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A Building Envelope Energy Standard for Malaysia

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ABSTRACT

We present the technical analysis in support of a proposed, new, commercial building, envelope energy standard for Malaysia. The methodology includes the use of a state-of-the-art computer simulation program and regression techniques to derive a simple equation for the standard. Five variables were found to capture most of the impacts of envelope design choices on the chiller load. They are: the window-to-wall ratio, the window shading coefficient, U-values for the opaque wall and glass areas, and the solar absorptance (color) of the exterior wall. These five variables were combined in an Overall Thermal Transfer Value (OTTV) formulation, similar to that being used in Singapore. Different forms of the OTTV equation were tested for accuracy in predicting chiller loads, and it was found that a simplified two-term equation accounting for heat conduction through the opaque walls and transmitted radiation through the fenestration was sufficiently accurate. Though the results of this study are fundamentally similar to those of an earlier Singapore study, two factors warrant a re-examination of Singapore's proposed OTTV standard update; these two factors are: the discovery of the importance of the solar absorptance term in the OTTV equation and an improved technique for determining the set of parametric computer runs, based on factorial analysis.

INTRODUCTION

Malaysia is developing an energy standard for new commercial buildings. The details of the standard, including criteria for lighting power and control and air-conditioning equipment and credits for the use of daylighting, are described in UTM (1987); the energy and economic impacts are presented in Deringer and Busch (1987). This paper reports on the development of the building envelope portion of the proposed standard. The analysis that follows uses the overall thermal transfer value (OTTV) concept previously adopted for the standard in Singapore (PWD 1979).

Like neighboring Singapore, Malaysia has recognized the need to curb the growth of energy use in the commercial sector. Total electricity consumption in 1985 was approximately 12,500 GWh. Commercial buildings now consume almost a third of Malaysia's electricity (MOE 1986). This estimate is conservative, as it does not include non-process energy use in industrial buildings. Between 1981 and 1985, commercial building energy use increased at an average annual rate of approximately 8%. This rate corresponds to a *doubling* of commercial sector demand every nine years.

Energy loads in new building construction are increasing as well. Designers are creating more comfortable, functionally efficient, and visually appealing interior environments in buildings. As a result, these buildings have higher lighting levels, higher solar-heat loads resulting from increased use of curtain wall construction in larger commercial buildings, and additional utilization of air conditioning to offset the resulting higher cooling loads.

The major commercial building energy end uses are air conditioning and lighting, shown in Figure 1. Air-conditioning loads are primarily made up of heat gains from the lights, heat and moisture gains from the outdoor air, solar gains, and conductive heat gains through the building envelope. The latter two components are treated in the proposed OTTV standard, which follows.

METHODOLOGY

The methodology discussion is presented in two parts. The first part describes the basic elements of the methodology used — the reference building, the DOE-2.1C computer program used to perform the analyses, and the local weather data. The second part describes the methodology for developing the OTTV equation using the basic building, weather, and computer program elements.

Basis for the Analysis

Reference Building Description. The lack of substantial data bases restricted the scope of the research that could be completed in a reasonable length of time.[1] Data bases are needed both for energy consumption in Malaysian buildings and for building construction/design procedures that are unique to Malaysia. In the absence of such data bases, the analyses used a "reference" building approach. A reference or "Base Case" building was developed to reflect a typical range of construction and energy use features prevalent in Malaysian new commercial building construction. The Base Case building is not intended to represent the "average" energy design in Malaysia today. Rather, it represents a building design that is between the average and a "worst-case" energy design that we might expect to be built today.

The Malaysian Base Case building is based upon a similar prototypical reference building developed for a 1984 parametric energy study for Singapore (Turiel *et al.* 1984). The Singapore building was developed to reflect typical building practices in Singapore, and such building practices are similar to those encountered in Malaysia today. However, modifications were made to more accurately reflect contemporary construction practices in Malaysia. A complete description of the changes is reported elsewhere (Deringer *et al.* 1987).

The Malaysian Base Case building is a 10-story office building with a total conditioned area of 5,200 m^2. The unconditioned core zone has a floor area of approximately 1,000 m^2, and the core region is assumed to be thermally insulated from the interior conditioned zone. The Base Case building has a window-to-wall ratio of 0.40, and the

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

shading coefficient of the windows is 0.69 (i.e., single-pane tinted glass). The lighting power density installed in the occupied areas is 21 W/m^2. A variable air volume (VAV) system was modeled with a ratio of 0.5 between the minimum airflow rate and the design airflow rate. A chiller with an EIR OF 0.244 (COP of 4.1), excluding fans and pumps, provides chilled water to the cooling coils. The characteristics of the building envelope, conditions of the interior space, and specifications of the air-conditioning equipment are summarized in Table 1.

DOE-2.1C. The DOE-2.1C Building Energy Simulation Program (BESG 1985) is the computer simulation program used for analyzing energy conservation in Malaysian buildings. The DOE-2 program is a tool for estimating the total and component energy consumption associated with a particular building design.

A building, examined thermodynamically, involves nonlinear flows of heat through and among all of its surfaces and enclosed volumes, driven by a variety of heat sources (e.g., the sun, the lights, the occupants, various types of equipment, etc). Mathematically, the thermodynamics are represented by a set of coupled integral-differential equations with complex boundary and initial conditions. The function of a program like DOE-2 is to simulate the thermodynamic behavior of the building by approximately solving the mathematical equations.

The simulation process in DOE-2.1C is performed sequentially in three programs. The first program (called LOADS) uses weather data, user input regarding the characteristics of the building envelope, and the building's schedule of occupancy in order 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, etc., to maintain temperature and humidity setpoints. In addition, control equipment, HVAC auxiliary equipment, and energy recovery equipment are also evaluated within the SYSTEMS program. The final program (PLANT) simulates the behavior of the primary HVAC systems (boilers, chillers, cooling towers, etc.) in meeting these demands and predicts the fuel electrical energy consumed.

Versions of DOE-2, up to DOE-2.1C, have been verified against manual calculations and against field measurements on existing buildings (LANL 1981; Diamond *et al* 1985; Birdsall 1985). These studies all show that, with few exceptions, the DOE-2 predictions agree well with ASHRAE calculation methods, manufacturers' data, and measured annual building energy consumption. DOE-2 results also agree well with predictions of other building energy analysis computer programs (e.g. BLAST, NBSLD). These 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.

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

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

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

OTTV Analysis

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

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

The OTTV formulation is performance-based. It allows a building designer freedom to vary important wall characteristics to meet specific design objectives and still comply with the OTTV requirements for the wall. 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) so long as the total value of the resulting OTTV is not greater than that required by the standard.

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

Among the envelope features, fenestration characteristics dominated the cooling load. The fenestration features examined were the shading coefficient (SC) of the window system, the window area in the form of the window-to-wall ratio (WWR), and the glass conductance (U_f).

Opaque wall parameters also showed a measurable impact on the cooling loads. The characteristics varied in the simulations were thermal mass (heat capacity) the solar absorptance in terms of the exterior surface color (α), and insulation levels in the walls (U_w).

Initial wall strategy and problems with results. The initial analytic strategy was to vary the DOE-2 input variables of interest over a range of sufficient breadth to ensure that the correlation results would be directly comparable with the 1984 Singapore OTTV approach (Turiel *et al.* 1984). The rationale was that the analysis would in all likelihood result in only a slight modification of the Singapore work 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, in the first analysis, some of the input parameters were not varied throughout their range of likely occurrence. The result was that the full impact of these parameters on cooling loads was either significantly under- or overestimated. These initial results were incorporated into the late 1986 draft proposed Malaysian standard (UTM 1986).

To eliminate these distortions, the approach was altered using a technique in experimental design called factorial analysis. Factorial analysis is a systematic way of covering an entire factor space by first defining the range of each key parameter and then combining the parameter extremes with each other, 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 each parameter in combination with the others.

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 is shown in Table 2.

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

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

where:

$\Delta \mathrm{Teq}$ = equivalent indoor-outdoor temperature difference for the opaque wall (°C);

U_w = U-value of the opaque wall ($\mathrm{W/m^2}$-°C);

WWR = window-to-wall ratio;

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

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

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

SC = shading coefficient.

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

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

Standard ASHRAE equations were used to convert diffuse and global horizontal radiation to direct vertical radiation for eight orientations. Total vertical radiation is equal to the sum of the direct vertical, 0.5 times the diffuse horizontal, and 0.11 times the global horizontal. Table 3 shows the magnitude of the solar factor for each of the eight orientations and the solar factor's direct and diffuse components.[2] The vertical radiation

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[2] Anomalous patterns occur in the solar data east and west orientations. For that reason it is not recommended that the SF values *by orientation* shown in Table 3 be used. However, the average

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 clear glass. 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 ΔTeq and ΔT were determined.

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

The results of these separate simulations for thermal mass and absorptance are shown in Figures 4 and 5. The exterior wall thermal mass had relatively little effect on the chiller load, changing it only 1%-2% over the range. This was not considered a large enough impact to increase the complexity of the OTTV equation by adding a separate thermal mass term. Neither roof mass nor roof color had a significant impact on the chiller load.

SF over all orientations was assumed to be reasonably accurate for the following OTTV analysis. Further examination of these data is warranted but was beyond the scope of this study.

However, opaque wall color, as indicated in the solar absorptance, had an 8-9% 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 Malaysia. This is especially true because typical Malaysian construction practice uses little or no insulation in the walls. Therefore, the original ASHRAE and Singapore OTTV equation has been modified to include the solar absorptance term.

Determining best way to add absorptance term to OTTV equation. A new form of the OTTV equation was needed to incorporate the solar absorptance term. To evaluate the best configuration, we executed two sets of 20 DOE-2 runs each using various combinations of the key design variables. In one set, the solar absorptance was varied, and in the other, it remained constant. The purpose of these two sets of runs was to evaluate the variation in the chiller load that was attributable to the changing absorptance. The computed variations in the chiller load were then compared to several different methods of incorporating the absorptance term, shown in Figures 6 through 8.

The first two figures show that neither the solar absorptance nor solar absorptance 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 absorptance multiplied by the opaque wall area ratio and the conductive heat loss factor (U-value) for the wall. This relationship clearly indicates that the appropriate way to incorporate the solar absorptance term into the OTTV equation is to include it as a multiplicative constant in the opaque wall term.

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

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

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

Regressions were run for several different forms of the OTTV equation. The final form of the Malaysian OTTV equation was chosen on the basis of the statistical regression results. The selection process and the recommended final form of the OTTV equation are described below.

Roof Analysis. For roof design, both the analyses and the provisions of the proposed standard for roof design are generally much simpler than those for walls, because the roof does not typically contain large areas of glazing (through which solar radiation can enter directly), like the walls do. No parametrics were conducted for the roof. Rather, the basic criteria used by both ASHRAE and Singapore were adapted and simplified. Credits were developed for roofs that are shaded or that use reflective surfaces that are reasonably impervious to moisture and mold degradation. The proposed roof criteria are discussed in the "Results" section.

RESULTS

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

Determining the Final Form of the Wall OTTV Equation

Using chiller load estimates from 33 DOE-2.1C simulations, a regression analysis was performed to evaluate the proper format of the OTTV equation and the unknown terms in it (ΔT, ΔTeq).

In all, six alternate forms of the OTTV equation were evaluated and are shown in Table 4. 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 4 (with all three terms) 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 absorptance is treated as a multiplicative constant within the wall conduction term.

The student's t-score for each of the three terms indicates that all three 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 all three terms more closely matches actual chiller loads than using the one- or two-term formulations (i.e., Form # 2 and 3, Table 4). Using Form #1 and the solar factor value determined elsewhere (SF = 194 W/m^2), the calculation of the temperature differences to use with the wall and window conduction terms can proceed. From the coefficients in this OTTV formulation, $\Delta Teq = 20.3°C$ and $\Delta T = 1.5°C$.

Simplifying the OTTV Equation

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

For the OTTV equation with one, two, and three terms, the discrepancies (in percentage terms) among predicted and observed chiller loads are shown in Table 5. The discrepancies are also depicted graphically in Figures 9 through 11, where terms are successively removed. Points in the figures in perfect agreement fall directly on the diagonal line. The scatter increases slightly going from three to two terms but is more pronounced in the one-term formulation. In other words, ignoring the heat gain contribution from window conduction in the OTTV equation results in little loss of accuracy. Eliminating this term reduces the calculation complexity by almost one third.

Proposed Wall OTTV Equation and Criteria

An improved and simplified version of the OTTV approach for walls is proposed for the Malaysian Standard:

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

It requires the input of four variables:

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

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

A good way to see the impacts of these changes is to compare the results obtained from the new proposed Malaysian wall OTTV equation with the results obtained by the ASHRAE and Singapore equations for a set of typical building design situations. Tables 6 and 7 show such a comparison for the Base Case building and Proposed Standard Case building used in the analyses in this study.

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

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

Proposed Roof Approach and Criteria

In contrast to the ASHRAE and Singapore approaches, the proposed roof criteria for Malaysia:

- are simpler: If there is no fenestration in the roof, no roof OTTV calculation is required.
- include additional factors: Because solar gain is so important for roofs as well as walls in the Malaysian climate, credits are provided for fully shaded roofs

and for roofs with reflective coatings.

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

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

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

CONCLUSIONS

This paper has described a technique for developing a simple and accurate OTTV equation that accounts for wall parameter effects on chiller loads. For Malaysia, a two-term equation describing conductive and radiative heat gains through the building envelope is recommended. This approach offers flexibility to building designers, is not too stringent for those who must comply with its criteria, and is easy to apply.

Implications for the ASEAN Region

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

Potential for Additional Research on Envelope Criteria

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

- Complete parametric analyses for roofs: This could be especially useful for roofs containing skylights, atria, and combinations of advanced technologies.
- Combined wall and roof expression: It may prove desirable to explore the benefits of developing a combined wall/roof OTTV expression, especially for buildings with large atria.
- Consideration of internal load on OTTV criteria: Proper envelope design includes consideration of thermal balances within a building. An important contributor to these balances is the level of internal loads, especially from the heat from lights. This factor is included in the latest ASHRAE 90.1P envelope formulations, but it has not been included in the current version of the Malaysian OTTV equation. It could be considered for inclusion in future versions to improve accuracy.

- Addition of daylighting term directly into OTTV equation: Because daylighting is such an untried technology in Malaysia, daylighting credits are provided independently of the OTTV calculation, as a change in OTTV criteria. If daylighting techniques become more common, it may be desirable to include a daylighting term in the OTTV equation. This is the case in the current proposed ASHRAE wall formulation in 90.1P.

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

TABLE 1
Characteristics of the Malaysian Base Case Building

Building Type:	10-story office building; 5,200 m^2 conditioned floor area; 1,000 m^2 unconditioned core.

Walls:	opaque wall U-value = 2.43 W/m^2-^{o}C;
	solar absorptivity = 0.45;
	mass = 250 kg/m^2;
	brick and lath construction.

Roof:	roof U-value = 0.60 W/m^2-^{o}C;
	solar absorptivity = 0.50;
	mass = 356 kg/m^2;
	built-up roofing.

Windows:	window-to-wall ratio = 0.4;
	shading coefficient = 0.69;
	glass U-value = 5.79 W/m^2;
	no window setback or external shading.

Lighting:	lighting power = 21 W/m^2; luminance = 500 lux.

Space Conditions:	outside ventilation air = 3.3 lit/sec/person;
	infiltration = 1.0 ach (when fans are off);
	cooling setpoint = 24 ^{o}C;
	night setback = 37 ^{o}C.

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

TABLE 2

Parameter Ranges for Wall OTTV Variables

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

TABLE 3

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

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

TABLE 4

FORMS OF THE OTTV EQUATION

	Independent Variables						
	X_{11} $\alpha(1-WWR)U_w$ (ΔT_{eq})	X_{12} $(1-WWR)U_w$ (ΔT_{eq})	X_{13} $\sqrt{\alpha}(1-WWR)U_w$ (ΔT_{eq})	X_{14} $\alpha^2(1-WWR)U_w$ (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				13.974	0.728	113.677	85.254
T-score				12.995	2.137	46.416	114.495
Physical Value				23.848	1.242	194	
$R^2 = 0.989$							

Note: In all cases, 33 observations were fitted.

TABLE 5

Comparison of Predicted vs. Actual Chiller Loads

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

TABLE 6

Impact of Changing Wall Absorptance

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

TABLE 7

Impact of Changing Glazing Conductance

			Malaysian OTTV Equation		Singapore OTTV Equation		ASHRAE OTTV Equation	
Wall Absorp.	Glazing Type	Base Case Chiller Load (MBtu)	Base Case	Std. Case	Base Case	Std. Case	Base Case	Std. Case
0.45	Single	4417	66	54	62	54	73	65
0.45	Double	4331	66	54	56	48	66	59

NOTE 1:

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

NOTE 2:

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

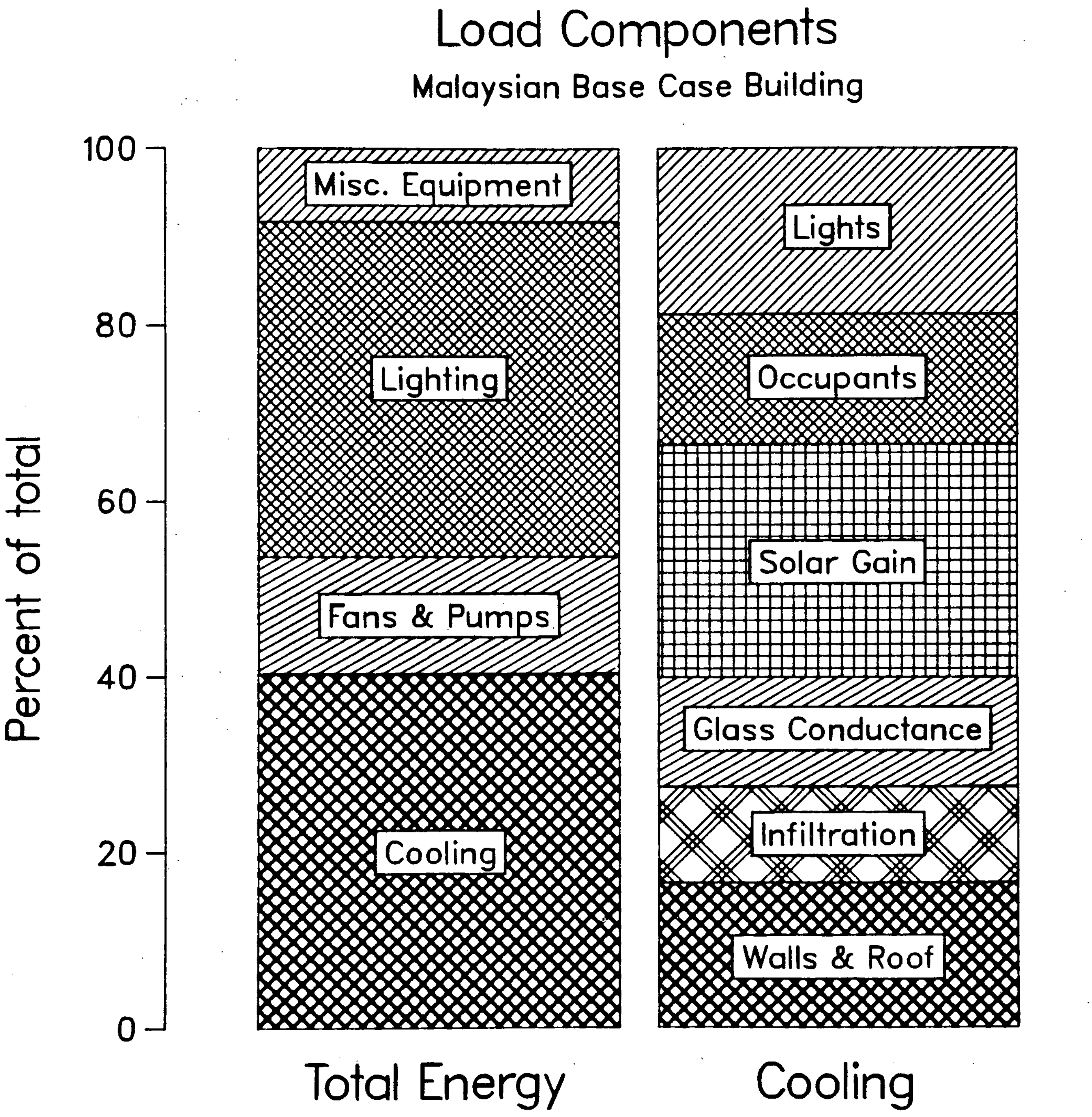

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Figure 1. Total energy and cooling loads breakdown for the Malaysian Base Case building. Note that the cooling load components do *not* include ventilation air.

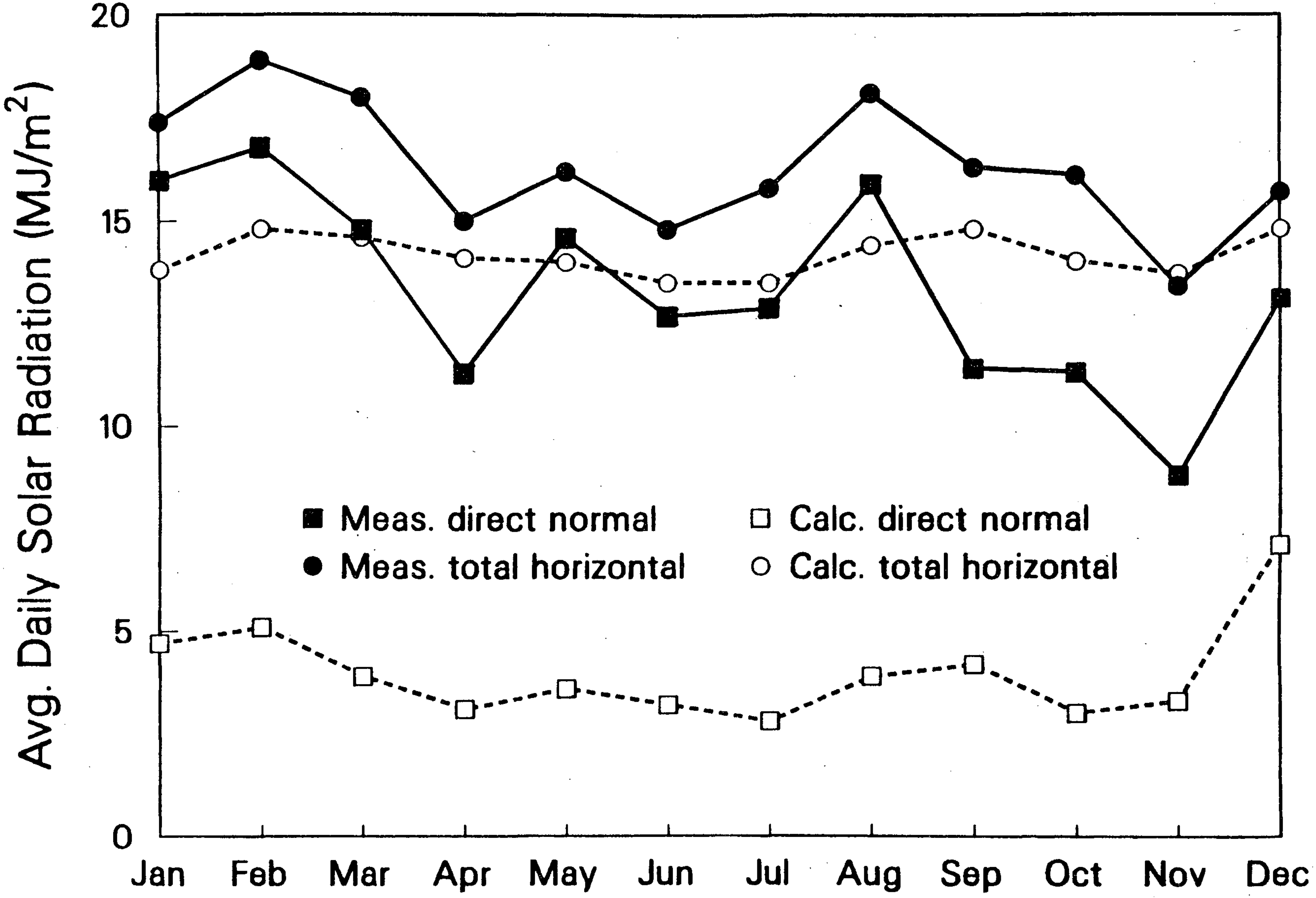


Figure 2. Calculated vs. measured solar radiation data for Singapore.

XCG 873-6787

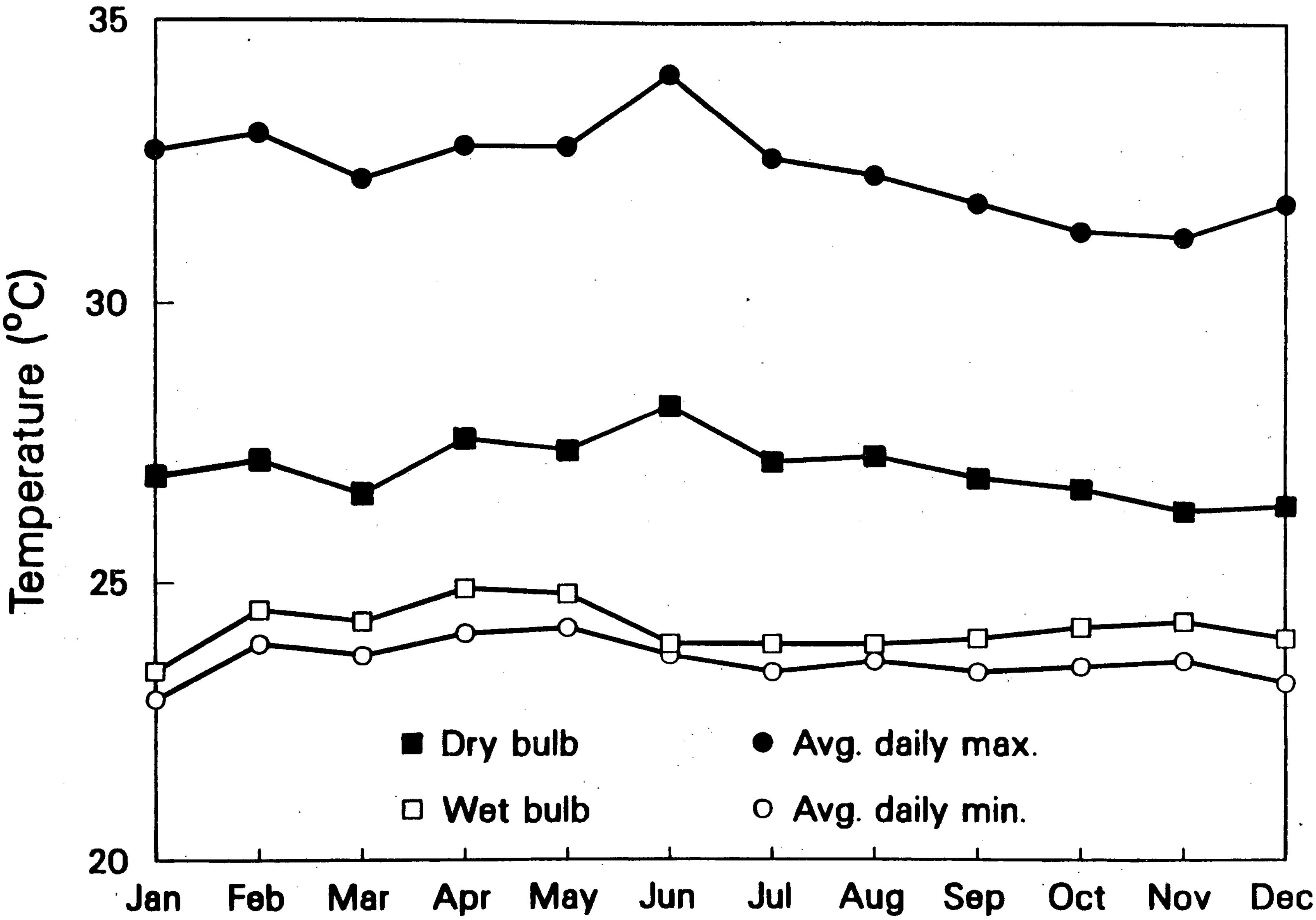
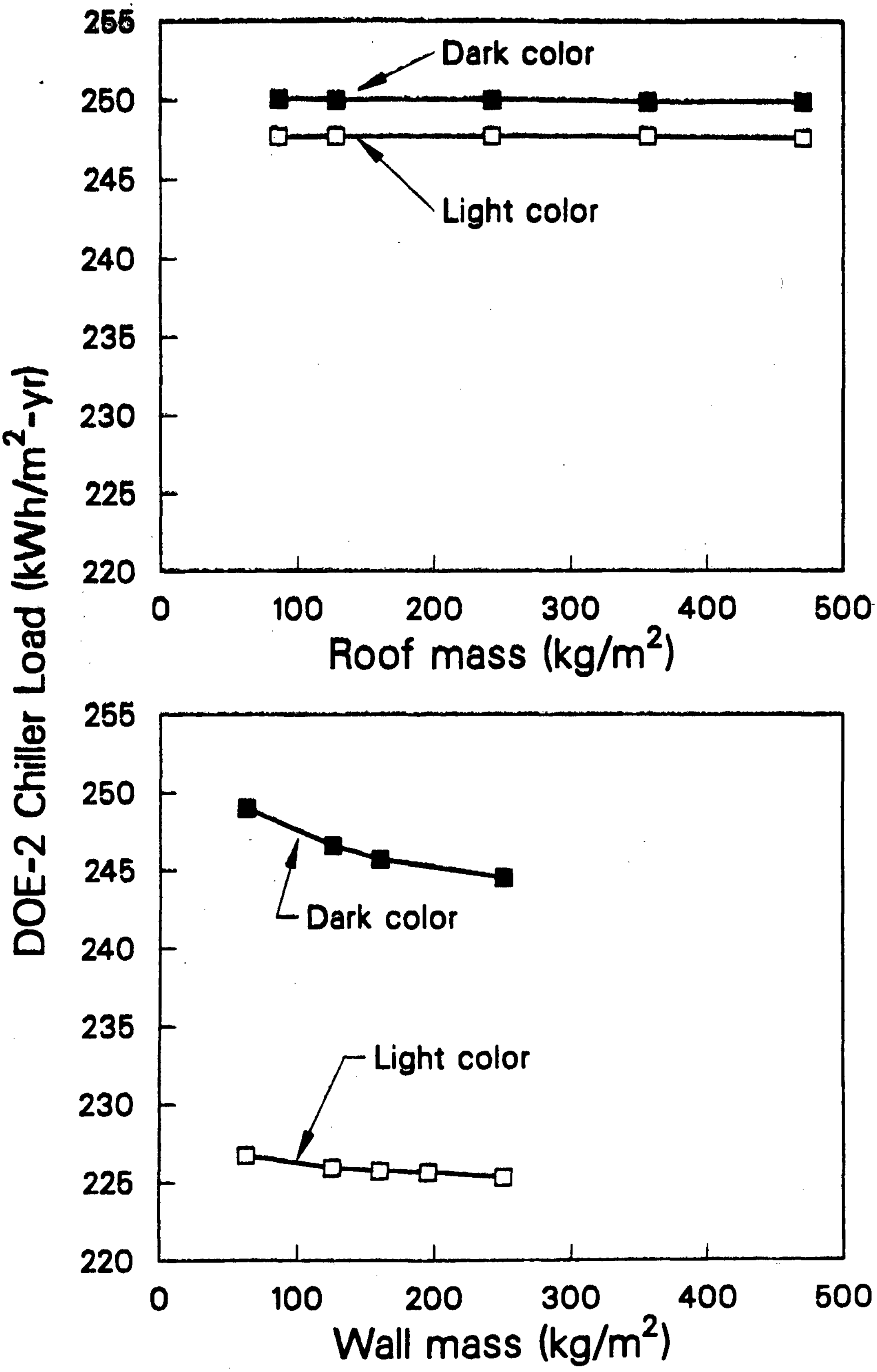


Figure 3. Measured temperature data for Kuala Lumpur in 1985.

XCG 873-6786



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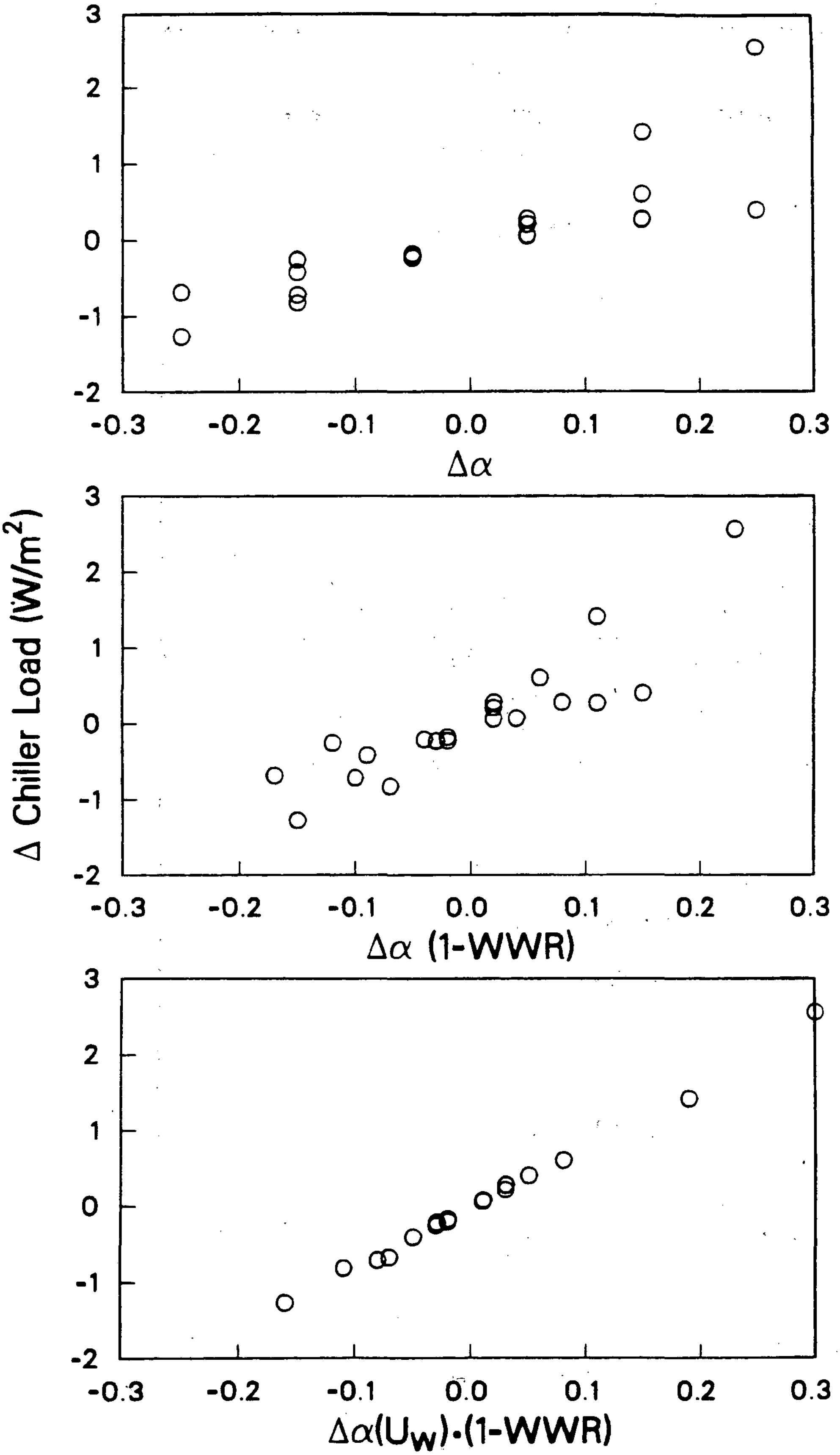
Figures 4 and 5. The effect of thermal mass and exterior surface color on chiller loads for roof (4) and walls (5).



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Figures 6 - 8. 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.

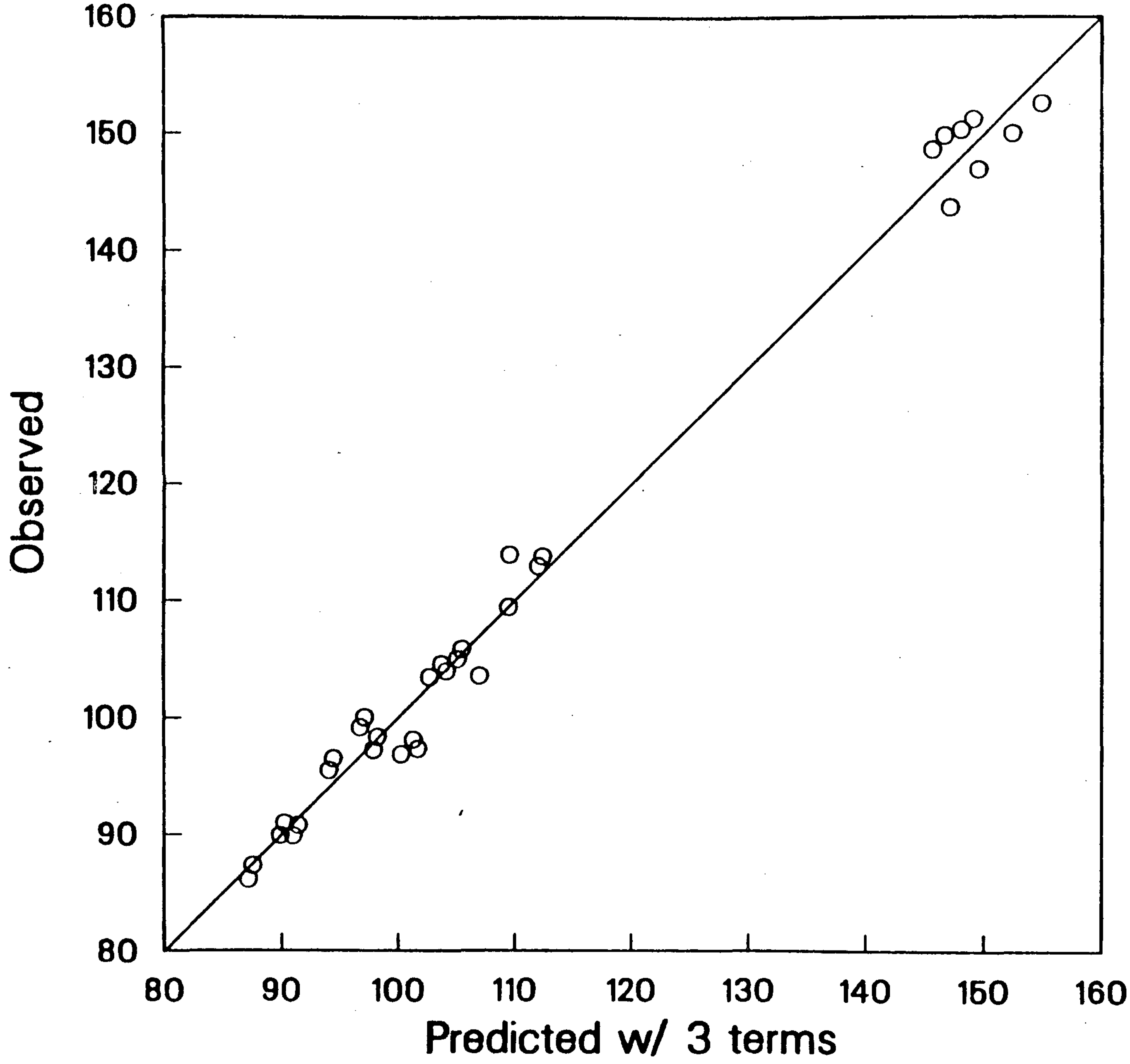

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Figure 9. Observed (DOE-2) vs. predicted chiller loads using the 3 term OTTV equation.

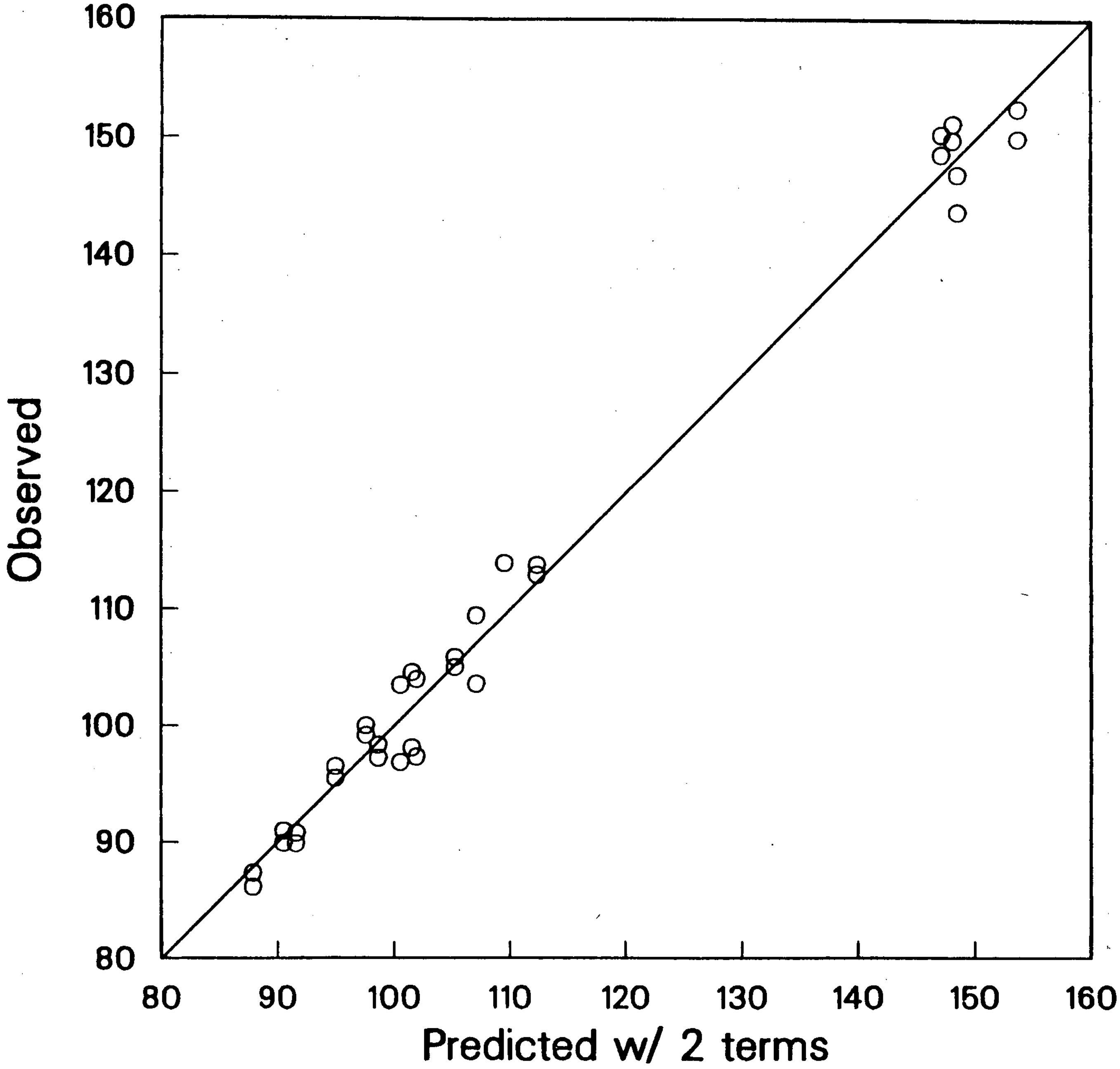

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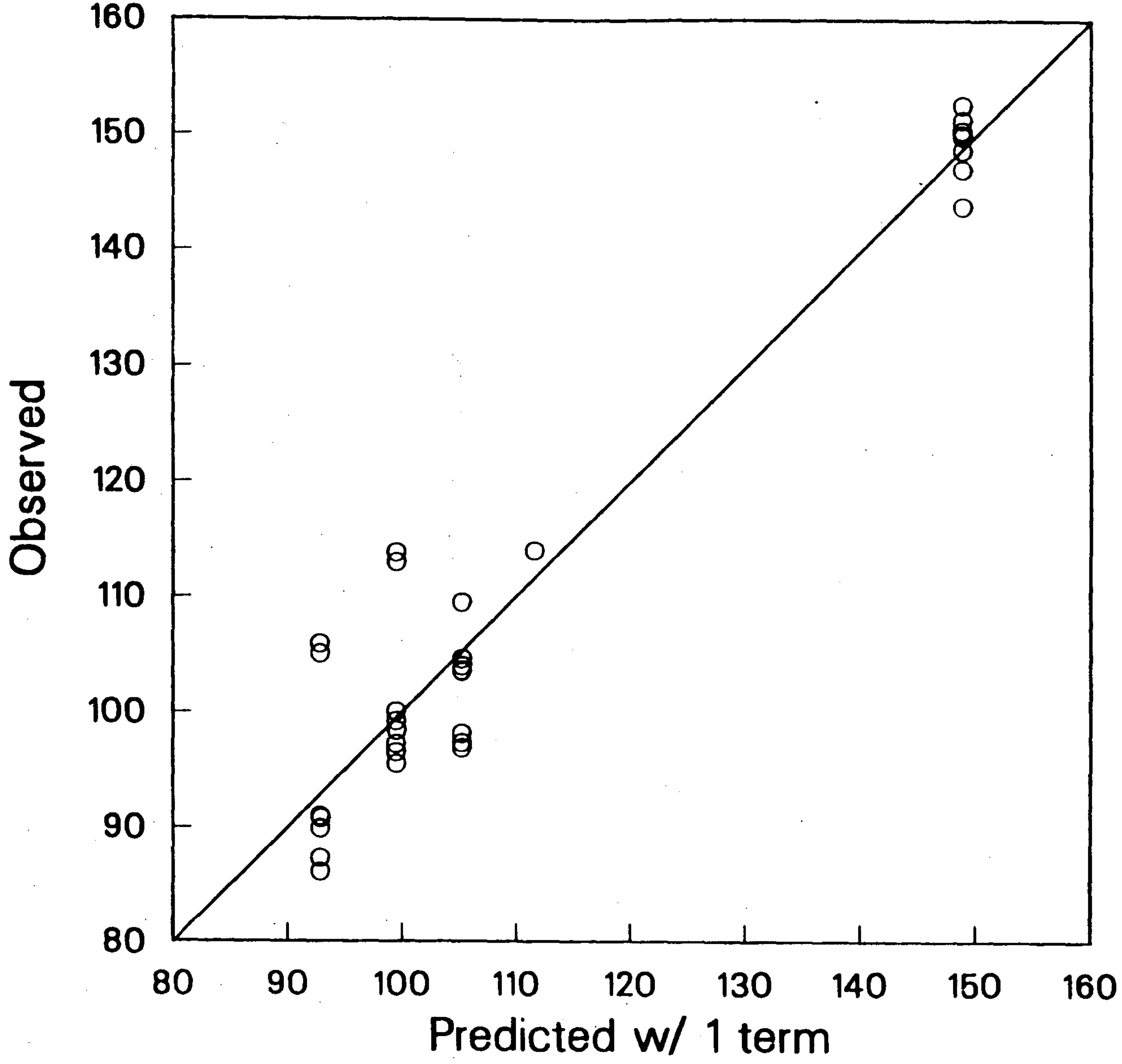
Figure 10. Observed (DOE-2) vs. predicted chiller loads using the 2 term OTTV equation.



XCG 873-6821

Figure 11. Observed (DOE-2) vs. predicted chiller loads using the 1 term OTTV equation.

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