.1   83.4
       18         80.8   81.5   82.0   84.5   85.1   85.4   83.1   83.3   81.4   80.0   79.7   76.9   82.0
       19         79.7   80.4   80.6   83.0   83.2   84.1   81.9   82.3   81.0   79.5   78.8   76.2   80.9
       20         78.9   78.7   79.1   81.4   81.9   82.9   80.8   81.3   80.2   78.8   78.3   75.9   79.9
       21         77.9   77.4   77.6   80.2   80.6   81.9   80.3   80.4   79.4   78.6   77.8   75.5   79.0
       22         77.0   76.2   76.5   78.9   79.9   80.8   79.1   79.2   79.2   78.6   77.2   75.3   78.2
       23         76.0   75.4   75.7   77.7   78.5   80.1   78.2   78.5   78.7   77.5   77.1   74.6   77.3


GROUND TEMPERATURES    530.0  530.0  531.0  532.0  532.0  533.0  534.0  535.0  534.0  533.0  532.0  530.0
CLEARNESS NUMBERS       1.06   1.05   1.03   1.01   0.99   0.97   0.99   0.98   1.00   1.00   1.04   1.05
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1988 SINGAPORE W/SOL MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 1.30 LONGITUDE = -103.80 TIME ZONE = -8

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
AVG. TEMP. (F) (DRYBULB)	78.7	79.4	79.7	81.0	82.4	82.2	80.8	80.3	80.4	81.6	79.5	78.3	80.4
AVG. TEMP. (F) (WETBULB)	74.5	74.8	75.3	76.3	77.0	76.6	77.6	77.7	77.4	77.9	76.8	74.8	76.4
AVG. DAILY MAX. TEMP.	84.4	87.7	86.1	88.4	87.6	87.8	86.0	85.1	85.9	86.1	85.6	84.8	86.3
AVG. DAILY MIN. TEMP.	75.3	74.8	75.3	76.5	78.3	77.2	76.4	76.5	76.6	77.5	74.8	74.3	76.1
HEATING DEG. DAYS (BASE 65)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. DAYS (BASE 80)	22.5	38.5	47.0	73.5	100.0	77.5	50.5	41.5	50.5	61.0	30.5	8.5	601.5
(BASE 75)	149.5	174.5	177.5	223.5	246.0	224.5	192.0	180.0	187.5	210.5	157.0	140.5	2263.0
(BASE 70)	304.5	314.5	331.5	373.5	401.0	374.5	347.0	335.0	337.5	365.5	306.5	295.5	4086.5
(BASE 65)	459.5	454.5	486.5	523.5	556.0	524.5	502.0	490.0	487.5	520.5	456.5	450.5	5911.5
HEATING DEG. HRS./24 (BASE 65)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. HRS./24 (BASE 80)	29.8	49.7	53.6	64.2	91.4	83.2	55.2	42.8	46.5	63.7	46.2	28.9	655.1
(BASE 75)	115.0	126.2	148.0	180.9	229.0	217.7	179.5	164.2	163.1	203.8	140.3	106.5	1974.3
(BASE 70)	268.9	264.2	299.8	330.9	383.8	367.2	333.6	318.7	312.5	358.6	285.9	257.3	3781.5
(BASE 65)	423.9	404.2	454.8	480.9	538.8	517.2	488.6	473.7	462.5	513.6	435.9	412.3	5606.5
MAXIMUM TEMP.	91	91	93	91	92	91	90	89	90	90	90	88	93
MINIMUM TEMP.	74	73	72	75	74	73	72	72	73	73	72	71	71
NO. DAYS MAX. 90 AND ABOVE	2	5	7	8	8	6	1	0	1	1	1	0	40
NO. DAYS MAX. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 0 AND BELOW	0	0	0	0	0	0	0	0	0	0	0	0	0
AVG. WIND SPEED (MPH)	3.0	2.9	2.5	3.1	4.2	4.9	5.0	4.6	4.9	4.8	4.2	4.6	4.1
AVG. WIND SPEED (DAY)	3.7	4.0	3.5	4.4	5.6	6.6	6.6	6.1	6.1	6.5	5.2	5.7	5.4
AVG. WIND SPEED (NIGHT)	2.5	2.2	1.9	2.1	3.1	3.8	3.9	3.6	4.0	3.4	3.5	3.8	3.2
AVG. TEMP. (DAY)	80.8	82.8	82.0	84.0	84.2	84.2	82.5	81.9	82.4	82.9	81.8	80.9	82.5
AVG. TEMP. (NIGHT)	77.3	77.3	78.1	78.9	81.1	80.9	79.6	79.2	79.0	80.5	77.8	76.5	78.9
AVG. SKY COVER (DAY)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
AVG. REL. HUM. AT 4AM	90.3	92.0	91.3	90.6	86.4	85.7	94.2	95.6	95.6	93.6	96.6	94.2	92.2
10AM	83.1	80.2	82.4	77.0	79.1	77.0	87.4	88.6	87.1	85.7	88.7	86.3	83.6
4PM	74.4	70.4	75.9	71.5	69.0	68.9	78.5	82.6	79.5	75.5	79.5	74.0	75.0
10PM	85.9	87.4	85.5	86.6	82.1	81.3	90.5	91.8	90.2	87.7	92.4	90.3	87.6

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1988 SINGAPORE W/SOL  MONTHLY WEATHER DATA SUMMARY                                    DOE-2.1

                    LATITUDE =   1.30              LONGITUDE = -103.80                TIME ZONE =  -8


                                        JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR
AVG. DAILY DIRECT NORMAL  SOLAR        537.2  958.2  637.8  920.9 1077.8 1161.5 1095.2  898.8  879.6  874.5  728.1  739.1  874.5
AVG. DAILY TOTAL HORIZNTL SOLAR       1044.7 1447.7 1171.7 1407.3 1398.7 1461.0 1397.4 1319.0 1404.1 1356.4 1219.1 1296.8 1325.5

MAX. DAILY DIRECT NORMAL  SOLAR       1416.0 1682.0 2096.0 2315.0 2218.0 2183.0 2054.0 2311.0 2048.0 2241.0 2159.0 1146.0 2315.0
MAX. DAILY TOTAL HORIZNTL SOLAR       1682.0 2071.0 2095.0 2241.0 2056.0 2064.0 1949.0 2087.0 2147.0 2151.0 2013.0 1641.0 2241.0
MIN. DAILY DIRECT NORMAL  SOLAR         15.0  133.0    6.0  101.0   20.0  128.0   44.0   47.0   62.0   73.0   25.0  186.0    6.0
MIN. DAILY TOTAL HORIZNTL SOLAR        341.0  521.0  123.0  793.0  383.0  349.0  248.0  449.0  429.0  529.0   96.0  780.0   96.0

MAX. HRLY  DIRECT NORMAL  SOLAR        231.0  267.0  258.0  288.0  277.0  315.0  279.0  289.0  280.0  301.0  285.0  277.0  315.0
MAX. HRLY  TOTAL HORIZNTL SOLAR        285.0  306.0  320.0  336.0  318.0  313.0  306.0  325.0  330.0  319.0  308.0  288.0  336.0
AVG. MAX. HRLY DIRECT NORML SOLAR      120.8  185.8  131.5  189.8  191.9  205.7  182.2  169.5  173.0  166.2  151.6  162.6  169.0
AVG. MAX. HRLY TOTAL HRZNTL SOLAR      184.6  250.6  206.6  248.3  237.0  251.9  237.1  234.6  253.9  234.5  215.8  221.7  231.1



AVG. DAILY TOTAL VERTICAL SOLAR
                 AZIMUTH
                    N                  404.5  472.4  478.9  708.7  858.5 1025.0  935.7  751.7  576.2  459.1  430.1  469.5  631.6
                    E                  758.4  983.6  796.0  929.2  768.0  852.2  787.6  816.4  834.1  759.2  754.5  863.6  823.8
                    S                  794.8  848.8  532.2  478.1  396.6  424.6  406.9  426.5  536.0  711.9  846.4  995.7  615.1
                    W                  588.7  748.7  665.8  743.7  765.7  807.3  794.5  752.8  841.2  861.3  737.0  714.3  751.4
MAX. DAILY TOTAL VERTICAL SOLAR
                 AZIMUTH
                    N                  522.9  606.3  755.5  999.0 1229.1 1395.5 1297.5 1112.3  816.4  614.5  558.7  581.0 1395.5
                    E                 1125.8 1270.7 1237.8 1212.2 1124.7 1068.2 1022.7 1140.0 1177.5 1128.0 1027.6 1145.7 1270.7
                    S                 1226.2 1058.4  932.1  653.5  545.6  558.6  553.6  553.5  710.6  974.9 1201.2 1226.9 1226.9
                    W                  901.2 1131.2 1196.0 1357.3 1107.4 1200.9 1193.0 1134.9 1266.2 1357.7 1229.8  983.5 1357.7
MAX. HRLY  TOTAL VERTICAL SOLAR
                 AZIMUTH
                    N                   75.5   85.5  104.9  132.4  169.1  179.4  172.4  152.2  118.1   94.9   83.6   82.8  179.4
                    E                  211.9  239.6  220.2  225.9  214.2  254.0  203.4  242.7  218.1  218.6  202.8  212.9  254.0
                    S                  177.3  154.1  140.8   96.9   81.4   76.4   81.3   93.2  110.4  134.8  181.0  188.1  188.1
                    W                  188.3  243.1  232.0  249.7  229.5  254.1  213.7  243.7  255.3  252.4  233.0  180.5  255.3
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1988 SINGAPORE W/SOL MONTHLY WEATHER DATA SUMMARY

DOE-2.1

DESIGN TEMPERATURES

	SUMMER		WINTER
PER CENT	T(DRY)	T(WET)	T(DRY)
1.0	89	81	73
2.5	88	80	74
5.0	87	80	

MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	76.7	76.3	77.3	78.5	80.6	80.6	79.2	78.9	78.6	80.2	77.1	75.8	78.3
1	76.5	76.1	77.2	78.3	80.4	80.5	79.0	78.7	78.1	79.8	76.7	75.6	78.1
2	76.3	75.9	76.9	78.1	80.1	80.0	78.7	78.4	77.9	79.5	76.5	75.4	77.8
3	76.0	75.6	76.7	77.8	80.1	79.7	78.6	78.2	77.6	79.0	76.5	75.3	77.6
4	75.8	75.5	76.5	77.4	80.0	79.4	78.6	78.2	77.4	78.8	76.2	75.1	77.4
5	75.5	75.2	76.4	77.3	79.8	79.2	78.5	78.0	77.3	78.9	76.1	74.8	77.3
6	75.5	75.1	76.1	77.0	79.5	79.0	78.4	77.9	77.1	78.7	76.0	74.7	77.1
7	75.9	75.2	76.3	77.4	79.7	79.5	78.6	77.8	77.6	78.7	76.3	74.9	77.3
8	77.1	77.2	77.7	79.6	81.3	81.3	79.8	79.3	79.4	80.2	77.9	76.5	78.9
9	78.9	80.2	80.3	83.3	83.1	83.2	81.3	81.2	81.2	81.6	80.1	78.5	81.1
10	80.5	82.9	82.4	85.2	84.0	84.1	82.5	81.9	82.4	82.8	82.0	80.7	82.6
11	82.1	84.8	83.8	86.1	84.5	84.7	83.5	82.9	83.5	83.5	83.0	82.3	83.7
12	83.1	85.9	84.5	86.6	85.5	85.8	83.9	83.5	84.2	84.4	84.5	83.5	84.6
13	83.1	86.5	84.6	87.3	86.1	85.9	84.1	83.4	84.8	84.7	84.5	84.3	84.9
14	82.7	85.8	84.1	86.2	86.4	86.2	84.1	83.2	84.0	84.7	83.7	83.8	84.6
15	82.3	84.6	82.8	84.7	86.1	85.9	83.8	83.0	83.6	84.7	83.7	83.0	84.0
16	81.4	83.0	82.7	83.8	85.3	85.0	83.0	82.6	83.2	84.6	82.8	81.4	83.2
17	80.5	81.4	82.1	82.4	84.5	84.3	82.4	81.9	82.3	84.1	82.1	80.0	82.3
18	79.6	80.2	80.8	81.2	83.2	83.2	81.6	81.0	81.3	82.8	80.5	79.2	81.2
19	78.7	79.1	79.7	80.0	82.1	82.2	80.6	80.1	80.3	81.8	79.5	78.0	80.2
20	78.1	78.2	78.9	79.6	81.5	81.6	79.6	79.4	79.9	81.5	78.9	77.2	79.5
21	77.5	77.6	78.5	79.3	81.4	81.2	79.5	79.2	79.6	81.2	78.5	76.7	79.2
22	77.4	77.2	78.0	79.0	81.1	80.8	79.5	79.0	79.5	80.9	77.9	76.5	78.9
23	77.0	76.8	77.6	78.7	80.9	80.6	79.5	78.9	79.2	80.5	77.6	76.1	78.6

GROUND TEMPERATURES	530.0	530.0	531.0	532.0	532.0	533.0	534.0	535.0	534.0	533.0	532.0	530.0
CLEARNESS NUMBERS	1.06	1.05	1.03	1.01	0.99	0.97	0.99	0.98	1.00	1.00	1.04	1.05

APPENDIX C

DOE-2 INPUT FILE OF PROTOTYPICAL PHILLIPINE OFFICE BUILDING

```
$ !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
$ ASEAN TYPICAL BUILDINGS          TEN-STORY OFFICE BUILDING
$ BASE CASE                           RHFS SYSTEM
$ FILE NAME:  PLO-ECOM.INP                  3-06-90
$ !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
$ DOE-2 input file for Philippines bldg energy standards study
$ Based on office prototype used in Singapore/Malaysia standards
$ studies & revised for the 1989 Philippines study using data
$ from a Philippine sample of 26 office buildings
$ created: 30 may 89
$ updated: 29 jul 89
$ j. busch

$ Adapted for MicroDOE2.1D
$ adapted: 3 mar 90
$ updated:  6 mar 90, 14 apr 90
$ j. deringer


TITLE  LINE-1  *PHIL OFC PROTOTYPE -  Manila83 -  RUN 2*
       LINE-2  *BASE CASE:               EIR=0.27 *
       LINE-3  *R-WALL=0.05;W-ABSORP=0.65;R-ABSORP=0.65*
       LINE-4  *WWR=0.49;SC=.88;GC=1.03;LITP&LITC=1.6  *
       LINE-5  *T-COOL=74;INFIL=1;STATIC=4.5;OA-RATE=20*
       ..

$ !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
$       INPUT LOADS
$ !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
INPUT LOADS ..
       DIAGNOSTIC CAUTIONS ..
       ABORT  ERRORS ..
LOADS-REPORT
$       VERIFICATION = (LV-A)
       SUMMARY = (LS-A)   ..
$       SUMMARY = (LS-A,LS-C)   ..

BUILDING-LOCATION
       LAT   = 14.5
       LON   = -121.
       T-Z   = -8
       ALT   = 10
$       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)
$       ATM-T = (.67,.67,.67,.67,.67,.67,.67,.67,.67,.67,.67,.67)
       D-S   = NO
       AZ    = 0 ..              $Manila$
```

```
 RUN-PERIOD  JAN 1 1983 THRU DEC 31 1983 ..

 $ !!!!! LOADS PARAMETERS !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

 PARAMETER
        R-WALL     = 0.05    $  R-Value of wall insulation only:  Base
        W-ABSORP   = 0.65    $  For Base
        R-ABSORP   = 0.65    $  For Base
        WWR        = 0.49    $  For Base
        SC         = 0.88    $  1st run, 1-pane, clear, no venetian blinds
        GC         = 1.03    $  for all cases
        OVERH-A    = 5.8     $  Base
        OVERH-W    = 23.0
        OVERH-D    = 3.28
        LFIN-A     = 0.0     $  no fins on Base
        LFIN-H     = 0.0
        LFIN-D     = 0.0
        RFIN-A     = 0.0
        RFIN-H     = 0.0
        RFIN-D     = 0.0
        LITP       = 1.6     $  Lighting Power, perimeter zones, Energy Intensive
        LITC       = 1.6     $  Lighting Power, core zone, Energy Intensive
        INFIL      = 1.0     $  Infiltration @ 1 ACH, for Energy Intensive
$ Other Parameters, defined, but not varied in this set of runs
        ORIENT     = 0       $  Building Orientation.
        COREAREA   = 5181    $  Sets value for Core Area of building, also sets Core
                             $  Volume, and Core Roof and Floor Areas.
        BRICKTH    =  .37    $  Thickness Of Brick In Extwall3
        RCBEAMTH   =  .33    $  Thickness Of Rc Beam In Extwall4
        R-ROOF     = 0.001   $  R-Value of roof insulation only
        EQUIP      = 1.0     $  Equipment, in W/Sqft
        SPACE-LITE = 1.0     $  Ratio:  Heat Gain To Space From Lights
        DAYLT-ON   = NO      $  Sets whether daylight in YES of NO in space cond
        GRND-R     = 0.20    $  Ground reflectivity
        FM         = 8       $  Number of Typical Floors excl. top & ground
        ..
$ !!!!! Building Operating Schedules, Occupancy !!!!!!!!!!!!!!
PEOP-OFFC-WD=D-SCH
        (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=D-SCH
        (1,6)(0) (7,8)(.1) (9,12)(.9) (13,17)(.1)
        (18,19)(.05) (20,24)(0) ..
PEOP-OFFC-SUN=D-SCH
        (1,6)(0) (7,18)(.05) (19,24)(0) ..
PEOP-OFFC-WK=W-SCH
        (SUN) PEOP-OFFC-SUN (WD) PEOP-OFFC-WD
        (SAT) PEOP-OFFC-SAT (HOL) PEOP-OFFC-SUN ..
PEOP-OFFC=SCH  THRU DEC 31 PEOP-OFFC-WK ..

$------ Lighting Schedule ------------------------------------
LITE-OFFC-WD=D-SCH
```

```
          (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=D-SCH
          (1,6)(.05) (7,8)(.1) (9,12)(.9) (13,17)(.15)
          (18,24)(.05) ..
LITE-OFFC-SUN=D-SCH
          (1,24)(.05) ..
LITE-OFFC-WK=W-SCH
          (SUN) LITE-OFFC-SUN  (WD) LITE-OFFC-WD
          (SAT) LITE-OFFC-SAT (HOL) LITE-OFFC-SUN  ..
LITE-OFFC=SCH THRU DEC 31 LITE-OFFC-WK ..

$------ Infiltration Schedule --------------------------------
INFILTWD=D-SCH   (1,6)(1) (7,17)(0)  (18,24)(1) ..
INFILTSAT=D-SCH  (1,6)(1) (7,12)(0)  (13,24)(1)  ..
INFILTWEH=D-SCH  (1,24)(1)  ..
INFILTWK=W-SCH   (SAT) INFILTSAT (HOL) INFILTWEH
                 (WD) INFILTWD (SUN) INFILTWEH  ..
INFILTSCH1=SCH THRU DEC 31 INFILTWK ..

$------ Window Management Schedule ---------------------------
SHADE-MULT=SCH  THRU DEC 31  (ALL)  (1,24)  (.75)  ..
TRANS-MULT=SCH  THRU DEC 31  (ALL)  (1,24)  (.35)  ..
CLOSE-SHADE=SCH  THRU DEC 31  (ALL) (1,24)  (40)  ..
REOPEN-PROB=SCH  THRU DEC 31  (ALL) (1,24)  (.5)  ..

$ !!!!! Materials and Constructions !!!!!!!!!!!!!!!!!!!!!!!!!!!
$ insulation is polystyrene, the thickness of
$ which equals its R-value x 0.02
INSUL   = MAT COND=.02   DENS=1.80  TH=1.0  S-H=0.29 ..
$ Reinforced Concrete (RC) Beam, 140 lb concrete
RCBEAM  = MAT COND=0.84  DENS=154.0 TH=1.0  S-H=0.2  ..
GLASS   = MAT COND=0.614 DENS=161.0 TH=1.0 S-H=0.19  ..
BRICK   = MAT COND=0.470 DENS=112.8 TH=1.0 S-H=0.20  ..
PLASTER = MAT COND=0.310 DENS=100.5 TH=1.0 S-H=0.20  ..
TILE    = MAT COND=0.757 DENS=162.0 TH=1.0 S-H=0.21  ..

$------ Constructions ----------------------------------------
$ Ground Floor South & East Facade
$ (Two Tile Constructions Not Used In Base Case Bldg)
TILERCPLAS1=LAYERS MAT=(TILE,AL11,RCBEAM) TH=(.039,1,.8125) I-F-R=0.68 ..
$ Ground Floor North Facade
TILERCPLAS2=LAYERS MAT=(TILE,AL11,RCBEAM) TH=(.039,1,.541)  I-F-R=0.68 ..
$ Upper Floors South & East FACADES
GLASSRC=LAYERS      MAT=(GLASS,AL11,INSUL,RCBEAM)
                 TH=(.026,1,R-WALL TIMES .02, .8125)    I-F-R=0.68 ..
GLASSBRICK=LAYERS  MAT=(GLASS,AL11,PLASTER,BRICK,INSUL,PLASTER)
        TH=(.026,1,.039,BRICKTH,R-WALL TIMES .02, .039) I-F-R=0.68  ..
CHBLOCK = LAYERS   MAT=(PLASTER,INSUL,CB26,PLASTER)
        TH=(.052,R-WALL TIMES .02,.5,.052)  I-F-R=0.68  ..
BRICKWL = LAYERS   MAT=(PLASTER,INSUL,BK01,PLASTER)
```

```
        TH=(.052,R-WALL TIMES .02,.3333,.052)  I-F-R=0.68 ..
$6 inch concrete deck, air layer, and acoustic tile
ROOFMAT = LAYERS   MAT=(CC04,INSUL,AL33,AC02)
        TH=(.5,R-ROOF TIMES .02,.50,1,.039)  I-F-R=0.68 ..
FLRMAT-GND=LAYERS  MAT=(CC04,CP01)  I-F-R=0.68          ..
$ FLRMAT models half of the 4 inch thick floor and thus avoids double
$ counting (since each zone has both a floor and a ceiling.)
FLRMAT  = LAYERS   MAT=(CC02) I-F-R=0.68 ..
CLGMAT  = LAYERS   MAT=(CC02,AL33,AC02)  I-F-R=0.68 ..
PARTMAT = LAYERS   MAT=(GP02,AL31,GP02)  I-F-R=0.68 ..
$ Marble Tile Wall (Thick)
EXTWALL1= CONS     ABS=0.58  ROUGHNESS=5  LAYERS=TILERCPLAS1 ..
$ Marble Tile Wall (Thin)
EXTWALL2= CONS     ABS=0.58  ROUGHNESS=5  LAYERS=TILERCPLAS2 ..
$ Glass Wall With Brick
EXTWALL3= CONS     ABS=W-ABSORP  ROUGHNESS=6  LAYERS=GLASSBRICK ..
$ Glass Wall With Concrete
EXTWALL4= CONS     ABS=W-ABSORP  ROUGHNESS=6  LAYERS=GLASSRC ..
EXTWALL5= CONS     ABS=W-ABSORP  ROUGHNESS=6  LAYERS=CHBLOCK ..
EXTWALL6= CONS     ABS=W-ABSORP  ROUGHNESS=6  LAYERS=BRICKWL ..
ROOF1   = CONS    ABS=R-ABSORP  LAYERS=ROOFMAT ..
GNDFLR  = CONS     LAYERS = FLRMAT-GND ..
PARTITION=CONS     LAYERS = PARTMAT ..
HALFLOOR= CONS      LAYERS = FLRMAT ..
HALFCEIL= CONS     LAYERS = CLGMAT ..

$-------- Glazing --------------------------------------------
GLASS1  = GLASS-TYPE
        S-C = SC
        VIS-TRANS = SC TIMES .67
        G-C = GC ..

$------- Set Defaults for Exterior Wall ----------------------
$ EXTWALL5 used for all cases of insulation R-Value
SET-DEFAULT FOR EXTERIOR-WALL
        H    = 11.1
        W    = 92
        AZ   = 180
        CONS = EXTWALL5 ..
$-------- Set Defaults for Windows ---------------------------
SET-DEFAULT FOR WINDOW
      W                = WWR TIMES 23.0
      H                = 11.0
      G-T              = GLASS1
      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
$ OH-A=  overhang offset from upper left corner of window which is
$       reset with WWR since overhang runs the length of wall section or
```

```
$       (23-(WWR*11.1*23)/11)/2
        OH-A  = OVERH-A
        OH-D  = OVERH-D
        OH-W  = OVERH-W
        L-F-A = LFIN-A
        R-F-A = RFIN-A
        L-F-D = LFIN-D
        L-F-H = LFIN-H
        R-F-D = RFIN-D
        R-F-H = RFIN-H
        ..
$------- Set Defaults for Space Conditions --------------------
SET-DEFAULT FOR SPACE
       T     = (75)
       I-M   = AIR-CHANGE
       I-SCH = INFILTSCH1
       A-C   = INFIL
       LIGHTING-W/SQFT     = LITP   $ Perimeter 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-ON
       LIGHT-REF-POINT1    = (11.5,10,2.5)
       LIGHT-SET-POINT1    = 50
       LIGHT-CTRL-TYPE1    = CONTINUOUS
       MAX-GLARE           = 22
       ..
$------ Space Descriptions, Typical Middle Floors -------------
SPACE-NORTH-MID=SPACE
        X=92  Y=184  AZ=180  A=1155  V=12705  N-O-P=8  F-M=FM ..
       EWL-NM1=E-W  ..
          WND-NM1=WINDOW    X=0  ..
          WND-NM2=WI  LIKE WND-NM1  X=23  ..
          WND-NM3=WI  LIKE WND-NM1  X=46  ..
          WND-NM4=WI  LIKE WND-NM1  X=69  ..
       IWL-NM1=I-W
          I-W-TYPE=STANDARD A=233 CONS=PARTITION
          N-T SPACE-EAST-MID   ..
       IWL-NM2=I-W  LIKE IWL-NM1  NEXT-TO SPACE-WEST-MID  ..
       CLG-NM1=I-W I-W-TYPE=ADIABATIC  A=1155  TILT=0 CONS=HALFCEIL ..
       FLR-NM1=I-W  LIKE CLG-NM1  TILT=180  CONS=HALFLOOR  ..

SPACE-EAST-MID=SPACE X=92  Y=0  AZ=-90  A=2535  V=27885  N-O-P=16  F-M=FM
..
       EWL-EM1=E-W  W=184 ..
          WND-EM1=WINDOW    X=0  ..
```

```
        WND-EM2=WI  LIKE WND-EM1  X=23  ..
        WND-EM3=WI  LIKE WND-EM1  X=46  ..
        WND-EM4=WI  LIKE WND-EM1  X=69  ..
        WND-EM5=WI  LIKE WND-EM1  X=92  ..
        WND-EM6=WI  LIKE WND-EM1  X=115  ..
        WND-EM7=WI  LIKE WND-EM1  X=138  ..
        WND-EM8=WI  LIKE WND-EM1  X=161  ..
    IWL-EM1=I-W I-W-TYPE=STANDARD A=233 CONS=PARTITION
        N-T SPACE-SOUTH-MID  ..
    CLG-EM1=I-W  LIKE CLG-NM1  A=2535  ..
    FLR-EM1=I-W  LIKE FLR-NM1  A=2535  ..

 SPACE-SOUTH-MID=SPACE LIKE SPACE-NORTH-MID  X=0  Y=0  AZ=0  ..
    EWL-SM1=E-W  LIKE EWL-NM1  ..
        WND-SM1=WINDOW  X=0  ..
        WND-SM2=WI  LIKE WND-SM1  X=23  ..
        WND-SM3=WI  LIKE WND-SM1  X=46  ..
        WND-SM4=WI  LIKE WND-SM1  X=69  ..
    IWL-SM1=I-W  LIKE IWL-NM1  N-T SPACE-WEST-MID  ..
    CLG-SM1=I-W  LIKE CLG-NM1  ..
    FLR-SM1=I-W  LIKE FLR-NM1  ..

 SPACE-WEST-MID=SPACE LIKE SPACE-EAST-MID  X = 0  Y = 184  AZ = 90  ..
    EWL-WM1=E-W  LIKE EWL-EM1  ..
        WND-WM1=WINDOW    X = 0  ..
        WND-WM2=WI  LIKE WND-WM1  X = 23  ..
        WND-WM3=WI  LIKE WND-WM1  X = 46  ..
        WND-WM4=WI  LIKE WND-WM1  X = 69  ..
        WND-WM5=WI  LIKE WND-WM1  X = 92  ..
        WND-WM6=WI  LIKE WND-WM1  X = 115  ..
        WND-WM7=WI  LIKE WND-WM1  X = 138  ..
        WND-WM8=WI  LIKE WND-WM1  X = 161  ..
    CLG-WM1=I-W  LIKE CLG-EM1  ..
    FLR-WM1=I-W  LIKE FLR-EM1  ..

$ CORE:  core size is reduced by 4367 ft2 from 9548 ft2/ floor
$ due to uncond. space equiv. to xx.x% of tot fl area
SPACE-CORE-MID=SPACE
        DAYLIGHTING=NO  A=COREAREA  V=COREAREA TIMES 11.1
        N-O-P=38  L-W=LITC  F-M=FM  ..
    IWL-CM1=I-W  LIKE IWL-NM1  A=682  N-T SPACE-NORTH-MID  ..
    IWL-CM2=I-W  LIKE IWL-NM1  A=1694  N-T SPACE-EAST-MID  ..
    IWL-CM3=I-W  LIKE IWL-CM1  N-T SPACE-SOUTH-MID  ..
    IWL-CM4=I-W  LIKE IWL-CM2  N-T SPACE-WEST-MID  ..
    CLG-CM1=I-W  LIKE CLG-NM1  A=COREAREA  ..
    FLR-CM1=I-W  LIKE FLR-NM1  A=COREAREA  ..

$ Top Floor -------------------------------------------------
SPACE-NORTH-TOP=SPACE
     LIKE SPACE-NORTH-MID  F-M=1  ..
    EWL-NT1=E-W  LIKE EWL-NM1  ..
        WND-NT1=WINDOW    X=0  ..
```

```
         WND-NT2=WI  LIKE WND-NT1  X=23 ..
         WND-NT3=WI  LIKE WND-NT1  X=46 ..
         WND-NT4=WI  LIKE WND-NT1  X=69 ..
      ROOF-NT1=ROOF  TILT=0  CONS=ROOF1  H=15  W=77 ..
      IWL-NT1=I-W  LIKE IWL-NM1  N-T SPACE-EAST-TOP ..
      IWL-NT2=I-W  LIKE IWL-NM2  N-T SPACE-WEST-TOP ..
      FLR-NT1=I-W  LIKE FLR-NM1  ..

SPACE-EAST-TOP=SPACE  LIKE SPACE-EAST-MID  F-M=1 ..
      EWL-ET1=E-W  LIKE EWL-EM1 ..
         WND-ET1=WINDOW   X=0 ..
         WND-ET2=WI  LIKE WND-ET1  X=23 ..
         WND-ET3=WI  LIKE WND-ET1  X=46 ..
         WND-ET4=WI  LIKE WND-ET1  X=69 ..
         WND-ET5=WI  LIKE WND-ET1  X=92 ..
         WND-ET6=WI  LIKE WND-ET1  X=115 ..
         WND-ET7=WI  LIKE WND-ET1  X=138 ..
         WND-ET8=WI  LIKE WND-ET1  X=161 ..
      ROOF-ET1=ROOF  LIKE ROOF-NT1  W=169 ..
      IWL-ET1=I-W  LIKE IWL-EM1  N-T SPACE-SOUTH-TOP  ..
      FLR-ET1=I-W  LIKE FLR-EM1 ..

SPACE-SOUTH-TOP=SPACE   LIKE SPACE-SOUTH-MID  F-M=1 ..
      EWL-ST1=E-W  LIKE EWL-SM1 ..
         WND-ST1=WINDOW   X=0 ..
         WND-ST2=WI  LIKE WND-ST1  X=23 ..
         WND-ST3=WI  LIKE WND-ST1  X=46 ..
         WND-ST4=WI  LIKE WND-ST1  X=69 ..
      ROOF-ST1=ROOF  LIKE ROOF-NT1  ..
      IWL-ST1=I-W  LIKE IWL-SM1  N-T SPACE-WEST-TOP ..
      FLR-ST1=I-W  LIKE FLR-SM1 ..

SPACE-WEST-TOP=SPACE  LIKE SPACE-WEST-MID  F-M=1 ..
      EWL-WT1=E-W  LIKE EWL-WM1 ..
         WND-WT1=WINDOW    X = 0 ..
         WND-WT2=WI  LIKE WND-WT1  X = 23 ..
         WND-WT3=WI  LIKE WND-WT1  X = 46 ..
         WND-WT4=WI  LIKE WND-WT1  X = 69 ..
         WND-WT5=WI  LIKE WND-WT1  X = 92 ..
         WND-WT6=WI  LIKE WND-WT1  X = 115 ..
         WND-WT7=WI  LIKE WND-WT1  X = 138 ..
         WND-WT8=WI  LIKE WND-WT1  X = 161 ..
      ROOF-WT1=ROOF  LIKE ROOF-ET1 ..
      FLR-WT1=I-W  LIKE FLR-WM1 ..

SPACE-CORE-TOP=SPACE   LIKE SPACE-CORE-MID  F-M=1 ..
      ROOF-CT1=ROOF  LIKE ROOF-NT1
       H=72  W=COREAREA TIMES 0.01389 ..
      IWL-CT1=I-W  LIKE IWL-CM1  N-T SPACE-NORTH-TOP ..
      IWL-CT2=I-W  LIKE IWL-CM2  N-T SPACE-EAST-TOP ..
      IWL-CT3=I-W  LIKE IWL-CM3  N-T SPACE-SOUTH-TOP ..
      IWL-CT4=I-W  LIKE IWL-CM4  N-T SPACE-WEST-TOP ..
```

```
      FLR-CT1=I-W  LIKE FLR-CM1  ..

$ Ground Floor ----------------------------------------------
SPACE-NORTH-GND=SPACE   LIKE SPACE-NORTH-MID  F-M=1  ..
      EWL-NG1=E-W  LIKE EWL-NM1  ..
          WND-NG1=WINDOW    X=0  ..
          WND-NG2=WI  LIKE WND-NG1  X=23  ..
          WND-NG3=WI  LIKE WND-NG1  X=46  ..
          WND-NG4=WI  LIKE WND-NG1  X=69  ..
      IWL-NG1=I-W  LIKE IWL-NM1  N-T SPACE-EAST-GND ..
      IWL-NG2=I-W  LIKE IWL-NM2  N-T SPACE-WEST-GND ..
      CLG-NG1=I-W  LIKE CLG-NM1  ..
      FLR-NG1=U-F  A=1155 TILT=180  U-EFF=.028  CONS=GNDFLR  ..

SPACE-EAST-GND=SPACE  LIKE SPACE-EAST-MID  F-M=1  ..
      EWL-EG1=E-W  LIKE EWL-EM1  ..
          WND-EG1=WINDOW    X=0  ..
          WND-EG2=WI  LIKE WND-EG1  X=23  ..
          WND-EG3=WI  LIKE WND-EG1  X=46  ..
          WND-EG4=WI  LIKE WND-EG1  X=69  ..
          WND-EG5=WI  LIKE WND-EG1  X=92  ..
          WND-EG6=WI  LIKE WND-EG1  X=115  ..
          WND-EG7=WI  LIKE WND-EG1  X=138  ..
          WND-EG8=WI  LIKE WND-EG1  X=161  ..
      IWL-EG1=I-W  LIKE IWL-EM1  N-T SPACE-SOUTH-GND   ..
      CLG-EG1=I-W  LIKE CLG-EM1  ..
      FLR-EG1=U-F  LIKE FLR-NG1  A=2535  ..

SPACE-SOUTH-GND=SPACE  LIKE SPACE-SOUTH-MID  F-M=1  ..
      EWL-SG1=E-W  LIKE EWL-SM1  ..
          WND-SG1=WINDOW    X=0  ..
          WND-SG2=WI  LIKE WND-SG1  X=23  ..
          WND-SG3=WI  LIKE WND-SG1  X=46  ..
          WND-SG4=WI  LIKE WND-SG1  X=69  ..
      IWL-SG1=I-W  LIKE IWL-SM1  N-T SPACE-WEST-GND ..
      CLG-SG1=I-W  LIKE CLG-SM1  ..
      FLR-SG1=U-F  LIKE FLR-NG1  ..

SPACE-WEST-GND=SPACE  LIKE SPACE-WEST-MID  F-M=1  ..
      EWL-WG1=E-W  LIKE EWL-WM1  ..
          WND-WG1=WINDOW    X=0  ..
          WND-WG2=WI  LIKE WND-WG1  X=23  ..
          WND-WG3=WI  LIKE WND-WG1  X=46  ..
          WND-WG4=WI  LIKE WND-WG1  X=69  ..
          WND-WG5=WI  LIKE WND-WG1  X=92  ..
          WND-WG6=WI  LIKE WND-WG1  X=115  ..
          WND-WG7=WI  LIKE WND-WG1  X=138  ..
          WND-WG8=WI  LIKE WND-WG1  X=161  ..
      CLG-WG1=I-W  LIKE CLG-WM1  ..
      FLR-WG1=U-F  LIKE FLR-EG1  ..

SPACE-CORE-GND=SPACE   LIKE SPACE-CORE-MID  F-M=1  ..
```

```
          IWL-CG1=I-W  LIKE IWL-CM1  N-T SPACE-NORTH-GND ..
          IWL-CG2=I-W  LIKE IWL-CM2  N-T SPACE-EAST-GND ..
          IWL-CG3=I-W  LIKE IWL-CM3  N-T SPACE-SOUTH-GND ..
          IWL-CG4=I-W  LIKE IWL-CM4  N-T SPACE-WEST-GND ..
          CLG-CG1=I-W  LIKE CLG-CM1 ..
          FLR-CG1=U-F  LIKE FLR-NG1  A=COREAREA ..

$-------Building Resource------------------------------------
BUILDING-RESOURCE  VERT-TRANS-KW=60  VERT-TRANS-SCH=PEOP-OFFC ..

 END ..
 COMPUTE LOADS ..

$ ***** INPUT SYSTEMS ******************************************
INPUT SYSTEMS  INPUT-UNITS  = ENGLISH  OUTPUT-UNITS = METRIC ..
SYSTEMS-REPORT  V=(SV-A)
       S=(SS-A,SS-C,SS-I) ..
$      S=(SS-A,SS-C,SS-H,SS-I,SS-J,SS-K,SS-N) ..

$ !!!!! SYSTEM PARAMETERS !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
PARAMETER
        SYSTYP   = RHFS
$ Hourly Temperature Schedule
        T-COOL    = 74
        T-COOL-SETBAK = 99
$ Fan Control
        MINCFM   = 1.0
        FC       = CONSTANT-VOLUME
        FANEFF   = .60
        STATIC   = 4.5
        NCC      = STAY-OFF
$ Outside-air
        OA-RATE  = 20
        OA-CONT  = FIXED
        MINAIRSB = -999.
$ Equipment Sizing
        SIZERA   = 1.0
        SIZEOP   = NON-COINCIDENT
        ..
$------ System Schedules ------------------------------------
FS-1     = D-SCH  (1,6)   (0) (7,17)  (1) (18,24) (0) ..
FS-2     = D-SCH  (1,24)  (0)        ..
FS-3     = D-SCH  (1,6) (0) (7,12) (1) (13,24)(0) ..
FW-1     = W-SCH  (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)  (1,6)(T-COOL-SETBAK) (7,17)(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)    ..
$ Reset Schedule
DRES1=DAY-RESET-SCH OUTSIDE-HI=90 SUPPLY-LO=45 OUTSIDE-LO=77
SUPPLY-HI=55 ..
RES1=RESET-SCHEDULE THRU DEC 31 (ALL) DRES1  ..
$ ----- System Description ------------------------------------
SET-DEFAULT FOR ZONE
   ZONE-TYPE        = CONDITIONED
   OA-CFM/PER       = OA-RATE
   CFM/SQFT         = 0.7
   DESIGN-HEAT-T    = 72
   DESIGN-COOL-T    = 77
   COOL-TEMP-SCH    = OFC-SCH-C
   T-TYPE           = PROPORTIONAL
   THROTTLING-RANGE = 2
   ..
SPACE-NORTH-MID  = ZONE ..
SPACE-EAST-MID   = ZONE ..
SPACE-WEST-MID   = ZONE ..
SPACE-SOUTH-MID  = ZONE ..
SPACE-CORE-MID   = ZONE ..
SPACE-NORTH-TOP  = ZONE ..
SPACE-EAST-TOP   = ZONE ..
SPACE-WEST-TOP   = ZONE ..
SPACE-SOUTH-TOP  = ZONE ..
SPACE-CORE-TOP   = ZONE ..
SPACE-NORTH-GND  = ZONE ..
SPACE-EAST-GND   = ZONE ..
SPACE-WEST-GND   = ZONE ..
SPACE-SOUTH-GND  = ZONE ..
SPACE-CORE-GND   = ZONE ..

$ System Control
SCONTROL-1 = SYSTEM-CONTROL
  MIN-SUPPLY-T     = 55
  HEATING-SCHEDULE = HEAT-1
  COOLING-SCHEDULE = COOL-1
  ..
$ System Fans
SFANS-1 = SYSTEM-FANS
  FAN-SCHEDULE     = FAN-1
  FAN-CONTROL      = FC
  N-C-C            = NCC
  SUPPLY-STATIC    = STATIC
  SUPPLY-EFF       = FANEFF
  ..
SYS1 =  SYSTEM
  SYSTEM-TYPE      = SYSTYP
  SYSTEM-CONTROL   = SCONTROL-1  $ System-controls
  MIN-AIR-SCH      = MINAIR-1    $ System-air
  OA-CONTROL       = OA-CONT
```

```
   SYSTEM-FANS     = SFANS-1     $ System-fans
   SIZING-RATIO    = SIZERA      $ System
   SIZING-OPTION   = SIZEOP
   MIN-CFM-RATIO   = 1.0         $ System-terminals
   RETURN-AIR-PATH = DUCT
   REHEAT-DELTA-T  = 0
   ZONE-NAMES      =             $ System-zone
   (SPACE-EAST-MID,SPACE-EAST-TOP,SPACE-EAST-GND,
    SPACE-NORTH-MID,SPACE-NORTH-TOP,SPACE-NORTH-GND,
    SPACE-SOUTH-MID,SPACE-SOUTH-TOP,SPACE-SOUTH-GND,
    SPACE-WEST-MID,SPACE-WEST-TOP,SPACE-WEST-GND,
    SPACE-CORE-MID,SPACE-CORE-TOP,SPACE-CORE-GND)
   ..
PL1 = PLANT-ASSIGNMENT  SYSTEM-NAMES    = (SYS1)  ..
END            ..
COMPUTE SYSTEMS  ..

$ * INPUT PLANT ************************************************
INPUT PLANT  INPUT-UNITS= ENGLISH  OUTPUT-UNITS= METRIC ..
PLANT-REPORT
  V = (PV-A)
$  S = (ALL-SUMMARY)     ..
  S = (PS-A,PS-B,BEPS)  ..
PL1 = PLANT-ASSIGNMENT   ..

$ !!!!! PLANT PARAMETERS !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
PARAMETER
  IN    =  2
  CTYPE =  HERM-CENT-CHLR  $per Philippine database
  EIR   =  0.27            $ for Base Case
  ..
$------ Plant Description --------------------------------------
CHILLER  = PLANT-EQUIPMENT
  TYPE  = CTYPE
  SIZE  = -999           $ chillers & towers autosized
  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 ..
```

APPENDIX D

OTTV_w ANALYSIS METHODS

Seven separate studies have been conducted in the ASEAN region since the early 1980s in an effort to improve on the accuracy of the original OTTV_w equation and to simplify compliance procedures. Virtually all of these studies have used variations of the same analysis methodology, which involves conducting parametric computer simulations of the annual energy impacts of envelope features. We briefly describe the main features of this methodology, and the options available, as a context for the descriptions of the ASEAN studies in the text of the report.

A word of caution seems appropriate here. Parametric energy simulations and regression analyses of the parametric results are powerful new tools being applied to building energy studies in general, and more specifically to energy standards and OTTV_w analyses. However, because of their very power, these tools can easily be misused, and have been. Improperly conceived or executed studies can produce results that make statistical sense but do not reflect reality, or reflect only part of reality. To avoid such pitfalls, each step in the process needs to be carefully done and checked. A guide to assure that results are useful (and used) is that equation formats, variables and their ranges, regression coefficients, and results should all "make sense" to thoughtful building design professionals.

Figure 8-1 shows a general nine-step process that can be used for developing or refining the OTTV_w equation, given the starting requirements of a simulation tool, climate data, and reference building. In each of the nine steps, valid and reasonable choices among options are available; the selection among these choice will influence the nature and type of results obtained from the analyses. As we have seen in discussing the ASEAN studies in the text of the report, a considerable variety of approaches have been taken. Various analysts have made different choices that have produced different results.

DETERMINE VARIABLES AND RANGES

The variables to be examined and their ranges must be selected. There are two basic choices: 1) the analysis can be limited to only those variables in the original OTTV_w equation, or 2) new variables might be considered to be added to the equation. This choice can have an important impact upon results. If a variable is not examined, its value will not be varied in the parametric analysis, and its impact will be invisible to the regression equations that result. The resulting regression equations may still do a very good job of explaining the impact of the variables that have been examined.

During the 1980s, US and ASEAN studies have added two different variables to OTTV_w-like equations for external wall thermal performance. In the US, a heat capacity term, HC ($\text{Btu/ft}^{2}\cdot{}^{\circ}\text{F}$), has been added to the new external wall system performance equations included in ASHRAE/IES Standard 90.1-1989, in order to account for thermal mass effects.* In ASEAN, an HC term was not added because its effects were found to be negligible in the ASEAN hot, humid climate. But studies in Malaysia, the Philippines, Indonesia and Singapore have added a solar absorptivity term, α, in order to account for the impact of solar radiation on vertical opaque surfaces. The US study did not examine the absorptivity α term, and two ASEAN studies, in Thailand and Singapore, used the original form of the OTTV_w expression, which did not incorporate α.

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* These equations are described in Attachment 8B to Section 8 of Standard 90.1-1989, and references related to their development are listed in Attachment 8D to Section 8.

Proper choice or ranges for variables can also impact study results. For example, an early $OTTV_w$ study in ASEAN [8] examined solar absorptivity (α) over a narrow range, and concluded that α had little energy impact. A later ASEAN study [22] used a broader range of α; this study concluded that α had sufficient impact to warrant adding the variable to the original $OTTV_w$ equation.

DETERMINE FORM OF EQUATION FOR NEW VARIABLES

This is an optional step, needed only if it has been decided to add one or more new terms into the equation. These new variables can be inserted in different ways to form alternate new equation formats. The new equation formats used should both make sense in physical terms and produce good statistical results from the regressions. Independent analyses can help to determine the most appropriate way to add the new terms. An example of such an analysis was discussed in Chapter 8 as part of the ASEAN study for the Malaysian standard.

DETERMINE SOLAR FACTOR

The solar factor is an important element of the OTTV method. It can be determined as an output of the regression analyses performed, or it can be determined directly from calculations performed using hourly solar data. The solar factor determination has been discussed above in Chapter 3. Various ASEAN $OTTV_w$ analyses discussed in Chapter 8 have used both methods for generating solar factors.

ANALYSIS OF BUILDING

The analysis can be for the energy results of the building as a whole, or for separate energy results by external zone. The analysis using energy results for the building as a whole is simpler, but imbeds in the results obtained both the moderating effects of internal zone(s) that have no external wall exposures and the implicit impacts of the geometry of the reference building used. All ASEAN studies used this approach, and incorporated orientation impacts via solar factor adjustments by orientation. This contrasts, for example, with US analyses for ASHRAE/IES Std 90.1-1989 that used a single floor of a prototype building, with results tabulated separately for each external zone, for the four cardinal orientations (N, E, S, and W).

SELECT SET OF PARAMETRIC RUNS

This is a critical step in the process, and choices made can radically influence results. On the one hand, one seeks to minimize the number of parametric runs, both to reduce computation time and to reduce time and effort to manage and analyze the results. On the other hand, sufficient runs must be made to isolate the affects of each variable over its range, to examine potential non-linearities, and to examine the effects of interacting variables upon each other. Too few runs will not permit adequate examination of each variable. Too many runs clustered in a small part of a variable's range can weight results to performance in that range.

This type of parametric approach has been used for external wall parametrics for ASHRAE/IES Std 90.1-1989, and for the Malaysia, Philippines, and Indonesia studies discussed in the text of the report. Another approach is to use judgment in selecting combinations of values of variables for the parametric simulations. This approach was used in two ASEAN studies for Singapore described in the text [8,9].

SELECT OUTPUT PARAMETERS

The selection of simulation output parameters to measure results is determined in large part by the objectives of the study and by how the envelope requirements are to be integrated with other elements of the energy standard. A number of choices are available here.

Type of Load

For example, the type of load can include, for the whole building or by orientation:

- A peak load
- An averaged annual load

The choice here involves policy objectives more than technical ones. If the primary objective is to make more efficient use of energy, then the average annual load is the likely choice. If the primary objective is to minimize the construction of costly new electrical power generating capacity, then peak load is the likely choice. For changes in most envelope parameters, there is a high degree of correlation between the magnitude of change in peak load and averaged annual load. For the various ASEAN parametric studies, the averaged annual load was chosen.

Point of Measurement

The load can be measured at different points in the simulation process:

- Envelope load on the HVAC distribution system
- Envelope load impact on the HVAC conversion equipment, including the loads imposed by the HVAC distribution equipment
- Total building HVAC peak or energy, including loads imposed by both HVAC distribution and conversion equipment.

The various ASEAN studies have used either the first or second choices for measuring results.

In ASEAN, there is no benefit to including HVAC equipment conversion (third choice above) in the analysis. Only cooling is considered, and virtually all cooling conversion equipment is electrical.* Since most energy standards include a separate section that specifies efficiency requirements for the HVAC conversion equipment, there is no need to include this portion in the envelope analysis.

Consistent with the first choice above, the original ASHRAE and Singapore $OTTV_w$ equations applied to cooling loads, estimating only the load transferred through the envelope to the interior spaces. As a limiting value in setting a standard, this approach to the $OTTV_w$ did not explicitly include the ventilation loads resulting from envelope heat gains.

Variation in envelope loads can have substantial impact on ventilation requirements. If large amounts of heat enter a space through the building envelope, enough of the heat must be extracted from the space to maintain comfort conditions during the building's occupied period. This can substantially increase the ventilation load as the envelope load increases. A question becomes whether it is appropriate, when analyzing the parameters for the $OTTV_w$, to include the fluctuations in the ventilation loads in examining

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* In climates for which both cooling and heating are to be included in the analysis, consideration of conversion equipment can be important to the study design. Some US residential envelope standards, for example, contain different envelope criteria for houses heated with gas or oil than for houses heated electrically, since both energy results and costs differ substantially.

the results of the analysis.

A number of studies have included these loads, by using the output from DOE-2 that includes the loads on the chiller. Such studies include those for ASHRAE/IES Standard 90.1-1989, and several of the recent ASEAN studies (see Chapter 8 of this volume).

PERFORM SIMULATIONS AND REGRESSIONS

This is actually the most routine of the steps, yet will consume the most time in the analysis. This step does not involve the kinds of choices that will impact the energy results.

SELECT EQUATIONS AND COEFFICIENTS

Selecting an appropriate form of the OTTV equation is an applicable step only if consideration is being given to adding, changing, or deleting terms from the equation to improve accuracy or to simplify compliance requirements. Compliance simplifications were suggested for Singapore by Turiel *et al.* [8], but not adopted. Malaysia has adopted a simplified form of the equation with the fenestration conduction term deleted. Otherwise, this step is limited to selecting appropriate coefficients for the various terms in the equation.

SELECT STRINGENCY LEVEL FOR THE $OTTV_w$ CRITERIA

Once the $OTTV_w$ equation and coefficients have been determined, the last step is to choose a stringency level for the proposed standard. This is a policy step that is probably best done by the designated policy committee, with input from the technical group. The process that has been typically used is to select values for each of the parameters in the equation that together will represent a minimum level of acceptable practice for the building type(s) covered. Insert these values into the equation and determine the resulting $OTTV_w$ value. This value (representing the selected building design features) then becomes the required minimum $OTTV_w$ value for the standard. Alternatively, several reasonable <u>sets</u> of values can selected, and the $OTTV_w$ equation solved for each set, and the requirement value selected based upon review of the combined set of solutions.

An option would be to select the $OTTV_w$ requirement level based upon cost-effectiveness criteria.* This approach is attractive and has a number of positive attributes. However, we are not aware of its direct use to date in setting an $OTTV_w$ requirement level. This is probably because of the following issues relating to window-to-wall ratio (WWR).

The construction cost of a square meter (ft^2) of fenestration invariably costs more than a square meter (ft^2) of opaque wall surface, and the heat gain through the area of the fenestration is greater than through the opaque surface. Thus, without daylighting to reduce electric lighting use, the most cost-effective amount of glazing is no glazing at all. Some judgment must be exercised to determine an appropriate amount of glazing to use as a base case. Data for the Philippines suggests a WWR = 0.50 for large offices. Available data for the US (Northern California only) indicates for highrise offices about 40% WWR average with standard deviation of over 20%. Other building types appear to have averages of about 20%, with standard deviation in the 15 to 20% range.

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* Cost-effectiveness is usually incorporated indirectly in the judgment used to set the requirement based upon a set of building features.

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