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# Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

## ENERGY & ENVIRONMENT DIVISION

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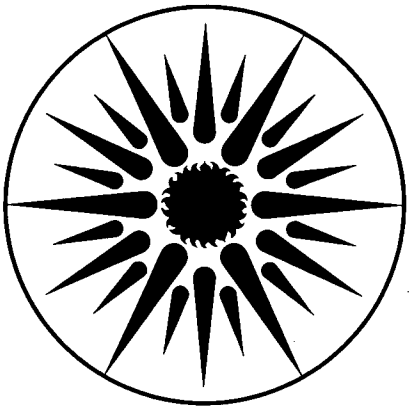
H. Akbari, O. Sezgen, J. Huang, S. Hakim, and R. Ritschard

July 1990



**ENERGY & ENVIRONMENT DIVISION**

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# Energy-Use Characteristics of Pakistani Prototypical Office Buildings and Single-Family Houses

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July, 1990

Prepared for

RCG/Hagler, Bailly, Inc.

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## Executive Summary and Conclusions

RCG/Hagler, Bailly, Inc. (RCG/HB) had contracted with the Lawrence Berkeley Laboratory (LBL) for the analysis of the energy conservation potential in residential and commercial (office) buildings in Pakistan. The major tasks performed and reported are as follows:

- preparation of survey forms for residential and commercial buildings and compilation of data to determine the characteristics of buildings in Pakistan,
- analysis of the weather data which was to be used for the simulations,
- construction of prototypical computer description models for residential buildings, office buildings converted from residential buildings and office buildings which reflect the major characteristics of these building types in Pakistan,
- determination of the promising energy conservation measures and base case parameter values for these measures,
- simple parametrics simulations where parameters are changed one by one,
- determination of promising and feasible combinations of conservation measures and simulations for these combined parametrics,
- examination of alternative HVAC systems for the office buildings,
- development of data manipulation methods for making use of the results to investigate unexplored combinations if the necessity arises in future.

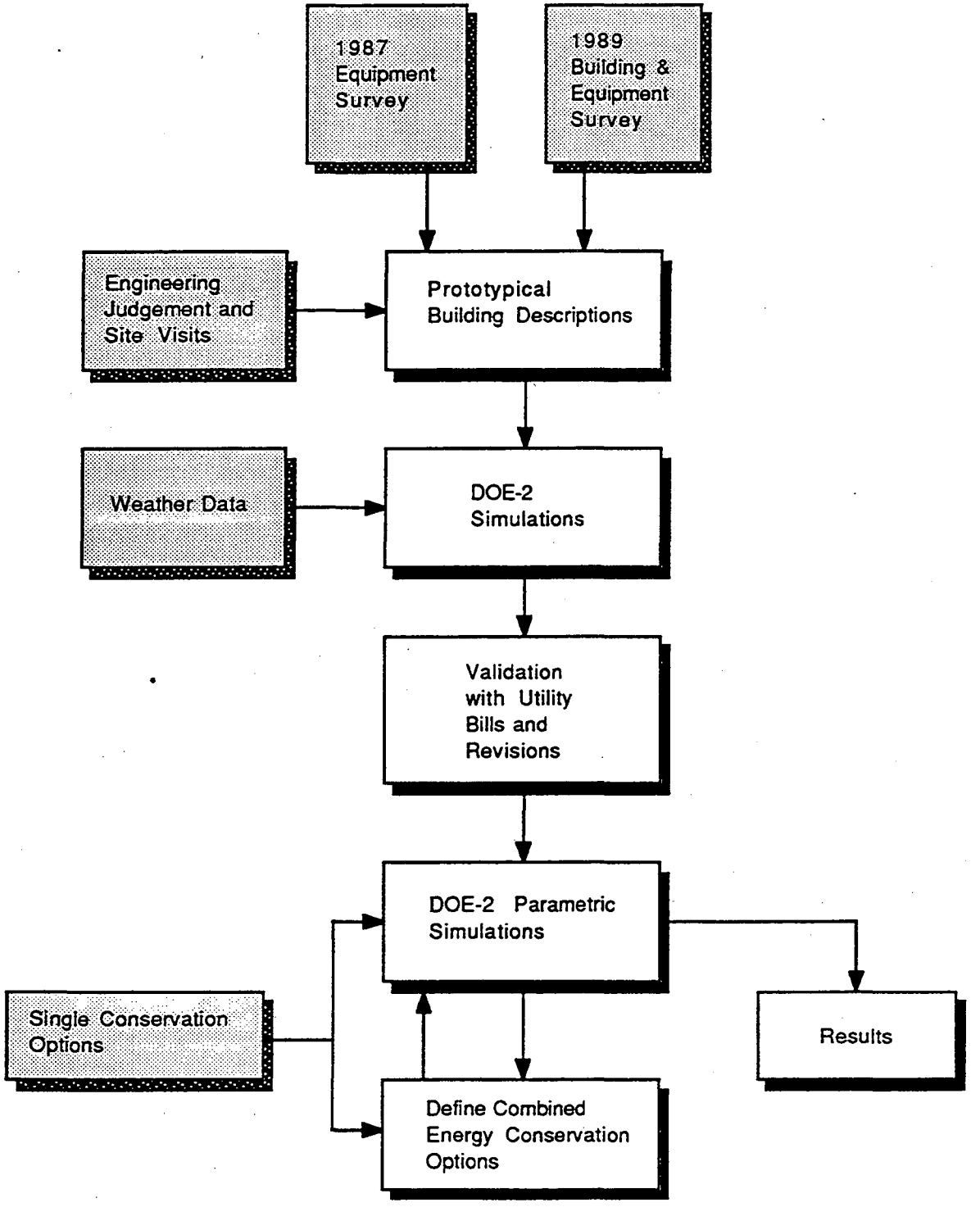
The purpose of this report is to:

1. summarize work performed in this area at LBL,
2. provide DOE-2.1D simulation results of the prototypical buildings,
3. discuss the impact of a series of energy conservation options (ECO) on energy use of the prototypical buildings, and
4. provide a database on DOE-2 parametrics simulations for follow-up research in Pakistan.

This report focuses on the development and discussion of simulation results for three prototypical buildings: a single-family detached house, a converted office from a single-family detached house, and an office building. Prototypes were developed for both individual offices (rooms) with window air conditioning units and large offices with central air conditioning units.

**Figure EX.1** outlines our general methodology for analyzing the impact of conservation measures for the selected building types in Pakistan. This effort included the description of the prototype buildings as well as the identification of energy conservation options for parametric simulations, and analysis of the DOE-2 results. A systematic series of DOE-2.1D simulations were performed and validated with monthly utility bills.

**Figure EX.1: Methodology**



The data used to develop the base case prototype was obtained from:

1. Two ENERCON reports: a 1987 survey of buildings and equipment (ENERCON 1987) and a proposed building energy code for Pakistan (ENERCON 1990),
2. Recently completed detailed surveys of buildings in Karachi, Islamabad, and Lahore, and
3. On-site visits to Karachi, Lahore, and Islamabad to inspect building conditions and building stock. Once a base case prototype had been benchmarked against measured utility bills, we performed parametric simulations in order to investigate the energy saving potentials of various conservation measures. The conservation measures considered include wall and ceiling insulation, exterior color of roof and walls, infiltration control, shading modifications (solar screens, reflective films), high COP airconditioning units, and energy efficient fluorescent lamps.

The energy saving potentials of conservation measures were analyzed in two stages of simple and combined parametric simulations. With simple parametric simulations, we studied the relative saving potential of each conservation measure with respect to the same base case. Upon the completion of the single parametric DOE-2 simulations, we performed some complementary simulations on a combination of promising energy conservation options (ECOs).

Normally, when conservation potentials in buildings are analyzed, a least-cost approach is taken to rank the measures and select the most promising measures first. The general idea is to first select those measures which have the shortest payback time (or the highest rate of return) on the conservation investment. In our analysis, we were unable to perform detailed economic analysis because of the lack of cost data for ECOs as related to the Pakistan market. Instead, we used engineering judgement in selecting and ranking the conservation measures, based mostly on the potential energy savings of the ECOs.

The following highlights the major conclusions of the report.

**Single-Family Detached House**

**Figures EX.2a&b** depict the impact of ECOs on cooling energy use for Karachi and heating energy use for Islamabad, respectively, for the prototypical single-family house. The cooling energy use is very sensitive to thermostat setting, air conditioning COP, roof and walls insulation, and roof color. The impacts of air change (infiltration), overhang length (distance from outside wall to the edge of the overhang furthest from the wall), and efficient lighting systems on air conditioning use are fairly low. Those measures that have the greatest impact on heating energy demand are roof and wall insulations (positive impact), roof color (negative impact), and control of infiltration (positive impact).

**Figures EX.3a&b** show the simulation results for a selected group of combined parametrics for Karachi and Islamabad houses. These parametrics include variation in wall and roof insulation, COP, and air infiltration. The highest relative savings are obtained by adding insulation to the

roofs and walls. The impact of roof insulation on reducing cooling and heating energy use is much higher than that of wall insulation. Our simulations indicate that **savings of the order of 50% in both heating and cooling energy use in Pakistani houses are easily achievable through the use of simple and available conservation measures. For cooling such measures would include appropriate thermostat setting and use of higher COP airconditioning units while savings in the heating energy use is possible by controlling infiltration. Better insulation of roof and walls would result in considerable savings in both heating and cooling energy use; on the other hand coloring the roof white would decrease the cooling load but increase the heating load.**

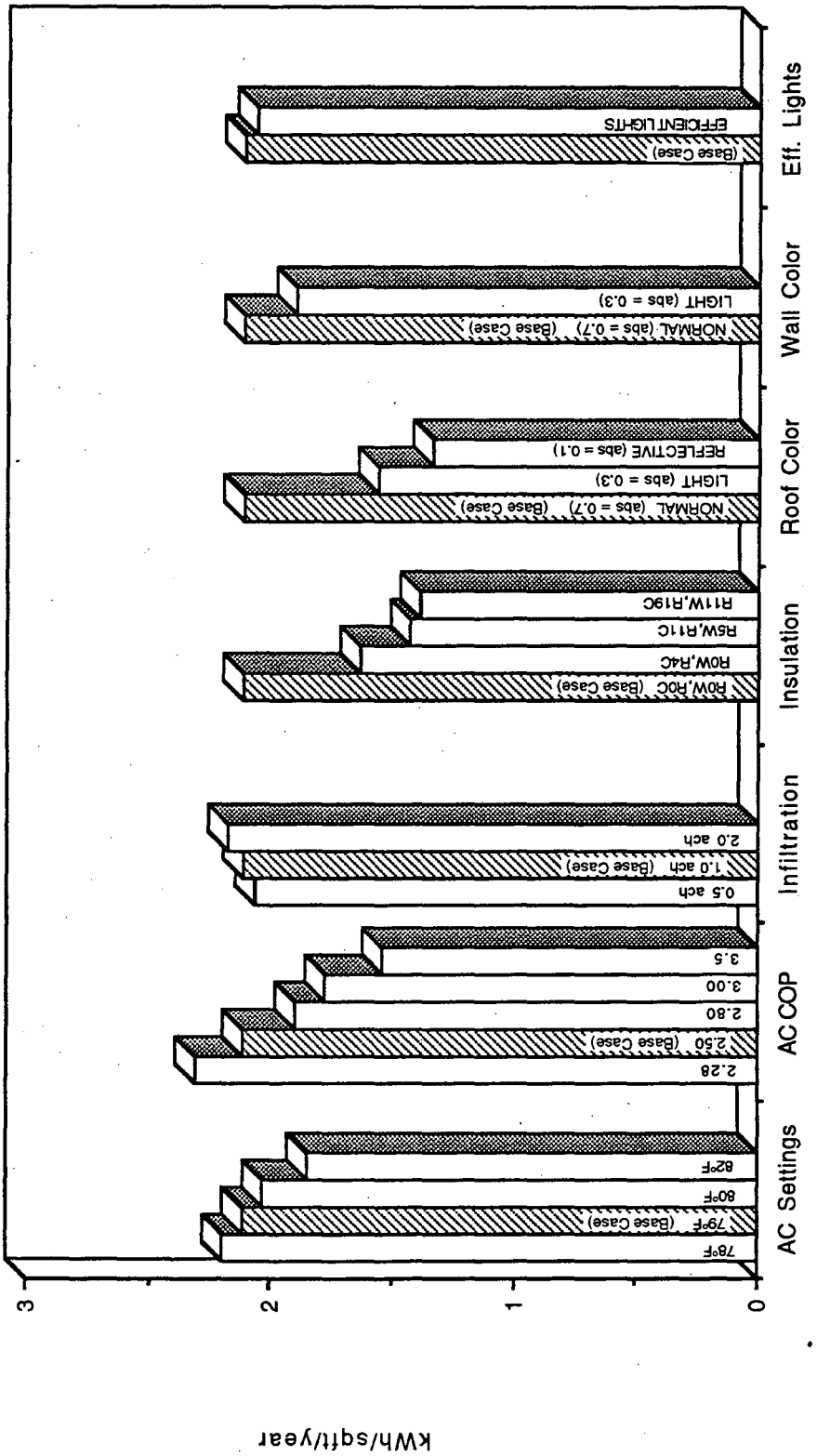



**Figure EX.2a. Simple Parametrics of Cooling Energy Use for a Prototypical Single-Family House in Karachi.**

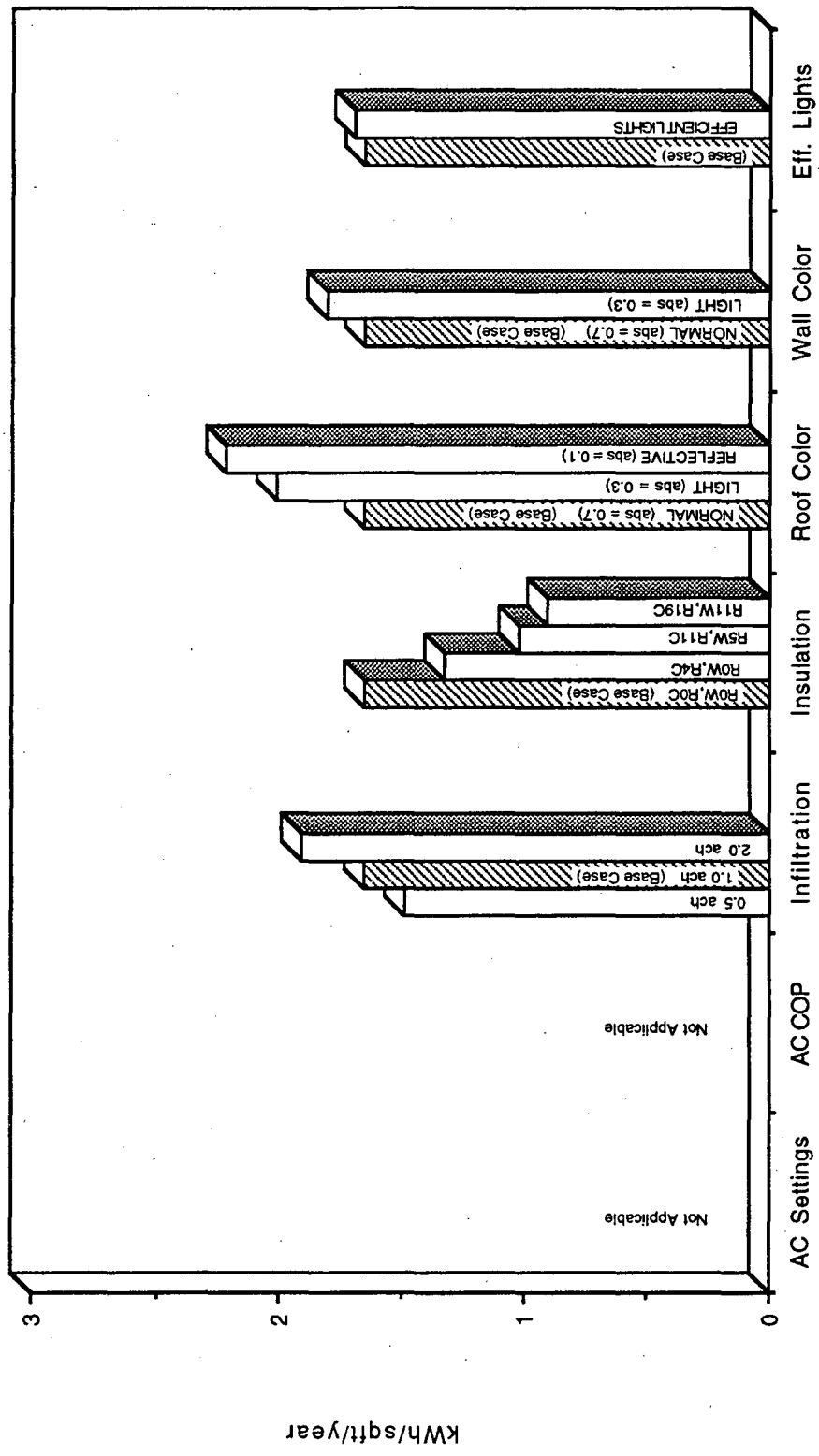
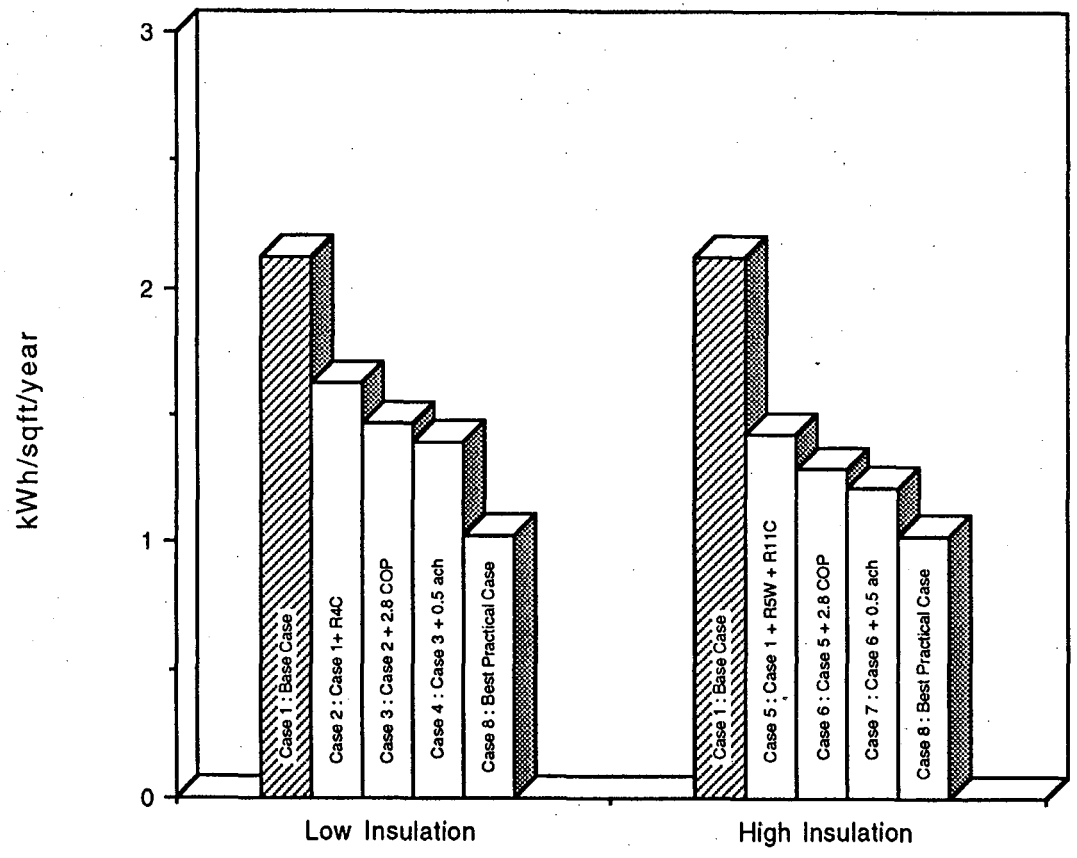


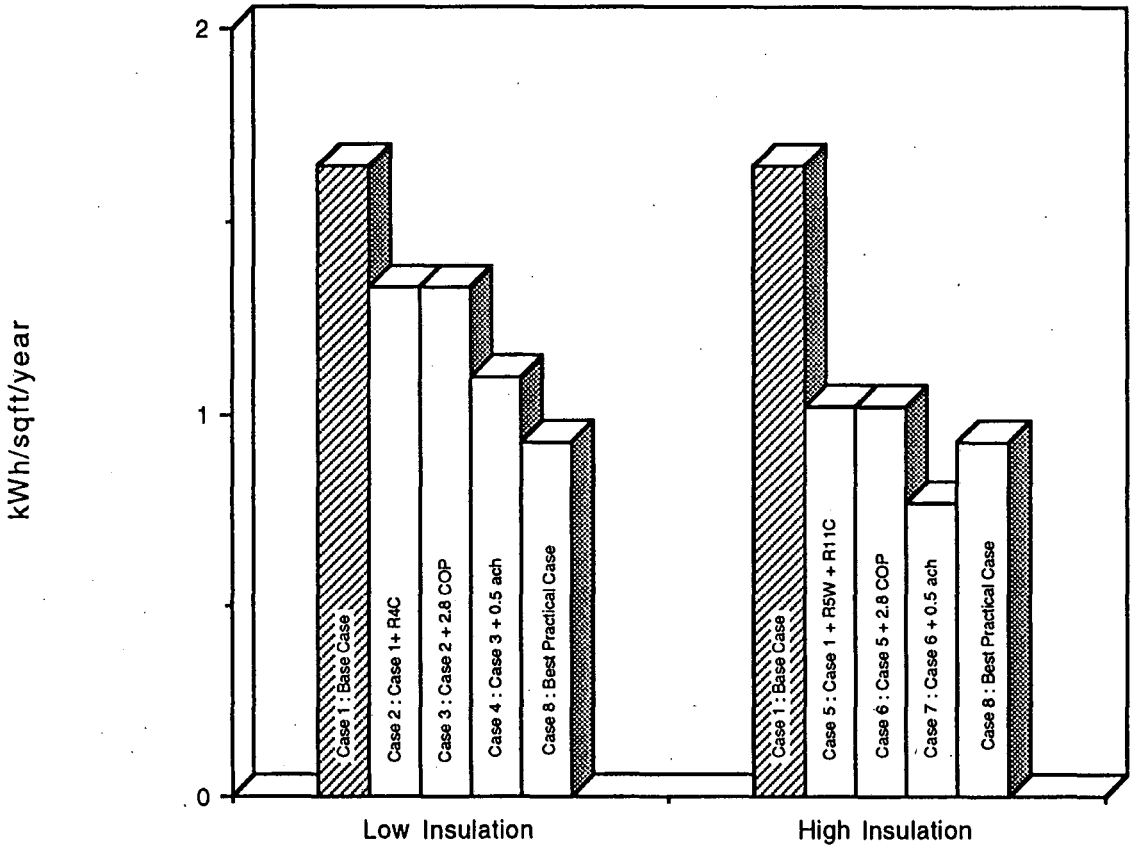

**Figure EX.2b. Simple Parametrics of Heating Energy Use for a Prototypical Single-Family House in Islamabad.**

**Figure EX.3a. Combined Parametrics of Cooling Energy Use for a Prototypical Single-Family House in Karachi.**




Best Practical Case: A/C temp 79F, A/C COP 3.0, 3-foot overhang, 0.5 ACH, roof colour absorptance 0.3, and for low insulation case R4 roof and for high insulation case R11 roof and R5 walls.

**Figure EX.3b. Combined Parametrics of Heating Energy Use for a Prototypical Single-Family House in Islamabad.**




Best Case: AC setting: 79F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Wall Colour: normal (0.7 absorbtance), Efficient Lighting: none, Insulation: R4 roof for low insulation case and R5 walls and R11 roof for high insulation case.

**Converted Office**

To a certain extend, the results of the parametric simulations for the converted office are comparable to those of the single-family houses. **Figures EX.4a&b** show some of the results of the simple parametric simulations for cooling energy use in Karachi and heating energy use in Islamabad. The cooling energy use is very sensitive to thermostat setting, air conditioning COP, infiltration, roof and walls insulation, and roof color. The impact of overhang length, and efficient lighting systems on air conditioning use is fairly low. Those measures that have the greatest impact on heating energy demand are roof and wall insulation (positive impact), roof color (negative impact), and control of infiltration (positive impact).

The combined parametrics include variation in walls and roof insulation, COP, and air infiltration. Based on these combined parametrics, we can identify ECOs for a "best practical case." **Figures EX.5a&b** show a selected group of combined parametrics for Karachi and Islamabad. As in the simple parametric simulations, the highest relative savings are still obtained by adding insulation on roofs and walls. The impact of roof insulation on reducing cooling energy use is much higher than that of wall insulation. Our DOE-2 simulations indicate that **the ECOs that would achieve savings of the order of 50% in both heating and cooling energy use in Single-Family Detached Houses can produce similar results in Converted Office Buildings.**

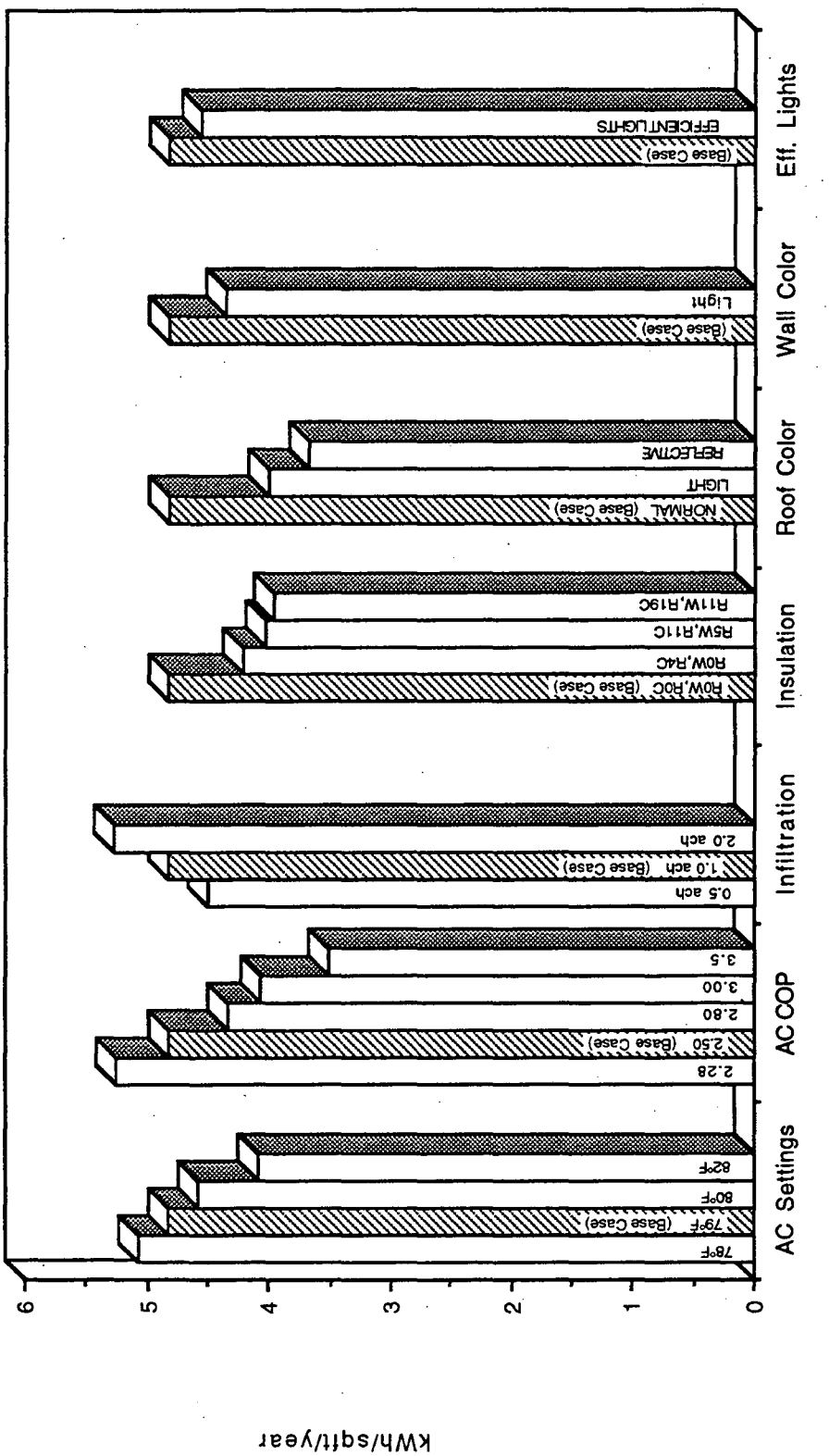



**Figure EX.4a. Simple Parametrics of Cooling Energy Use for a Prototypical Converted Office Building in Karachi.**

**Figure EX.4b. Simple Parametrics of Heating Energy Use for a Prototypical Converted Office Building in Islamabad.**

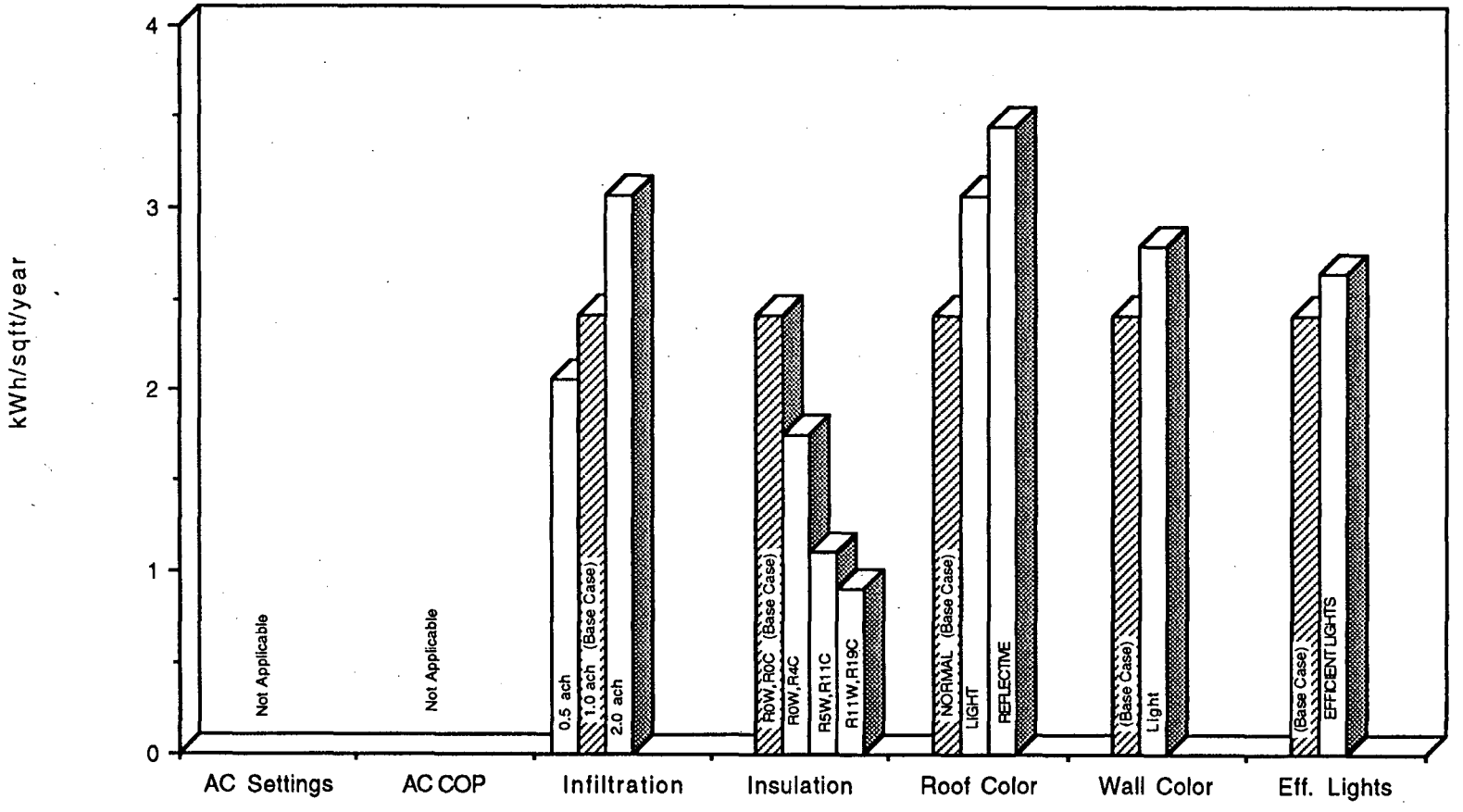
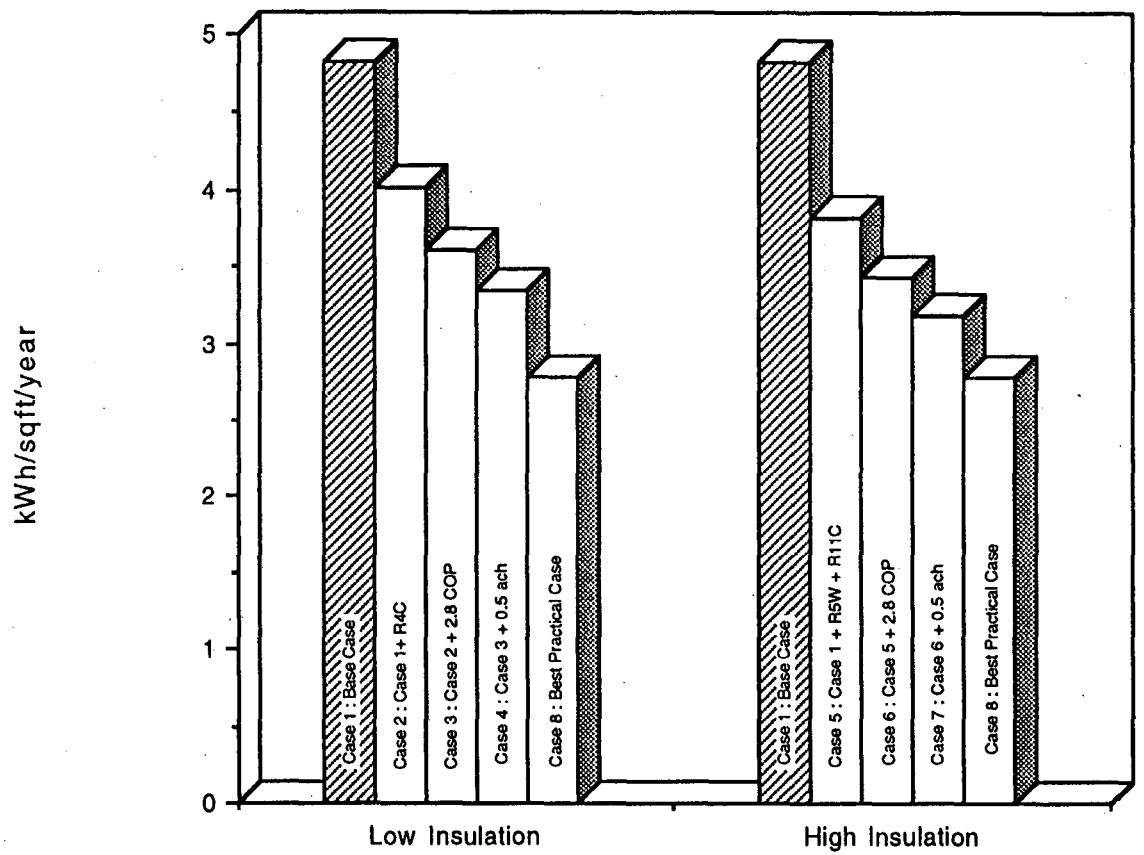
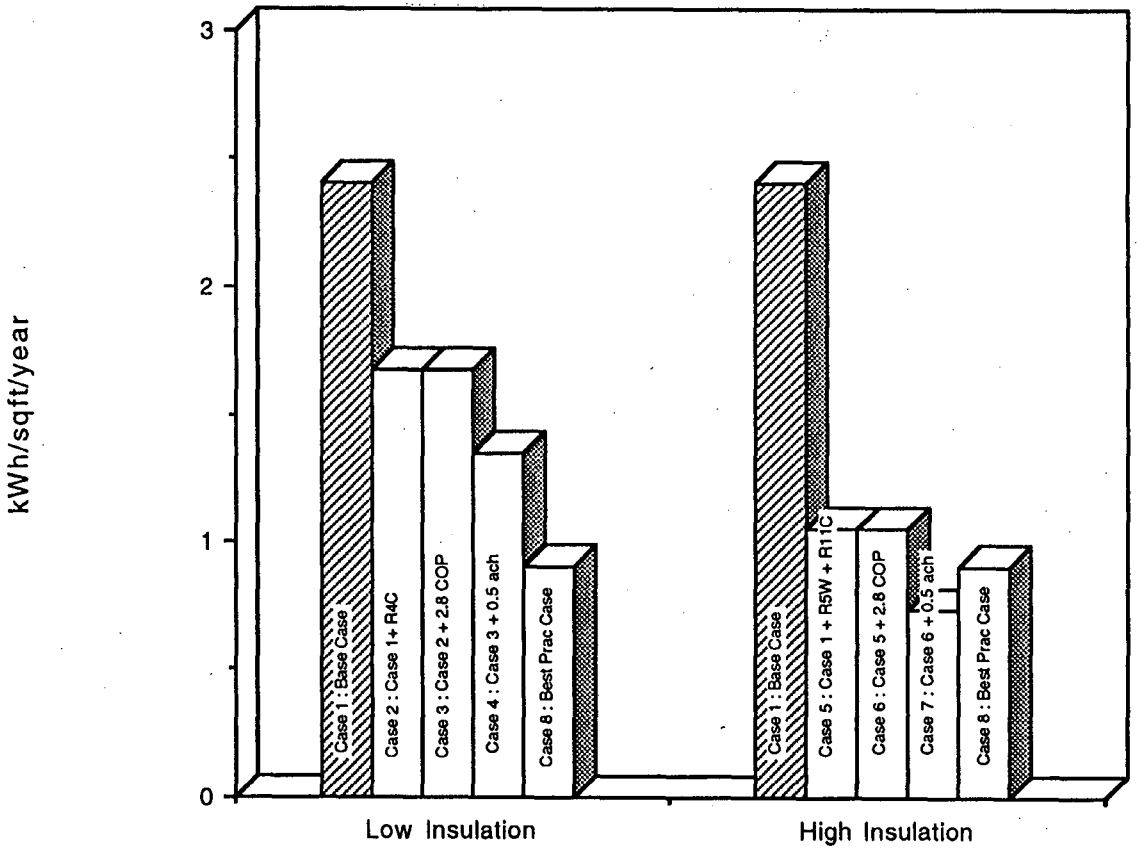


**Figure EX.5a. Combined Parametrics of Cooling Energy Use for a Prototypical Converted Office Building in Karachi.**




Best Practical Case: AC setting: 79F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ACH, Wall Colour: normal (0.7 absorbtance), Roof Colour: light (0.3 absorbtance), Insul: R4 roof for low case and R11 roof and R5 walls for high case

**Figure EX.5b. Combined Parametrics of Heating Energy Use for a Prototypical Converted Office Building in Islamabad.**




Best Practical Case: AC setting: 79F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ACH Wall Colour: normal (0.7 absorbtance), Roof Colour: light (0.3 absorbtance), Insulation: R4 roof for low case and R11 roof and R5 Walls for high case

## Office

We have performed approximately 10,000 simulations to analyze energy conservation potentials in Pakistani office buildings. **Figures EX.6a&b** show the simulated cooling and heating energy use for Karachi and Islamabad office buildings, respectively. The factors effecting the cooling energy use most are air condition COP, window film, roof and walls insulation, and roof color whereas the impact of overhang length, wall color, efficient lighting systems, day lighting, and infiltration is fairly low. For the heating energy demand, better roof and wall insulations and infiltration control has positive impacts whereas a white roof has a negative impact.

The combined parametrics for office buildings include variation in walls and roof insulation, roof color, air conditioning COP, and air infiltration. Selected combined parametric results are presented in **Figures EX.7a&b** for Karachi and Islamabad, respectively. Like single family houses and converted offices, the highest relative savings are obtained by adding insulation on roof and walls. The impact of roof insulation on reducing cooling energy use is much larger than that of wall insulations. Again, our simulations indicate that **savings of the order of 30 to 60% in both heating and cooling energy use in Pakistani Office Buildings are easily achievable by employing the same measures as those used in the case of Converted Offices and Single-Family Detached Houses.**

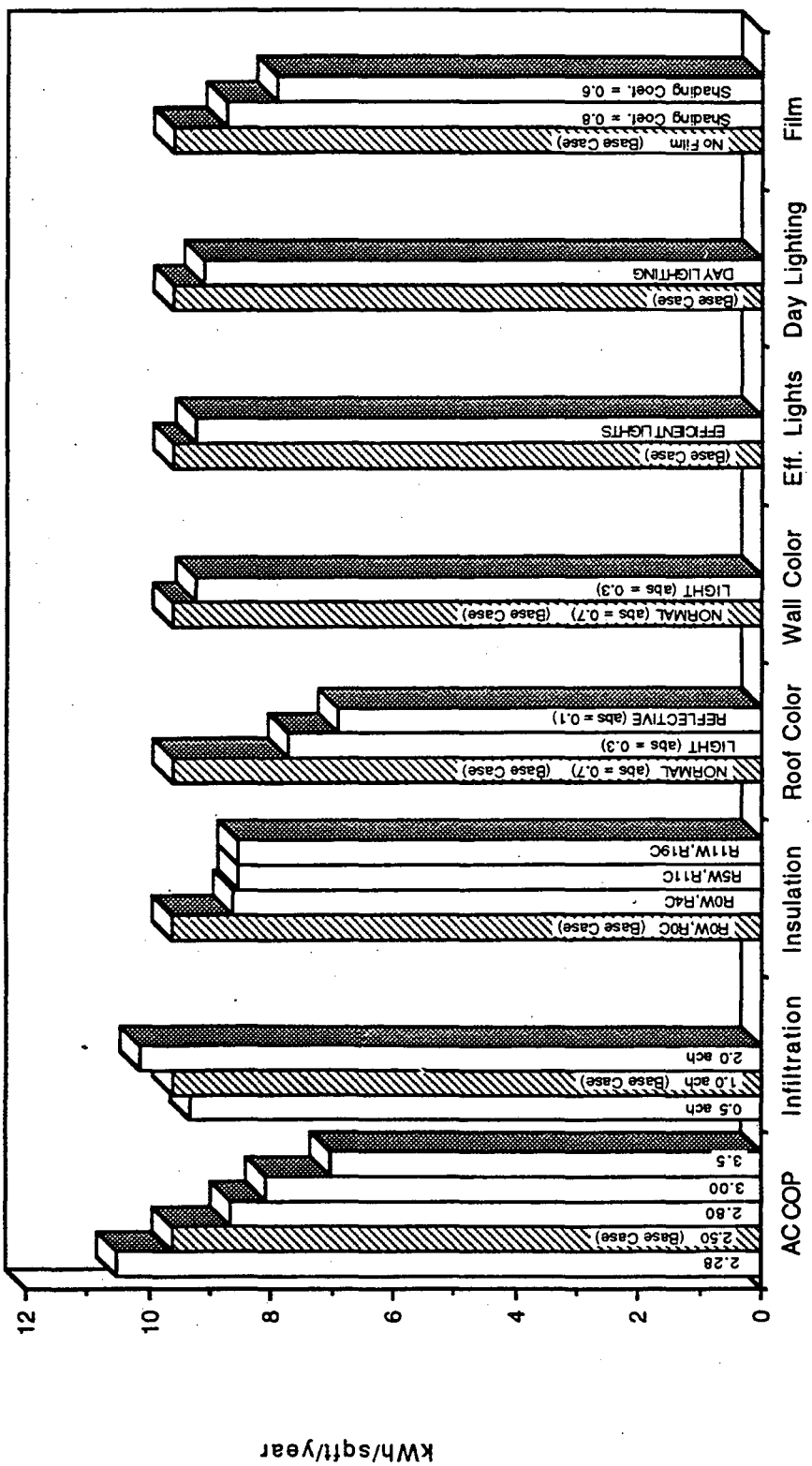



**Figure EX.6a. Simple Parametrics of Cooling Energy Use for a Prototypical Office Building in Karachi.**

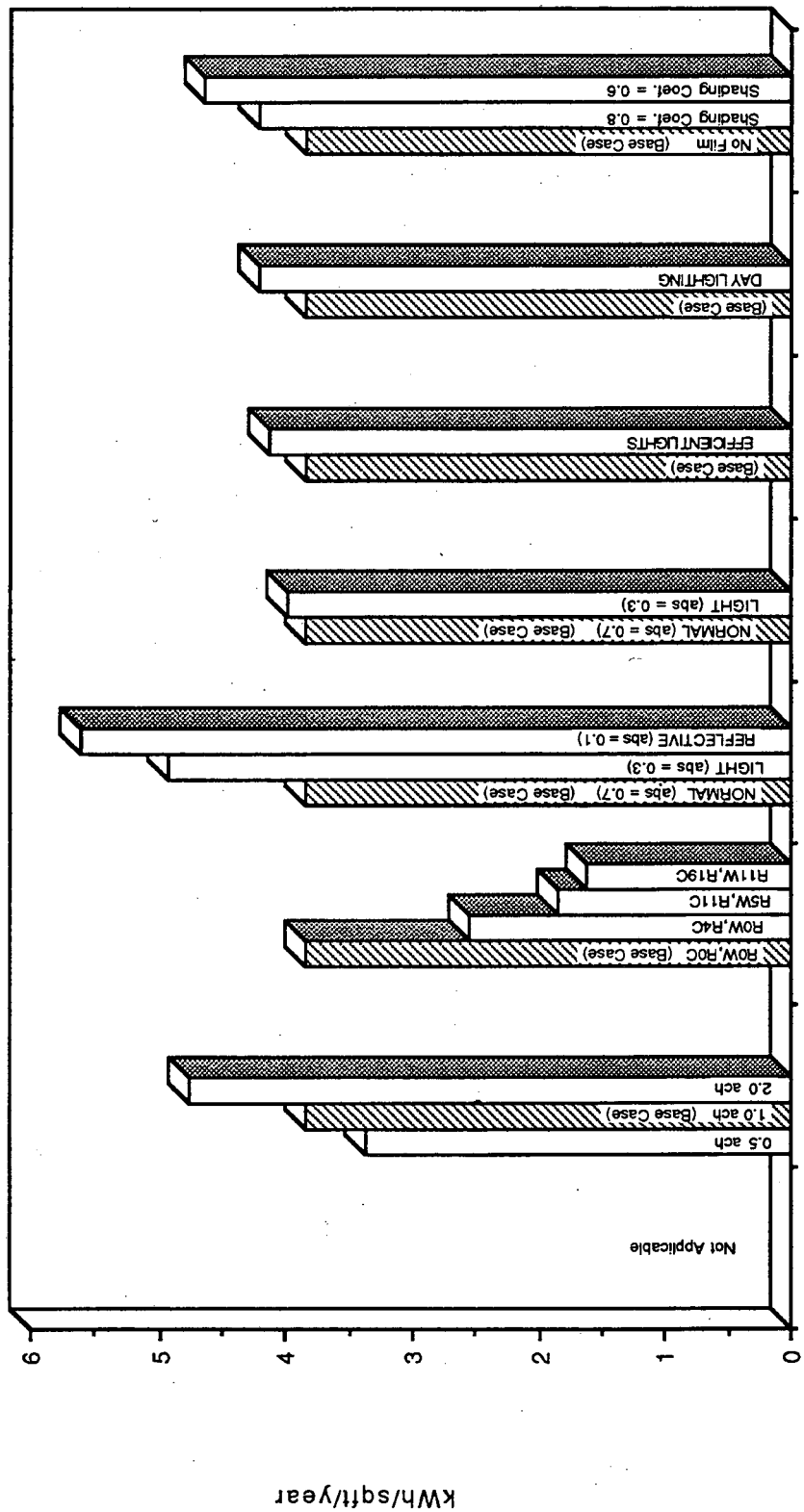
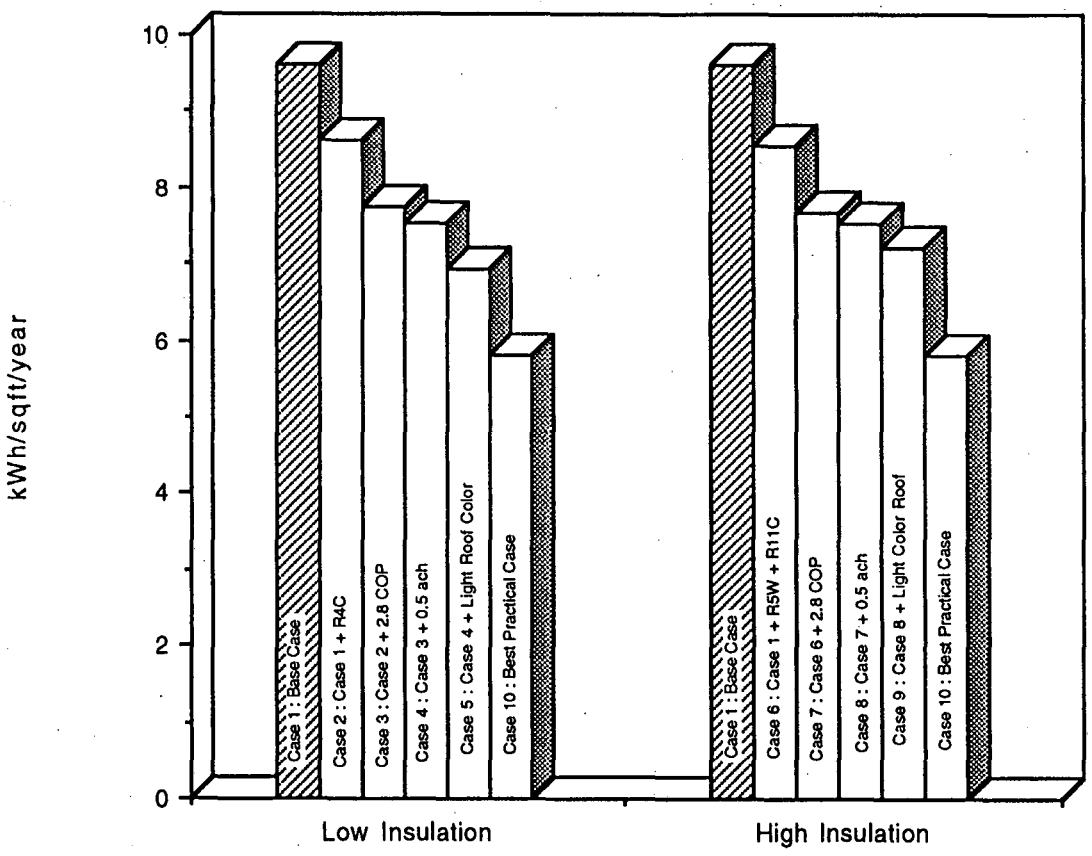


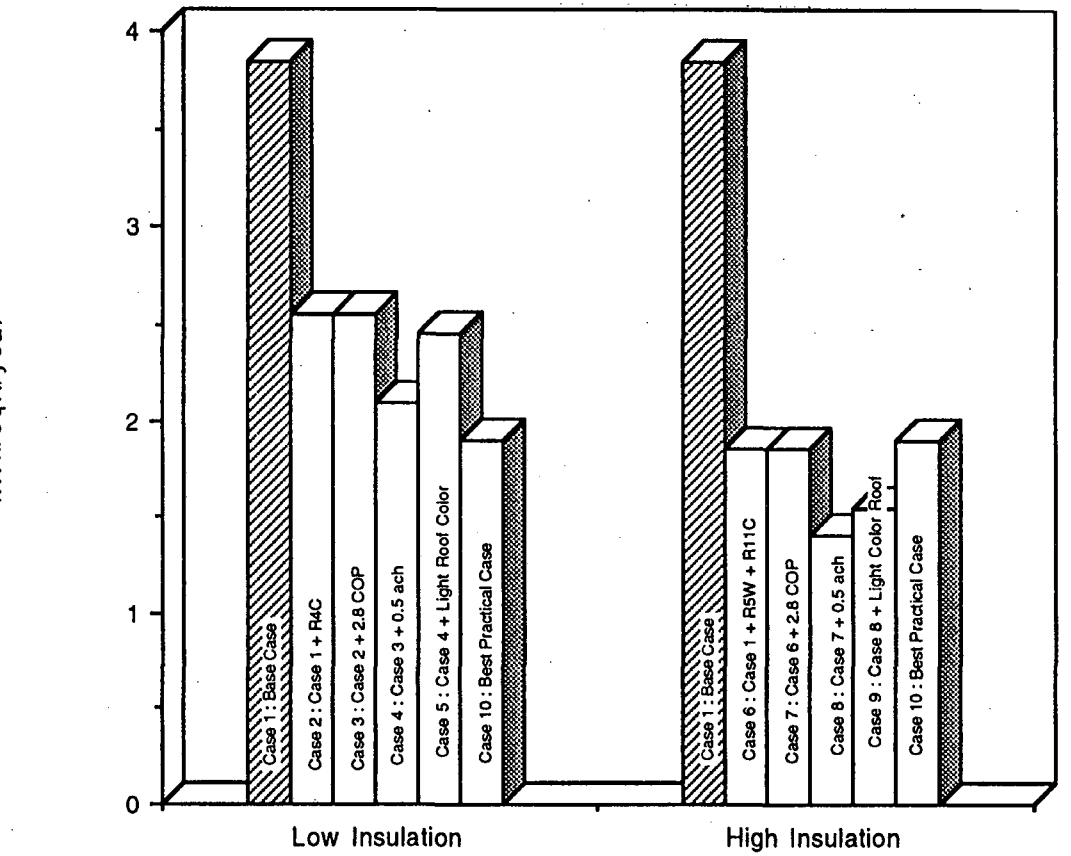

**Figure EX.6b. Simple Parametrics of Heating Energy Use for a Prototypical Office Building in Islamabad.**

**Figure EX.7a. Combined Parametrics of Cooling Energy Use for a Prototypical Office Building in Karachi.**




Best Practical Case: AC setting:79F, AC COP:3.0, Overhang:3ft, Infilt: 0.5 ACH, Wall Colour: normal (0.7 abs), Roof Colour: light (0.3 abs), Film Shading Coeff: 0.8, Insul: R4 roof for low case and R11 roof and R5 walls for high case

**Figure EX.7b. Combined Parametrics of Heating Energy Use for a Prototypical Office Building in Islamabad.**




Best Pracitcal Case: AC setting: 79F, AC COP, 3.0, Overhang: 3ft, Infilt:0.5 ACH, Wall Colour: normal (0.7 abs), Roof Colour: light (0.3 abs), Film Shading Coeff: 0.8, Insul: R4 Roof for low case and R11 roof and R5 walls for the high case

It should be noted that this report does not include any cost benefit analysis and it does not rank the ECOs in terms of return on investment. A detailed economic analysis involving the costs of certain measures, costs of available alternative energy sources (electricity, fuel etc. ), and purchase, installation, and maintenance costs of equipment should be done to prioritize these measures in Pakistan.

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*Chapter 1*

# Introduction, Purpose, and Overview

## Introduction

RCG/Hagler, Bailly, Inc. (RCG/HB) had contracted with the Lawrence Berkeley Laboratory (LBL) to assist them with the analyses of the energy conservation potential in residential and commercial (office) buildings in Pakistan. The proposed methodology included developing prototypical building descriptions for offices and residences and then performing DOE-2.1D simulations of these buildings in six climate regions represented by Karachi, Lahore, Islamabad, Multan, Peshawar, and Quetta.

The aim of the prototype development was to characterize the Pakistani building stock in terms of construction, heating, ventilation, and air-conditioning (HVAC) systems, as well as their operational conditions. Following this characterization, DOE-2.1D simulations were used to determine the base case heating and cooling energy use of typical Pakistani office and residential buildings. Further DOE-2.1D simulations were performed to evaluate the energy saving potentials of various energy conservation options (ECOs) in both residential and commercial buildings.

## Purpose

The purpose of this report is to:

1. summarize work performed in this area at LBL,
2. provide DOE-2.1D simulation results of the prototypical buildings,
3. discuss the impact of a series of energy conservation options (ECO) on energy use of the prototypical buildings, and
4. provide a database on DOE-2 parametrics simulations for follow-on research at Pakistan.

The DOE-2 simulation results provide a basis for energy efficient practices and options which can be incorporated in an upcoming course on energy efficient building design given by 2 LBL staff scientists to Pakistani researchers, architects and engineers.

The input data to the project consist of:

1. Two ENERCON reports: a 1987 survey of buildings and equipment (ENERCON 1987) and a proposed building energy code for Pakistan (ENERCON 1990),
2. Recently completed detailed surveys of buildings in Karachi, Islamabad, and Lahore, and
3. On-site visits to Karachi, Lahore, and Islamabad to inspect building conditions and building stock.

This report will focus on the development and discussion of simulation results for three prototypical buildings: a Single-Family Detached (SFD) house, a Converted Office (CO) from a single-family detached house, and an Office (O) building. Prototypes were developed for both individual offices (rooms) with window air conditioning units and large offices with central air conditioning units.

**Overview of the Report**

This report is composed of seven chapters. In Chapter 2, we will review the available data to characterize Pakistani prototypical buildings, which was simulated with DOE-2.1D to obtain their major end-use characteristics. Subsequently, a variety of parametric simulations were performed to determine the effectiveness of typical energy conservation options.

The prototype building descriptions were developed using the following sources: 1) a survey done by ENERCOM in 1987 that provided aggregate information on building and equipment characteristics for 43 buildings including houses, offices, and hotels; 2) a recent survey of 48 houses and offices in Karachi, Islamabad, and Lahore; and 3) on-site visits to several buildings by both LBL and RCG/HB staff in Pakistan. In addition to discussing these data sources, Chapter 2 will also describe the development of the survey forms used in the 1989 survey.

Hourly weather data is required for performing building energy simulations. We obtained weather data for six locations in Pakistan: Islamabad, Karachi, Lahore, Multan, Peshawar, and Quetta. Chapter 2 will present summary tables of this hourly weather data and discuss their highlights.

Chapter 3 will discuss our methodology for developing the prototypical buildings and defining their characteristics. This effort includes the description of the prototype buildings as well as the identification of energy conservation options for parametric simulations, and analysis of the DOE-2 results.

Chapters 4, 5, and 6 are similar chapters describing the prototypical analysis for the single-family detached house, the converted office, and the office building, respectively. Each chapter will discuss the main characteristics of the prototype in terms of floor plan, zones, construction, internal loads and schedules, and cooling and heating systems and their schedules. Following the prototype descriptions, each chapter will discuss the DOE-2 simulations in three sections corresponding to "basecase", "energy conservation options", and "parametric simulations." Each chapter concludes with a presentation and discussion of the DOE-2 parametric results.

*Chapter 2*

## Input Data

To estimate the energy use of any building, input information is needed on both the building characteristics and the local climate conditions. The input information for describing the prototypical building conditions were based on a 1987 survey of equipment and appliances in 43 buildings in Karachi and Lahore (ENERCON 1987) and a recent survey of 48 offices and houses in Karachi, Lahore, and Islamabad. These data were complemented by site visits to several buildings by both LBL and RCG/HB staff in Pakistan.

*Single-Family Detached Houses*

The input information available for developing the single-family detached prototype was limited to 1) aggregate building and equipment characteristics for 10 houses (ENERCON 1987) and 2) a survey of 28 houses in Karachi, Islamabad Lahore. Because of the limited size of the sample, one cannot claim that the resultant prototype descriptions and simulation results are statistically representative of all single-family houses in Pakistan. However we consider the prototypical single-family detached house in this report to be fairly representative of the newer, air-conditioned houses in Pakistan.

*Converted Offices*

The input information for developing the prototype of a converted office building came from the recent (1989) survey of six converted offices in Karachi and Lahore, and the ENERCON (1987) report on a survey of buildings and equipment. Although the sample of six buildings is very small to statistically determine the characteristics of the building stock of Pakistan in this category, there were substantial similarities between the six buildings in terms of layout, equipment requirements and use, lighting preferences etc. that justify such an effort. The data from the surveys of these six buildings was augmented with the data from the (ENERCON 1987) report to come up with a prototype model for office buildings converted from single family residences.

*Office Buildings*

The input information for developing the prototype of an office building came from the recent survey of 14 offices in Islamabad, Karachi, and Lahore, and the ENERCON (1987) report on buildings and equipment. Although the sample of 14 buildings is too small to statistically determine the characteristics of these type of buildings in Pakistan, there were significant similarities between the 14 buildings in terms of layout, equipment requirements and use, lighting preferences etc. that justified our development of prototypes based on such a small sample. The data from the surveys of these 14 buildings was augmented with the data from the (ENERCON 1987) report to develop prototype models for office buildings.

Once a prototypical building description was prepared, hourly weather data was used to simulate the energy consumption of the building, using a building energy simulation program such as DOE-2. The development of "typical" weather tapes is a fairly involved procedure based on historical data from many years or decades and the selection of monthly weather data, that have been judged most "typical" by a set of predefined criteria. Clarke (1985) provides prescriptions for developing "typical" weather tapes from historical data. Because of unavailability of long-term weather data, it was not possible within the limited scope of this project to develop such "typical" weather data. Instead, the analysis in this study was done using "actual" weather data for a single year (1986). Strictly speaking, therefore, the results from our building simulations are valid only for 1986. However we are confident that the conclusions of this study should be applicable to other years barring drastic changes in the regional climate.

In the following sections, we will discuss the ENERCON survey (1987), the recent 1989 surveys, and the weather data used in this project.

**1987 Building Survey**

In 1987, RCG/HB conducted a preliminary building energy survey to help ENERCON plan specific conservation programs. A total of 43 buildings in Karachi and Lahore were examined. (See **Table 2.1.**)

**Table 2.1. 1987 Survey Summary:**
**Sample Size by Building Type**

| Building Type | Karachi | Lahore |
|---|---|---|
| Single family detached residence | 4 | 6 |
| Single family flat | 4 | 2 |
| Low-rise commercial building | 9 | 6 |
| High-rise commercial building | 3 | 4 |
| Hotel - Unitary air conditioning | 2 | 1 |
| Hotel - Central air conditioning | 1 | 1 |

Source: ENERCON 1987.

We reviewed this data to extract building and equipment characteristics to complement our 1989 detailed building survey. The ENERCON (1987) report mainly documents the installed equipment and rated capacity found in the buildings. The report does not provide information on either the building characteristics or operation schedules. The type of information available

from the ENERCON report is outlined in **Table 2.2.**

**Table 2.2. 1987 Survey:**
**Building and Equipment Characteristics Information**

| | |
|---|---|
| Total sample size: | 43 commercial and residential buildings |
| Residential sample: | 16 single family residences |
| Office sample: | 22 high rise and low-rise offices |
| Air conditioning units: | Number of units and types |
| Electrical appliances: | Number of units, types, and range of rated capacities |
| Gas appliances: | Number of units, types, and range of rated capacities |
| Lighting: | Number of lights, types, and rated wattages |
| Energy conservation measures: | Number and types of energy conservation measures |

We used the building equipment information from this data base to characterize the installed equipment for the prototypical office and single-family house.

*Single-Family Detached Houses*

10 single-family detached residences (4 in Karachi, 6 in Lahore, see **Table 2.1**) were included in the survey. The information gathered is summarized in **Table 2.3.**

The following building equipment characteristics were incorporated in the prototype description for the single-family detached house.

- In the 10 houses, there were 22 window air conditioning units, and 5 evaporative coolers. In our prototype buildings, we have simulated window units to cool half of the space.
- The number of fans used in each house was quite high--14 ceiling and portable fans per house. This indicates that all rooms have at least one fan. The fans are assumed to run full time except in the sleeping quarters when airconditioners are running. Accordingly, we simulated our prototype building to take account of the effects of ventilative cooling on comfort conditions and to add the electrical consumption of the fans to that of the entire house.

**Table 2.3 1987 Survey:**
**Summary of Buildings and Equipment Characteristics for Residences**

| | |
|---|---|
| Total sample size: | 43 commercial and residential buildings |
| Residential sample: | 10 single family detached residences (4 in Karachi, 6 in Lahore) |
| Air conditioning units: | - 60% of the 43 buildings have window units.<br>- In the 10 residential buildings, there are 22 window units (1-2 tons; 5-10 kW), and 5 evaporative units. No other A/C units are used. |
| Electrical appliances: | In the 10 residential buildings, there are 140 fans (both ceiling and portable) (0.05-0.1 kW), 13 refrigerators (0.05-0.1 kW), 15 televisions (0.05-0.1 kW), 7 ovens (0.5-2 kW), and 7 irons (1.0-1.9 kW). |
| Gas appliances: | In the 10 residential buildings, there are 16 cookers (100-149 $ft^3$/hr), 9 geysers (10-20 $ft^3$/hr), and 9 heaters. |
| Lighting: | - Incandescent lights are preferred in dining rooms and living areas.<br>- Bulbs in living areas are 30% 50-60 watts, 70% 80-100 watts.<br>- Bulbs in dining areas are 100-200 watts. |
| Energy conservation measures: | Out of 10 buildings 2 have insulation and 8 have shaded A/C units. |

- Other electrical equipment included refrigerators and televisions. The survey indicated existence of electrical ovens in seven houses. Since the survey also indicated that all houses have gas cookers, we simulated the prototypes with gas cooking only.
- Lighting was mostly incandescent with an intensity of 50 - 200 watts in each room.
- Most houses in the survey did not report any significant energy conserving options. In fact, no conservation measures besides the shading of A/C units was reported.

*Converted Offices*

Out of the ENERCON (1987) survey of 43 buildings, 15 were low rise commercial buildings. Out of 15 low rise commercial buildings, 12 were low rise offices (7 in Karachi and 5 in Lahore), excluding a single low rise government building. Although, none of the buildings surveyed in 1987 was a 'converted' office, we used the characteristics and patterns for low rise office buildings to supplement the survey data from the more recent surveys of the 10 buildings.

The following building equipment and characteristics were noted in the 1987 survey.

- In the 12 low rise office buildings, 108 window air conditioning units and 21 split air-cooled systems were counted.
- Window units were dominantly in the 1 - 2 ton, 5 - 10 kW range.
- In these 12 buildings there were
  119 computers (0.2 - 0.3 kW) each,
  304 fans (0.05 - 0.1 kW) each,
  20 heaters (1 - 2 kW) each,
  15 refrigerators (0.05 - 0.1 kW),
  14 photocopiers (1 - 2 kW),
  37 typewriters (0.05 - 0.1 kW),
  19 water coolers (0.2 - 0.4 kW),
  8 telephone exchanges (0.1 - 0.2 kW).
- The gas appliances consisted of: 24 cookers(100 - 150 cft/hr), 8 heaters and 1 geyser (10 - 20 cft/hr).
- In the office areas of the 43 buildings, there were 21,314 fluorescent lights (mostly in the 40 - 50 Watt range) and 1,865 incandescent lights (50% in the 80 - 100 Watt range and 40% in the 100 - 200 Watt range).
- Significant energy conservation measures included: reflective film (10 out of 12 buildings), roof insulation (6 out of 12 buildings), shaded A/C (6 out of 12 buildings), and reflectors for fluorescent lamps (4 out of 12 buildings). In 4 out of the 12 buildings, incandescent lights were replaced with fluorescent lights.

*Office Buildings*

The 1987 survey did not distinguish between converted offices and regular offices.

**Current 1989 Survey**

As part of the activities of this project, LBL designed two DOE-2 data sheet forms for collecting data on residential and office buildings. Copies of these forms are reproduced in the Appendix A1. These data sheets were completed by local consultants for 48 houses and offices in Lahore, Karachi, and Islamabad. The forms were used to define the building characteristics and operational conditions for both the residential (single family or duplex buildings) and commercial (office) buildings. The highlights of these survey instruments are discussed below.

*Residential Form*

The residential form was designed in 23 pages and in three major parts: general information, building characteristics, and energy use.

Part I: General Information. This section gathered information on:

- name of building owner,
- building address,
- name of the auditor,
- building type (single family detached or duplex),
- number of floors,
- various areas of the building required for the analysis (total, conditioned, etc.),
- energy sources and historical energy use, and
- age of building.

For most buildings one year of monthly utility bills were collected.

Part II: Building Characteristics. This section asked for detailed information on building physical characteristics, equipment and appliances in the buildings, and the building operational characteristics and schedules. This part of the survey form asked specifically for the following:

- photographs of the building exterior and its surrounding,
- access to sunlight and breeze, including information on
  - density of nearby construction
  - adjacent buildings
  - other obstructions
- sketches of the building shape, dimensions, and orientation,
- interior and exterior lighting types, intensities, and schedules,
- building construction materials of
  - exterior walls
  - interior walls
  - roofs
  - windows
  - window shadings
  - doors
- mechanical systems,
  - heating system (type, fuel, capacity, and schedule)
  - cooling system (type, fuel, capacity, and schedule)
- domestic hot water,
- kitchen, washer/dryer, refrigerator, and other appliances, and
- occupancy and operational schedules of the building.

Part III: Energy Use. This part collected information on energy use changes of the residences over the last 10 years, changes in the building, addition of major appliances, and on energy conservation retrofits to the building. Information from this category allowed us to do a better characterization of the prototype buildings and their calibration with respect to utility bills.

*Commercial Form*

Since commercial buildings are much more complicated in terms of their design and operation, we devised a separate and thorough survey form for collecting information for these building categories. Building data for the commercial sector were collected in four parts: general information, building characteristics, energy use, and type of building ownership.

Part I: General Information. The information collected in this section included:

- name of building *(if any)*,
- address,
- name of building owner,
- name of building tenant,
- name of person interviewed including company and telephone number,
- name of auditor,
- building type,
- number of floors,
- floor(s) monitored (*if any*),
- monitored area of building (*if any*),
- energy sources and historical energy use, and
- age of building
    - year of the construction completion
    - major renovations or additions within last year.

For most buildings one year of monthly utility bills were collected.

Part II: Building Characteristics. This section asked for detailed information on building physical characteristics, equipment and appliances in the buildings, and the building operational characteristics and schedules. This part of the survey form asks specifically for the following:

- photos of entire building exterior, and the monitored area,
- access to sunlight and breeze, including information on
    - density of nearby construction
    - adjacent buildings
    - other obstructions
- sketches of the building shape, dimensions and orientation, including
    - general site and roof plan
    - monitored floors
- interior and exterior lighting types, intensities, control, and schedules,
- building constructions materials,
    - exterior walls
    - interior walls
    - roofs
    - windows
    - window shadings

doors
mechanical systems
heating systems (type, fuel, capacity, and schedule)
cooling systems (type, fuel, capacity, and schedule)
fan systems (air handling systems)
controls
domestic hot water,
type of DHW distribution and control system,
office equipment,
occupancy and operational schedules of the building, equipment, and systems.

Part III: Energy Use. This part collected information on energy use changes of the building over the last 10 years, changes in the building, addition of major equipment, and on energy conservation retrofits to the building. Information of this category allowed us to do a better characterization of the prototype buildings and their calibration with respect to utility bills.

Part IV: Type of Building Ownership. In this section, we were interested in the nature of the current ownership of the building, the size and type of organization that owns the building, and its experience with building energy conservation. We were also interested in the ownership of the building when it was constructed. This information can be very useful in understanding the energy consumption of the building.

*Single-Family Detached Houses*

The residential data sheets were completed for 5, 13 and 10 houses in Islamabad, Karachi, and Lahore, respectively. Appendix A3 shows an example of a completed data sheet for a two-story house.

We reviewed the completed data sheets for completeness and consistency. The building and schedule descriptions are outlined in **Table 2.4(a,b,c)** for Islamabad, Karachi, and Lahore. Besides differences in building size and fraction of air-conditioned area, most houses were inherently similar:

- they generally had two floors with the second story about half the size of the first;
- less than 50% of each house was usually air conditioned with a similar April to November schedule;
- gas space heaters were used in Islamabad and Lahore and there was no space heating in Karachi;
- the house constructions were fairly similar, all with concrete walls and roofs (some roofs are sloped) in Karachi, and brick walls and concrete roofs in Islamabad and Lahore;

- all windows were single pane and had some overhangs;
- cooking and water heating were done with gas;
- the electric appliances were fairly similar to those of the 1987 survey;
- standard incandescent lights in the range of 50-200 watts were used in all houses.

We incorporated these characteristics in the description of our prototypical house. House No. 50 in Karachi was used as the basis for the prototypical house.

*Converted Offices*

Out of the 20 office buildings surveyed recently, six were offices converted from single family residences. The characteristics of these six buildings are shown in **Table 2.5a** and **Table 2.5b**. Common characteristics of these buildings can be summarized as follows:

- they had two floors with the second story usually about half the size of the first;
- air conditioning was mainly done with window units;
- fluorescent lights were used in office areas (0.5 - 1 W/sqft);
- the constructions were fairly similar, all with concrete roofs, concrete walls in Karachi and brick walls in Lahore;
- all windows were single pane and had some overhangs, there was hardly any window operation;
- occupation schedules were very similar, with working hours roughly between 8 a.m. to 5 p.m. Sunday through Thursday.

*Office Buildings*

Out of the 20 office buildings surveyed, 14 were explicitly designed for use as offices. The characteristics of these 14 buildings are shown in **Tables 2.6(a,b,c)** and summarized as follows:

- most buildings had less than four floors (a majority of them had one or two floors); one had 9 and one 5;
- mainly window air conditioning units were used for cooling; only three buildings (two in Karachi, one in Islamabad) had central air conditioning;
- fluorescent lights were used in office areas (0.5 - 1.5 W/sqft, mostly ~1 W/sqft);
- the constructions were fairly similar, concrete walls in Karachi and brick walls in Islamabad and Lahore, concrete roofs in all three cities;
- all windows were single pane and had some overhangs, windows were not operated;
- occupancy schedules were very similar—the working hours were roughly between 8 a.m. to 5 p.m. Sunday through Thursday.

## Table 2.4a. Characteristics of Islamabad Residences Surveyed in 1989.

| House No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 80 (Islamabad) | 3105 (1491) | 2 | Elec/Gas | GroundFL:Drawing, Dining,Kitchen,2BR, Lounge,2 Bath, 1stFL: 2BR, Lounge,2 Bath. | Mostly incandescent | Brick | Sloped concrete | Clear, wood frame, (2.75-4.25ft) Overhangs. | 6WAC's (9 tons) 5 Rm.Gas 1 Elec. Radiative | Cooling Apr-Nov Heating Nov-Feb |
| 81 (Islamabad) | 1289 (495) | 1 | Elec/Gas | Drawing,Dining, Kitchen,3BR 3 Bath, Lounge. | Fluorescent and incandescent used together. | Brick | Flat, sloped concrete | Clear, steel frame, 2.75ft. Overhangs. | 3WAC's (4.5 tons) 2 Rm.Gas | Cooling Apr-Sep Heating Nov-Feb |
| 82 (Islamabad) | 2517 (1235) | 2 | Elec/Gas | GroundFL:Drawing, Dining,Kitchen, Lounge,1BR,1 Bath. 1stFL:3BR, Lounge, 3 Bath. | Incandescent | Brick, some exterior walls have stone facing | Flat, sloped concrete, air gap, tiles | Clear, mostly steel, frames, 2.13ft. Overhangs. | 5WAC's (8.5 tons) | N/A |
| 83 (Islamabad) | 4600 (4560) | 2+ Basement | Elec/Gas | GroundFL:Dining, Drawing,Kitchen, Lounge,3BR,3 Bath. 1stFL:4BR, 4 Bath, Lounge. | Fluorescent and incandescent used together. | Brick | Flat, sloped concrete | Clear, wood frame, 2.75 and 8.25ft. Overhangs. | 5WAC's (5.5 tons) 8 Rm.Gas 1 Elec. Res. | Cooling May-Sep Heating Nov-Feb |
| 84 (Islamabad) | 3919 (995) | 2 | Elec/Gas | GroundFL:Dining, Drawing,Kitchen, 3BR,Lounge,3 Bath. 1stFL:3BR, Kitchen,2 Lounges, 3 Bath. | Mostly incandescent | Brick, marble facing | Flat concrete | Clear some ground, steel frame, 2.5ft. Overhangs. | 4WAC's (7 tons) 2 Elec. Res. 9 Rm.Gas | Cooling Apr-Oct Heating Dec-Feb |

## Table 2.4b. Characteristics of Karachi Residences Surveyed in 1989.

| House No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Sched. |
|---|---|---|---|---|---|---|---|---|---|---|
| 50 (Karachi) | 3484 (1122) | 2 | Elec/Gas | Ground:2BR,Dining, Drawing,Kitchen, Lounge. 1stFL:2BR, Lounge. | Standard incandescent | Solid concrete | Flat and sloped concrete. | Clear, wood frame. Overhangs. | 5WAC's (7.5tons) | AC Apr-Nov |
| 51 (Karachi) | 2383 (852) | 2 | Elec/Gas | Ground:Dining, Drawing,Kitchen, 3BR,2 Bath. 1stFL:4BR, 3 Bath. | Standard incandescent | Solid concrete | Flat concrete | Clear, steel frame, (1-4.5ft). Overhangs. | 6WAC's (9.5 tons) | AC Mar-Nov |
| 52 (Karachi) | 3294 (3294) | 2 | Elec/Gas | Ground:4BR,Dining, Drawing,Kitchen, Lounge. | N/A | Solid concrete | Flat concrete | Clear, wood frame. Overhangs. | 2 central DX units (16 tons) | Apr-Nov |
| 53 (Karachi) | 6622 (5678) | 1 | Elec/Gas | Main Bldg:Dining, Drawing,Kitchen, Familyroom, 4 Bath,5BR. Guest House: Drawing,Dining, 2BR,2 Bath, Kitchen. Servant House: 5BR,Bath. | Fluorescent and incandescent mixed. | Solid concrete | Sloped concrete | Tinted, wood frame, (1.5-6ft). Overhangs. | 1 central unit (25 tons) | AC Jan-Dec |
| 55 (Karachi) | 4512 (2550) | 2 | Elec. | Ground:Drawing, Dining,Kitchen, 3 extra rooms, Bath. 1stFl: 5BR,2 Bath. | Mostly incandescent, some fluorescent. | Solid concrete | Flat concrete | Clear, aluminum frame, 2ft. Overhangs. | 6WAC's (9 tons) | AC Mar-Nov |

## Table 2.4b. Characteristics of Karachi Residences Surveyed in 1989. (cont.)

| House No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 56 (Karachi) | 2003 (1198) | 1 | Elec/Gas | N/A | Fluorescent and incandescent used together. | Solid concrete | Flat concrete | Tinted, wood frame, (1.5-3ft). Overhangs. | 6WAC's (9.5 tons) | AC Mar-Nov |
| 57 (Karachi) | 6716 (4314) | 2 | Elec/Gas | N/A | Incandescent in living areas. | Solid concrete | Flat sloped concrete | Tinted, wood frame, 2ft. Overhangs. | 9WAC's (13.5 tons) 4 Split Systems (11 tons) | AC Mar-Nov |
| 60 (Karachi) | 4023 (2212) | 2 | Elec. | Ground:Drawing, Dining,Kitchen Lounge,GuestBR, Hobby Room, Bath. 1stFloor: 4BR,Lounge, 4 Bath. | Incandescent | Concrete (Hollow core) | Flat concrete | Tinted, aluminum frame, (2-4ft). Overhangs. | 9WAC's (14 tons) 2 Elec. Res. | AC Mar-Nov Heating Dec-Jan |
| 61 (Karachi) | 3941 (N/A) | 2 | Elec. | Ground:Drawing, Dining,Kitchen, 3 Rooms. 1stFloor:3BR, 3 Bath. | Incandescent | Solid Concrete | Flat concrete | Clear, wood frame, (2-4ft). Overhangs. | 6WAC's (9.5 tons) | AC Mar-Nov |
| 62 (Karachi) | 5650 (4007) | 2 | Elec/Gas | Very peculiar layout | Mostly incandescent, some 1x4 fluorescent. | Solid concrete | Flat and sloped concrete | Clear, wood/alum. frame. Overhangs and some grill. | 12WAC's (15.5 tons) | AC Apr-Nov |

**Table 2.4b. Characteristics of Karachi Residences Surveyed in 1989. (cont.)**

| House No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 63 (Karachi) | 2950 (1461) | 2 | Elec/Gas | Ground:2BR, Dining,Drawing, Kitchen,Lounge, 1stFloor:2BR, Lounge. | Standard incandescent | Concrete (Hollow core) | Flat concrete | Tinted, wood frame, horiz., sliding. Overhangs. | 2 split systems and WAC's (8.2 tons) | AC Apr-Nov |
| 64 (Karachi) | 4654 (3381) | 2 | Elec/Gas | Ground:2BR, Dining,Drawing, Kitchen. 1stFloor:4BR, 3 living spaces, kitchen. | Stardard incandescent | Solid concrete | Flat and sloped concrete | Clear, wood/alum., steel frame. Overhangs grill. | 11WAC's (17 tons) | |
| 65 (Karachi) | 2700 (965) | 1 | Elec/Gas | 3BR,Dining, Drawing,Kitchen, Study,3 Bath. | Incandescent | Solid concrete | Flat Concrete | Clear, wood frame, mostly 2ft. Overhangs. | 4WAC's (5.8tons) | AC Feb-Mar |

## Table 2.4c. Characteristics of Lahore Residences Surveyed in 1989

| House No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 70 (Lahore) | 3562 (3065) | 1 | Elec/Gas | Dining,Drawing 4BR,Kitchen, 4 Bath. | Incandescent | Brick | Flat concrete | Clear, steel/wood framing, (2-2.5ft). Overhangs. | 3WAC's (4 tons) 2 Elec. Resis. 3 Rm.Gas 1 Elec. Radiative | Cooling June-Oct Heating Dec-Jan |
| 71 (Lahore) | 2794 (1906) | 2 | Elec/Gas | Ground:Drawing, Dining,Lounge, 1BR,Kitchen, Servant Room, 2 Bath. 1stFL:N/A | Incandescent | Brick | Sloped concrete | Clear, wood frame, (1-5ft). Overhangs. | 4WAC's (6.5 tons) 2 Elec.Res. 2 Rm. Gas 1 Elec. Radiative | Cooling May-Oct Heating Dec-Jan |
| 72 (Lahore) | 2816 (1330) | 2 | Elec. | Ground:Dining, Drawing, Kitchen,2BR, 2 Bath. 1stFL:3BR, 3 Bath, Lounge. | Fluorescent and incandescent mixed. | Brick | Flat concrete | Clear, steel frame. | 6WAC's (9.5 tons) 1 Rm Gas | Cooling Apr-Sep Heating Dec-Feb |
| 73 (Lahore) | 6065 (5023) | 2 | Elec/Gas | N/A | Incandescent | Brick | Flat and sloped concrete, insulation, tiles | Reflective, wood frame, (3-3.5ft). Overhangs. | 1 Central System (10 tons) 4WAC's (4 tons) 6 Rm.Gas | Cooling Mar-Oct Heating Dec-Jan |
| 74 (Lahore) | 2481 (926) | 2 | Elec/Gas | Ground:4BR, Dining,Drawing, Kitchen,3 Bath. 1stFL:2BR, 2 Bath,1 com-mon space. | Fluorescent and incandescent used together. | Brick | Flat concrete, earthfill, tiles. | Clear, steel frame 2ft. Overhangs. | 4WAC'S (6.5 tons) 4 Rm. Gas | Cooling Apr-Sep Heating Dec-Jan |

## Table 2.4c. (contd.)

| House No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 75 (Lahore) | 3061 (1306) | 2 | Elec/Gas | Ground:Drawing, Dining,Lounge, Kitchen,2BR, 2 Bath. 1stFL:3BR, 2 Bath, 1 common rm. | Fluorescent and incandescent used together. | Brick | Flat concrete | Clear, steel/wood frame, (3-5ft). Overhangs. | 6WAC's (9 tons) 3 Rm.Gas | Cooling Apr-Oct Heating Dec-Jan |
| 76 (Lahore) | 2460 (1808) | 1 | Elec/Gas | Drawing, Dining, Kitchen, 5BR,3 Bath. | Mostly incandescent | Brick, exterior walls with air gap of 1½"west side,dark color,east side light color. | Flat concrete, false ceiling, mud fill. | Clear, steel casing, (1.5-6ft). Overhangs. | 2WAC's (3 tons) 1 Elec.Res. 1 Rm.Gas | Cooling Apr-Sep Heating Dec-Feb |
| 77 (Lahore) | 4200 (3205) | 1 | Elec/Gas | Drawing, Dining, Kitchen,2 Lounges, 4BR,5 Bath. | Mostly incandescent | Cavity exterior walls (Brick) | Flat, concrete, earthfill, tiles. | Tinted, wood frame, (1ft & 8ft). Overhangs. | 9WAC's (11.5 tons) 5 Rm.Gas | Cooling Apr-Oct Heating Dec-Jan |
| 78 (Lahore) | 3024 (2680) | 1 | Elec/Gas | Drawing,Dining, Kitchen,4BR, 4 Bath, 1 Lounge. | In some rooms, fluorescent, in some rooms incandescent lights are used. | Brick | Flat concrete | Film is used in living sections, wood frame, (2-18ft). Overhangs. | 1 Central (10 tons) 6WAC's (10 tons) 5 Rm.Gas | Cooling Apr-Sep Heating Dec-Jan |
| 79 (Lahore) | 3203 (1233) | 2 | Elec/Gas | Ground:Dining, Drawing,Kitchen, 3BR,Lounge, 3 Bath. 1stFL:Lounge, 2BR,3 Bath. | Mostly incandescent, some fluorescent. | Brick | Flat concrete earthfill, tiles | Clear, wood frame, 3ft. Overhangs. | 4WAC's (6 tons) 2 Elec.Res. 1 Rm.Gas | Cooling Mar-Oct Heating Dec-Feb |

## Table 2.5a. Characteristics of Karachi Converted Office Buildings Surveyed in 1989

| Building No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 (Karachi) | 2160 (1693) | 2 | Elec. | Conversion | Fluorescent in offices, incandescent in common spaces. | Solid concrete | Flat concrete | Mostly gound wood frame and casing | 5WAC's (8.5 tons) | |
| 12 (Karachi) | 4900 (3326) | 2 | Elec. | Conversion | Fluorescent lamps | Solid concrete | Flat concrete | Clear, wood frame casing | 12WAC's (20 tons) | |
| 17 (Karachi) | 1800 (1389) | 2 | Elec/Gas | Conversion | Fluorescent in offices, incandescent in common spaces. | Solid concrete | Flat concrete | Ground wood frame casing | 4WAC's (7.4 tons) | |

## Table 2.5b. Characteristics of Lahore Converted Office Buildings Surveyed in 1989

| Building No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 22 (Lahore) | 3521 (2433) | 2 | Elec/Gas | Detached. Resembles a conversion. | Incandescent and fluorescent mixed in the offices. | Brick | Flat concrete. Tilted concrete and tile. | Clear, wood frame, (½-2ft). Overhangs. | 9WAC's (13.5 tons) 3 Elec.Res. Heaters 6 Rm.Gas Heaters | |
| 23 (Lahore) | 1996 (1182) (ALL) | 2 | Elec/Gas | Conversion | Fluorescent, and incandescent mixed. 1watt/sq.ft. | Brick | Flat concrete | Clear, steel frame, (1-4ft). Overhangs. | 6WAC's (10.5 tons) 3 Elec.Res. 4 Rm.Gas | Cooling Apr-Sep Heating Dec-Feb |
| 24 (Lahore) | 2450 (1780) | 2+ Basement | Elec/Gas | Detached. Resembles a conversion. | Fluorescent and incandescent used together. | Brick | Flat concrete | Clear, wood frame, 1.5ft. Overhangs. | 6WAC's (9.4 tons) 1 Elec.Res. Heaters 6 Rm.Gas Heaters | Cooling Apr-Oct Heating Dec-Jan |

## Table 2.6a. Characteristics of Islamabad Office Buildings Surveyed in 1989

| Building No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 (Islamabad) | 15284 (8691) | 2 | Elec. | Standalone. Regular office bldg. | Fluorescent 1.15watts/sq.ft. | Brick | Flat concrete | Clear, alum. frame, 2.5ft. Overhangs. | 4WAC's (7.4 tons) 2 Central systems (60 tons) 2 Elec.Res. | Cooling May-Sep Heating Nov-Mar |
| 31 (Islamabad) | 7462 (3120) | 1 | Elec/Gas | Standalone. Consists of two independent structures. Regular. | Mostly fluorescent 0.6 watts/sq.ft | Brick | Flat concrete | Clear, steel frame, 2.75ft. Overhangs. | 1 Central system (7.4 tons) 1 Fan Coil. | Cooling Apr-Oct Heating Dec-Mar |
| 32 (Islamabad) | 4402 (3553) | 2 | Elec/Gas | Attached on two opposite sides. | Fluorescent and incandescent mixed | Brick | Flat concrete | Clear, steel frame, (1-2.5ft). Overhangs. | 6WAC's (10.5 tons) 1 Elec.Res. 4 Rm.Gas | Cooling May-Sep Heating Nov-Feb |
| 33 (Islamabad) | 2829 (2391) | 2 | Elec/Gas | Standalone. Regular office bldg. | Mostly fluorescent 1.5watts/sq.ft. | Brick | Concrete, false ceiling | Clear, steel frame, 3.25ft. Overhangs. | 6WAC's (17 tons) 5 Rm.Gas | Cooling May-Sep Heating Nov-Feb |

## Table 2.6b. Characteristics of Karachi Office Buildings Surveyed in 1989

| Building No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 (Kararchi) | 3200 (3200) | 5 | Elec. | Attached on two opposite sides | Fluorescent in offices. 1watt/sq.ft | Solid concrete | Flat concrete | Clear, alum. frame, 3ft. Overhangs. | Central system (15 tons) | Cooling Jan-Dec |
| 13 (Karachi) | 1432 (801) | 1 | Elec. | Semi detached. Irregular layout. | Fluorescent in offices. 0.8watts/sq.ft. | Solid concrete | Flat concrete | Clear, alum. frame | 5WAC's (8 tons) | Cooling Feb-Nov |
| 14 (Karachi) | 2366 (1890) | 1 | Elec. | Semi detached. Regular layout. | Fluorescent in offices. 0.5watts/sq.ft. | Solid concrete | Sloped asbestos sheet, styropore | Clear, steel frame, 3ft. Overhangs. | 10WAC's (10 tons) | Cooling Mar-Nov |
| 15 (Karachi) | 6911 (6200) | 9 | Elec. | | Fluorescent 1.5watts/sq.ft. | Solid concrete | Flat concrete | Clear, alum. frame, 4ft. Overhangs. | Central system (19 tons) | Cooling Mar-Nov |
| 16 (Karachi) | 2200 (1444) | 4 | Elec. | Attached on two opposite sides. | Fluorescent in offices 0.8 watts/sq.ft. | Solid concrete | Flat concrete | Clear, alum. frame, 1.5ft. Overhangs. | 4WAC's (6.5 tons) | Cooling Mar-Nov |

**Table 2.6b. (contd.)**

| Building No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 18 (Karachi) | 2234 (955) | 4 | Elec. | Attached on one side, each floor has two units which were probably built as residences. | Mostly incandescent 0.8 watts/sq.ft. | Solid concrete | Flat concrete | Clear, wood frame, 2ft. Overhangs. | 6WAC's (9 tons) | Cooling Mar-Nov |
| 19 (Karachi) | 3203 (2989) | 3 | Elec. | Standalone. Regular office bldg. | Mostly incandescent 1.5 watts/sq.ft. in office areas. | Solid concrete | Flat concrete | Clear, alum/wood frame, (1.25-1.50ft). Overhangs. | 7WAC's (16.5 tons) | Cooling Mar-Nov |

## Table 2.6c. Characteristics of Lahore Office Buildings Surveyed in 1989

| Building No. | Area (A/C Area) | No. of Floors | Energy Sources | Plan Characteristics | Lighting Characteristics | Wall Construction | Roof Construction | Windows | Equipment | Schedules |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 (Lahore) | 2535 (2436) (ALL) | 2 | Elec. | Not an office, it is like a small manufacturing shop. | Fluorescent in offices 1watt/sq.ft. | Brick | Flat concrete | Clear, wood frame. Few overhangs. | 3WAC's (4.5 tons) | Cooling May-Sep |
| 21 (Lahore) | 2363 (1929) (ALL) | 1 | Elec/Gas | Detached. Highly irregular, high exterior wall to area ratio. | Fluorescent 0.9watts/sq.ft. | Brick | Flat concrete | Tinted/ clear, wood/ alum/steel frame, (2-3ft). Overhangs. | 8WAC's (14.5 tons) 6 Elec.Res. 1 Rm.Gas 1 Elec. Radiative | Cooling Apr-Oct Heating Dec-Feb |
| 25 (Lahore) | 2435 (2007) (Top Floor) | 2+ Basement | Elec/Gas | Standalone. Regular office building. | Fluorescent 1watt/sq.ft. | Concrete | Flat concrete | Clear, wood frame, 8". Overhangs. | 6WAC's (8 tons) 8 Elec.Res. Heaters | Cooling Apr-Dec Heating Dec-Feb |

**Weather Data**

Hourly weather data is crucial to an accurate simulation of building heating and cooling energy loads. The DOE-2 building energy simulation code is an hourly program that calculates the heating and cooling energy of a building based on the building's description, building operational schedules, and hourly weather data including insulation.

The required hourly weather data include:

dry-bulb temperature
wet-bulb temperature *or* humidity ratio and air enthalpy
wind speed
total solar radiation *or* amount of cloud cover
direct solar radiation cloud type
atmospheric pressure
air density
air enthalpy
monthly clearness number (optional)
monthly ground temperature (optional).

The above climate parameters are not all mutually independent, i.e. some can be calculated from the others. For instance, humidity ratio and air enthalpy can be calculated from the dry-bulb, wet-bulb temperature, at a given atmospheric pressure. Also, some data, such as direct and indirect solar, are not recorded at all weather stations. Using empirical equations, DOE-2 can estimate the direct and indirect solar radiation based on a weather station's latitude and reported cloud cover. The accuracy of the DOE-2 empirical equations for estimating the **indirect** solar radiation in humid climates is unknown. Extensive measured data are required to develop more accurate empirical equations for estimating indirect solar radiation.

We received hourly data for six locations in Pakistan for the year 1986 : Islamabad, Karachi, Lahore, Multan, Peshawar, and Quetta. These locations are indicated on the map of Pakistan ( **Figure 2.1**). The hourly data included:

dry-bulb temperature
wet-bulb temperature
wind speed
atmospheric pressure
amount of cloud cover
cloud type

In addition, the data also included monthly ground temperatures, but the same clearness number was used for all months. We ran the DOE-2 weather utility program to estimate other weather variables.

Before generating a complete DOE-2 weather file, we plotted the raw data for a quick inspection of errors. Two types of errors where detected:

1. Out of range variables: Some temperature and wind data for a given hour were totally out of range of their adjacent hours. We interpreted these data as errors and replaced them with the average of the adjacent hours.
2. Wind speeds: We noticed that very little wind speeds were recorded for nonworking hours (Hours 0-8 and 18-24) (see **Table 2.7**).

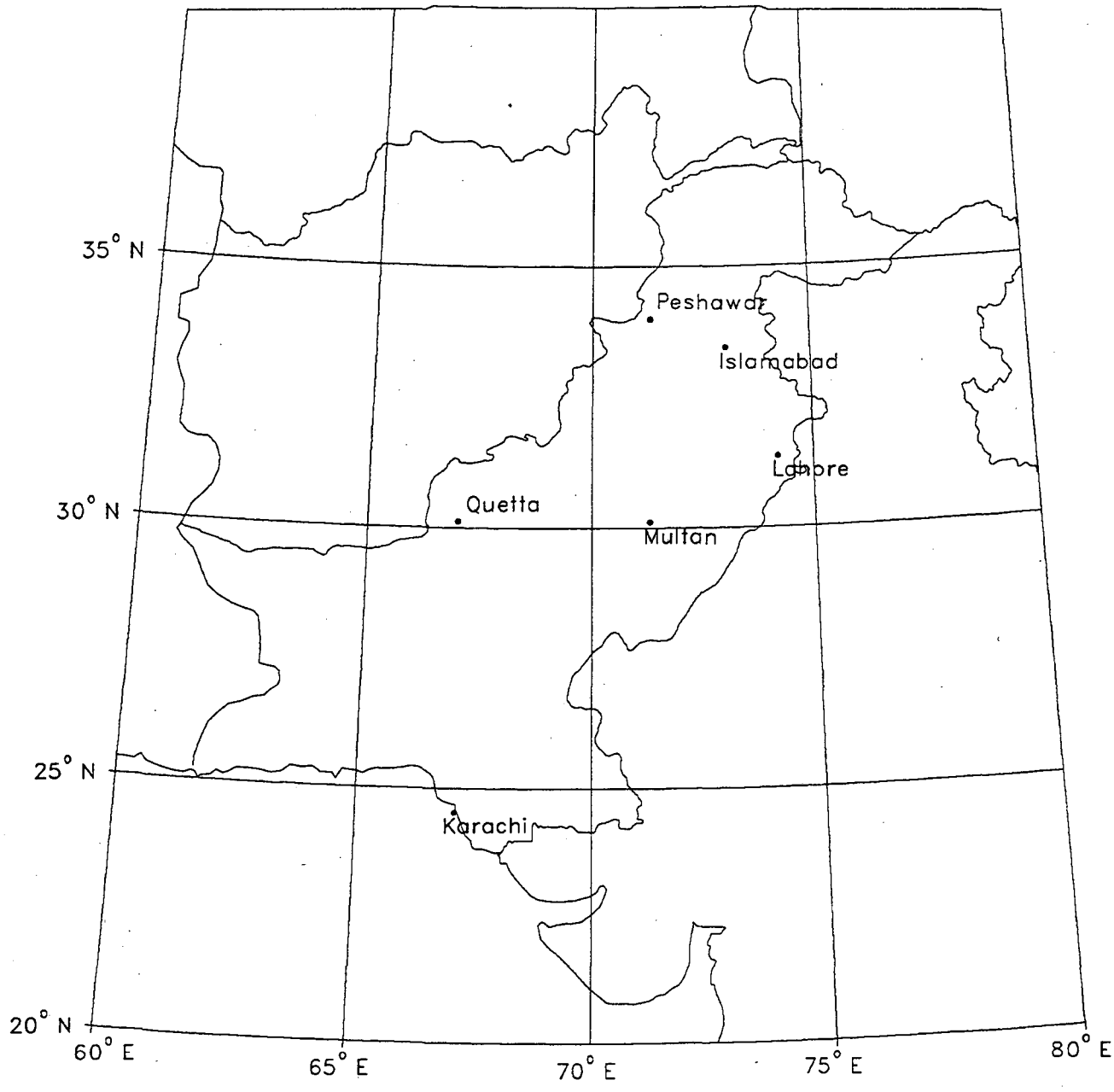
**Table 2.7. Comparison of Wind Speeds Recorded between Working and Nonworking Hours**

| City | Average Wind Speeds (mph) Hours 0-8,18-24 | Hours 8-18 | Ratio of Wind Speeds |
|---|---|---|---|
| Islamabad | 0.0684 | 0.578 | 0.118 |
| Karachi | 0.382 | 4.472 | 0.086 |
| Lahore | 0.059 | 0.8981 | 0.066 |
| Multan | 0.102 | 1.843 | 0.056 |
| Peshawar | 0.112 | 1.181 | 0.095 |
| Quetta | 0.480 | 2.389 | 0.201 |

We further investigated the wind data by reviewing the frequency of non-zero wind speed for 24-hours of the day (**Figure 2.2**). These plots, however, did not show a possible and obvious recording error. Therefore, we use the available wind speed data with the explanation that wind speeds are lower during the night time (indicated with more zero-wind speeds during the night for most locations) than during the day.

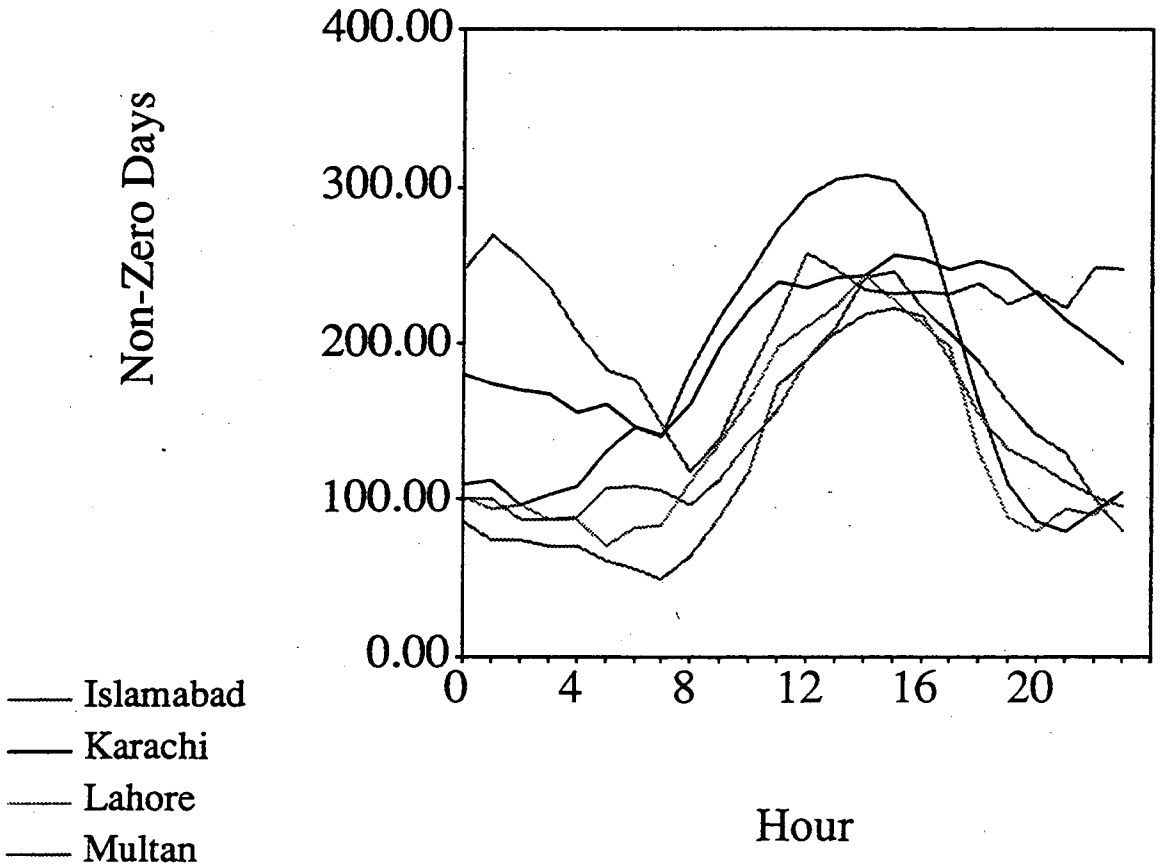
We ran the raw weather data through a DOE-2 utility program and have summarized the results in **Tables 2.8 - 2.13**. These tables show the monthly statistics of temperatures (°F), wind speed (mph), cloud cover(%), solar intensity (Btu/$ft^2$), heating and cooling degree days, and design-day temperatures. For comparison, we have also summarized the heating and cooling degree days summary in **Table 2.14.**

# Figure 2.1 Pakistan Locations



# Fig 2.2

Annual Non-Zero Wind Data



## Table 2.8 Islamabad 1986 Weather Summary

LATITUDE = 33.80 LONGITUDE = -73.00 TIME ZONE = -5

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. TEMP. (F) (DRYBULB) | | 48.3 | 52.8 | 59.5 | 71.4 | 78.5 | 86.0 | 84.5 | 82.3 | 78.9 | 70.4 | 60.6 | 50.5 | 68.7 |
| AVG. TEMP. (F) (WETBULB) | | 42.8 | 47.2 | 52.4 | 60.0 | 64.0 | 70.1 | 76.1 | 75.9 | 69.7 | 63.2 | 54.2 | 46.0 | 60.2 |
| AVG. DAILY MAX. TEMP. | | 64.7 | 65.9 | 71.2 | 85.3 | 92.4 | 99.5 | 93.5 | 91.5 | 91.9 | 85.8 | 76.7 | 64.1 | 81.9 |
| AVG. DAILY MIN. TEMP. | | 35.9 | 42.4 | 49.9 | 58.4 | 64.6 | 71.4 | 76.4 | 74.6 | 68.0 | 59.0 | 49.0 | 41.0 | 57.6 |
| HEATING DEG. DAYS | (BASE 65) | 455.0 | 305.0 | 143.5 | 9.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 87.0 | 386.0 | 1386.0 |
| | (BASE 60) | 300.0 | 170.0 | 44.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 19.5 | 234.0 | 767.5 |
| | (BASE 55) | 145.0 | 48.5 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 106.0 | 302.5 |
| | (BASE 50) | 16.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.0 | 37.0 |
| COOLING DEG. DAYS | (BASE 80) | 0.0 | 0.0 | 0.0 | 4.5 | 39.5 | 172.5 | 158.5 | 107.0 | 56.5 | 0.0 | 0.0 | 0.0 | 538.5 |
| | (BASE 75) | 0.0 | 0.0 | 0.0 | 27.0 | 128.5 | 313.5 | 309.0 | 250.5 | 161.0 | 41.5 | 0.0 | 0.0 | 1231.0 |
| | (BASE 70) | 0.0 | 0.0 | 0.0 | 99.0 | 263.5 | 463.5 | 464.0 | 405.5 | 299.0 | 108.5 | 0.0 | 0.0 | 2103.0 |
| | (BASE 65) | 0.0 | 0.0 | 6.0 | 215.0 | 418.5 | 613.5 | 619.0 | 560.5 | 449.0 | 230.5 | 22.5 | 0.0 | 3134.5 |
| HEATING DEG. HRS./24 | (BASE 65) | 519.7 | 356.1 | 226.5 | 56.9 | 7.7 | 0.6 | 0.0 | 0.0 | 1.7 | 72.6 | 215.2 | 457.0 | 1913.9 |
| | (BASE 60) | 384.4 | 241.5 | 124.2 | 21.3 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 30.9 | 120.4 | 321.1 | 1244.7 |
| | (BASE 55) | 267.9 | 140.9 | 47.0 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.5 | 49.3 | 203.0 | 721.2 |
| | (BASE 50) | 167.2 | 62.0 | 7.8 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.4 | 108.8 | 357.0 |
| COOLING DEG. HRS./24 | (BASE 80) | 0.0 | 0.3 | 0.4 | 47.6 | 126.8 | 243.8 | 173.5 | 122.7 | 105.6 | 36.2 | 5.1 | 0.0 | 862.1 |
| | (BASE 75) | 0.0 | 0.5 | 8.0 | 92.9 | 203.2 | 353.5 | 301.1 | 234.4 | 178.6 | 80.9 | 20.1 | 0.0 | 1473.2 |
| | (BASE 70) | 0.0 | 3.0 | 25.7 | 160.2 | 301.0 | 485.7 | 451.0 | 382.7 | 282.5 | 147.5 | 45.8 | 1.4 | 2286.5 |
| | (BASE 65) | 3.1 | 15.4 | 56.4 | 247.9 | 426.5 | 629.2 | 605.9 | 537.1 | 417.8 | 241.2 | 83.3 | 8.3 | 3272.2 |
| MAXIMUM TEMP. | | 71 | 88 | 83 | 98 | 102 | 111 | 103 | 99 | 98 | 93 | 85 | 75 | 111 |
| MINIMUM TEMP. | | 31 | 37 | 44 | 47 | 57 | 62 | 69 | 68 | 62 | 49 | 44 | 33 | 31 |
| NO. DAYS MAX. 90 AND ABOVE | | 0 | 0 | 0 | 6 | 21 | 27 | 24 | 22 | 21 | 7 | 0 | 0 | 128 |
| 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 | | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| NO. DAYS MIN. 0 AND BELOW | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| AVG. WIND SPEED (MPH) | | 1.6 | 2.8 | 3.6 | 3.7 | 3.9 | 4.1 | 3.2 | 2.6 | 1.9 | 1.4 | 1.3 | 1.4 | 2.6 |
| AVG. WIND SPEED (DAY) | | 2.6 | 4.0 | 4.2 | 4.7 | 5.0 | 4.7 | 3.5 | 2.9 | 2.3 | 1.8 | 1.8 | 2.0 | 3.4 |
| AVG. WIND SPEED (NIGHT) | | 0.9 | 2.0 | 3.1 | 2.7 | 2.6 | 3.4 | 2.8 | 2.2 | 1.4 | 1.0 | 0.9 | 1.0 | 1.9 |
| AVG. TEMP. (DAY) | | 54.7 | 57.6 | 63.7 | 76.8 | 83.7 | 90.7 | 87.0 | 84.9 | 83.5 | 76.4 | 67.2 | 55.6 | 75.0 |
| AVG. TEMP. (NIGHT) | | 44.1 | 49.4 | 55.8 | 65.4 | 71.8 | 79.5 | 81.4 | 79.3 | 74.1 | 65.0 | 55.4 | 47.0 | 62.7 |
| AVG. SKY COVER (DAY) | | 2.2 | 4.3 | 5.0 | 4.4 | 3.4 | 3.6 | 5.1 | 5.1 | 2.8 | 2.3 | 3.0 | 4.4 | 3.8 |
| AVG. REL. HUM. AT | 4AM | 89.0 | 87.1 | 82.7 | 75.6 | 68.1 | 66.7 | 82.6 | 87.8 | 80.9 | 88.7 | 87.9 | 90.1 | 82.3 |
| | 10AM | 82.8 | 81.2 | 69.6 | 53.6 | 46.7 | 49.7 | 73.0 | 78.3 | 68.1 | 72.7 | 77.4 | 86.1 | 69.9 |
| | 4PM | 39.4 | 47.3 | 46.9 | 34.9 | 29.2 | 33.9 | 55.2 | 61.8 | 46.1 | 42.0 | 42.1 | 49.1 | 44.0 |
| | 10PM | 73.5 | 72.6 | 67.6 | 59.4 | 56.5 | 51.5 | 70.5 | 79.4 | 70.2 | 78.3 | 79.2 | 81.9 | 70.1 |

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 1724.3 | 1405.3 | 1356.3 | 1549.4 | 1882.0 | 1787.9 | 1310.2 | 1292.7 | 1799.5 | 1845.2 | 1572.8 | 1189.4 | 1559.6 |
| TOTAL HORIZNTL | 948.0 | 1034.0 | 1439.1 | 1809.9 | 2053.2 | 2102.9 | 1975.3 | 1825.2 | 1654.6 | 1308.6 | 977.7 | 754.3 | 1492.4 |
| MAX. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 2285.4 | 2368.2 | 2595.8 | 2779.0 | 2784.5 | 2785.3 | 2566.4 | 2444.6 | 2586.0 | 2386.2 | 2313.3 | 2109.8 | 2785.3 |
| TOTAL HORIZNTL | 1205.6 | 1419.1 | 1782.5 | 2197.5 | 2330.4 | 2429.3 | 2233.6 | 1971.0 | 2051.0 | 1482.1 | 1331.8 | 1037.2 | 2429.3 |
| MIN. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 623.6 | 483.4 | 553.9 | 834.3 | 859.0 | 838.2 | 768.4 | 549.4 | 702.6 | 822.5 | 440.8 | 605.8 | 440.8 |
| TOTAL HORIZNTL | 694.8 | 755.6 | 1221.5 | 1572.7 | 1798.2 | 1901.4 | 1824.0 | 1671.1 | 1319.0 | 957.7 | 620.6 | 630.8 | 620.6 |
| MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 280.2 | 283.6 | 283.4 | 268.9 | 261.9 | 253.3 | 250.0 | 257.5 | 264.5 | 273.1 | 273.2 | 272.3 | 283.6 |
| TOTAL HORIZNTL | 195.4 | 229.7 | 260.6 | 277.8 | 286.3 | 287.5 | 285.6 | 268.1 | 266.7 | 234.6 | 204.8 | 171.8 | 287.5 |
| AVG MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORML | 238.5 | 182.7 | 172.4 | 186.7 | 209.2 | 194.9 | 148.8 | 150.3 | 206.3 | 232.4 | 214.1 | 174.5 | 192.6 |
| TOTAL HORIZNTL | 159.7 | 170.0 | 227.1 | 253.9 | 269.1 | 271.1 | 258.3 | 249.8 | 241.7 | 211.2 | 161.4 | 126.9 | 216.9 |

## Table 2.8 Islamabad 1986 Weather Summary (continued)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 181.1 | 247.9 | 435.5 | 555.2 | 622.0 | 726.9 | 783.2 | 648.2 | 406.8 | 272.7 | 204.8 | 188.0 | 440.6 |
| E | 630.2 | 683.4 | 955.0 | 1152.3 | 1248.6 | 1258.1 | 1253.9 | 1203.8 | 1029.5 | 836.3 | 645.1 | 502.0 | 951.3 |
| S | 1509.7 | 1251.1 | 1290.3 | 1137.8 | 916.4 | 851.1 | 971.4 | 1097.5 | 1225.8 | 1435.7 | 1388.6 | 1208.9 | 1190.3 |
| W | 602.8 | 653.4 | 912.9 | 1131.9 | 1186.8 | 1233.6 | 1254.4 | 1152.6 | 1011.0 | 800.6 | 607.6 | 493.3 | 921.4 |
| MAX. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 258.9 | 376.0 | 608.0 | 747.6 | 846.5 | 909.4 | 942.7 | 815.1 | 600.6 | 501.1 | 268.1 | 238.1 | 942.7 |
| E | 774.8 | 950.6 | 1098.2 | 1300.5 | 1438.5 | 1442.9 | 1403.1 | 1327.4 | 1342.7 | 1053.1 | 835.6 | 667.9 | 1442.9 |
| S | 1830.1 | 1823.5 | 1689.6 | 1234.7 | 1140.8 | 1048.1 | 1087.3 | 1151.7 | 1410.0 | 1762.3 | 1801.4 | 1805.8 | 1830.1 |
| W | 752.3 | 824.2 | 1096.7 | 1258.7 | 1330.4 | 1425.8 | 1424.9 | 1284.6 | 1193.9 | 1004.3 | 842.8 | 680.0 | 1425.8 |
| MAX. HRLY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 41.7 | 79.6 | 94.1 | 101.2 | 104.0 | 104.9 | 104.5 | 104.2 | 94.3 | 86.4 | 41.4 | 38.2 | 104.9 |
| E | 191.4 | 218.3 | 228.9 | 239.0 | 235.4 | 230.9 | 231.1 | 233.0 | 232.2 | 222.2 | 201.7 | 171.2 | 239.0 |
| S | 264.1 | 255.4 | 232.3 | 199.2 | 174.8 | 155.5 | 165.5 | 179.9 | 209.6 | 245.3 | 259.8 | 263.9 | 264.1 |
| W | 196.3 | 202.9 | 221.8 | 236.9 | 235.8 | 232.7 | 232.1 | 193.1 | 228.4 | 210.6 | 198.5 | 175.1 | 236.9 |

| DESIGN TEMPERATURES | SUMMER | | WINTER |
|---|---|---|---|
| PER CENT | T(DRY) | T(WET) | T(DRY) |
| 1.0 | 105 | 82 | 34 |
| 2.5 | 102 | 81 | 35 |
| 5.0 | 98 | 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 | 41.9 | 47.5 | 54.1 | 63.5 | 70.9 | 78.2 | 80.6 | 78.7 | 73.2 | 64.2 | 54.4 | 46.0 | 62.8 |
| 1 | 40.5 | 46.5 | 53.0 | 62.4 | 69.7 | 77.0 | 79.9 | 78.1 | 72.2 | 63.2 | 53.5 | 44.9 | 61.8 |
| 2 | 39.6 | 45.4 | 52.3 | 61.7 | 68.6 | 76.0 | 79.2 | 77.5 | 71.7 | 62.2 | 52.6 | 44.1 | 61.0 |
| 3 | 39.0 | 44.8 | 51.9 | 60.9 | 67.7 | 74.5 | 78.7 | 77.0 | 70.9 | 61.5 | 52.1 | 43.7 | 60.3 |
| 4 | 38.4 | 44.4 | 51.3 | 59.9 | 66.6 | 73.5 | 78.2 | 76.5 | 69.9 | 60.6 | 51.4 | 43.2 | 59.6 |
| 5 | 37.5 | 43.7 | 51.0 | 59.3 | 65.9 | 73.0 | 77.3 | 76.0 | 69.3 | 59.8 | 50.7 | 42.6 | 58.9 |
| 6 | 36.9 | 43.2 | 50.5 | 59.0 | 66.4 | 74.4 | 77.2 | 75.7 | 68.7 | 59.4 | 50.1 | 42.0 | 58.7 |
| 7 | 36.3 | 43.0 | 50.6 | 61.0 | 70.0 | 78.0 | 78.7 | 76.6 | 69.6 | 59.5 | 49.7 | 41.6 | 59.6 |
| 8 | 36.8 | 44.0 | 53.4 | 67.3 | 76.6 | 82.7 | 81.6 | 79.2 | 74.1 | 63.5 | 51.6 | 42.0 | 62.8 |
| 9 | 42.0 | 49.0 | 58.1 | 72.4 | 80.6 | 87.0 | 83.7 | 81.8 | 78.5 | 68.8 | 58.0 | 46.3 | 67.3 |
| 10 | 49.1 | 54.1 | 61.7 | 75.9 | 83.7 | 90.3 | 86.0 | 83.8 | 82.1 | 73.9 | 63.9 | 51.1 | 71.4 |
| 11 | 54.9 | 58.3 | 65.0 | 79.3 | 86.5 | 92.9 | 88.0 | 85.5 | 85.0 | 77.8 | 69.3 | 55.9 | 74.9 |
| 12 | 59.9 | 61.5 | 67.7 | 81.5 | 88.6 | 95.4 | 89.1 | 87.1 | 87.3 | 81.3 | 72.9 | 59.4 | 77.7 |
| 13 | 62.7 | 63.6 | 69.4 | 83.0 | 90.1 | 97.2 | 90.6 | 88.8 | 88.8 | 83.1 | 74.9 | 61.6 | 79.5 |
| 14 | 63.9 | 64.5 | 69.8 | 84.0 | 91.4 | 98.2 | 92.0 | 89.5 | 89.8 | 84.8 | 75.8 | 62.9 | 80.6 |
| 15 | 64.1 | 65.2 | 70.2 | 84.2 | 91.9 | 99.0 | 92.5 | 89.6 | 90.7 | 85.5 | 75.7 | 63.1 | 81.0 |
| 16 | 62.9 | 63.7 | 69.3 | 83.9 | 91.5 | 98.7 | 92.2 | 90.1 | 91.0 | 84.4 | 74.1 | 61.8 | 80.4 |
| 17 | 60.0 | 62.0 | 68.3 | 82.9 | 89.7 | 97.4 | 91.5 | 89.1 | 89.2 | 80.9 | 70.2 | 59.0 | 78.4 |
| 18 | 56.2 | 59.5 | 66.1 | 80.1 | 87.0 | 95.6 | 90.2 | 87.0 | 85.0 | 75.9 | 64.7 | 55.5 | 75.3 |
| 19 | 52.5 | 57.1 | 63.5 | 76.3 | 82.7 | 91.6 | 87.9 | 84.9 | 80.5 | 71.8 | 61.1 | 52.4 | 71.9 |
| 20 | 49.3 | 54.8 | 60.6 | 72.3 | 77.8 | 87.0 | 86.0 | 82.8 | 78.9 | 69.4 | 59.0 | 50.2 | 69.1 |
| 21 | 47.0 | 52.4 | 58.8 | 69.3 | 75.2 | 83.6 | 84.1 | 80.9 | 76.7 | 67.7 | 57.3 | 48.8 | 66.9 |
| 22 | 45.2 | 50.5 | 56.7 | 67.3 | 73.4 | 81.8 | 82.5 | 80.2 | 75.4 | 66.4 | 56.1 | 47.9 | 65.4 |
| 23 | 43.4 | 49.2 | 55.1 | 65.4 | 71.9 | 79.9 | 81.5 | 79.3 | 74.3 | 65.0 | 55.1 | 46.7 | 64.0 |
| GROUND TEMPERATURES | 521.7 | 518.8 | 518.6 | 519.9 | 525.4 | 530.9 | 535.6 | 538.6 | 538.8 | 536.4 | 531.8 | 526.5 | |
| CLEARNESS NUMBERS | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | |

## Table 2.9 Karachi 1986 Weather Summary

LATITUDE = 24.80 LONGITUDE = -67.10 TIME ZONE = -5

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. TEMP. (F) (DRYBULB) | | 62.9 | 67.5 | 75.7 | 83.2 | 87.4 | 88.4 | 85.0 | 82.3 | 82.0 | 81.9 | 74.7 | 62.9 | 77.9 |
| AVG. TEMP. (F) (WETBULB) | | 49.9 | 56.4 | 64.5 | 72.3 | 75.9 | 79.6 | 78.1 | 76.1 | 74.6 | 70.1 | 61.8 | 50.4 | 67.5 |
| AVG. DAILY MAX. TEMP. | | 78.9 | 80.6 | 89.2 | 94.6 | 98.2 | 96.8 | 90.2 | 88.0 | 88.7 | 94.7 | 90.1 | 78.0 | 89.0 |
| AVG. DAILY MIN. TEMP. | | 47.9 | 54.7 | 64.4 | 74.0 | 78.4 | 82.8 | 81.2 | 78.2 | 77.2 | 72.2 | 62.3 | 50.1 | 68.7 |
| HEATING DEG. DAYS | (BASE 65) | 62.0 | 7.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 95.5 | 164.5 |
| | (BASE 60) | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 31.0 | 36.0 |
| | (BASE 55) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.0 | 4.0 |
| | (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) | 0.0 | 0.0 | 6.0 | 129.0 | 259.0 | 294.5 | 176.0 | 96.5 | 88.0 | 110.0 | 10.0 | 0.0 | 1169.0 |
| | (BASE 75) | 0.0 | 0.0 | 75.5 | 278.5 | 412.0 | 444.5 | 331.0 | 251.0 | 237.5 | 261.0 | 73.5 | 0.0 | 2364.5 |
| | (BASE 70) | 0.0 | 5.0 | 211.0 | 428.5 | 567.0 | 594.5 | 486.0 | 406.0 | 387.5 | 416.0 | 188.0 | 15.5 | 3705.0 |
| | (BASE 65) | 11.5 | 81.5 | 366.0 | 578.5 | 722.0 | 744.5 | 641.0 | 561.0 | 537.5 | 571.0 | 336.0 | 66.0 | 5216.5 |
| HEATING DEG. HRS./24 | (BASE 65) | 179.8 | 74.8 | 9.7 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 21.8 | 179.3 | 466.1 |
| | (BASE 60) | 102.6 | 28.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.9 | 101.6 | 237.2 |
| | (BASE 55) | 43.4 | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 47.3 | 94.5 |
| | (BASE 50) | 11.6 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 18.1 | 30.0 |
| COOLING DEG. HRS./24 | (BASE 80) | 1.3 | 7.1 | 63.2 | 143.0 | 235.2 | 252.8 | 157.1 | 84.9 | 81.2 | 132.9 | 66.8 | 10.1 | 1235.7 |
| | (BASE 75) | 15.3 | 29.2 | 125.1 | 253.9 | 385.1 | 402.6 | 309.5 | 226.6 | 211.4 | 243.3 | 125.0 | 26.9 | 2354.0 |
| | (BASE 70) | 54.5 | 75.4 | 215.7 | 395.4 | 539.9 | 552.6 | 464.5 | 381.6 | 361.3 | 375.1 | 206.7 | 59.3 | 3682.0 |
| | (BASE 65) | 113.9 | 144.0 | 342.7 | 545.1 | 694.7 | 702.6 | 619.5 | 536.6 | 511.3 | 523.0 | 313.0 | 115.0 | 5161.5 |
| MAXIMUM TEMP. | | 82 | 88 | 95 | 102 | 109 | 102 | 93 | 95 | 93 | 104 | 99 | 90 | 109 |
| MINIMUM TEMP. | | 39 | 46 | 55 | 68 | 59 | 79 | 77 | 75 | 72 | 63 | 54 | 37 | 37 |
| NO. DAYS MAX. 90 AND ABOVE | | 0 | 0 | 20 | 29 | 31 | 30 | 24 | 10 | 11 | 30 | 17 | 2 | 204 |
| 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) | | 4.7 | 3.6 | 5.3 | 7.9 | 9.4 | 11.4 | 13.6 | 12.8 | 10.3 | 6.0 | 3.1 | 4.9 | 7.8 |
| AVG. WIND SPEED (DAY) | | 6.6 | 5.3 | 6.8 | 9.3 | 10.9 | 12.4 | 14.5 | 14.5 | 11.6 | 7.5 | 4.3 | 7.2 | 9.5 |
| AVG. WIND SPEED (NIGHT) | | 3.4 | 2.5 | 4.1 | 6.5 | 7.9 | 10.4 | 12.6 | 11.2 | 9.1 | 4.8 | 2.1 | 3.3 | 6.3 |
| AVG. TEMP. (DAY) | | 68.6 | 72.3 | 80.5 | 87.9 | 91.5 | 91.7 | 87.1 | 84.5 | 84.5 | 86.2 | 80.4 | 67.9 | 82.7 |
| AVG. TEMP. (NIGHT) | | 59.2 | 64.2 | 72.0 | 78.8 | 83.1 | 85.0 | 82.8 | 80.2 | 79.9 | 78.3 | 70.4 | 59.5 | 73.8 |
| AVG. SKY COVER (DAY) | | 0.8 | 2.7 | 1.7 | 2.7 | 1.8 | 4.4 | 7.2 | 7.0 | 2.9 | 0.6 | 1.2 | 1.5 | 3.0 |
| AVG. REL. HUM. AT | 4AM | 59.5 | 72.2 | 80.5 | 81.9 | 79.5 | 82.9 | 82.4 | 83.1 | 83.0 | 76.7 | 69.7 | 62.5 | 76.2 |
| | 10AM | 49.0 | 56.5 | 59.2 | 63.4 | 58.6 | 64.6 | 73.4 | 71.6 | 71.5 | 61.3 | 52.4 | 48.8 | 60.9 |
| | 4PM | 21.0 | 34.7 | 35.2 | 39.1 | 40.1 | 53.4 | 63.5 | 69.0 | 57.2 | 35.5 | 26.6 | 21.8 | 41.4 |
| | 10PM | 40.4 | 50.6 | 59.2 | 64.9 | 69.4 | 76.4 | 76.9 | 81.5 | 75.1 | 65.3 | 61.0 | 45.1 | 63.9 |

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 2297.7 | 1936.5 | 2295.2 | 2005.0 | 2237.8 | 1506.5 | 738.5 | 763.3 | 1838.9 | 2417.7 | 2188.8 | 2036.3 | 1854.2 |
| TOTAL HORIZNTL | 1383.7 | 1475.1 | 1884.6 | 1994.3 | 2218.0 | 2066.0 | 1850.1 | 1759.3 | 1821.6 | 1736.6 | 1389.2 | 1198.0 | 1732.5 |
| MAX. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 2576.2 | 2709.8 | 2780.4 | 2755.6 | 2744.6 | 2710.4 | 1483.2 | 1497.8 | 2561.9 | 2593.0 | 2529.8 | 2417.1 | 2780.4 |
| TOTAL HORIZNTL | 1579.1 | 1859.9 | 2138.6 | 2287.6 | 2369.9 | 2386.2 | 2031.3 | 1985.7 | 2096.2 | 1906.3 | 1650.1 | 1414.6 | 2386.2 |
| MIN. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 1138.9 | 601.5 | 567.8 | 1126.8 | 984.9 | 535.5 | 524.2 | 494.1 | 1067.2 | 1953.9 | 1301.4 | 1054.5 | 494.1 |
| TOTAL HORIZNTL | 938.2 | 1140.5 | 1454.2 | 1779.3 | 1973.4 | 1795.8 | 1755.5 | 1617.5 | 1608.7 | 1491.5 | 1058.2 | 921.6 | 921.6 |
| MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 290.1 | 291.0 | 289.6 | 277.9 | 265.4 | 255.6 | 225.7 | 237.9 | 272.3 | 282.0 | 283.8 | 285.4 | 291.0 |
| TOTAL HORIZNTL | 235.8 | 264.8 | 287.6 | 295.8 | 296.1 | 295.3 | 272.4 | 272.9 | 284.8 | 269.9 | 242.5 | 218.2 | 296.1 |
| AVG MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORML | 275.2 | 239.7 | 253.8 | 227.4 | 231.8 | 175.5 | 90.6 | 108.5 | 228.6 | 277.9 | 264.9 | 257.5 | 219.1 |
| TOTAL HORIZNTL | 216.4 | 236.9 | 267.6 | 278.0 | 286.8 | 271.1 | 247.8 | 247.8 | 265.6 | 255.7 | 223.4 | 188.4 | 248.8 |

## Table 2.9 Karachi 1986 Weather Summary (continued)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 221.7 | 306.5 | 375.9 | 502.0 | 667.2 | 897.6 | 972.6 | 799.2 | 445.5 | 288.4 | 230.4 | 195.3 | 493.1 |
| E | 816.5 | 900.3 | 1127.0 | 1132.6 | 1228.0 | 1249.9 | 1248.7 | 1180.8 | 997.8 | 940.7 | 837.5 | 710.8 | 1031.7 |
| S | 1725.5 | 1436.4 | 1263.8 | 885.0 | 667.7 | 750.4 | 928.8 | 997.1 | 1085.3 | 1474.3 | 1598.1 | 1591.2 | 1199.7 |
| W | 827.1 | 866.0 | 1095.5 | 1174.9 | 1281.2 | 1276.8 | 1255.0 | 1197.5 | 1132.0 | 1034.4 | 805.7 | 713.8 | 1056.1 |
| MAX. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 295.4 | 530.1 | 657.1 | 725.5 | 975.8 | 1033.8 | 1044.9 | 915.2 | 627.2 | 382.0 | 285.6 | 262.1 | 1044.9 |
| E | 929.6 | 1082.4 | 1414.0 | 1355.4 | 1344.5 | 1354.2 | 1328.9 | 1362.3 | 1343.9 | 1085.5 | 967.4 | 840.9 | 1414.0 |
| S | 1864.7 | 1770.2 | 1530.8 | 1064.4 | 918.9 | 937.4 | 980.2 | 1040.5 | 1281.3 | 1683.6 | 1782.7 | 1866.3 | 1866.3 |
| W | 939.0 | 1073.0 | 1193.0 | 1385.5 | 1423.1 | 1561.6 | 1360.2 | 1337.2 | 1258.4 | 1148.6 | 961.6 | 836.4 | 1561.6 |
| MAX. HRLY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 69.7 | 93.4 | 103.5 | 105.9 | 119.1 | 124.0 | 123.2 | 114.5 | 103.2 | 70.6 | 75.4 | 42.4 | 124.0 |
| E | 216.0 | 232.0 | 244.7 | 244.4 | 240.1 | 232.7 | 207.5 | 209.2 | 236.4 | 232.2 | 218.4 | 198.5 | 244.7 |
| S | 250.1 | 232.3 | 207.8 | 172.3 | 143.5 | 133.7 | 143.7 | 169.0 | 197.1 | 222.2 | 244.6 | 251.1 | 251.1 |
| W | 216.7 | 237.7 | 246.0 | 246.0 | 240.0 | 232.7 | 205.7 | 215.0 | 236.6 | 228.5 | 217.2 | 200.2 | 246.0 |

| DESIGN TEMPERATURES | SUMMER | | WINTER |
|---|---|---|---|
| PER CENT | T(DRY) | T(WET) | T(DRY) |
| 1.0 | 99 | 83 | 43 |
| 2.5 | 95 | 82 | 45 |
| 5.0 | 93 | 82 | |

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 | 56.6 | 62.8 | 71.1 | 77.9 | 82.0 | 84.4 | 82.4 | 79.8 | 79.2 | 76.9 | 68.2 | 57.7 | 73.3 |
| 1 | 54.9 | 61.5 | 69.5 | 77.0 | 82.2 | 84.3 | 82.3 | 79.5 | 78.7 | 76.4 | 67.0 | 56.1 | 72.5 |
| 2 | 53.6 | 59.7 | 68.2 | 76.1 | 81.6 | 83.7 | 82.0 | 79.4 | 78.5 | 75.1 | 66.1 | 54.6 | 71.6 |
| 3 | 52.1 | 58.0 | 66.9 | 75.6 | 81.3 | 83.4 | 81.8 | 79.5 | 77.8 | 74.3 | 65.3 | 53.3 | 70.8 |
| 4 | 51.0 | 57.2 | 65.9 | 74.7 | 80.8 | 83.2 | 81.8 | 79.3 | 77.8 | 74.3 | 64.6 | 52.2 | 70.3 |
| 5 | 49.9 | 56.1 | 65.8 | 74.2 | 80.3 | 83.2 | 81.5 | 79.4 | 77.7 | 73.5 | 63.8 | 51.0 | 69.8 |
| 6 | 48.8 | 55.5 | 65.2 | 74.6 | 80.9 | 83.8 | 81.6 | 80.1 | 77.5 | 72.4 | 63.0 | 50.6 | 69.6 |
| 7 | 48.9 | 56.1 | 66.6 | 77.6 | 82.5 | 85.6 | 82.7 | 81.3 | 78.5 | 73.6 | 63.4 | 50.9 | 70.7 |
| 8 | 51.5 | 59.6 | 69.0 | 80.0 | 84.9 | 87.7 | 84.3 | 82.4 | 80.4 | 76.1 | 66.8 | 53.0 | 73.0 |
| 9 | 56.3 | 63.7 | 72.7 | 82.7 | 87.7 | 89.6 | 85.7 | 84.1 | 81.5 | 78.8 | 70.2 | 56.6 | 75.8 |
| 10 | 62.1 | 67.4 | 76.5 | 86.0 | 90.6 | 91.4 | 87.1 | 84.9 | 82.7 | 82.2 | 74.7 | 61.0 | 78.9 |
| 11 | 69.2 | 72.2 | 80.6 | 89.2 | 93.1 | 92.6 | 88.2 | 85.8 | 84.6 | 86.1 | 80.7 | 65.8 | 82.4 |
| 12 | 73.1 | 75.8 | 84.5 | 91.4 | 94.9 | 94.1 | 88.9 | 86.2 | 86.0 | 89.7 | 85.5 | 71.9 | 85.2 |
| 13 | 75.5 | 78.3 | 85.8 | 92.7 | 96.5 | 95.2 | 89.7 | 86.2 | 87.3 | 91.4 | 88.0 | 74.7 | 86.8 |
| 14 | 78.2 | 79.6 | 87.5 | 93.9 | 97.1 | 95.9 | 90.0 | 86.2 | 88.3 | 92.8 | 89.4 | 77.2 | 88.0 |
| 15 | 78.1 | 79.6 | 88.4 | 94.4 | 97.6 | 96.2 | 89.6 | 85.5 | 88.1 | 94.2 | 89.4 | 77.7 | 88.3 |
| 16 | 76.6 | 78.8 | 87.6 | 92.6 | 96.0 | 94.4 | 88.4 | 85.2 | 87.4 | 92.8 | 87.2 | 76.6 | 87.0 |
| 17 | 75.0 | 77.0 | 85.0 | 90.5 | 93.1 | 91.9 | 87.2 | 84.0 | 86.2 | 90.3 | 84.7 | 74.5 | 85.0 |
| 18 | 72.6 | 75.3 | 82.3 | 87.5 | 90.3 | 90.6 | 86.3 | 82.8 | 84.4 | 87.5 | 81.8 | 72.2 | 82.8 |
| 19 | 70.3 | 73.0 | 79.3 | 85.0 | 87.4 | 88.5 | 85.2 | 81.8 | 83.2 | 84.9 | 79.7 | 70.1 | 80.7 |
| 20 | 67.1 | 70.9 | 77.4 | 82.7 | 85.5 | 86.6 | 83.7 | 81.1 | 81.7 | 82.5 | 77.1 | 66.7 | 78.6 |
| 21 | 64.7 | 68.9 | 75.2 | 81.0 | 84.5 | 86.1 | 83.5 | 80.6 | 80.8 | 80.7 | 74.3 | 63.8 | 77.0 |
| 22 | 62.9 | 67.1 | 74.0 | 79.7 | 83.6 | 85.1 | 83.3 | 80.3 | 80.5 | 79.7 | 72.5 | 62.3 | 75.9 |
| 23 | 60.0 | 65.2 | 72.8 | 78.9 | 83.1 | 84.7 | 82.5 | 80.0 | 80.1 | 78.2 | 69.4 | 59.8 | 74.6 |
| GROUND TEMPERATURES | 533.1 | 531.1 | 531.0 | 531.9 | 535.6 | 539.3 | 542.5 | 544.6 | 544.7 | 543.1 | 539.9 | 536.4 | |
| CLEARNESS NUMBERS | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | |

## Table 2.10 Lahore 1986 Weather Summary

LATITUDE = 31.50 LONGITUDE = -74.30 TIME ZONE = -5

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. TEMP. (F) (DRYBULB) | | 54.3 | 59.6 | 68.4 | 79.5 | 84.9 | 92.3 | 86.7 | 87.2 | 83.7 | 76.4 | 66.8 | 55.4 | 74.7 |
| AVG. TEMP. (F) (WETBULB) | | 48.7 | 53.1 | 59.8 | 65.0 | 68.6 | 76.1 | 79.5 | 79.2 | 74.1 | 67.9 | 59.5 | 50.0 | 65.2 |
| AVG. DAILY MAX. TEMP. | | 68.2 | 71.5 | 79.8 | 92.8 | 97.9 | 103.7 | 95.2 | 94.9 | 94.4 | 89.3 | 81.2 | 69.0 | 86.5 |
| AVG. DAILY MIN. TEMP. | | 43.0 | 49.8 | 57.8 | 66.9 | 72.4 | 81.2 | 78.9 | 80.1 | 75.2 | 65.9 | 56.2 | 45.0 | 64.4 |
| HEATING DEG. DAYS | (BASE 65) | 291.5 | 124.5 | 12.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 21.0 | 248.5 | 698.0 |
| | (BASE 60) | 136.5 | 15.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 123.5 | 275.0 |
| | (BASE 55) | 16.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 34.0 | 50.0 |
| | (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) | 0.0 | 0.0 | 0.0 | 68.5 | 173.0 | 377.5 | 219.5 | 232.5 | 162.5 | 29.0 | 0.0 | 0.0 | 1262.5 |
| | (BASE 75) | 0.0 | 0.0 | 1.5 | 166.0 | 314.0 | 524.0 | 374.0 | 387.5 | 294.5 | 102.0 | 0.0 | 0.0 | 2163.5 |
| | (BASE 70) | 0.0 | 0.0 | 36.5 | 296.5 | 469.0 | 674.0 | 529.0 | 542.5 | 444.0 | 237.5 | 44.0 | 0.0 | 3273.0 |
| | (BASE 65) | 0.0 | 2.5 | 129.5 | 446.0 | 624.0 | 824.0 | 684.0 | 697.5 | 594.0 | 391.0 | 133.0 | 0.0 | 4525.5 |
| HEATING DEG. HRS./24 | (BASE 65) | 343.8 | 194.5 | 63.1 | 9.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 15.0 | 95.6 | 324.8 | 1046.6 |
| | (BASE 60) | 228.5 | 102.5 | 18.7 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 34.3 | 210.2 | 596.3 |
| | (BASE 55) | 130.9 | 36.5 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.8 | 120.0 | 295.4 |
| | (BASE 50) | 56.7 | 7.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 55.8 | 119.5 |
| COOLING DEG. HRS./24 | (BASE 80) | 0.0 | 0.0 | 11.4 | 127.0 | 218.1 | 382.5 | 223.1 | 228.9 | 164.7 | 78.2 | 17.0 | 0.0 | 1450.8 |
| | (BASE 75) | 0.0 | 1.8 | 39.9 | 207.4 | 330.3 | 522.2 | 366.9 | 377.8 | 276.2 | 147.8 | 45.7 | 0.5 | 2316.5 |
| | (BASE 70) | 0.1 | 13.1 | 90.2 | 314.9 | 466.7 | 669.2 | 518.6 | 532.7 | 411.7 | 246.0 | 89.4 | 7.3 | 3360.0 |
| | (BASE 65) | 13.5 | 42.8 | 169.1 | 445.0 | 616.8 | 819.2 | 673.5 | 687.7 | 560.6 | 366.8 | 150.2 | 27.7 | 4573.1 |
| MAXIMUM TEMP. | | 71 | 80 | 89 | 107 | 109 | 115 | 103 | 99 | 100 | 94 | 89 | 78 | 115 |
| MINIMUM TEMP. | | 38 | 42 | 52 | 55 | 61 | 70 | 69 | 74 | 67 | 58 | 50 | 37 | 37 |
| NO. DAYS MAX. 90 AND ABOVE | | 0 | 0 | 0 | 20 | 26 | 28 | 29 | 29 | 24 | 14 | 0 | 0 | 170 |
| 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) | | 0.6 | 2.0 | 2.5 | 2.5 | 3.1 | 3.3 | 2.6 | 2.3 | 1.7 | 1.0 | 1.0 | 0.9 | 2.0 |
| AVG. WIND SPEED (DAY) | | 1.3 | 2.9 | 3.1 | 3.2 | 3.4 | 3.7 | 2.8 | 2.9 | 2.1 | 1.4 | 1.5 | 1.5 | 2.6 |
| AVG. WIND SPEED (NIGHT) | | 0.1 | 1.3 | 1.9 | 1.6 | 2.8 | 2.8 | 2.4 | 1.6 | 1.1 | 0.6 | 0.6 | 0.5 | 1.4 |
| AVG. TEMP. (DAY) | | 60.2 | 64.1 | 72.5 | 84.4 | 89.2 | 95.5 | 88.7 | 89.4 | 87.6 | 81.6 | 72.9 | 61.1 | 80.3 |
| AVG. TEMP. (NIGHT) | | 50.2 | 56.1 | 64.7 | 74.1 | 79.2 | 88.0 | 84.2 | 84.6 | 79.6 | 71.4 | 61.7 | 51.2 | 69.1 |
| AVG. SKY COVER (DAY) | | 1.6 | 3.1 | 3.3 | 2.8 | 2.4 | 2.3 | 4.6 | 4.3 | 2.3 | 1.3 | 1.6 | 3.1 | 2.8 |
| AVG. REL. HUM. AT | 4AM | 87.2 | 84.2 | 80.0 | 65.9 | 63.0 | 61.7 | 84.6 | 82.5 | 80.8 | 86.3 | 85.2 | 89.5 | 79.3 |
| | 10AM | 73.2 | 72.4 | 64.8 | 46.7 | 44.2 | 51.9 | 76.0 | 72.6 | 67.3 | 66.4 | 68.6 | 75.2 | 65.0 |
| | 4PM | 43.9 | 45.2 | 42.5 | 30.6 | 32.0 | 37.9 | 61.6 | 59.5 | 50.1 | 45.0 | 43.8 | 45.0 | 44.8 |
| | 10PM | 78.4 | 73.8 | 66.9 | 53.5 | 49.4 | 54.3 | 76.6 | 73.3 | 69.9 | 73.2 | 76.6 | 78.6 | 68.7 |

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 1931.7 | 1729.4 | 1814.7 | 2002.7 | 2124.5 | 2095.1 | 1433.0 | 1497.5 | 1972.1 | 2151.5 | 1928.7 | 1521.9 | 1849.6 |
| TOTAL HORIZNTL | 1067.6 | 1206.1 | 1601.2 | 1968.1 | 2132.9 | 2209.3 | 1991.7 | 1894.9 | 1764.3 | 1491.1 | 1138.7 | 896.9 | 1615.2 |
| MAX. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 2386.3 | 2599.1 | 2748.2 | 2778.1 | 2774.0 | 2758.9 | 2702.0 | 2574.6 | 2595.2 | 2465.3 | 2377.8 | 2203.5 | 2778.1 |
| TOTAL HORIZNTL | 1324.6 | 1630.9 | 2030.4 | 2276.3 | 2385.4 | 2430.0 | 2395.6 | 2099.6 | 2087.1 | 1705.9 | 1424.2 | 1130.1 | 2430.0 |
| MIN. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 1011.9 | 496.6 | 632.9 | 861.7 | 735.0 | 767.6 | 553.8 | 534.2 | 657.3 | 909.6 | 618.5 | 607.8 | 496.6 |
| TOTAL HORIZNTL | 801.6 | 802.6 | 1346.8 | 1686.9 | 1772.7 | 1829.7 | 1709.5 | 1689.3 | 1385.2 | 1152.8 | 703.3 | 656.5 | 656.5 |
| MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 283.1 | 285.6 | 285.2 | 276.0 | 262.5 | 254.7 | 250.5 | 258.4 | 267.2 | 275.9 | 276.2 | 275.9 | 285.6 |
| TOTAL HORIZNTL | 205.8 | 239.8 | 271.2 | 284.4 | 288.6 | 289.2 | 288.5 | 275.9 | 271.4 | 247.4 | 215.4 | 186.4 | 289.2 |
| AVG MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORML | 257.7 | 218.3 | 230.0 | 230.7 | 230.9 | 224.4 | 169.9 | 180.2 | 232.0 | 266.7 | 242.5 | 211.3 | 224.5 |
| TOTAL HORIZNTL | 175.9 | 194.1 | 242.8 | 266.4 | 276.2 | 276.0 | 263.0 | 258.4 | 252.6 | 229.0 | 180.0 | 148.3 | 230.4 |

## Table 2.10 Lahore 1986 Weather Summary (continued)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 185.1 | 256.3 | 389.7 | 505.4 | 599.4 | 730.2 | 764.4 | 625.0 | 405.7 | 276.5 | 203.2 | 192.7 | 428.8 |
| E | 691.1 | 786.7 | 1008.2 | 1209.0 | 1233.9 | 1263.5 | 1242.0 | 1229.1 | 1096.6 | 951.1 | 713.4 | 597.9 | 1002.9 |
| S | 1604.1 | 1394.6 | 1321.0 | 1080.2 | 823.7 | 763.2 | 887.5 | 1033.5 | 1213.8 | 1529.7 | 1554.7 | 1399.1 | 1216.3 |
| W | 651.5 | 744.6 | 986.7 | 1180.5 | 1219.3 | 1307.1 | 1224.9 | 1157.2 | 1031.7 | 850.1 | 713.9 | 580.0 | 971.5 |
| MAX. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 246.4 | 420.7 | 578.2 | 747.8 | 832.0 | 937.5 | 930.5 | 825.5 | 624.4 | 433.6 | 269.4 | 256.1 | 937.5 |
| E | 830.2 | 992.5 | 1184.7 | 1408.4 | 1516.3 | 1515.0 | 1388.8 | 1354.4 | 1221.9 | 1168.0 | 871.5 | 719.6 | 1516.3 |
| S | 1847.4 | 1821.6 | 1662.5 | 1203.1 | 1098.0 | 1001.6 | 1041.6 | 1109.3 | 1342.2 | 1751.2 | 1808.7 | 1838.8 | 1847.4 |
| W | 824.4 | 989.3 | 1242.2 | 1404.3 | 1457.5 | 1510.9 | 1433.5 | 1316.3 | 1211.2 | 1018.9 | 881.5 | 724.5 | 1510.9 |
| MAX. HRLY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 42.6 | 84.8 | 96.2 | 103.9 | 105.4 | 111.3 | 110.0 | 105.2 | 96.6 | 85.0 | 43.4 | 41.5 | 111.3 |
| E | 198.6 | 226.9 | 240.5 | 240.3 | 234.6 | 230.7 | 229.8 | 233.0 | 232.6 | 224.6 | 206.2 | 186.4 | 240.5 |
| S | 261.3 | 252.5 | 225.1 | 191.7 | 169.1 | 148.8 | 159.8 | 174.6 | 207.0 | 240.7 | 257.7 | 261.2 | 261.3 |
| W | 202.3 | 223.5 | 236.7 | 237.5 | 234.7 | 231.1 | 230.5 | 231.0 | 231.4 | 224.6 | 203.9 | 181.9 | 237.5 |

| DESIGN TEMPERATURES | SUMMER | | WINTER |
|---|---|---|---|
| PER CENT | T(DRY) | T(WET) | T(DRY) |
| 1.0 | 110 | 86 | 39 |
| 2.5 | 107 | 85 | 40 |
| 5.0 | 102 | 83 | |

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 | 48.6 | 54.7 | 63.4 | 73.2 | 78.3 | 87.2 | 83.5 | 84.0 | 78.8 | 70.4 | 60.4 | 49.7 | 69.4 |
| 1 | 47.7 | 53.6 | 62.5 | 71.8 | 77.1 | 86.1 | 82.9 | 83.4 | 78.1 | 69.3 | 59.5 | 48.8 | 68.5 |
| 2 | 46.7 | 52.8 | 61.5 | 70.7 | 75.9 | 85.1 | 82.2 | 82.8 | 77.2 | 68.3 | 58.8 | 47.9 | 67.6 |
| 3 | 46.1 | 52.0 | 60.6 | 69.5 | 74.6 | 84.2 | 81.8 | 82.3 | 76.8 | 67.7 | 58.2 | 47.1 | 66.8 |
| 4 | 45.5 | 51.4 | 59.7 | 68.3 | 73.7 | 83.2 | 81.6 | 81.8 | 76.3 | 67.0 | 57.7 | 46.5 | 66.1 |
| 5 | 44.8 | 50.7 | 59.1 | 67.6 | 72.8 | 82.1 | 81.3 | 81.5 | 75.8 | 66.5 | 57.3 | 46.1 | 65.5 |
| 6 | 43.8 | 50.2 | 58.6 | 68.2 | 74.0 | 82.9 | 81.4 | 81.6 | 76.2 | 66.3 | 56.8 | 45.5 | 65.5 |
| 7 | 43.3 | 50.2 | 59.1 | 69.9 | 76.2 | 84.5 | 81.9 | 82.5 | 77.3 | 67.2 | 57.2 | 45.4 | 66.3 |
| 8 | 44.1 | 51.4 | 61.7 | 73.6 | 79.8 | 86.7 | 82.9 | 84.0 | 79.0 | 69.7 | 58.5 | 46.2 | 68.2 |
| 9 | 51.3 | 56.6 | 66.7 | 79.7 | 85.9 | 91.3 | 85.2 | 87.2 | 83.6 | 75.7 | 65.6 | 52.8 | 73.5 |
| 10 | 57.8 | 61.5 | 70.8 | 84.1 | 90.0 | 93.9 | 87.5 | 89.2 | 86.9 | 80.7 | 71.2 | 58.6 | 77.8 |
| 11 | 62.2 | 65.4 | 74.3 | 87.1 | 92.6 | 96.6 | 89.4 | 90.8 | 90.0 | 84.3 | 75.2 | 62.9 | 80.9 |
| 12 | 64.9 | 67.7 | 76.1 | 89.3 | 94.3 | 99.0 | 91.3 | 92.2 | 91.8 | 86.8 | 78.0 | 65.4 | 83.1 |
| 13 | 66.2 | 69.2 | 77.5 | 90.4 | 95.3 | 100.9 | 92.4 | 92.6 | 92.7 | 88.0 | 79.5 | 67.2 | 84.4 |
| 14 | 67.7 | 70.6 | 78.8 | 91.6 | 96.4 | 102.0 | 93.0 | 92.8 | 92.9 | 88.8 | 80.9 | 68.4 | 85.4 |
| 15 | 67.3 | 71.0 | 79.4 | 91.9 | 96.3 | 102.9 | 92.5 | 93.1 | 92.4 | 88.2 | 80.3 | 68.2 | 85.3 |
| 16 | 66.3 | 70.4 | 78.8 | 91.6 | 95.6 | 103.2 | 92.8 | 92.9 | 92.0 | 87.4 | 78.8 | 67.1 | 84.8 |
| 17 | 64.5 | 68.6 | 77.7 | 90.2 | 95.3 | 102.3 | 93.2 | 92.5 | 91.1 | 85.3 | 76.2 | 65.2 | 83.6 |
| 18 | 60.3 | 65.4 | 74.8 | 86.8 | 93.0 | 100.1 | 91.4 | 90.8 | 88.2 | 81.8 | 72.3 | 61.1 | 80.6 |
| 19 | 57.0 | 63.0 | 71.9 | 83.2 | 89.5 | 97.4 | 89.2 | 89.5 | 85.6 | 78.6 | 68.4 | 58.2 | 77.7 |
| 20 | 54.5 | 60.9 | 69.8 | 80.5 | 86.2 | 94.6 | 87.8 | 87.9 | 83.7 | 76.2 | 65.7 | 55.1 | 75.3 |
| 21 | 52.8 | 59.2 | 67.9 | 78.3 | 83.5 | 91.5 | 86.6 | 86.7 | 82.2 | 74.5 | 63.8 | 53.7 | 73.5 |
| 22 | 51.1 | 57.5 | 66.2 | 76.4 | 81.3 | 89.6 | 85.5 | 85.5 | 80.7 | 72.6 | 62.4 | 52.2 | 71.8 |
| 23 | 49.6 | 56.0 | 64.8 | 74.9 | 79.4 | 88.1 | 84.4 | 84.6 | 79.3 | 71.1 | 61.0 | 50.7 | 70.4 |
| GROUND TEMPERATURES | 527.5 | 524.6 | 524.4 | 525.8 | 531.3 | 536.8 | 541.6 | 544.6 | 544.9 | 542.4 | 537.8 | 532.4 | |
| CLEARNESS NUMBERS | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | |

## Table 2.11 Multan 1986 Weather Summary

LATITUDE = 30.20 LONGITUDE = -71.50 TIME ZONE = -5

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. TEMP. (F) (DRYBULB) | | 53.3 | 59.6 | 68.7 | 81.3 | 89.3 | 95.0 | 90.1 | 88.2 | 85.5 | 78.8 | 66.1 | 54.3 | 75.9 |
| AVG. TEMP. (F) (WETBULB) | | 46.8 | 51.8 | 59.2 | 65.6 | 70.1 | 77.3 | 79.8 | 79.3 | 74.8 | 68.6 | 58.5 | 48.1 | 65.1 |
| AVG. DAILY MAX. TEMP. | | 69.5 | 73.1 | 80.7 | 94.5 | 102.7 | 107.0 | 98.9 | 97.1 | 97.2 | 92.2 | 82.3 | 70.0 | 88.8 |
| AVG. DAILY MIN. TEMP. | | 39.2 | 47.3 | 56.9 | 67.7 | 75.9 | 83.8 | 81.5 | 80.3 | 74.9 | 67.9 | 53.8 | 41.8 | 64.3 |
| HEATING DEG. DAYS | (BASE 65) | 330.0 | 144.0 | 13.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 30.5 | 281.5 | 799.5 |
| | (BASE 60) | 175.0 | 36.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 140.0 | 351.5 |
| | (BASE 55) | 31.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 39.0 | 70.5 |
| | (BASE 50) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.5 |
| COOLING DEG. DAYS | (BASE 80) | 0.0 | 0.0 | 0.0 | 89.0 | 289.0 | 462.5 | 315.0 | 269.0 | 180.5 | 88.5 | 0.0 | 0.0 | 1693.5 |
| | (BASE 75) | 0.0 | 0.0 | 0.5 | 200.5 | 442.5 | 612.5 | 470.0 | 424.0 | 330.5 | 166.5 | 0.0 | 0.0 | 2647.0 |
| | (BASE 70) | 0.0 | 0.0 | 35.0 | 334.0 | 597.5 | 762.5 | 625.0 | 579.0 | 480.5 | 312.0 | 36.5 | 0.0 | 3762.0 |
| | (BASE 65) | 0.0 | 9.0 | 130.5 | 483.5 | 752.5 | 912.5 | 780.0 | 734.0 | 630.5 | 467.0 | 123.0 | 0.0 | 5022.5 |
| HEATING DEG. HRS./24 | (BASE 65) | 385.8 | 208.2 | 63.5 | 7.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.4 | 117.5 | 364.9 | 1156.7 |
| | (BASE 60) | 273.7 | 122.1 | 18.9 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 51.8 | 249.0 | 717.8 |
| | (BASE 55) | 173.9 | 55.4 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 15.9 | 150.8 | 398.8 |
| | (BASE 50) | 92.5 | 19.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.7 | 79.2 | 193.5 |
| COOLING DEG. HRS./24 | (BASE 80) | 0.0 | 0.9 | 16.1 | 149.5 | 316.0 | 456.8 | 321.1 | 258.0 | 195.3 | 113.3 | 21.4 | 0.0 | 1848.5 |
| | (BASE 75) | 0.0 | 6.1 | 47.4 | 243.0 | 451.3 | 600.7 | 469.9 | 410.7 | 318.5 | 200.8 | 51.0 | 1.9 | 2801.0 |
| | (BASE 70) | 1.6 | 22.5 | 100.6 | 360.8 | 599.7 | 749.9 | 624.5 | 565.6 | 464.7 | 310.6 | 93.0 | 11.0 | 3904.3 |
| | (BASE 65) | 23.2 | 58.1 | 178.5 | 496.5 | 753.9 | 899.9 | 779.5 | 720.6 | 614.6 | 437.1 | 151.8 | 33.0 | 5146.7 |
| MAXIMUM TEMP. | | 73 | 83 | 88 | 109 | 113 | 118 | 107 | 101 | 100 | 101 | 90 | 79 | 118 |
| MINIMUM TEMP. | | 37 | 38 | 47 | 54 | 65 | 70 | 72 | 73 | 68 | 57 | 46 | 35 | 35 |
| NO. DAYS MAX. 90 AND ABOVE | | 0 | 0 | 0 | 22 | 30 | 29 | 30 | 31 | 30 | 20 | 1 | 0 | 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) | | 0.8 | 1.9 | 2.9 | 2.6 | 3.3 | 3.6 | 3.3 | 4.0 | 2.7 | 1.7 | 1.4 | 0.9 | 2.4 |
| AVG. WIND SPEED (DAY) | | 1.8 | 3.3 | 3.6 | 3.4 | 3.8 | 4.5 | 3.9 | 5.7 | 3.9 | 2.8 | 2.7 | 2.0 | 3.5 |
| AVG. WIND SPEED (NIGHT) | | 0.1 | 0.9 | 2.4 | 1.7 | 2.7 | 2.5 | 2.7 | 2.2 | 1.5 | 0.7 | 0.4 | 0.2 | 1.4 |
| AVG. TEMP. (DAY) | | 59.9 | 64.7 | 72.8 | 85.6 | 93.4 | 98.3 | 92.2 | 90.8 | 89.9 | 84.0 | 72.9 | 61.0 | 81.9 |
| AVG. TEMP. (NIGHT) | | 48.9 | 56.0 | 65.2 | 76.9 | 84.5 | 90.8 | 87.7 | 85.5 | 81.2 | 74.1 | 60.8 | 49.6 | 70.4 |
| AVG. SKY COVER (DAY) | | 1.3 | 2.8 | 2.9 | 2.7 | 0.8 | 2.0 | 2.6 | 2.7 | 1.0 | 0.4 | 1.2 | 2.6 | 1.9 |
| AVG. REL. HUM. AT | 4AM | 83.8 | 77.1 | 72.0 | 55.8 | 48.5 | 56.0 | 72.5 | 77.9 | 74.6 | 76.4 | 84.0 | 83.4 | 71.8 |
| | 10AM | 76.2 | 74.9 | 66.9 | 49.7 | 42.7 | 53.7 | 70.7 | 73.5 | 67.0 | 65.0 | 69.3 | 76.5 | 65.5 |
| | 4PM | 35.5 | 38.8 | 39.6 | 29.5 | 25.9 | 34.3 | 52.1 | 53.5 | 44.6 | 38.9 | 36.5 | 38.0 | 39.0 |
| | 10PM | 75.1 | 67.1 | 63.2 | 51.3 | 46.5 | 50.3 | 66.0 | 69.6 | 66.8 | 69.5 | 79.4 | 79.5 | 65.4 |

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 2010.8 | 1836.2 | 1923.8 | 2031.4 | 2546.0 | 2220.2 | 1982.0 | 1925.9 | 2310.9 | 2385.7 | 2059.7 | 1666.0 | 2076.0 |
| TOTAL HORIZNTL | 1111.8 | 1272.2 | 1646.0 | 1964.1 | 2275.6 | 2247.2 | 2185.0 | 2005.1 | 1857.4 | 1605.2 | 1225.8 | 959.5 | 1698.3 |
| MAX. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 2420.5 | 2635.5 | 2713.2 | 2777.9 | 2771.1 | 2753.2 | 2713.5 | 2609.1 | 2593.6 | 2524.4 | 2406.8 | 2241.7 | 2777.9 |
| TOTAL HORIZNTL | 1372.9 | 1672.8 | 1964.9 | 2229.6 | 2398.7 | 2426.3 | 2413.4 | 2184.1 | 2112.2 | 1800.7 | 1470.3 | 1222.1 | 2426.3 |
| MIN. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 952.9 | 533.9 | 980.3 | 849.5 | 1218.2 | 769.8 | 694.8 | 757.8 | 1305.8 | 1243.0 | 517.4 | 224.3 | 224.3 |
| TOTAL HORIZNTL | 835.7 | 876.7 | 1330.4 | 1697.0 | 1867.6 | 1909.7 | 1864.3 | 1836.7 | 1502.3 | 1139.1 | 710.2 | 571.1 | 571.1 |
| MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 284.7 | 286.9 | 286.3 | 276.8 | 263.7 | 254.9 | 251.4 | 258.8 | 268.8 | 276.9 | 277.4 | 278.3 | 286.9 |
| TOTAL HORIZNTL | 212.2 | 242.9 | 275.7 | 287.7 | 291.1 | 291.4 | 290.6 | 281.6 | 275.5 | 251.1 | 219.5 | 193.8 | 291.4 |
| AVG MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORML | 262.1 | 239.9 | 232.8 | 230.8 | 250.4 | 230.2 | 213.3 | 210.9 | 255.0 | 270.9 | 253.7 | 230.9 | 240.1 |
| TOTAL HORIZNTL | 179.5 | 210.2 | 248.5 | 271.0 | 287.0 | 283.5 | 276.0 | 268.3 | 260.2 | 234.8 | 188.5 | 159.5 | 239.0 |

## Table 2.11 Multan 1986 Weather Summary (continued)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 183.2 | 255.7 | 371.6 | 485.3 | 563.4 | 701.3 | 726.2 | 549.6 | 354.7 | 268.1 | 214.0 | 185.6 | 405.8 |
| E | 694.8 | 784.1 | 1002.6 | 1168.8 | 1259.3 | 1268.3 | 1264.5 | 1202.0 | 1082.9 | 957.6 | 769.8 | 590.4 | 1004.8 |
| S | 1618.9 | 1425.4 | 1296.1 | 1027.7 | 743.4 | 697.4 | 793.9 | 949.7 | 1202.1 | 1579.6 | 1626.5 | 1457.8 | 1200.4 |
| W | 686.0 | 777.7 | 984.1 | 1156.2 | 1262.9 | 1237.5 | 1297.0 | 1176.2 | 1087.4 | 953.9 | 758.5 | 627.2 | 1001.6 |
| MAX. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 254.6 | 446.1 | 573.8 | 732.1 | 831.1 | 971.2 | 977.9 | 867.6 | 558.7 | 338.0 | 287.1 | 268.0 | 977.9 |
| E | 841.8 | 1046.7 | 1177.0 | 1317.3 | 1318.0 | 1375.2 | 1479.6 | 1326.5 | 1220.7 | 1058.9 | 893.8 | 741.4 | 1479.6 |
| S | 1851.2 | 1814.3 | 1643.0 | 1183.7 | 1035.3 | 1007.5 | 1053.4 | 1060.6 | 1363.8 | 1741.9 | 1835.2 | 1846.2 | 1851.2 |
| W | 840.1 | 1007.0 | 1154.0 | 1253.3 | 1383.2 | 1383.1 | 1510.5 | 1311.4 | 1207.2 | 1060.5 | 895.9 | 770.1 | 1510.5 |
| MAX. HRLY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 40.1 | 86.4 | 96.9 | 103.2 | 109.4 | 111.8 | 113.7 | 104.3 | 91.7 | 76.4 | 44.4 | 42.5 | 113.7 |
| E | 200.5 | 224.7 | 242.7 | 242.9 | 237.7 | 232.2 | 232.1 | 235.0 | 234.8 | 227.5 | 209.5 | 187.8 | 242.9 |
| S | 260.5 | 248.5 | 221.3 | 187.5 | 167.3 | 148.2 | 157.3 | 164.1 | 203.9 | 236.5 | 254.8 | 260.6 | 260.6 |
| W | 202.4 | 222.5 | 239.9 | 240.2 | 237.6 | 232.9 | 232.5 | 233.1 | 230.6 | 226.5 | 209.3 | 189.5 | 240.2 |

| DESIGN TEMPERATURES | SUMMER | | WINTER |
|---|---|---|---|
| PER CENT | T(DRY) | T(WET) | T(DRY) |
| 1.0 | 113 | 85 | 37 |
| 2.5 | 109 | 84 | 37 |
| 5.0 | 104 | 83 | |

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 | 47.3 | 54.2 | 63.9 | 76.0 | 83.5 | 90.1 | 87.2 | 85.3 | 80.5 | 73.6 | 59.8 | 48.6 | 70.9 |
| 1 | 46.1 | 53.2 | 62.9 | 75.0 | 82.7 | 89.2 | 86.5 | 84.2 | 79.5 | 72.5 | 58.9 | 47.7 | 70.0 |
| 2 | 44.8 | 52.1 | 61.8 | 74.1 | 81.9 | 87.9 | 85.1 | 83.1 | 78.4 | 71.7 | 58.1 | 46.9 | 68.9 |
| 3 | 43.7 | 51.0 | 60.9 | 73.2 | 81.0 | 86.9 | 84.3 | 82.3 | 77.2 | 71.0 | 57.1 | 46.1 | 68.0 |
| 4 | 42.5 | 49.8 | 60.0 | 71.9 | 79.4 | 85.5 | 83.6 | 81.3 | 76.1 | 70.3 | 56.0 | 45.3 | 66.9 |
| 5 | 41.3 | 49.6 | 58.8 | 69.9 | 77.4 | 84.7 | 83.2 | 82.1 | 76.4 | 69.7 | 55.6 | 43.5 | 66.1 |
| 6 | 40.3 | 48.9 | 57.8 | 68.2 | 76.6 | 84.3 | 82.5 | 81.5 | 75.7 | 68.9 | 54.7 | 42.7 | 65.3 |
| 7 | 39.6 | 48.1 | 57.7 | 68.9 | 78.1 | 85.8 | 83.3 | 82.0 | 76.3 | 68.4 | 54.4 | 42.3 | 65.5 |
| 8 | 40.4 | 48.9 | 60.3 | 74.1 | 83.1 | 88.6 | 85.3 | 83.8 | 79.5 | 71.1 | 56.3 | 42.7 | 67.9 |
| 9 | 47.0 | 54.4 | 65.4 | 79.3 | 87.3 | 92.4 | 87.9 | 86.0 | 83.6 | 76.5 | 63.4 | 49.6 | 72.8 |
| 10 | 55.3 | 61.0 | 70.0 | 83.9 | 91.5 | 96.0 | 90.2 | 88.6 | 88.4 | 82.1 | 69.6 | 57.2 | 77.9 |
| 11 | 61.5 | 66.0 | 73.9 | 87.5 | 95.3 | 99.5 | 92.1 | 91.5 | 91.6 | 85.9 | 74.4 | 62.7 | 81.9 |
| 12 | 64.9 | 69.1 | 76.6 | 90.0 | 97.5 | 102.3 | 94.0 | 93.0 | 94.0 | 88.3 | 77.3 | 65.6 | 84.4 |
| 13 | 67.1 | 70.8 | 78.6 | 91.7 | 99.7 | 104.4 | 95.9 | 94.8 | 96.0 | 90.4 | 80.4 | 68.3 | 86.6 |
| 14 | 68.8 | 72.1 | 79.6 | 92.7 | 101.2 | 105.6 | 97.3 | 96.0 | 96.7 | 91.5 | 82.0 | 69.5 | 87.8 |
| 15 | 69.3 | 72.4 | 79.9 | 93.6 | 102.1 | 106.4 | 98.0 | 96.6 | 96.9 | 91.9 | 82.1 | 69.6 | 88.3 |
| 16 | 69.0 | 72.2 | 80.4 | 93.6 | 102.1 | 106.5 | 98.0 | 96.4 | 96.4 | 91.1 | 81.4 | 69.4 | 88.1 |
| 17 | 67.2 | 71.4 | 79.5 | 92.6 | 101.3 | 105.5 | 98.1 | 95.3 | 94.8 | 89.0 | 77.8 | 66.7 | 86.7 |
| 18 | 62.7 | 68.1 | 77.2 | 90.5 | 99.3 | 103.9 | 96.5 | 93.6 | 91.6 | 84.4 | 71.3 | 59.9 | 83.3 |
| 19 | 57.0 | 64.3 | 73.5 | 86.2 | 95.1 | 99.9 | 94.5 | 90.9 | 88.3 | 80.1 | 67.6 | 55.9 | 79.5 |
| 20 | 53.9 | 61.5 | 70.5 | 82.5 | 90.9 | 96.7 | 91.9 | 88.9 | 85.9 | 78.1 | 65.0 | 53.2 | 76.6 |
| 21 | 51.4 | 59.2 | 68.3 | 80.2 | 87.4 | 94.0 | 90.3 | 87.9 | 84.0 | 76.2 | 62.8 | 51.1 | 74.5 |
| 22 | 49.8 | 57.2 | 66.5 | 78.6 | 85.2 | 92.5 | 89.2 | 86.8 | 82.5 | 74.7 | 61.3 | 49.8 | 72.9 |
| 23 | 48.3 | 55.8 | 65.2 | 77.2 | 84.1 | 91.3 | 88.5 | 86.0 | 81.3 | 73.8 | 60.2 | 48.9 | 71.8 |
| GROUND TEMPERATURES | 528.1 | 524.9 | 524.7 | 526.2 | 532.2 | 538.3 | 543.5 | 546.9 | 547.1 | 544.4 | 539.3 | 533.5 | |
| CLEARNESS NUMBERS | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | |

## Table 2.12 Peshawar 1986 Weather Summary

LATITUDE = 34.00 LONGITUDE = -71.60 TIME ZONE = -5

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. TEMP. (F) (DRYBULB) | | 49.8 | 54.7 | 60.5 | 72.7 | 83.2 | 90.9 | 89.2 | 86.1 | 82.6 | 73.9 | 61.6 | 52.3 | 71.5 |
| AVG. TEMP. (F) (WETBULB) | | 43.9 | 48.3 | 54.4 | 62.5 | 66.3 | 72.8 | 77.8 | 77.4 | 72.3 | 65.1 | 55.3 | 48.2 | 62.1 |
| AVG. DAILY MAX. TEMP. | | 65.2 | 66.5 | 71.0 | 85.4 | 96.1 | 103.9 | 99.0 | 95.7 | 94.5 | 87.7 | 75.5 | 64.4 | 83.8 |
| AVG. DAILY MIN. TEMP. | | 38.7 | 44.7 | 51.5 | 60.8 | 70.2 | 78.2 | 80.5 | 78.4 | 72.8 | 63.6 | 52.3 | 44.0 | 61.4 |
| HEATING DEG. DAYS | (BASE 65) | 404.0 | 264.0 | 129.0 | 8.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 81.0 | 334.0 | 1220.0 |
| | (BASE 60) | 249.0 | 126.0 | 39.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 26.0 | 186.0 | 626.5 |
| | (BASE 55) | 94.0 | 27.5 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.0 | 69.0 | 197.0 |
| | (BASE 50) | 6.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.5 | 14.5 |
| COOLING DEG. DAYS | (BASE 80) | 0.0 | 0.0 | 0.0 | 9.0 | 130.5 | 331.0 | 302.0 | 221.5 | 115.0 | 18.0 | 0.0 | 0.0 | 1127.0 |
| | (BASE 75) | 0.0 | 0.0 | 0.0 | 44.5 | 261.0 | 480.5 | 457.0 | 373.0 | 259.5 | 81.5 | 0.0 | 0.0 | 1957.0 |
| | (BASE 70) | 0.0 | 0.0 | 0.0 | 124.0 | 406.5 | 630.5 | 612.0 | 528.0 | 409.5 | 177.5 | 2.5 | 0.0 | 2890.5 |
| | (BASE 65) | 0.0 | 0.0 | 12.5 | 251.0 | 561.5 | 780.5 | 767.0 | 683.0 | 559.5 | 330.5 | 48.0 | 0.0 | 3993.5 |
| HEATING DEG. HRS./24 | (BASE 65) | 476.0 | 307.6 | 196.8 | 38.4 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 32.0 | 175.9 | 403.6 | 1631.8 |
| | (BASE 60) | 343.0 | 196.5 | 96.1 | 13.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.2 | 87.0 | 268.5 | 1010.7 |
| | (BASE 55) | 226.5 | 103.2 | 29.8 | 3.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 29.9 | 152.5 | 545.8 |
| | (BASE 50) | 126.1 | 38.6 | 3.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.3 | 64.6 | 238.2 |
| COOLING DEG. HRS./24 | (BASE 80) | 0.0 | 0.0 | 0.5 | 48.3 | 191.9 | 351.3 | 294.2 | 205.1 | 144.4 | 54.0 | 2.4 | 0.0 | 1292.1 |
| | (BASE 75) | 0.0 | 0.1 | 8.2 | 97.9 | 294.0 | 484.9 | 441.7 | 345.6 | 244.8 | 112.1 | 14.1 | 0.1 | 2043.6 |
| | (BASE 70) | 0.0 | 3.9 | 26.6 | 170.2 | 421.0 | 628.1 | 595.5 | 499.9 | 380.8 | 198.9 | 36.6 | 1.5 | 2963.1 |
| | (BASE 65) | 4.3 | 19.7 | 56.2 | 269.0 | 565.5 | 777.5 | 750.5 | 654.9 | 529.0 | 308.1 | 74.2 | 9.6 | 4018.7 |
| MAXIMUM TEMP. | | 70 | 76 | 84 | 100 | 106 | 118 | 106 | 103 | 102 | 96 | 85 | 77 | 118 |
| MINIMUM TEMP. | | 35 | 37 | 44 | 48 | 60 | 67 | 71 | 72 | 65 | 55 | 44 | 37 | 35 |
| NO. DAYS MAX. 90 AND ABOVE | | 0 | 0 | 0 | 8 | 25 | 30 | 30 | 26 | 27 | 12 | 0 | 0 | 158 |
| 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) | | 0.9 | 2.4 | 2.2 | 2.9 | 6.0 | 4.1 | 4.0 | 3.3 | 2.3 | 1.3 | 0.9 | 1.2 | 2.6 |
| AVG. WIND SPEED (DAY) | | 1.0 | 2.7 | 3.0 | 3.6 | 6.2 | 4.5 | 5.2 | 4.4 | 3.3 | 2.1 | 0.9 | 1.4 | 3.4 |
| AVG. WIND SPEED (NIGHT) | | 0.8 | 2.2 | 1.5 | 2.1 | 5.7 | 3.6 | 2.4 | 2.1 | 1.3 | 0.6 | 0.9 | 1.2 | 1.9 |
| AVG. TEMP. (DAY) | | 55.3 | 59.2 | 63.8 | 76.8 | 87.1 | 94.8 | 91.2 | 88.5 | 86.4 | 78.6 | 66.2 | 56.2 | 77.1 |
| AVG. TEMP. (NIGHT) | | 46.3 | 51.6 | 57.6 | 68.3 | 78.3 | 85.8 | 86.8 | 83.5 | 78.9 | 69.8 | 58.1 | 49.7 | 66.4 |
| AVG. SKY COVER (DAY) | | 2.0 | 4.2 | 4.7 | 3.8 | 2.6 | 2.8 | 3.0 | 4.2 | 2.2 | 1.1 | 2.9 | 4.5 | 3.2 |
| AVG. REL. HUM. AT | 4AM | 80.4 | 81.2 | 84.4 | 75.8 | 58.6 | 56.2 | 70.8 | 78.4 | 76.2 | 78.0 | 81.9 | 87.1 | 75.8 |
| | 10AM | 71.6 | 71.3 | 75.8 | 58.5 | 43.7 | 45.3 | 65.3 | 73.7 | 65.6 | 70.2 | 78.9 | 82.5 | 66.9 |
| | 4PM | 40.6 | 45.7 | 53.5 | 41.5 | 31.0 | 30.8 | 49.7 | 55.7 | 44.4 | 42.4 | 47.0 | 55.7 | 44.9 |
| | 10PM | 74.6 | 72.3 | 75.5 | 65.5 | 48.1 | 45.9 | 62.1 | 70.1 | 68.4 | 70.7 | 76.8 | 83.2 | 67.8 |

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 1741.2 | 1422.4 | 1427.0 | 1720.1 | 2100.7 | 2027.6 | 1911.5 | 1554.8 | 1994.3 | 2184.5 | 1559.8 | 1166.3 | 1735.7 |
| TOTAL HORIZNTL | 942.3 | 1030.0 | 1449.4 | 1838.3 | 2104.4 | 2178.1 | 2123.6 | 1870.2 | 1705.3 | 1412.3 | 959.7 | 743.3 | 1532.3 |
| MAX. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 2303.6 | 2426.8 | 2598.0 | 2716.5 | 2786.8 | 2777.0 | 2751.9 | 2435.0 | 2567.3 | 2447.0 | 2308.8 | 2105.8 | 2786.8 |
| TOTAL HORIZNTL | 1229.9 | 1436.3 | 1704.1 | 2115.5 | 2305.1 | 2439.4 | 2425.1 | 2009.6 | 2032.0 | 1636.1 | 1325.0 | 1031.7 | 2439.4 |
| MIN. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 710.0 | 496.0 | 582.3 | 801.7 | 835.6 | 1038.5 | 815.5 | 638.6 | 949.2 | 1202.2 | 433.3 | 530.2 | 433.3 |
| TOTAL HORIZNTL | 679.1 | 776.5 | 1207.3 | 1589.9 | 1788.6 | 1961.8 | 1887.6 | 1717.4 | 1367.2 | 1086.6 | 619.3 | 609.2 | 609.2 |
| MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 280.0 | 283.5 | 283.3 | 275.4 | 262.7 | 253.1 | 250.4 | 257.5 | 264.9 | 272.7 | 272.7 | 272.1 | 283.5 |
| TOTAL HORIZNTL | 194.6 | 227.8 | 247.8 | 278.0 | 286.8 | 287.8 | 287.1 | 270.6 | 266.8 | 239.3 | 203.2 | 171.3 | 287.8 |
| AVG MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORML | 237.1 | 189.7 | 175.8 | 197.8 | 227.1 | 227.0 | 202.2 | 182.5 | 233.6 | 259.8 | 214.9 | 170.0 | 209.9 |
| TOTAL HORIZNTL | 157.5 | 170.8 | 227.5 | 255.9 | 273.9 | 277.0 | 270.3 | 254.7 | 246.5 | 217.7 | 152.8 | 124.6 | 219.4 |

## Table 2.12 Peshawar 1986 Weather Summary (continued)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 176.2 | 241.7 | 423.6 | 519.5 | 587.4 | 689.8 | 678.4 | 581.1 | 373.0 | 239.7 | 204.7 | 189.3 | 409.7 |
| E | 621.4 | 674.4 | 958.6 | 1178.6 | 1275.7 | 1290.0 | 1244.3 | 1185.3 | 1021.9 | 885.8 | 641.2 | 506.3 | 958.5 |
| S | 1514.0 | 1251.5 | 1298.6 | 1132.7 | 888.6 | 819.1 | 874.5 | 1057.8 | 1257.7 | 1543.6 | 1378.0 | 1197.0 | 1184.3 |
| W | 601.9 | 647.4 | 914.1 | 1093.5 | 1160.5 | 1193.1 | 1246.4 | 1097.8 | 1008.3 | 822.2 | 627.5 | 488.7 | 909.8 |
| MAX. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 255.8 | 388.4 | 615.8 | 748.6 | 857.8 | 907.6 | 930.6 | 813.3 | 585.0 | 329.2 | 266.6 | 238.0 | 930.6 |
| E | 778.8 | 928.6 | 1174.6 | 1342.1 | 1462.0 | 1445.9 | 1399.5 | 1323.2 | 1188.4 | 1003.1 | 836.0 | 667.1 | 1462.0 |
| S | 1829.9 | 1763.8 | 1703.0 | 1300.8 | 1144.9 | 1046.2 | 1098.6 | 1152.2 | 1410.8 | 1750.0 | 1802.0 | 1806.8 | 1829.9 |
| W | 778.3 | 803.1 | 1026.1 | 1226.1 | 1349.3 | 1408.6 | 1393.8 | 1328.3 | 1159.3 | 993.6 | 838.7 | 675.5 | 1408.6 |
| MAX. HRLY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 40.6 | 78.9 | 95.8 | 101.4 | 104.2 | 103.8 | 104.3 | 104.1 | 95.5 | 68.7 | 42.4 | 38.6 | 104.3 |
| E | 193.0 | 216.9 | 235.9 | 240.5 | 237.2 | 232.2 | 232.8 | 233.7 | 232.7 | 222.5 | 201.1 | 172.6 | 240.5 |
| S | 264.6 | 255.9 | 233.1 | 198.2 | 175.7 | 155.1 | 165.2 | 179.0 | 209.5 | 245.0 | 255.3 | 264.6 | 264.6 |
| W | 194.7 | 200.2 | 219.2 | 238.6 | 237.3 | 233.6 | 232.8 | 226.2 | 228.1 | 221.0 | 199.4 | 175.4 | 238.6 |

| DESIGN TEMPERATURES | SUMMER | | WINTER |
|---|---|---|---|
| PER CENT | T(DRY) | T(WET) | T(DRY) |
| 1.0 | 109 | 85 | 37 |
| 2.5 | 105 | 84 | 38 |
| 5.0 | 102 | 83 | |

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 | 44.5 | 49.9 | 56.5 | 67.5 | 77.4 | 84.1 | 86.1 | 83.0 | 78.3 | 69.0 | 57.5 | 49.1 | 67.0 |
| 1 | 43.5 | 49.2 | 55.5 | 66.1 | 76.5 | 83.0 | 85.1 | 82.3 | 77.3 | 68.1 | 56.7 | 48.4 | 66.1 |
| 2 | 42.6 | 48.3 | 54.9 | 64.9 | 75.7 | 82.2 | 83.9 | 81.5 | 76.4 | 67.2 | 55.9 | 47.7 | 65.2 |
| 3 | 41.8 | 47.5 | 54.4 | 63.8 | 73.9 | 81.3 | 83.6 | 81.0 | 75.6 | 66.4 | 55.2 | 47.0 | 64.4 |
| 4 | 40.9 | 46.7 | 53.6 | 63.1 | 72.4 | 79.6 | 82.3 | 80.4 | 74.3 | 65.6 | 54.4 | 46.2 | 63.4 |
| 5 | 40.2 | 46.3 | 52.9 | 61.9 | 71.2 | 79.2 | 81.7 | 79.9 | 73.7 | 65.3 | 53.7 | 45.3 | 62.7 |
| 6 | 39.7 | 45.8 | 52.4 | 61.3 | 70.5 | 79.1 | 81.4 | 79.6 | 73.2 | 64.3 | 53.1 | 44.8 | 62.2 |
| 7 | 39.3 | 45.7 | 51.9 | 61.7 | 72.8 | 81.1 | 82.5 | 80.1 | 73.4 | 63.7 | 52.8 | 44.5 | 62.5 |
| 8 | 39.5 | 46.6 | 53.6 | 65.2 | 77.4 | 85.4 | 84.5 | 81.7 | 76.2 | 65.2 | 53.1 | 44.5 | 64.5 |
| 9 | 43.1 | 50.8 | 57.8 | 72.0 | 83.2 | 91.1 | 86.8 | 84.2 | 79.9 | 69.5 | 56.0 | 46.8 | 68.5 |
| 10 | 49.2 | 56.8 | 62.0 | 76.9 | 87.5 | 95.3 | 89.0 | 86.8 | 84.0 | 74.6 | 61.0 | 50.5 | 72.8 |
| 11 | 54.5 | 60.2 | 65.1 | 79.7 | 89.7 | 97.3 | 91.4 | 89.0 | 86.9 | 79.1 | 65.5 | 54.8 | 76.2 |
| 12 | 58.7 | 62.5 | 67.0 | 80.9 | 92.2 | 99.9 | 93.7 | 91.2 | 89.7 | 83.1 | 69.7 | 58.9 | 79.0 |
| 13 | 62.2 | 63.6 | 68.1 | 82.3 | 93.5 | 100.9 | 95.3 | 93.0 | 92.0 | 85.3 | 72.6 | 61.9 | 81.0 |
| 14 | 63.3 | 64.9 | 69.1 | 83.1 | 94.6 | 101.5 | 95.8 | 93.9 | 93.4 | 86.6 | 74.2 | 63.3 | 82.0 |
| 15 | 64.6 | 65.5 | 69.5 | 84.1 | 94.5 | 102.2 | 97.4 | 93.9 | 93.9 | 87.3 | 75.1 | 64.1 | 82.7 |
| 16 | 64.7 | 65.6 | 69.7 | 84.1 | 94.2 | 101.6 | 97.5 | 93.6 | 93.4 | 86.5 | 74.5 | 63.3 | 82.5 |
| 17 | 62.8 | 64.3 | 69.0 | 82.8 | 93.4 | 101.3 | 96.5 | 92.2 | 91.7 | 84.5 | 70.9 | 60.1 | 80.9 |
| 18 | 56.9 | 61.2 | 66.8 | 80.4 | 91.8 | 100.1 | 95.1 | 90.2 | 89.2 | 79.6 | 65.7 | 56.3 | 77.8 |
| 19 | 52.5 | 58.3 | 64.1 | 77.5 | 88.4 | 97.6 | 93.9 | 88.8 | 85.9 | 76.3 | 62.9 | 53.9 | 75.1 |
| 20 | 50.0 | 55.7 | 61.6 | 74.0 | 84.8 | 93.8 | 91.8 | 86.9 | 83.7 | 74.0 | 61.4 | 52.3 | 72.6 |
| 21 | 48.2 | 54.1 | 59.8 | 71.7 | 82.0 | 90.4 | 89.9 | 85.7 | 81.8 | 72.1 | 60.1 | 51.3 | 70.7 |
| 22 | 46.8 | 52.4 | 58.6 | 70.3 | 80.2 | 88.1 | 88.5 | 84.5 | 80.4 | 70.8 | 58.9 | 50.5 | 69.2 |
| 23 | 45.5 | 51.2 | 57.3 | 69.2 | 78.7 | 86.0 | 87.5 | 83.6 | 79.2 | 69.7 | 57.8 | 49.6 | 68.0 |
| GROUND TEMPERATURES | 523.8 | 520.7 | 520.4 | 521.9 | 527.9 | 533.9 | 539.0 | 542.3 | 542.6 | 539.9 | 534.9 | 529.1 | |
| CLEARNESS NUMBERS | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | |

## Table 2.13 Quetta 1986 Weather Summary

LATITUDE = 30.20 LONGITUDE = -67.00 TIME ZONE = -5

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. TEMP. (F) (DRYBULB) | | 38.0 | 42.3 | 49.7 | 65.1 | 73.6 | 81.6 | 81.8 | 77.8 | 69.5 | 62.5 | 50.3 | 40.0 | 61.1 |
| AVG. TEMP. (F) (WETBULB) | | 32.0 | 37.3 | 43.4 | 50.5 | 55.0 | 58.7 | 59.1 | 59.6 | 51.8 | 47.2 | 40.3 | 33.0 | 47.4 |
| AVG. DAILY MAX. TEMP. | | 50.2 | 52.0 | 59.9 | 78.1 | 87.0 | 95.1 | 94.6 | 90.7 | 85.5 | 78.6 | 65.5 | 54.0 | 74.4 |
| AVG. DAILY MIN. TEMP. | | 25.5 | 32.1 | 39.3 | 50.0 | 55.3 | 65.0 | 66.8 | 64.7 | 52.2 | 45.1 | 35.5 | 26.7 | 46.6 |
| HEATING DEG. DAYS | (BASE 65) | 842.0 | 641.5 | 478.0 | 70.0 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 138.0 | 435.5 | 764.0 | 3370.5 |
| | (BASE 60) | 687.0 | 501.5 | 323.0 | 21.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 66.0 | 285.5 | 609.0 | 2493.0 |
| | (BASE 55) | 532.0 | 361.5 | 184.5 | 6.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 17.0 | 155.0 | 459.5 | 1715.5 |
| | (BASE 50) | 377.0 | 226.0 | 91.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 72.5 | 324.5 | 1092.0 |
| COOLING DEG. DAYS | (BASE 80) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 63.0 | 47.0 | 25.5 | 0.0 | 0.0 | 0.0 | 0.0 | 135.5 |
| | (BASE 75) | 0.0 | 0.0 | 0.0 | 0.0 | 2.5 | 165.0 | 181.0 | 104.5 | 0.0 | 0.0 | 0.0 | 0.0 | 453.0 |
| | (BASE 70) | 0.0 | 0.0 | 0.0 | 4.5 | 72.0 | 300.5 | 333.0 | 241.5 | 10.0 | 0.5 | 0.0 | 0.0 | 962.0 |
| | (BASE 65) | 0.0 | 0.0 | 0.0 | 42.0 | 192.0 | 450.5 | 488.0 | 394.0 | 115.5 | 40.0 | 0.0 | 0.0 | 1722.0 |
| HEATING DEG. HRS./24 | (BASE 65) | 836.8 | 635.0 | 477.5 | 131.4 | 53.7 | 7.0 | 2.5 | 10.1 | 91.3 | 211.4 | 465.9 | 779.2 | 3701.8 |
| | (BASE 60) | 681.8 | 496.2 | 337.9 | 69.5 | 19.9 | 1.5 | 0.1 | 1.4 | 40.2 | 131.2 | 345.3 | 631.5 | 2756.4 |
| | (BASE 55) | 527.2 | 361.7 | 216.7 | 31.3 | 4.2 | 0.2 | 0.0 | 0.0 | 10.5 | 70.6 | 236.8 | 491.2 | 1950.5 |
| | (BASE 50) | 381.5 | 237.5 | 121.2 | 12.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.9 | 32.4 | 144.8 | 364.3 | 1295.0 |
| COOLING DEG. HRS./24 | (BASE 80) | 0.0 | 0.0 | 0.0 | 7.5 | 66.0 | 169.8 | 157.8 | 101.2 | 32.8 | 15.5 | 0.0 | 0.0 | 550.6 |
| | (BASE 75) | 0.0 | 0.0 | 0.0 | 27.8 | 131.1 | 263.7 | 255.4 | 178.6 | 82.5 | 40.0 | 0.2 | 0.2 | 979.2 |
| | (BASE 70) | 0.0 | 0.0 | 0.0 | 71.0 | 217.2 | 375.3 | 378.3 | 279.5 | 146.2 | 78.0 | 6.0 | 0.5 | 1552.0 |
| | (BASE 65) | 0.0 | 0.1 | 3.6 | 135.3 | 321.8 | 503.9 | 522.6 | 406.5 | 226.4 | 133.8 | 25.0 | 3.2 | 2282.2 |
| MAXIMUM TEMP. | | 57 | 66 | 71 | 89 | 93 | 105 | 100 | 99 | 89 | 87 | 77 | 79 | 105 |
| MINIMUM TEMP. | | 15 | 25 | 26 | 34 | 47 | 52 | 58 | 54 | 46 | 32 | 26 | 11 | 11 |
| NO. DAYS MAX. 90 AND ABOVE | | 0 | 0 | 0 | 0 | 13 | 23 | 26 | 21 | 0 | 0 | 0 | 0 | 83 |
| NO. DAYS MAX. 32 AND BELOW | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| NO. DAYS MIN. 32 AND BELOW | | 27 | 17 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 10 | 22 | 82 |
| NO. DAYS MIN. 0 AND BELOW | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| AVG. WIND SPEED (MPH) | | 7.9 | 8.4 | 9.8 | 10.0 | 14.2 | 10.9 | 11.4 | 9.4 | 6.8 | 7.7 | 5.5 | 6.1 | 9.0 |
| AVG. WIND SPEED (DAY) | | 7.4 | 7.2 | 10.5 | 11.3 | 16.9 | 12.0 | 11.1 | 9.3 | 7.4 | 9.6 | 6.0 | 5.4 | 9.8 |
| AVG. WIND SPEED (NIGHT) | | 8.2 | 9.1 | 9.2 | 8.7 | 11.3 | 9.7 | 11.8 | 9.5 | 6.2 | 6.2 | 5.1 | 6.6 | 8.4 |
| AVG. TEMP. (DAY) | | 41.4 | 44.6 | 52.6 | 69.6 | 78.4 | 86.4 | 85.9 | 82.0 | 75.7 | 68.9 | 56.6 | 45.7 | 67.5 |
| AVG. TEMP. (NIGHT) | | 36.0 | 40.9 | 47.5 | 60.9 | 68.5 | 76.1 | 77.4 | 73.7 | 64.0 | 57.3 | 45.8 | 36.3 | 55.7 |
| AVG. SKY COVER (DAY) | | 1.8 | 4.1 | 4.2 | 3.3 | 1.4 | 2.3 | 2.1 | 2.4 | 0.3 | 0.5 | 2.0 | 2.5 | 2.2 |
| AVG. REL. HUM. AT | 4AM | 75.8 | 74.9 | 76.8 | 55.2 | 47.0 | 39.7 | 41.0 | 55.0 | 51.7 | 54.5 | 70.9 | 63.5 | 58.8 |
| | 10AM | 70.7 | 80.7 | 72.4 | 44.4 | 33.7 | 29.9 | 35.7 | 48.3 | 38.8 | 43.5 | 53.8 | 37.3 | 48.9 |
| | 4PM | 41.4 | 54.1 | 53.2 | 27.2 | 24.2 | 18.7 | 18.0 | 23.6 | 18.6 | 19.5 | 30.0 | 58.3 | 32.2 |
| | 10PM | 57.7 | 70.5 | 66.9 | 37.3 | 32.7 | 27.5 | 28.4 | 37.9 | 30.7 | 34.4 | 47.9 | 75.1 | 45.5 |

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 1902.4 | 1484.2 | 1552.7 | 1862.3 | 2378.3 | 2110.6 | 2137.2 | 2006.1 | 2481.6 | 2366.6 | 1873.1 | 1675.4 | 1988.9 |
| TOTAL HORIZNTL | 1110.9 | 1203.0 | 1591.7 | 1910.2 | 2219.1 | 2217.9 | 2207.1 | 2025.6 | 1916.9 | 1585.1 | 1137.0 | 965.7 | 1676.7 |
| MAX. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 2426.7 | 2602.3 | 2754.1 | 2772.0 | 2779.2 | 2757.8 | 2715.7 | 2616.7 | 2582.7 | 2535.6 | 2410.0 | 2225.6 | 2779.2 |
| TOTAL HORIZNTL | 1373.9 | 1635.1 | 2054.8 | 2226.7 | 2394.1 | 2428.6 | 2414.3 | 2218.7 | 2093.9 | 1814.7 | 1469.4 | 1179.1 | 2428.6 |
| MIN. DAILY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 704.4 | 507.8 | 545.3 | 856.6 | 1399.4 | 971.9 | 822.2 | 526.9 | 1940.0 | 1328.4 | 480.4 | 675.4 | 480.4 |
| TOTAL HORIZNTL | 788.3 | 871.7 | 1294.6 | 1649.2 | 2022.7 | 1981.1 | 1894.3 | 1659.4 | 1717.1 | 1149.3 | 704.5 | 729.9 | 704.5 |
| MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORMAL | 284.6 | 286.7 | 283.0 | 277.2 | 263.5 | 254.1 | 251.5 | 259.2 | 270.1 | 277.2 | 277.8 | 278.0 | 286.7 |
| TOTAL HORIZNTL | 211.6 | 242.2 | 275.3 | 288.4 | 291.8 | 292.0 | 290.8 | 283.2 | 276.1 | 253.8 | 221.1 | 191.8 | 292.0 |
| AVG MAX HRLY SOLAR | | | | | | | | | | | | | |
| DIRECT NORML | 250.7 | 204.3 | 189.3 | 216.8 | 247.9 | 222.4 | 226.8 | 218.2 | 262.3 | 269.5 | 237.5 | 233.1 | 231.8 |
| TOTAL HORIZNTL | 179.5 | 202.5 | 240.4 | 266.6 | 283.1 | 279.6 | 278.6 | 270.9 | 264.0 | 236.1 | 178.5 | 161.1 | 236.9 |

## Table 2.13 Quetta 1986 Weather Summary (continued)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 206.3 | 304.8 | 448.0 | 507.5 | 593.9 | 733.6 | 690.2 | 532.1 | 334.1 | 262.5 | 204.5 | 183.6 | 417.4 |
| E | 717.0 | 807.0 | 1038.7 | 1181.8 | 1280.1 | 1284.0 | 1308.4 | 1205.4 | 1112.9 | 948.4 | 710.7 | 608.9 | 1018.0 |
| S | 1599.5 | 1335.4 | 1283.0 | 1033.2 | 769.8 | 724.8 | 754.8 | 938.3 | 1228.3 | 1553.5 | 1496.8 | 1463.8 | 1181.2 |
| W | 679.2 | 730.1 | 977.0 | 1102.0 | 1224.6 | 1253.4 | 1224.6 | 1149.9 | 1078.1 | 935.3 | 697.8 | 587.0 | 971.2 |
| MAX. DAILY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 288.3 | 450.1 | 627.2 | 673.9 | 881.0 | 976.7 | 969.3 | 859.0 | 379.7 | 302.7 | 287.6 | 265.6 | 976.7 |
| E | 845.1 | 1039.0 | 1254.6 | 1372.5 | 1488.7 | 1487.5 | 1508.2 | 1369.0 | 1185.7 | 1062.3 | 899.3 | 728.7 | 1508.2 |
| S | 1851.7 | 1817.1 | 1494.6 | 1183.7 | 988.7 | 1011.0 | 1061.0 | 1073.1 | 1455.9 | 1742.3 | 1827.0 | 1843.0 | 1851.7 |
| W | 854.1 | 987.8 | 1177.5 | 1251.6 | 1485.3 | 1444.9 | 1359.2 | 1267.0 | 1185.8 | 1069.1 | 889.2 | 729.4 | 1485.3 |
| MAX. HRLY TOTAL VERTICAL SOLAR | | | | | | | | | | | | | |
| N | 44.2 | 86.1 | 97.6 | 103.2 | 109.0 | 112.2 | 111.5 | 105.2 | 73.5 | 51.9 | 44.9 | 42.2 | 112.2 |
| E | 205.3 | 226.0 | 241.3 | 242.6 | 240.1 | 233.6 | 233.1 | 234.3 | 234.1 | 227.1 | 206.5 | 186.1 | 242.6 |
| S | 260.8 | 248.0 | 216.8 | 189.4 | 159.0 | 150.1 | 156.2 | 163.5 | 198.8 | 237.7 | 255.9 | 261.0 | 261.0 |
| W | 202.1 | 225.2 | 242.7 | 243.1 | 239.7 | 233.5 | 232.9 | 235.1 | 234.4 | 221.6 | 208.3 | 185.5 | 243.1 |

| DESIGN TEMPERATURES | SUMMER | | WINTER |
|---|---|---|---|
| PER CENT | T(DRY) | T(WET) | T(DRY) |
| 1.0 | 100 | 72 | 17 |
| 2.5 | 98 | 69 | 21 |
| 5.0 | 96 | 67 | |

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 | 35.7 | 40.6 | 47.0 | 59.9 | 67.7 | 75.0 | 76.6 | 73.2 | 62.5 | 56.6 | 45.0 | 32.9 | 56.1 |
| 1 | 34.3 | 39.7 | 45.9 | 58.4 | 66.3 | 72.9 | 74.9 | 71.4 | 60.5 | 54.6 | 43.3 | 32.3 | 54.6 |
| 2 | 32.9 | 38.6 | 44.7 | 56.4 | 63.6 | 70.7 | 73.2 | 70.0 | 58.9 | 52.7 | 41.6 | 33.0 | 53.1 |
| 3 | 31.4 | 37.8 | 43.8 | 54.5 | 61.7 | 69.2 | 71.6 | 68.5 | 57.3 | 50.8 | 40.0 | 33.9 | 51.8 |
| 4 | 29.8 | 36.0 | 42.9 | 53.0 | 59.6 | 67.6 | 69.9 | 67.2 | 55.5 | 48.9 | 38.5 | 34.7 | 50.4 |
| 5 | 28.4 | 34.6 | 41.5 | 51.6 | 57.2 | 66.5 | 68.5 | 66.3 | 53.9 | 47.1 | 37.6 | 35.4 | 49.1 |
| 6 | 27.1 | 33.7 | 40.7 | 50.7 | 56.1 | 66.0 | 67.2 | 65.3 | 52.6 | 46.1 | 37.0 | 35.9 | 48.3 |
| 7 | 26.3 | 33.3 | 40.7 | 52.2 | 59.3 | 69.6 | 69.4 | 66.1 | 53.1 | 45.9 | 37.4 | 36.7 | 49.2 |
| 8 | 27.2 | 33.9 | 42.5 | 57.2 | 67.8 | 76.5 | 74.6 | 70.6 | 59.8 | 51.8 | 41.3 | 38.3 | 53.6 |
| 9 | 31.4 | 37.1 | 46.7 | 63.2 | 74.1 | 82.4 | 80.7 | 75.6 | 67.9 | 59.3 | 47.3 | 42.0 | 59.1 |
| 10 | 37.1 | 40.5 | 51.1 | 67.7 | 78.4 | 86.2 | 84.7 | 79.4 | 73.2 | 65.7 | 52.7 | 45.6 | 63.7 |
| 11 | 40.6 | 44.1 | 53.5 | 71.4 | 81.7 | 89.3 | 88.0 | 83.1 | 77.9 | 70.5 | 57.5 | 46.8 | 67.2 |
| 12 | 43.8 | 46.5 | 55.4 | 74.1 | 83.5 | 91.2 | 90.7 | 86.1 | 81.5 | 74.6 | 61.0 | 47.5 | 69.8 |
| 13 | 46.3 | 48.6 | 56.8 | 76.0 | 85.0 | 92.8 | 92.5 | 87.7 | 83.4 | 76.8 | 63.6 | 48.2 | 71.6 |
| 14 | 48.0 | 49.7 | 57.5 | 77.1 | 85.7 | 93.7 | 93.0 | 89.2 | 84.5 | 78.0 | 64.5 | 48.6 | 72.6 |
| 15 | 49.2 | 50.9 | 57.8 | 77.8 | 86.4 | 94.2 | 93.7 | 89.9 | 85.1 | 78.1 | 64.5 | 48.6 | 73.1 |
| 16 | 49.7 | 51.1 | 58.1 | 77.5 | 86.2 | 94.5 | 93.6 | 89.7 | 85.1 | 77.8 | 63.4 | 47.3 | 72.9 |
| 17 | 48.7 | 50.3 | 57.5 | 76.1 | 85.8 | 93.0 | 92.8 | 89.0 | 84.2 | 76.8 | 61.6 | 45.4 | 71.9 |
| 18 | 46.0 | 48.7 | 55.9 | 74.3 | 84.5 | 92.2 | 91.4 | 87.2 | 81.9 | 73.5 | 58.0 | 42.3 | 69.7 |
| 19 | 43.3 | 46.4 | 53.6 | 71.3 | 81.6 | 90.1 | 89.3 | 83.9 | 76.6 | 67.7 | 54.5 | 39.8 | 66.6 |
| 20 | 41.0 | 45.1 | 52.0 | 69.0 | 78.7 | 85.4 | 84.9 | 79.5 | 72.1 | 64.9 | 52.0 | 38.2 | 63.7 |
| 21 | 39.4 | 43.6 | 50.5 | 66.4 | 74.5 | 81.8 | 82.2 | 77.6 | 69.2 | 62.5 | 50.0 | 36.6 | 61.3 |
| 22 | 38.0 | 42.8 | 49.1 | 64.5 | 72.1 | 79.6 | 80.5 | 75.9 | 66.8 | 60.8 | 48.2 | 35.2 | 59.5 |
| 23 | 36.6 | 42.1 | 47.8 | 62.7 | 70.0 | 77.2 | 78.7 | 74.5 | 64.5 | 58.3 | 46.6 | 34.2 | 57.8 |
| GROUND TEMPERATURES | 512.9 | 509.5 | 509.3 | 510.9 | 517.2 | 523.6 | 529.1 | 532.6 | 532.9 | 530.0 | 524.7 | 518.5 | |
| CLEARNESS NUMBERS | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | |

**Table 2.14. 1986 Heating and Cooling Degree Days**

| | Islamabad | Karachi | Lahore | Multan | Peshawar | Quetta |
|---|---|---|---|---|---|---|
| Heating Deg. Days | | | | | | |
| (Base 65) | 1386 | 164 | 698 | 799 | 1220 | 3370 |
| (Base 60) | 767 | 36 | 275 | 351 | 626 | 2493 |
| (Base 55) | 302 | 4 | 50 | 70 | 197 | 1715 |
| (Base 50) | 37 | 0 | 0 | 0 | 14 | 1092 |
| Cooling Deg. Days | | | | | | |
| (Base 80) | 538 | 1169 | 1262 | 1693 | 1127 | 135 |
| (Base 75) | 1231 | 2364 | 2163 | 2647 | 1957 | 453 |
| (Base 70) | 2103 | 3705 | 3273 | 3762 | 2890 | 962 |
| (Base 65) | 3134 | 5216 | 4525 | 5022 | 3993 | 1722 |

Also plotted are the hourly temperature and wind data in **Figures 2.3 - 2.8 (a&b)** respectively. In Figures 2.3-2.8a, the solid line is drybulb temperature and the dashed line is wetbulb temperature. Note that the reported night time wind data on the figures seem to be missing in all cities except Karachi.

We have compared the 1986 design-day temperature data with ASHRAE data, ENERCON data, and U.S. Air Force data in **Table 2.15.** Note that not all data were available from all sources. In general, there is a good agreement between the wetbulb temperature data from all sources. Variations between 1986 drybulb temperature data and other sources are considered statistically insignificant.

We used the modified 1986 hourly weather data for simulating the Pakistani prototypical buildings with DOE-2.

Figure 2.3 a Weather Data for Islamabad (1986)

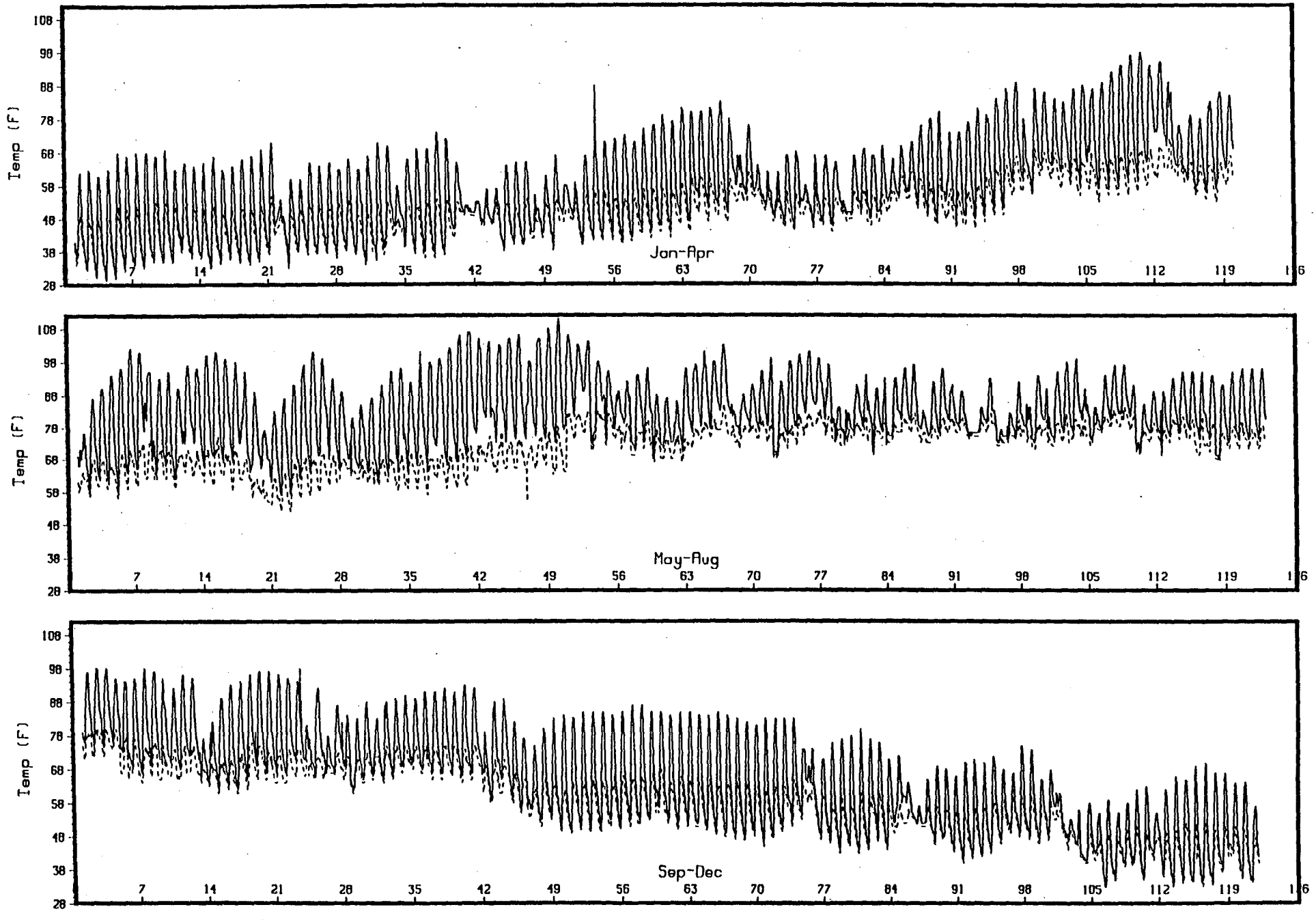


Figure 2.3 b Weather Data for Islamabad (1986)

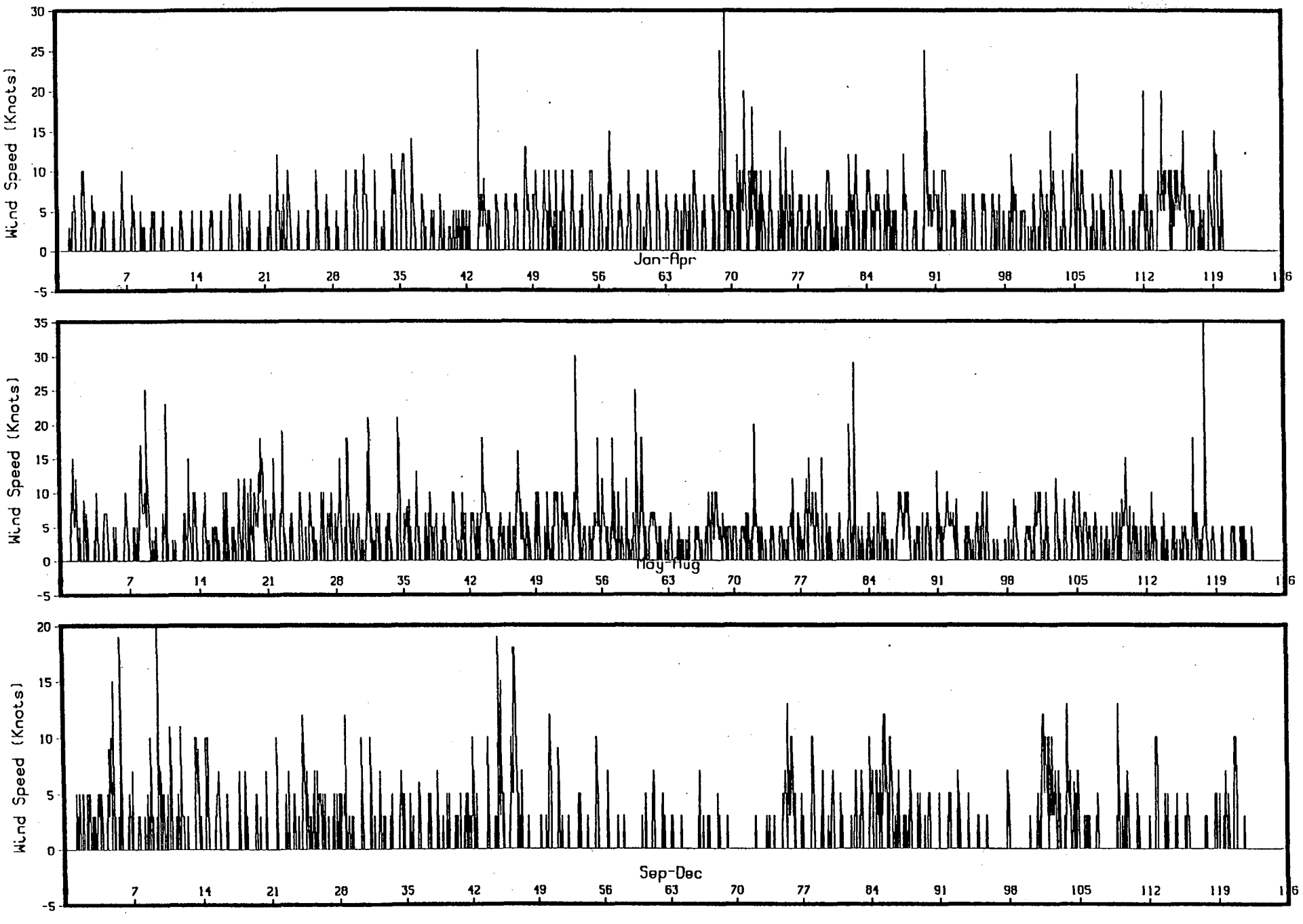


Figure 2.4 a Weather Data for Karachi (1986)

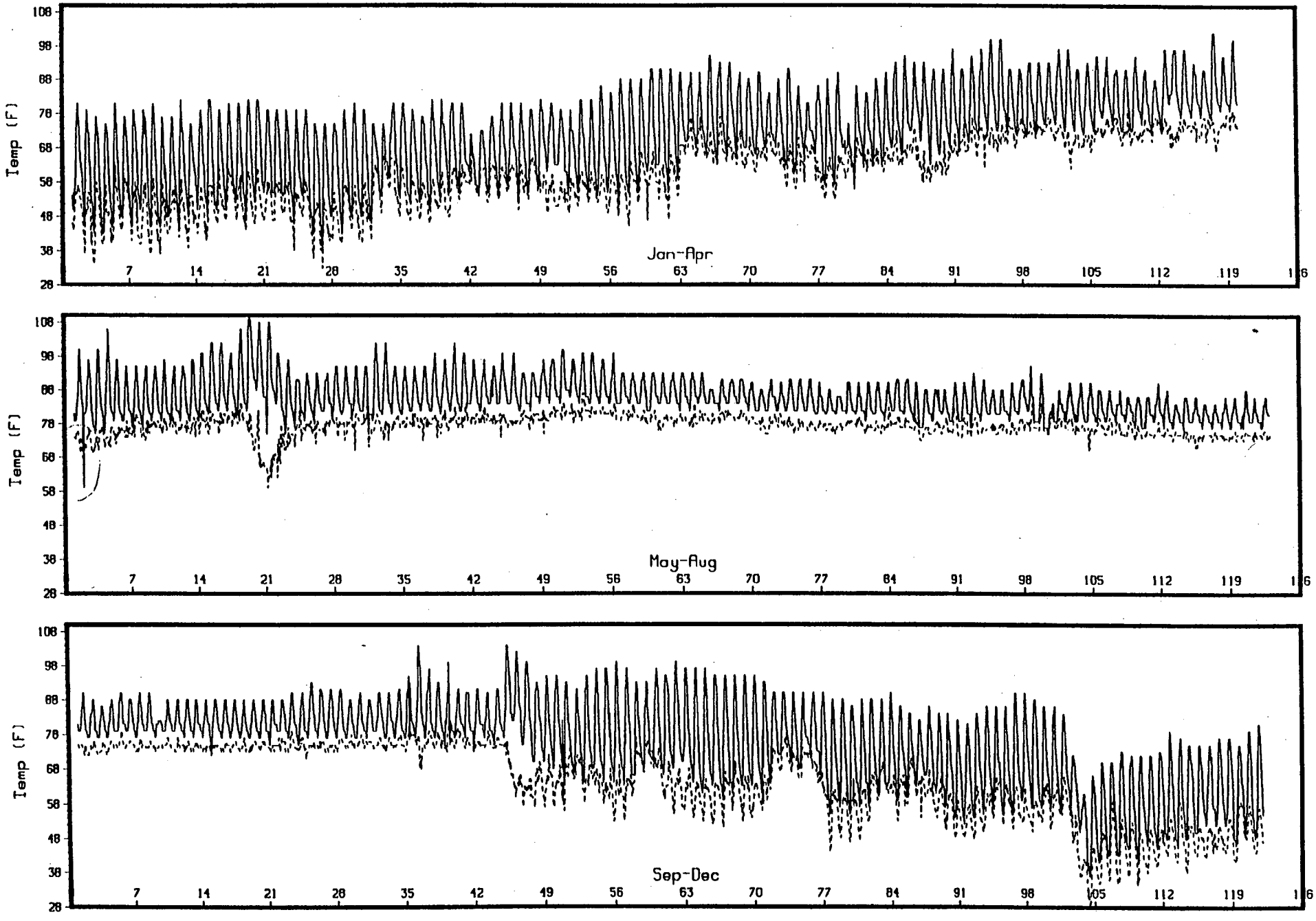


Figure 2.4 b Weather Data for Karachi (1986)

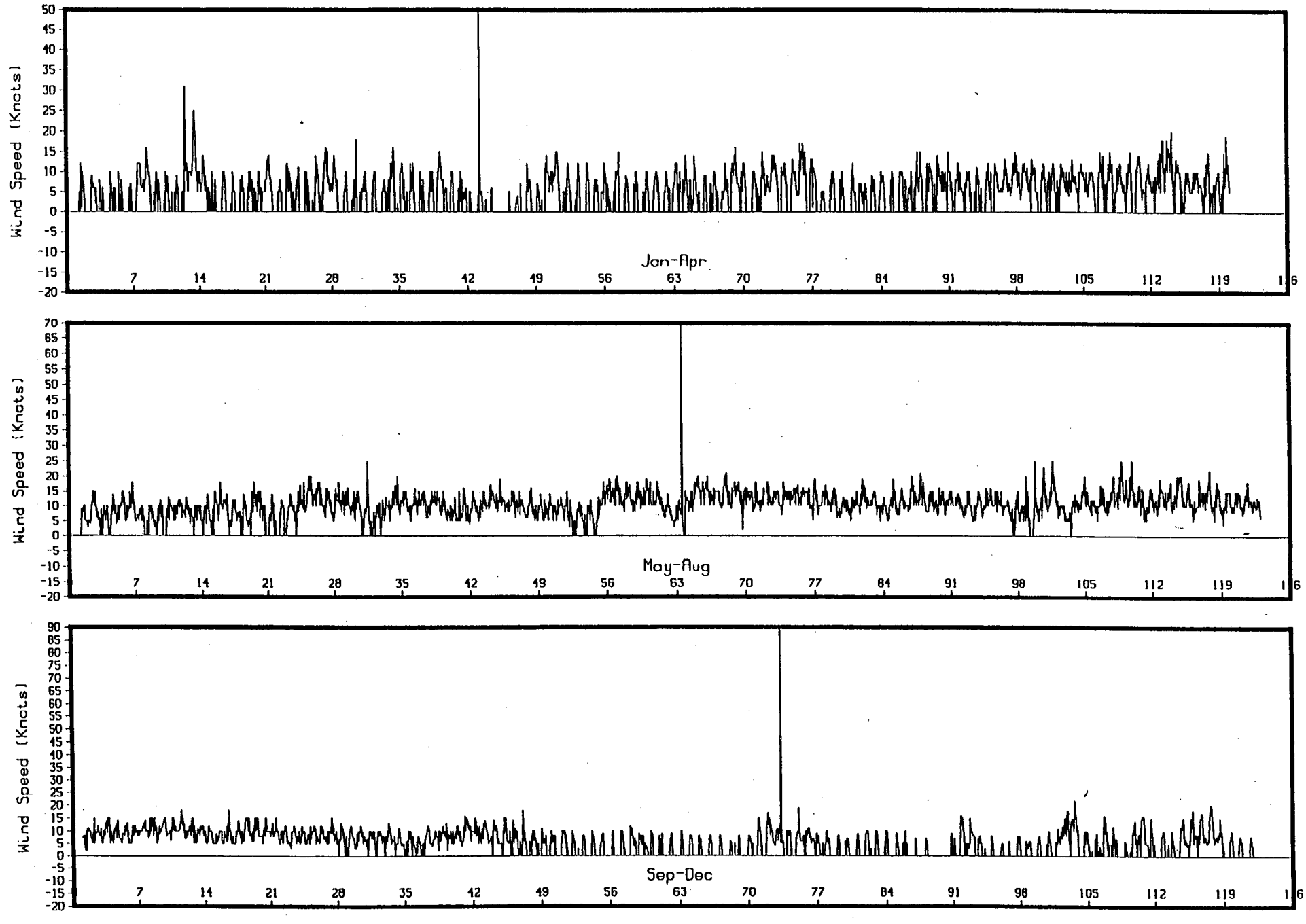


Figure 2.5 a Weather Data for Lahore (1986)

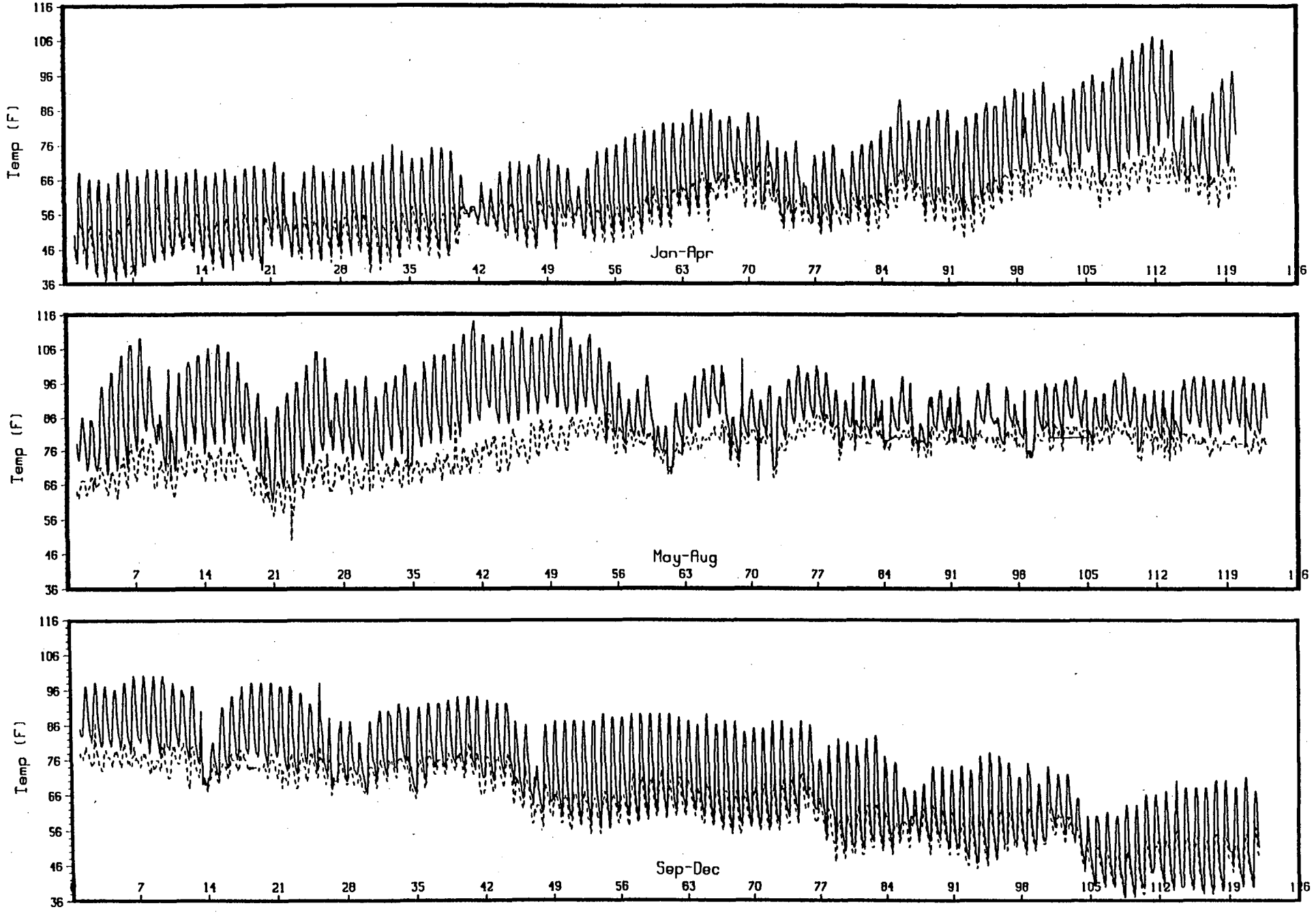


Figure 2.5 b Weather Data for Lahore (1986)

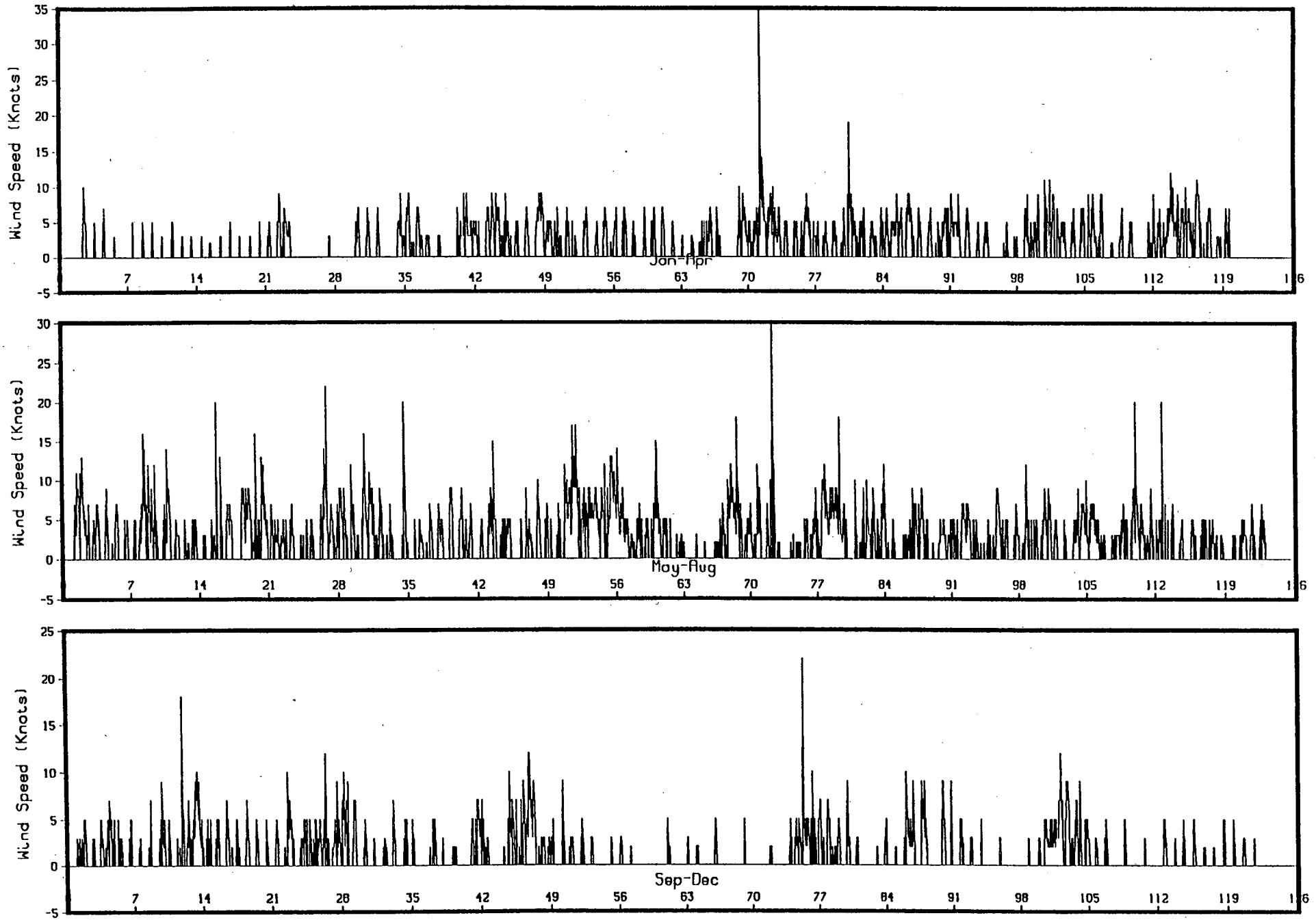


Figure 2.6 a Weather Data for Multan (1986)

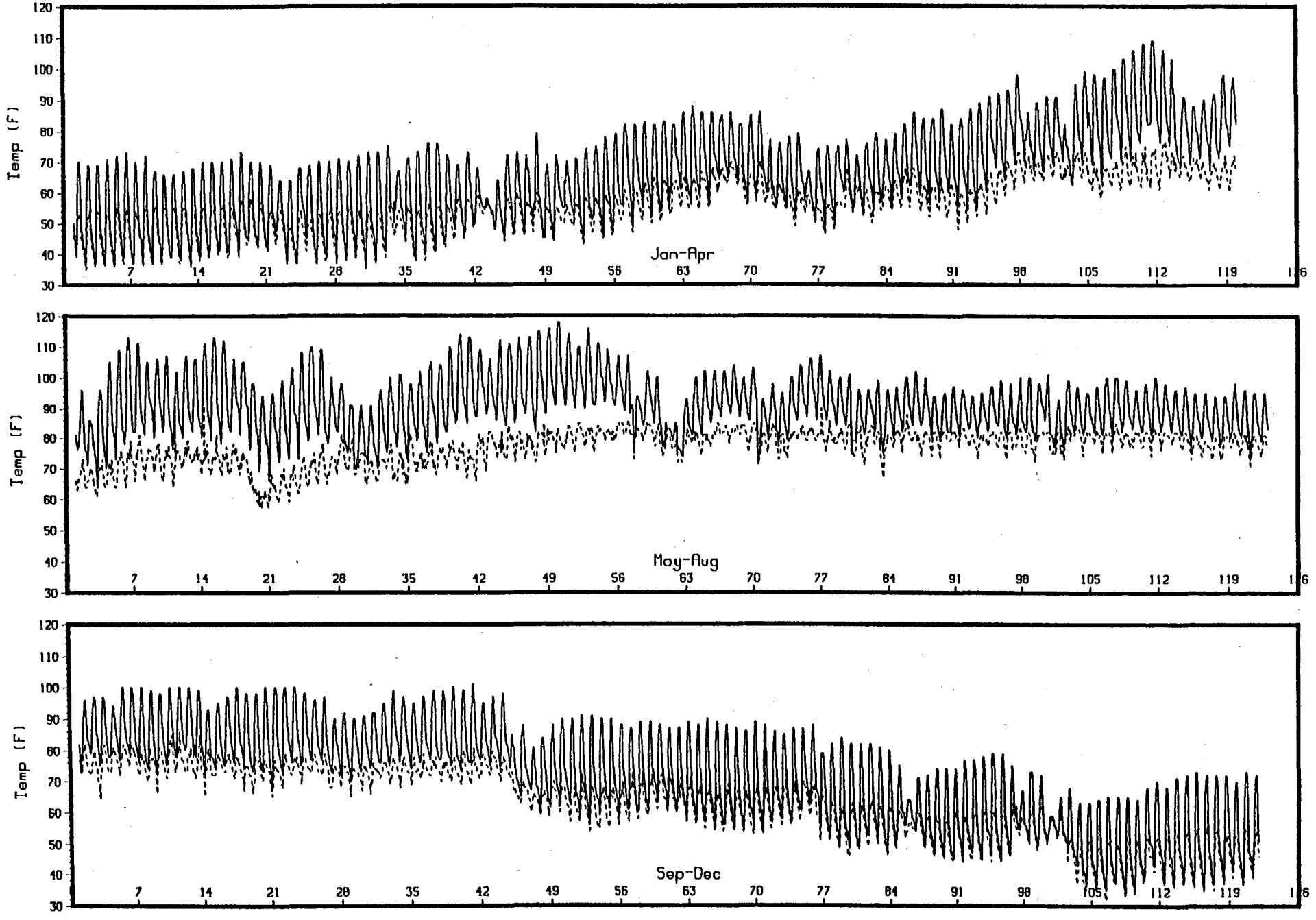


Figure 2.6 b Weather Data for Multan (1986)

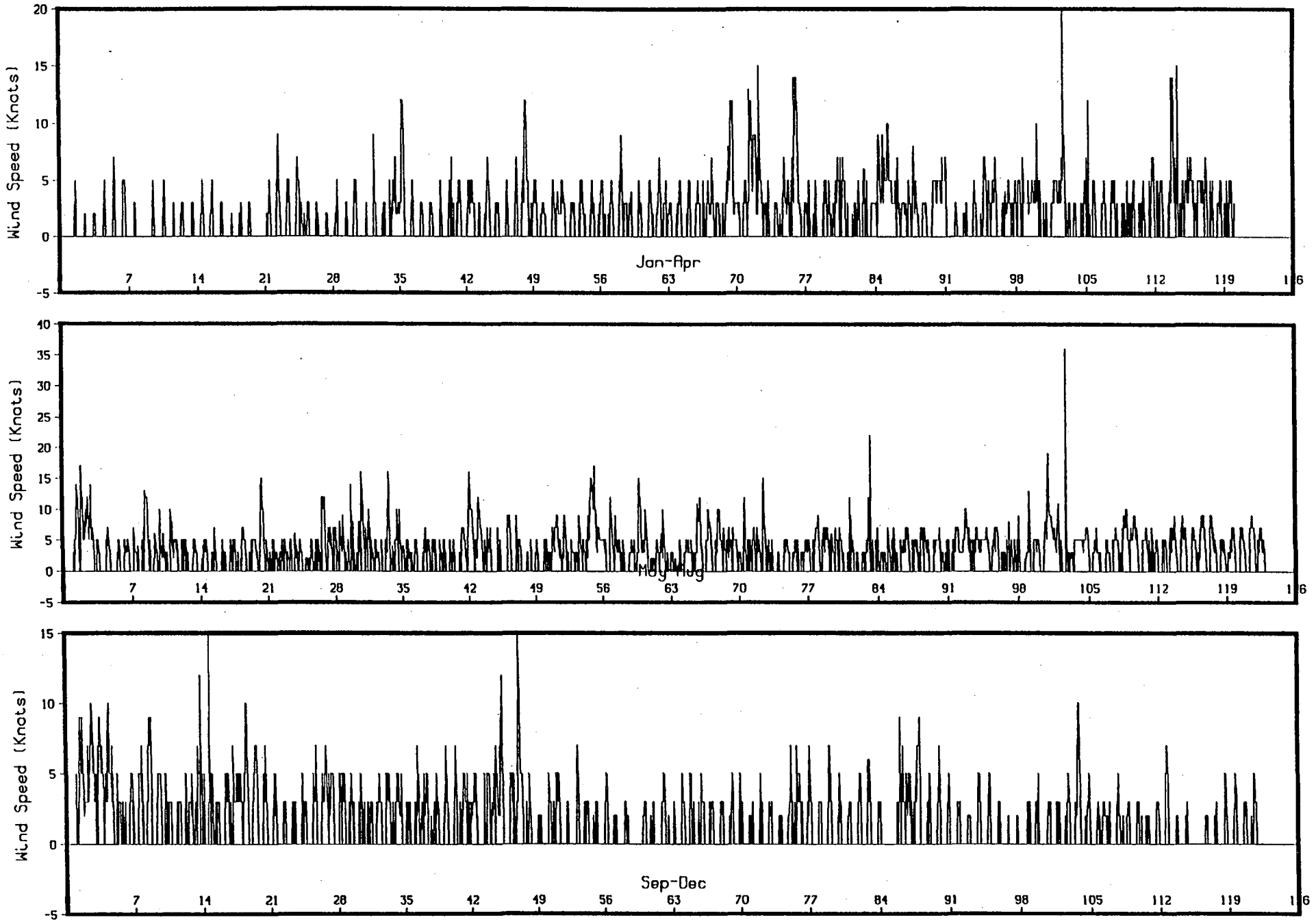


Figure 2.7 a Weather Data for Peshawar (1986)

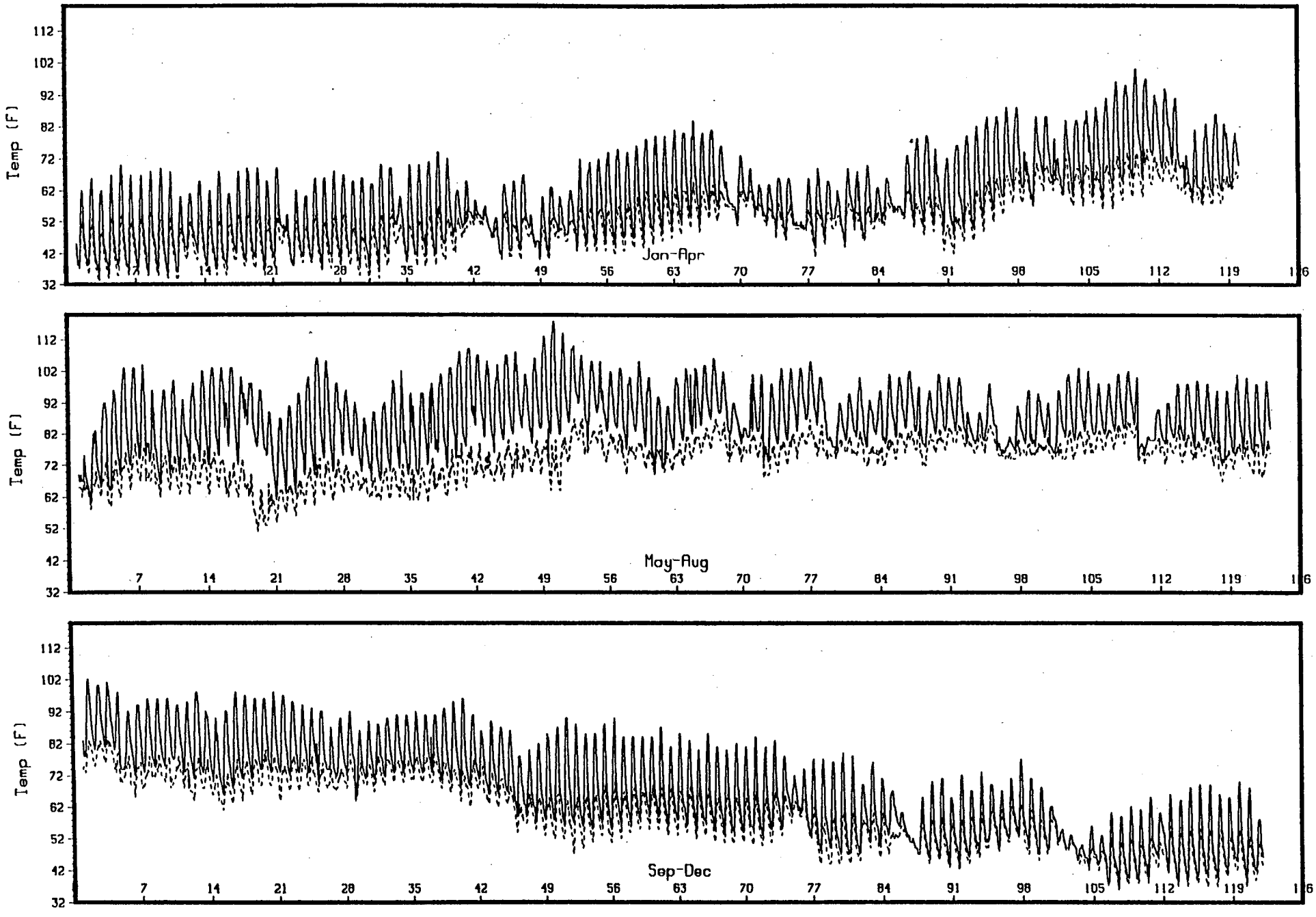


Figure 2.7 b Weather Data for Peshawar (1986)

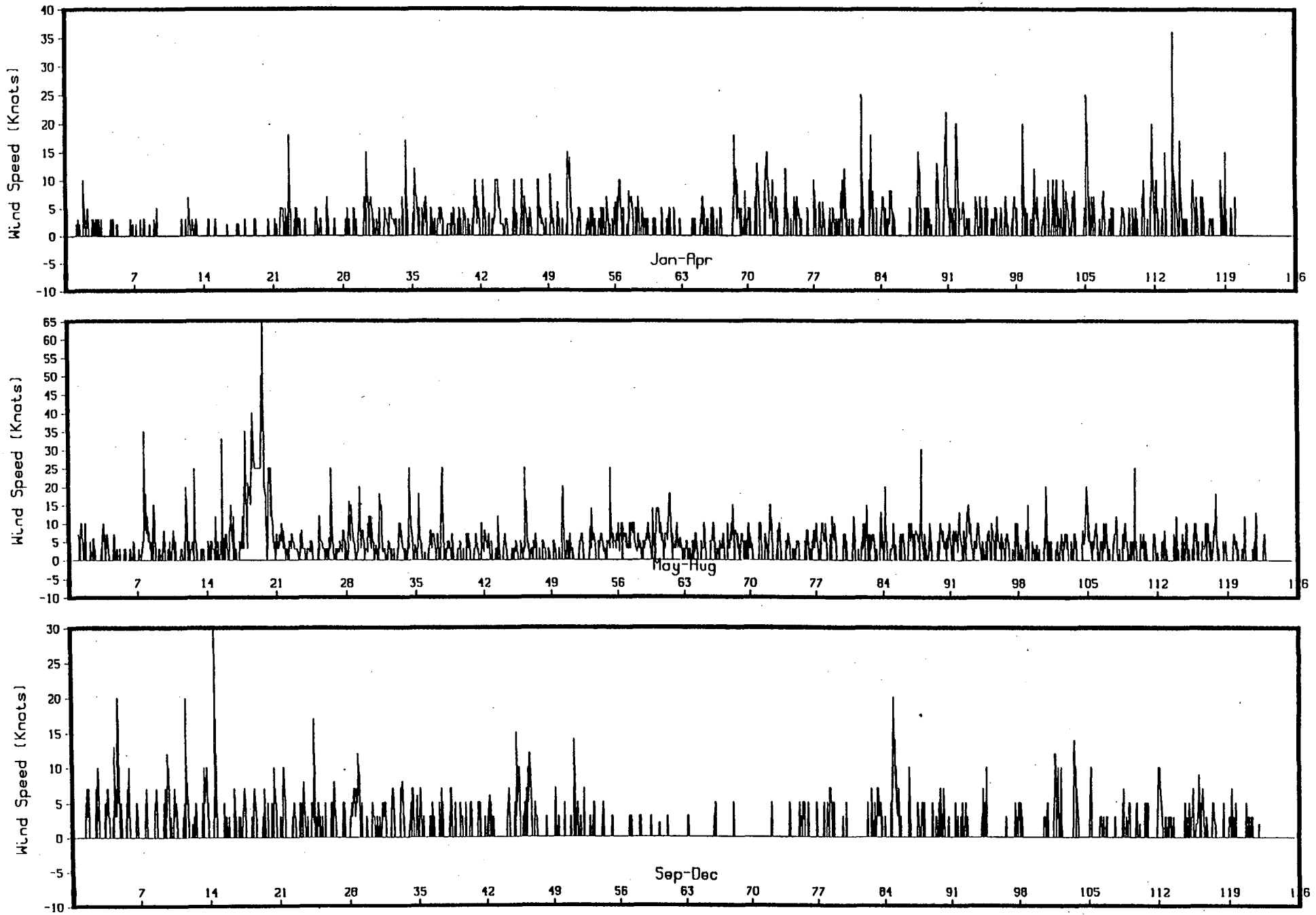


Figure 2.8 a Weather Data for Quetta (1986)

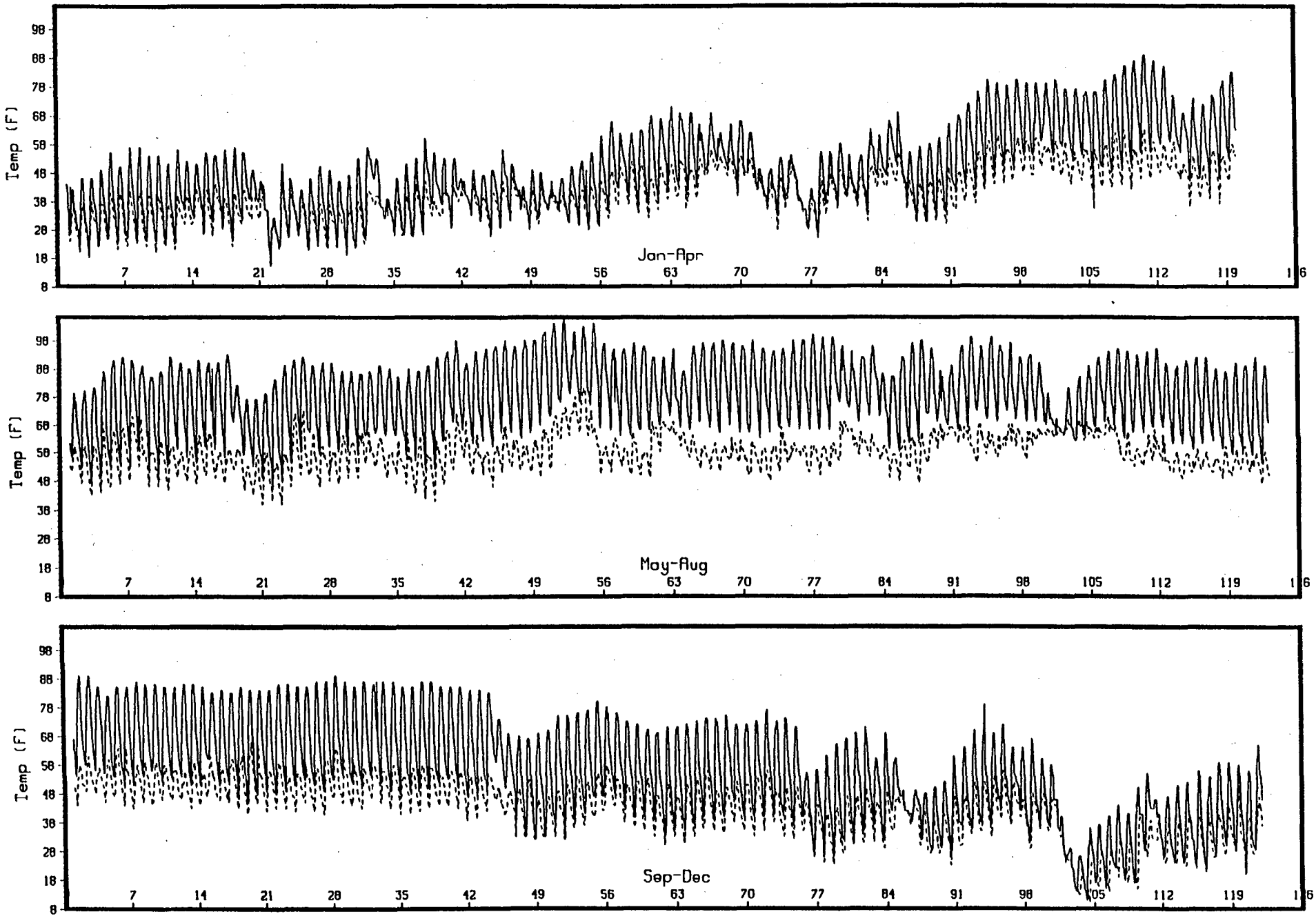


Figure 2.8 b Weather Data for Quetta (1986)

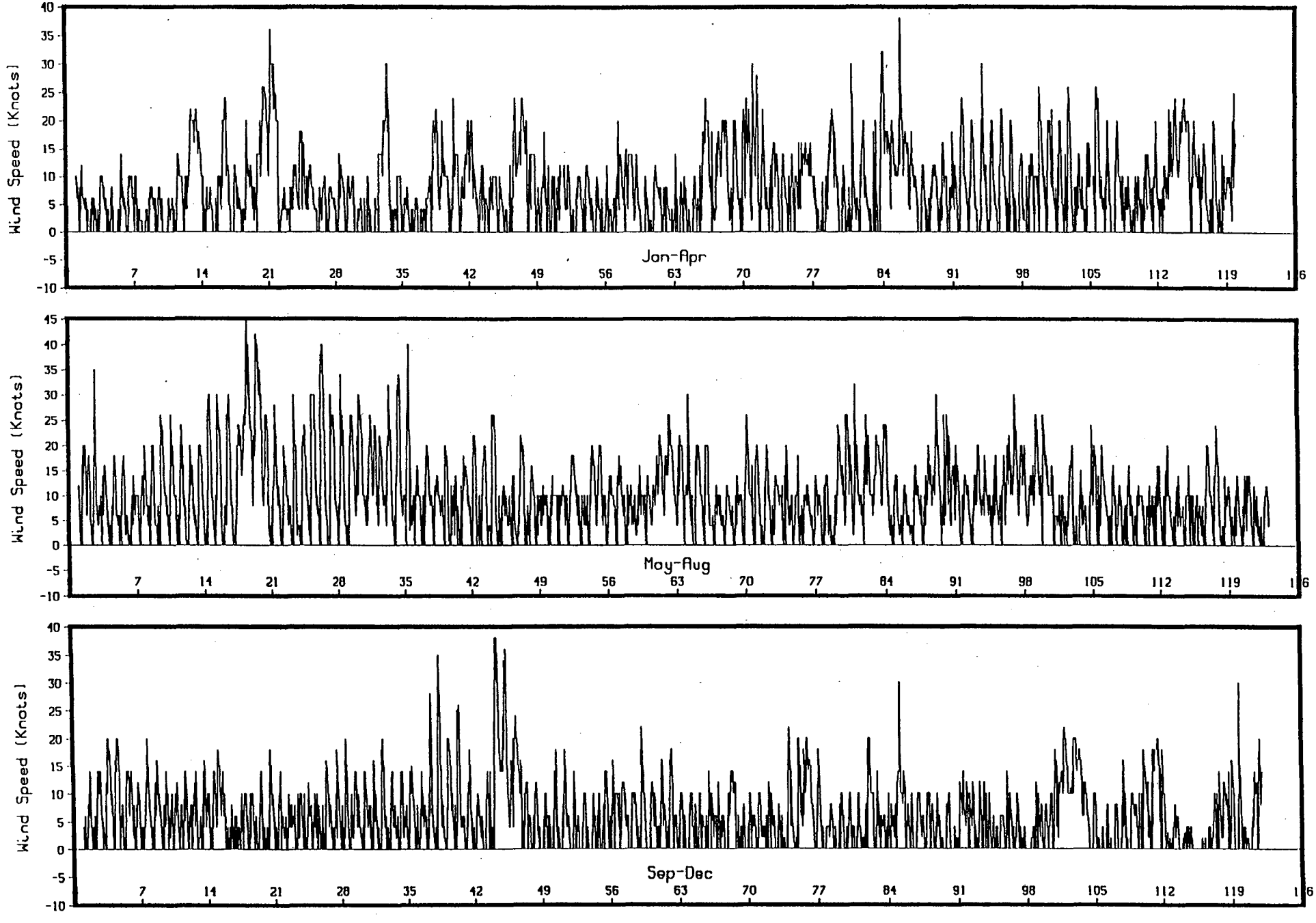


**Table 2.15. Design Day Temperatures.**
**Comparison of Pakistan 1986 weather data with other sources.**

| | Summer | | | | | | | Winter | |
|---|---|---|---|---|---|---|---|---|---|
| | DB [°F] | | | | WB [°F] | | | DB [°F] | |
| | 1% | 2.5% | 5% | Range | 1% | 2.5% | 5% | 1% | 2.5% |
| **Islamabad** | | | | | | | | | |
| ENERCON[a] | 111 | 107 | 103 | 24 | 83 | 81 | 79 | 33 | 37 |
| 1986 Data | 105 | 102 | 98 | | 82 | 81 | 80 | 34 | 35 |
| **Karachi** | | | | | | | | | |
| ASHRAE[b] | 100 | 98 | 95 | 14 | 82 | 82 | 81 | 49 | 51 |
| ENERCON | 106 | 104 | 95 | 20 | 85 | 83 | 82 | 44 | 49 |
| 1986 Data | 99 | 95 | 93 | | 83 | 82 | 82 | 43 | 45 |
| Air Force[c] | 102 | 99 | 95 | | 84 | 83 | 82 | 48 | 50 |
| **Lahore** | | | | | | | | | |
| ASHRAE | 109 | 107 | 105 | 27 | 83 | 82 | 81 | 35 | 37 |
| ENERCON | 112 | 108 | 105 | 22 | 84 | 82 | 81 | 35 | 37 |
| 1986 Data | 110 | 107 | 102 | | 86 | 85 | 83 | 39 | 40 |
| Air Force | 107 | 104 | 102 | | 84 | 84 | 83 | 34 | 36 |
| **Multan** | | | | | | | | | |
| ENERCON | 115 | 111 | 107 | 28 | 82 | 81 | 79 | 40 | 42 |
| 1986 Data | 113 | 109 | 104 | | 85 | 84 | 83 | 37 | 37 |
| **Peshawar** | | | | | | | | | |
| ASHRAE | 109 | 106 | 103 | 29 | 81 | 80 | 79 | 35 | 37 |
| ENERCON | 112 | 108 | 104 | 23 | 83 | 82 | 80 | 31 | 33 |
| 1986 Data | 109 | 105 | 102 | | 85 | 84 | 83 | 37 | 38 |
| Air Force | 106 | 104 | 101 | | 82 | 82 | 81 | 31 | 34 |
| **Quetta** | | | | | | | | | |
| ENERCON | 100 | 95 | 93 | 23 | 74[d] | 71 | 69 | 14 | 20 |
| 1986 Data | 100 | 98 | 96 | | 72 | 69 | 67 | 17 | 21 |

a. Source: Building Energy Code of Pakistan (ENERCON), 5th Draft, 1990.

b. Source: 1985 ASHRAE Fundamentals.

c. Source: Engineering Weather Data, U.S. Air Force, July 1, 1978.

d. Pakistan Building Code reports 83°F; we have corrected to 74°F.

*Chapter 3*

# Methodology

We used computer simulation as a methodology for estimating energy conservation potentials of a variety of Energy Conservation Options (ECOs) in Pakistani buildings. The building energy simulation code used for these analyses was DOE-2.1D (see following section). DOE-2.1D basically requires two sets of input data to simulate the energy performance of a building: 1) an input file describing the physical and operational characteristics of the building and its systems, and 2) an hourly weather data file. We discussed weather data in Chapter 2. For prototypical building and system description, we used other data sources discussed in Chapter 2. Building and equipment description data are supplemented with engineering judgement and site visits of a few buildings. Also, in order to simulate the energy saving characteristics of ECOs, we needed data on applicable ECOs on Pakistani buildings. Information on ECOs were obtained from ENERCOM reports and general data bases at LBL.

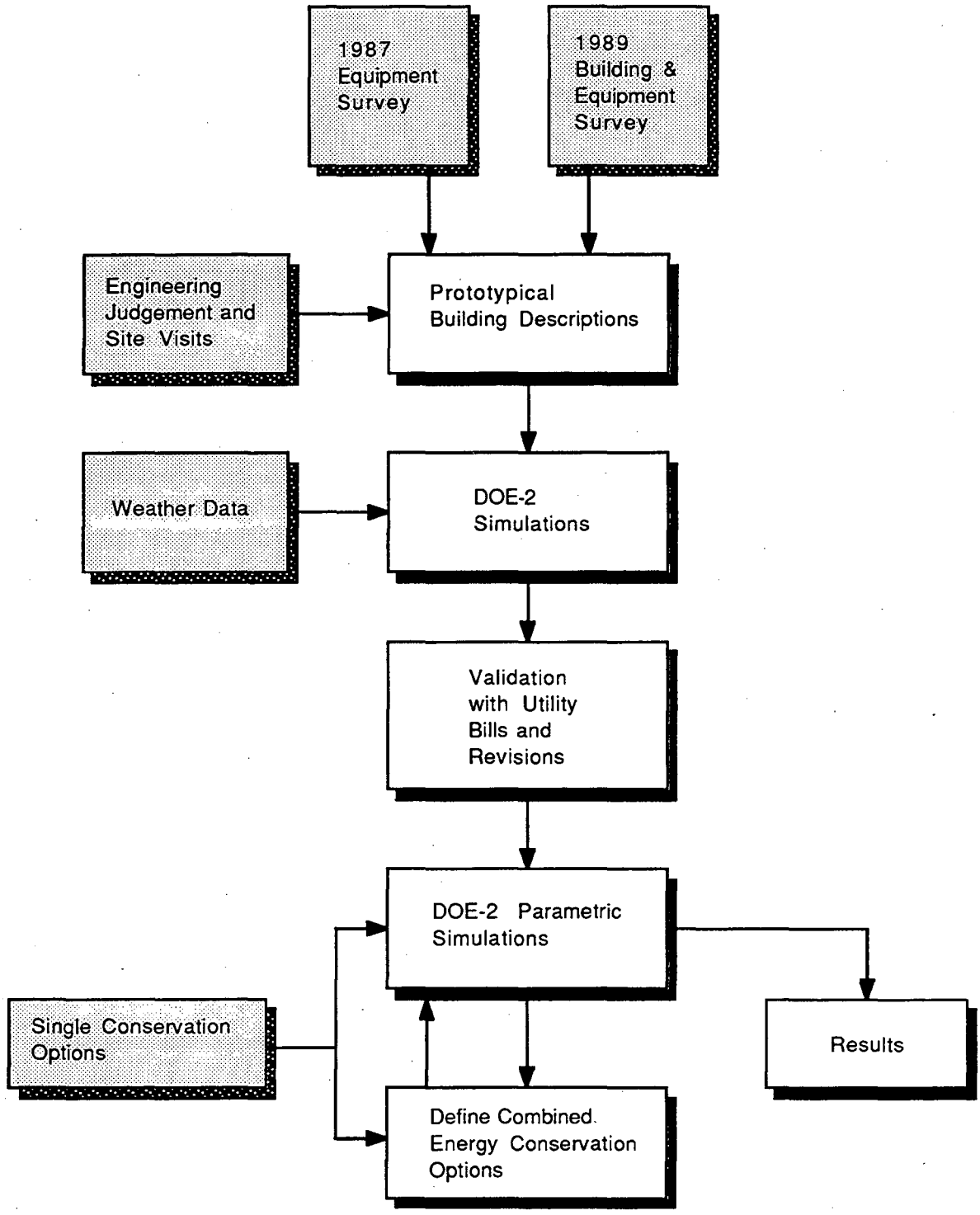
**Figure 3.1** summarizes our overall methodology. The "1987 ENERCON Building Equipment Survey" and "1989 Building and Equipment On-Site Survey" constitute the major input data for prototype building descriptions. The prototype buildings were simulated with DOE-2.1D using 1986 hourly weather data discussed in Chapter 2. Preliminary DOE-2 simulation results were then compared with available measured data (from utility bills)and based on the results of these comparisons, the inputs for the prototypical building characteristics, equipment and appliance energy use, or operational schedules were modified.

Once the prototypes were validated, we performed parametric simulations for single conservation options to estimate the energy saving potential of each ECO. The promising ECOs were combined together for more detailed DOE-2 parametric simulations. This process was repeated to identify the combination measures which offer the highest saving potentials. The output of the simulations were sent to Pakistan in the electronic form and the same are summarized in this report in the form of tables.

We have used our experience and engineering judgement in defining combined ECOs for parametric simulations. While we anticipate that this way of selecting ECOs, will provide satisfactory results, a more rigorous approach would additionally utilize economic analysis considering the cost, rate of return, and payback period of each ECO. Because of the absence of cost data, we were unable to do such an economic analysis of the selected ECO's. However, the simulations have been performed and results presented in such a way that an economic analysis of the ECOs can be performed later.

It is important to notice that the DOE-2 simulations are usually performed to estimate the characteristics of heating, ventilation, and air conditioning (HVAC) end uses. In addition to HVAC end-use analysis, DOE-2 can be used to estimate the impact of daylighting on reducing

Figure 3.1 METHODOLOGY



lighting energy use.

Our focus in this report is on reducing the energy use of space heating and cooling (HVAC) systems. We pursued this objective by modifying the characteristics, operations, and internal loads of the prototype buildings. We did not have enough statistical data to analyze energy conservation options for non-HVAC end uses such as refrigerators, interior lights, or water heaters. Analyzing the energy conservation potentials for non-HVAC end uses should be the subject of a detailed follow-on study.

In the remainder of this chapter the highlights of the DOE-2 simulation code, selection of energy conservation options, and the methodology for developing prototypes for the single family detached house, the converted office building, and the multi-story office building will be discussed.

### DOE-2.1D Building Energy Simulation Program

DOE-2 is a public-domain computer program developed by LBL to simulate the energy performance of a building hour-by-hour depending on its climate, building construction, equipment characteristics and operating schedules. The development of the DOE-2 program was a major technical effort sponsored by the U.S. Department of Energy for over ten years. An overview of the DOE-2 program is given in an LBL Report (BESG 1985). The DOE-2 program has been continually upgraded and enhanced, with the latest version being DOE-2.1D released in early 1989. The DOE-2 program is well documented with a 2-volume User's Manual (BESG 1984), and numerous supplements for later releases, the latest for Version 2.1D (Simulation Research Group 1989). The technical basis of the DOE-2 program is given in a separate Engineers Manual (BESG 1982). Both the DOE-2 program and documentation are available from the U.S. National Technical Information Center in Springfield, Virginia. A PC-based version of the DOE-2 program is also available from a private company, Micro-DOE, in Colorado.

### Selection of Energy Conservation Options

The initial energy conservation options for residential and office buildings were prepared, based on LBL experience . These options were reviewed with RCG/HB staff in Pakistan and final lists of conservation options for DOE-2 simulations were prepared. Typical conservation measures usually considered for residential applications include envelope retrofit measures to control heating and cooling loads of the building, energy efficient lighting, energy efficient appliances (refrigerators, air conditioners, washers and driers, etc.), and retrofit to domestic water heating tanks. For commercial applications, many measures ranging from envelope retrofit to systems and lighting modifications and to computerized controls are frequently considered. **Table 3.1** shows a list of technologies that may be applicable to Pakistani buildings. Those technologies considered for our parametric analyses are printed in **boldface**. We will discuss the

conservation options for each prototype in subsequent chapters.

**Table 3.1.**
**Conservation Technologies for Residential and Office Buildings**
(The impact of boldfaced ECOs were simulated in this study)

Cooling/Heating

1. **Ceiling insulation**
2. Floor insulation
3. **Wall insulation**
4. **Exterior color of roofs and walls**
4. Multiple glazing
5. **Reduce infiltration** (weather stripping and caulking)
6. Movable window insulation
7. **Shading modifications (solar screens, reflective films)**
8. Insulate ductwork
9. Auto night setback (heating only)
10. Whole-house fan/night time cooling
11. **High COP air conditioning units**
12. Evaporative coolers

Lighting

13. **Energy efficient fluorescent lamps**
14. Lighting controls
15. Selective switching

Domestic Water Heating

16. Insulate hot water tanks
17. Solar water heater
18. Local water heaters (Geysers)

### Effects of Building Orientation

The methodology we used for developing the single family house and converted office prototypes differs slightly from that of the multi-story office building in the way the building orientation is treated. In residential buildings, the air-conditioned rooms can be located on any side of a building. The orientation will affect the room's cooling load because of differences in the amount of solar gain. Since our objective is to develop prototypes which describe the average

characteristics of buildings, we need to estimate the energy use characteristics of an average room. One way to do this is to simulate a typical building in various orientations and then average their energy use. An alternate and simpler approach is to define a physically meaningless *average condition* that yields the same average energy use characteristics. This is done by assuming that all the thermal zones of the building have walls and windows equally distributed in all four cardinal directions.

This averaging technique is suitable when the **non-directional** energy conservation options (e.g., high COP window units) are studied. Obviously, for directional ECOs such as window overhang or window reflective films, it is trivial that the analysis should be performed using the proper direction for the zone. For that reason, we developed directional prototype office rooms in multi-story buildings for analyzing the effect of the exterior walls, windows, and window shades.

*Chapter 4*

# Single-Family Detached House

In this chapter the prototype single-family detached house is simulated with DOE-2.1D to obtain its major end-use characteristics. Subsequently, a variety of parametric simulations are performed to determine the effectiveness of typical conservation measures.

## Prototypical Single-Family Detached House

The prototype for the single-family detached house was developed from data bases described in chapter 2; in this section we discuss its highlights.

Three major factors were considered in developing the prototype:

1. the physical layout of the house, floor plan, zones, and construction materials;
2. the internal loads and schedules for each zone; and
3. cooling and heating (not applicable to Karachi) systems and schedules.

*Floor plan, zones, and construction*

Data for the description of the floor plans and zones were obtained from the recent survey of buildings in Pakistan. Data for construction materials were obtained from Pakistan building codes (ENERCON 1990).

The simulated prototype building for Pakistan is a two-story single-family detached house of concrete construction for Karachi and brick construction for Islamabad and Lahore. **Figure 4.1a&b** show sketches of the floor plan for our prototype house. The total area of the house was 4014 $ft^2$ (373 $m^2$) of which 700 $ft^2$ (65 $m^2$) was air conditioned. A total area of 3314 $ft^2$ was air conditioned during June and July from 6 p.m. to 10 p.m. The total window area of the building was 760 $ft^2$ (71 $m^2$). All windows were single-pane glass and had 1.5-3.5 ft overhangs. In Karachi, walls

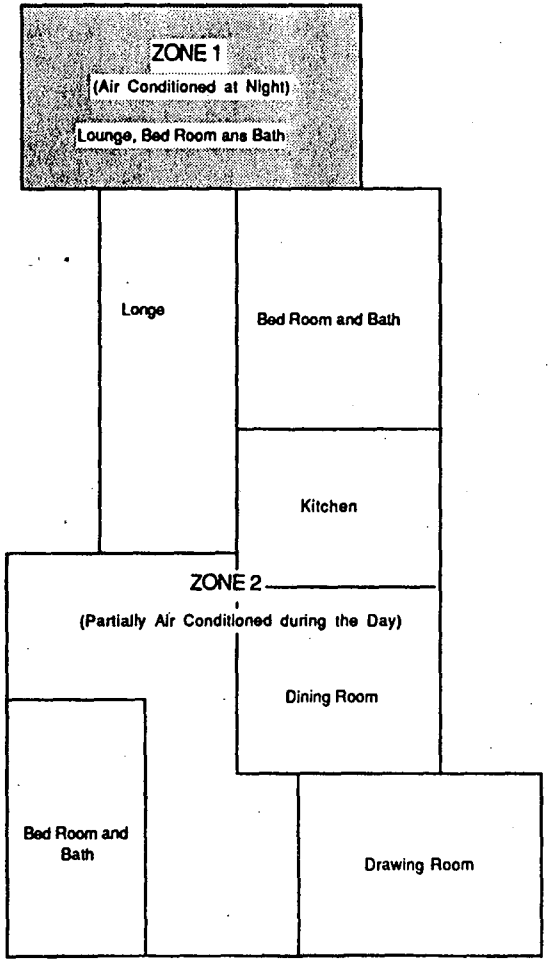



Figure 4.1 a General Floor Plan of the Prototype Single Family House (Ground Floor)

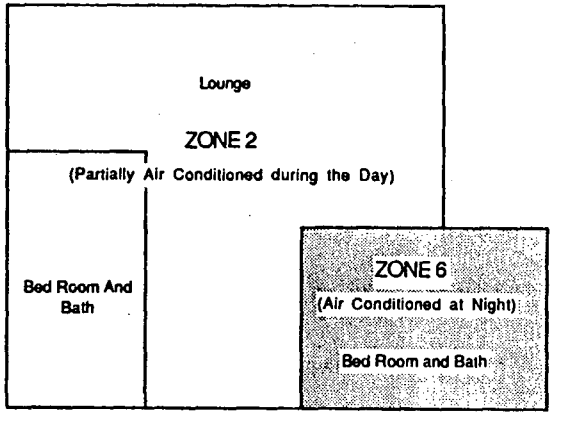



Figure 4.1 b General Floor Plan of the Prototype Single Familiy House (First Floor)

were 6 inches of concrete with ½ " of plaster on both sides. In Lahore and Islamabad, the walls were made of 9½ " thick bricks. The roofs in all three cities were made of 6 inches of concrete slab with ½ " of roofing and ½ " of plaster inside. The house had four bedrooms, a drawing room, a kitchen, and a lounge. The house construction was assumed to be fairly loose with an infiltration rate of 1 ACH (air-change per hour). **Table 4.1** summarizes the highlights of the prototype.

**Table 4.1.**
**Prototypical House Description in Pakistan**

| | |
|---|---|
| Number of stories: | 2 |
| Total floor area: | 4014 $ft^2$ |
| Total conditioned area: | 700 $ft^2$ |
| Total window area: | 760 $ft^2$ |
| Window construction: | single-pane glass, with 1.5-3.5 ft overhangs |
| Wall construction: | In Karachi, 6" concrete with ½ " plaster on either side<br>In Islamabad and Lahore, 9½ " brick with ½ " plater on either side |
| Roof construction: | 6" concrete with ½ " plaster inside, ½ " roofing outside |
| Number of occupants: | 7 |
| Lighting: | Incandescent, 600 watt peak |
| Lighting schedule: | 18.00 - 24.00 |
| Internal loads: | a refrigerator, a freezer, a television, gas stove and oven, and 200 watt of miscellaneous |
| Air conditioning: | Three 1.5 tons window units with 2.5 COP |
| Fans: | six 100-watt fans |
| Heating: | Electric resistance and gas |
| Thermostat setting: | Cooling 79°F, Heating 65°F |
| Others: | Roofs and walls have absorptivity of 0.7 |

To avoid any directional bias in the simulation results, the external walls and windows were distributed equally in the four cardinal directions.

*Internal loads and schedules*

Data for the characteristics of the prototypical internal loads and schedules were obtained from the recent survey of 28 houses in Pakistan and ENERCON (1987).

The prototype house was simulated with a refrigerator with an average usage of 150 watts (~1300 kWh per year), a freezer with an average usage of 150 watts, a 150-watt television used about six hours per day, and other miscellaneous electric usage of 200 watts. The cooking was

done with gas. A 36 gallon gas water heater was located outside the house. Lighting was all incandescent with a peak usage of about 600 watts and a daily average usage of about 4 kWh. The occupancy of the prototype house was 7 people at night and 3 people during the day. **Table 4.1** also summarizes the internal loads of the house.

*Cooling and heating systems and schedules*

Data for cooling and heating equipment are obtained from the ENERCOM reports (1987, 1990) and the recent survey.

The prototype building was simulated with two air conditioned and one partially-conditioned zones. The air conditioning was used mainly in the bedrooms and the drawing rooms during the hot evening and night time hours. 1.5 tons window air conditioners with a COP of ~2.5 are the typical units used in homes in Pakistan. Although, most newer houses are equipped with more than two window units, the additional units are only used during the extreme hot conditions. For more moderate conditions, fans (both ceilings and portables) only are used to provide comfort. The house is simulated with six 100-watt fans operated up to 18 hours per day during March through November. The air conditioning season is April through November.

The recent survey showed that no heating is done in the residential buildings in Karachi. However, ENERCON (1987) noted that some electrical heating appliances are present in Karachi. In our simulations for Karachi, we use electric resistance heating for the for the few days of heating. For other climates convective/radiative room gas unit are more common.[1]

**DOE-2.1D Parametric Simulation**

A systematic series of DOE-2.1D simulations were performed and validated with monthly utility bills. Once the base case prototype has been benchmarked against measured utility bills, parametric simulations were performed in order to investigate the energy saving potentials of various conservation measures.

*Base Case*

The base case simulations were performed with the heating thermostat at 65°F between 7 pm and 9 a.m., and the cooling thermostat at 79°F from 10 p.m. to 7 a.m. During the heating season, window venting was assumed when indoor temperatures rise above 78°F, while in the cooling season, venting was assumed down to 72°F if the following criteria were met: (1) the outdoor temperature was lower than that indoor and not higher than 78°F, (2) the enthalpy of outside air was lower than that indoor, and (3) the air conditioning load that hour could be met totally through natural ventilation. Since occupants typically do not adjust windows after going to bed, window conditions were assumed to be fixed (either open or closed) from 11:00 p.m. to

[1] The DOE-2 simulations are performed with electric resistance heating and the results may be divided by the efficiency of the in-room gas space heater to obtain the gas consumption rates.

5:00 a.m.

Based on the recent surveys, the window air-conditioners were assumed to have COPs of 2.5. The roofs and walls were assumed to be uninsulated, and the windows were assumed to have single-pane clear glass, with moderately dense drapes closed during the cooling season giving a net shading-coefficient of 0.60. Shading from adjoining buildings was ignored in the base case, but analyzed in the parametric analysis.

*Energy conserving measures*

Once the base case prototype was simulated and validated, a series of parametric simulations to estimate the energy saving potentials of conservation options were performed. Typical conservation measures usually considered for residential buildings include envelope retrofit measures to control heating and cooling loads of the building, energy efficient lighting, energy efficient appliances (refrigerators, air conditioners, washers and driers, etc.), and retrofit to domestic hot water tanks. **Table 4.2** shows a list of technologies that may be applicable to Pakistan buildings. Those technologies considered for our parametric analyses are printed in **boldface**.

Our focus on residential conservation technologies agrees with those recommeded in ENERCON (1987) (see **Table 4.3**).

*Parametic Simulations*

Our parametric simulations were focused on three subjects: envelope modification, efficient window air conditioners, and improved operational strategies. These parametrics include four levels of insulation in walls and roofs, two levels of infiltration, four levels of air conditioning COPs, three cooling thermostat settings, one level of wall color and two levels of roof colors, and two levels of overhang size. In addition, we investigated the effects of adjoining houses on energy consumption. (See **Table 4.4** for details.)

Upon the completion of the single parametric DOE-2 simulations, some complementary simulations on a combination of promising ECOs were performed. Normally, when conservation potentials in buildings are analyzed, a least-cost approach is taken to rank the measures and select the promising measures first. The general idea is to select first those measures which have the shortest payback time (or the highest rate of return) on the conservation investment. In our analysis, we were not able to perform detailed economic analysis because of the lack of cost data for ECOs as related to the Pakistan market. Instead, we used our engineering judgement in selecting and ranking the conservation measures, based mostly on the potential energy savings of the ECOs. The combined parametric simulations include simultaneous variations of insulation levels on walls and roofs, change in infiltration rate, and change in coefficient of performance of air conditioning unit.

**Table 4.2.**
**Residential Conservation Technologies**
(The impact of boldfaced ECOs were simulated in this study)

Cooling/Heating

1. **Ceiling insulation**
2. Floor insulation
3. **Wall insulation**
4. **Building color**
5. Multiple glazing
6. **Reduce infiltration** (weather stripping and caulking)
7. Movable window insulation
8. Shading modifications (solar screens, reflective films)
9. Insulate ductwork
10. Auto night setback (heating only)
11. Whole-house fan/night time cooling
12. **High COP air conditioning units**
13. Evaporative coolers

Lighting

14. **Energy efficient fluorescent lamps**
15. Lighting controls
16. Selective switching

Domestic Water Heating

16. Insulate hot water tanks
17. Solar water heater
18. Local water heaters (Geysers)

**Results**

The simulation results for single and combined parametrics are presented in **Tables 4.5a-f** and **Tables 4.6a-f**, respectively. Parametrics for climate regions of Islamabad, Karachi, Lahore, Multan, Peshawar, and Quetta are denoted with letters **a** through **f**. Table 4.5 presents simulation results for total household, and cooling and heating end uses; both household energy use and normalized energy use ($kWh/ft^2$) are presented. This table also provides data on peak

**Table 4.3.**
**Energy Conservation Measures Identified in Single Family Houses by ENERCON study**

| Measure | No. of Cases |
|---|---|
| Reduce Outside Air Infiltration | 1 |
| Reflective Film/Shade | 1 |
| Reflective Paint | 1 |
| Insulate Roof | 2 |
| Shade A/C | 8 |

Source: ENERCON 87.

electric demand on the building. For illustration and discussion purposes, we have also plotted the parametric results for Karachi (cooling dominated) and Islamabad (both cooling and heating are needed) in **Figures 4.2** and **4.3**, respectively.

*Simple Parametrics*

Cooling

The total simulated electricity use for the base-case building in Karachi was 20,562 kWh per year of which 8504 kWh was for cooling and 933 kWh for heating (See Table 4.5b and **Figure 4.2a**). Lighting, fans, refrigerators, and other miscellaneous end uses account for the remaining 11,125 kWh of electricity use.

We discuss the impact of ECOs on cooling energy use only for Karachi. The conclusions made for Karachi buildings can be extended to other climate zones. As Figure 4.2a indicates, the cooling energy use is very sensitive to thermostat setting, air conditioning COP, roof and walls insulation, and roof color. The impacts of air change (infiltration), overhang length, and efficient lighting systems on air conditioning use are fairly low. Increasing the air conditioning temperature setpoint from 79°F to 82°F decreases the cooling energy use by 13% (~4% per °F) or 1,075 kWh per year.

The base case prototype house was simulated with no added insulation on walls and roofs. Insulating the roofs of the building to meet the Pakistani proposed standards (no insulation on walls and R4 total resistance of the roofs) decreases the cooling energy use of the building by 1,952 kWh per year (23%). Further increase in wall and roof insulation to R5 on walls combined with R11 on roof decreased the cooling energy use from the base case by 2,747 kwh (32%) and

**Table 4.4: DOE-2.1D Parametric Simulations for Single Family Residential Prototype House**

| Parametric simulation | Description |
|---|---|
| **Base Case** | R0 in walls and roofs; 1 ACH; A/C COP of 2.5; cooling thermostat setting of 79°F; 2-ft overhangs on windows; walls and roof have absorptivity of 0.7; no shading from adjoining buildings. |
| **Simple Parametrics** | |
| Insulation | Four cases: walls R0, roofs R4; walls R5, roof R11; walls R11 roofs R19; walls R11 roofs R19 (insulation inside). |
| Infiltration | Two cases: 0.5, and 2.0 ACH |
| A/C COP | Four cases: 2.28, 2.8, 3.0, and 3.5 |
| Cooling thermostat setting | Three cases: 78, 80, and 82 °F |
| Overhangs | Two cases: 1-ft and 3-ft |
| Shading from adjoining buildings | Two Cases: two and three buildings |
| Wall color | One case: light (absorptivity 0.3) |
| Roof color | Two cases: light (abs 0.3), very light (abs 0.1) |
| Energy efficient lighting and fans | One case: consumption is reduced by 50% |

R11 on walls combined with R19 on roof decreased the cooling energy use from the base case by 2,941 kWh (35%).

In all the simulations it is assumed that the insulation on the walls and roof are placed on the outside surface of the building to take advantage of the thermal mass of walls and ceilings. To analyze the impact of insulation location (either on the inside or outside), we repeated the R11 walls combined with R19 roof simulation with interior insulation. The results show moderate increases in both heating and cooling energy demand.

The cooling energy use, as it might be expected, was also very sensitive to the efficiency of the window air conditioning units. Increasing the COP of the window units from the base case of 2.5 to 3.5 resulted in a decrease of 2,306 kWh per year (27%). The Pakistani code suggests a minimum COP of 2.28 for window units. Changing the standards to the most efficient system in the market will result in energy savings of 3,085 kWh per year per house or 36%.

Changing the dark roof color with absorptivity of 0.7 to a lighter one with an absorptivity of 0.3 resulted in a 2,260 kWh (27%) reduction in air conditioning use. A further decrease in the roof absorptivity to 0.1 increased these savings to 3125 kWh (37%). A change in wall color to an effective absorptivity of 0.3 had a lower impact on cooling energy use, only 881 kWh (10%). It should be noticed that lightening the color of the roofs will have a negative impact on heating energy use. In Karachi, where the heating energy demand is fairly low, this change in color only increased the heating energy use by less than 500 kWh per year. But, as will be discussed later, the DOE-2 results for Islamabad indicated that the impact of roof color on heating energy requirement may be fairly significant (up to 2252 kWh).

It is important to notice that horizontal surfaces (and to a certain extent, vertical surfaces) tend to collect dust. Dusty white roofs have lower reflectance than clean white roofs. Consequently, the energy saving potentials of the white color roofs might decrease with time. However, the reflectivity of a dusty white surface is still high and of the order of 40 to 50%. Absorptances of various surface types are given in Appendix C.

The cooling energy use of the building was less sensitive to infiltration than we was expected. This was probably because of the fact that the air conditioners were assumed to be operating only from 10 p.m to 7 a.m. when outdoor air temperatures are not very high. Increasing the infiltration rate from 1 ACH (base case) to 2 ACH increased the cooling energy use by only 259 kWh per year; about 3%. Decreasing infiltration to 0.5 ACH reduced cooling energy use by 239 kWh. The effect of infiltration significantly increases as the hours of air conditioning expand to include daytime hours. This effect is clearly manifested in the DOE-2 simulations of the converted office buildings (see Chapter 5).

The base case prototype was a single family house not shaded by any adjacent building. This is a characteristic of low density suburban neighborhoods. In the denser urban environment, houses are typically shaded by adjacent buildings. To estimate the shading impacts of adjacent buildings, simulations were performed with adjacent buildings on **two** and **three** sides of the prototype house. Shading the building on two sides reduced the cooling energy use by 617 kWh per year (7%). The impact of the shading on the third side was an additional reduction of 211 kWh (2%).

Cooling energy use was found to be fairly insensitive to the overhang length. Increasing the overhang length from 2 feet to 3 feet reduced the cooling energy use by 239 kWh, while decreasing the length to 1 foot increased the cooling use by 366 kWh.

Also, the effects of efficient lighting and other appliances on cooling energy demand were fairly low. This is mainly because of the fact that during the air conditioning periods (mainly at nights) the lights are out and also because most appliances are located in non-conditioned areas.

Heating

As we discussed in the preceding section, some of the measures considered for reducing cooling energy use may have a negative impact on heating energy use (e.g., roof color). Other measures may produce savings in both heating and cooling (e.g., roof and wall insulations) or may have no effect on heating energy use (e.g., air conditioning set point temperature). We will review the impact of the proposed ECOs on heating energy use in Islamabad (**Figure 4.2b**). Data for all climate zones are presented in Tables 4.5.

Measures which had the greatest impact on heating energy demand were roof and wall insulation (positive impact), roof color (negative impact), and control of infiltration (positive impact). The total household energy use for the Islamabad house was 24,742 kWh of that 6,978 kWh was for cooling and 6,640 kWh for heating.[2]

The effect of added insulation on roofs [R4] was to decrease heating energy use by 1,321 kWh (20%). Further increase in insulation of walls and roofs [R11 in walls, R19 in roofs] increased the energy savings to 3,047 kWh (46%).

The impact of an increase in infiltration from 1.0 ACH to 2.0 ACH was an increase of 1,034 kWh (0.16%) in heating energy need. Decreasing infiltration from 1.0 ACH to 0.5 ACH resulted in a decrease of 1,321 kWh (20%) in energy use.

Changing the dark roof color to white or reflective colors increased heating energy use by 1,447 (22%) and 2,252 kWh (34%), respectively. The effect of wall colors on heating energy use was also significant (607 kWH or 9%).

Efficient appliances such as lights also slightly increased the heating energy use of the building (173 KWh).

*Combined Parametrics*

Through the simple parametric simulations those measures that have the highest impact on both heating and cooling energy requirements of prototypical houses in all climate regions were identified. The combined parametrics include variation in walls and roof insulation, COP, and air infiltration. Based on these combined parametrics, ECOs for a "best practical case" have been identified. **Tables 4.6a-f** present the results of 31 parametric simulations for each climate zones.

[2] Consumption data for heating are obtained with electric resistance heating. To estimate the heating energy use by in-room gas convective heater, divide the electric heating demands by the efficiency of the gas heater, usually in the range of 55 to 75%.

A selected groups of combined parametrics for Karachi is plotted in **Figure 4.3a**. Two series of cases are presented: low insulation (Case 1) and high insulation (Case 5). The low insulation case considers R4 insulation on roofs and the high insulation case considers R11 insulation on roofs and R5 insulation on walls. To each case has progressively been added the impact of COP increase from 2.5 to 2.8 (Cases 3 and 6) and reduced infiltration (Cases 4 and 7). Finally, simulation results for the "best practical case" (Case 8), defined as an A/C temperature setting of 79°F, A/C COP of 3.0, 3-foot overhang, 0.5 ACH, R5 insulation of walls, R11 insulation on roof, light roof color (abs 0.3), and efficient lighting, have been shown.

As in the simple parametric simulations, the highest relative savings are obtained by adding insulation to the roofs and walls. The impact of roof insulation on reducing cooling energy use was much higher that the wall insulations. The cooling energy difference between the base case and the "best case" was 4,421 kWh per year (52%). In other words, **52% of cooling energy use in single-family houses in Karachi can be saved through simple, practical, and readily available measures and technologies in Pakistan.**

In analysis of heating energy use for Islamabad (**Figure 4.3b**) similar results were obtained. The difference between the base case and the "best case" heating energy use was 2,925 kWh per year (44%). Most of heating energy savings were realized through roof and wall insulation and infiltration control.

In summary, the DOE-2 parametrics show that **savings of the order of 50% in both heating and cooling energy use in Pakistani houses are achievable through the use of simple and available conservation measures such as insulating roofs and walls, control of infiltration, use of high COP air conditioning units, and coloring the roofs white.** An economic analysis is needed to evaluate the cost effectiveness of the proposed measures. This we could not perform due to the lack of cost data.

**Table 4.5a. Summary of Simple Parametric Simulations for Prototypical Single-Family House in Islamabad (a=4014 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 24742 | 6978 | 6640 | 6.16 | 1.74 | 1.65 | 9.66 |
| AC Setting | 78 | 24929 | 7165 | 6640 | 6.21 | 1.79 | 1.65 | 9.89 |
| | 80 | 24568 | 6803 | 6640 | 6.12 | 1.69 | 1.65 | 9.40 |
| | 82 | 24222 | 6458 | 6640 | 6.03 | 1.61 | 1.65 | 8.93 |
| AC COP | 2.28 | 25328 | 7562 | 6640 | 6.31 | 1.88 | 1.65 | 10.37 |
| | 2.8 | 24092 | 6327 | 6640 | 6.00 | 1.58 | 1.65 | 8.86 |
| | 3.0 | 23730 | 5965 | 6640 | 5.91 | 1.49 | 1.65 | 8.59 |
| | 3.5 | 23008 | 5244 | 6640 | 5.73 | 1.31 | 1.65 | 8.59 |
| Adj. Shade | 2 Houses | 24757 | 6578 | 7053 | 6.17 | 1.64 | 1.76 | 9.60 |
| | 3 Houses | 24762 | 6426 | 7211 | 6.17 | 1.60 | 1.80 | 9.58 |
| Overhang | 1 ft | 24792 | 7222 | 6444 | 6.18 | 1.80 | 1.61 | 9.68 |
| | 3 ft | 24761 | 6834 | 6801 | 6.17 | 1.70 | 1.69 | 9.64 |
| Infilt. | 0.5 ach | 24039 | 6929 | 5985 | 5.99 | 1.73 | 1.49 | 9.34 |
| | 2.0 ach | 25823 | 7024 | 7674 | 6.43 | 1.75 | 1.91 | 9.88 |
| Insul. | R0W,R4C | 21219 | 4775 | 5319 | 5.29 | 1.19 | 1.33 | 8.96 |
| | R5W,R11C | 19188 | 3980 | 4083 | 4.78 | 0.99 | 1.02 | 8.48 |
| | R11W,R19C | 18460 | 3742 | 3593 | 4.60 | 0.93 | 0.90 | 8.28 |
| | R11W,R19C** | 18792 | 4048 | 3620 | 4.68 | 1.01 | 0.90 | 8.28 |
| Roof Color | Light | 23506 | 4294 | 8087 | 5.86 | 1.07 | 2.01 | 9.17 |
| | Reflec. | 23461 | 3444 | 8892 | 5.84 | 0.86 | 2.22 | 8.92 |
| Wall C. | Light | 24698 | 6326 | 7247 | 6.15 | 1.58 | 1.81 | 9.51 |
| Eff. Lights | | 20535 | 6845 | 6813 | 5.12 | 1.71 | 1.70 | 9.10 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 4.5b. Summary of Simple Parametric Simulations for Prototypical Single-Family House in Karachi (a=4014 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 20562 | 8504 | 933 | 5.12 | 2.12 | 0.23 | 9.16 |
| AC Setting | 78 | 20907 | 8847 | 933 | 5.21 | 2.20 | 0.23 | 9.30 |
| | 80 | 20217 | 8156 | 933 | 5.04 | 2.03 | 0.23 | 9.05 |
| | 82 | 19487 | 7429 | 933 | 4.85 | 1.85 | 0.23 | 8.66 |
| AC COP | 2.28 | 21341 | 9283 | 933 | 5.32 | 2.31 | 0.23 | 9.82 |
| | 2.8 | 19698 | 7639 | 933 | 4.91 | 1.90 | 0.23 | 8.42 |
| | 3.0 | 19217 | 7159 | 933 | 4.79 | 1.78 | 0.23 | 8.01 |
| | 3.5 | 18258 | 6198 | 933 | 4.55 | 1.54 | 0.23 | 7.62 |
| Adj. | 2 Houses | 20057 | 7921 | 1009 | 5.00 | 1.97 | 0.25 | 9.09 |
| Shade | 3 Houses | 19876 | 7710 | 1042 | 4.95 | 1.92 | 0.26 | 9.10 |
| Overhang | 1 ft | 20888 | 8870 | 892 | 5.20 | 2.21 | 0.22 | 9.18 |
| | 3 ft | 20362 | 8265 | 972 | 5.07 | 2.06 | 0.24 | 9.14 |
| Infilt. | 0.5 ach | 20205 | 8265 | 815 | 5.03 | 2.06 | 0.20 | 9.03 |
| | 2.0 ach | 21038 | 8763 | 1149 | 5.24 | 2.18 | 0.29 | 9.30 |
| Insul. | R0W,R4C | 18224 | 6552 | 545 | 4.54 | 1.63 | 0.14 | 8.79 |
| | R5W,R11C | 17064 | 5757 | 183 | 4.25 | 1.43 | 0.05 | 8.02 |
| | R11W,R19C | 16796 | 5563 | 108 | 4.18 | 1.39 | 0.03 | 7.88 |
| | R11W,R19C** | 17227 | 5921 | 180 | 4.29 | 1.48 | 0.04 | 7.90 |
| Roof | Light | 18573 | 6244 | 1205 | 4.63 | 1.56 | 0.30 | 9.04 |
| Color | Reflec. | 17899 | 5379 | 1394 | 4.46 | 1.34 | 0.35 | 8.91 |
| Wall C. | Light | 19814 | 7623 | 1066 | 4.94 | 1.90 | 0.27 | 9.09 |
| Eff. Lights | | 16180 | 8329 | 975 | 4.03 | 2.07 | 0.24 | 8.59 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 4.5c. Summary of Simple Parametric Simulations for Prototypical Single-Family House in Lahore (a=4014 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 25549 | 11741 | 2681 | 6.36 | 2.93 | 0.67 | 9.50 |
| AC Setting | 78 | 25757 | 11949 | 2681 | 6.42 | 2.98 | 0.67 | 9.53 |
| | 80 | 25349 | 11541 | 2681 | 6.32 | 2.88 | 0.67 | 9.39 |
| | 82 | 24952 | 11145 | 2681 | 6.22 | 2.78 | 0.67 | 8.99 |
| AC COP | 2.28 | 26608 | 12801 | 2681 | 6.63 | 3.19 | 0.67 | 10.20 |
| | 2.8 | 24370 | 10565 | 2681 | 6.07 | 2.63 | 0.67 | 8.73 |
| | 3.0 | 23716 | 9910 | 2681 | 5.91 | 2.47 | 0.67 | 8.30 |
| | 3.5 | 22410 | 8603 | 2681 | 5.58 | 2.14 | 0.67 | 7.62 |
| Adj. | 2 Houses | 25400 | 11203 | 3071 | 6.33 | 2.79 | 0.77 | 9.52 |
| Shade | 3 Houses | 25347 | 10986 | 3237 | 6.31 | 2.74 | 0.81 | 9.56 |
| Overhang | 1 ft | 25701 | 12048 | 2529 | 6.40 | 3.00 | 0.63 | 9.50 |
| | 3 ft | 25472 | 11526 | 2820 | 6.35 | 2.87 | 0.70 | 9.50 |
| Infilt. | 0.5 ach | 24946 | 11564 | 2257 | 6.21 | 2.88 | 0.56 | 9.35 |
| | 2.0 ach | 26418 | 11916 | 3377 | 6.58 | 2.97 | 0.84 | 9.56 |
| Insul. | R0W,R4C | 21858 | 8767 | 1966 | 5.45 | 2.18 | 0.49 | 9.70 |
| | R5W,R11C | 19538 | 7114 | 1301 | 4.87 | 1.77 | 0.32 | 9.05 |
| | R11W,R19C | 18691 | 6537 | 1031 | 4.66 | 1.63 | 0.26 | 8.79 |
| | R11W,R19C** | 19206 | 7058 | 1023 | 4.78 | 1.76 | 0.25 | 8.68 |
| Roof | Light | 22938 | 7836 | 3979 | 5.71 | 1.95 | 0.99 | 9.79 |
| Color | Reflec. | 21753 | 5973 | 4656 | 5.42 | 1.49 | 1.16 | 9.60 |
| Wall C. | Light | 25096 | 10820 | 3152 | 6.25 | 2.70 | 0.79 | 9.47 |
| Eff. Lights | | 21272 | 11552 | 2844 | 5.30 | 2.88 | 0.71 | 8.96 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 4.5d. Summary of Simple Parametric Simulations for Prototypical Single-Family House in Multan (a=4014 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 28143 | 13906 | 3111 | 7.01 | 3.46 | 0.78 | 9.95 |
| AC Setting | 78 | 28338 | 14101 | 3111 | 7.06 | 3.51 | 0.78 | 9.99 |
| | 80 | 27951 | 13715 | 3111 | 6.96 | 3.42 | 0.78 | 9.73 |
| | 82 | 27572 | 13336 | 3111 | 6.87 | 3.32 | 0.78 | 9.34 |
| AC COP | 2.28 | 29406 | 15170 | 3111 | 7.33 | 3.78 | 0.78 | 10.69 |
| | 2.8 | 26738 | 12502 | 3111 | 6.66 | 3.11 | 0.78 | 9.13 |
| | 3.0 | 25960 | 11723 | 3111 | 6.47 | 2.92 | 0.78 | 8.67 |
| | 3.5 | 24401 | 10165 | 3111 | 6.08 | 2.53 | 0.78 | 7.76 |
| Adj. | 2 Houses | 28021 | 13411 | 3487 | 6.98 | 3.34 | 0.87 | 9.95 |
| Shade | 3 Houses | 27978 | 13212 | 3643 | 6.97 | 3.29 | 0.91 | 9.94 |
| Overhang | 1 ft | 28306 | 14232 | 2949 | 7.05 | 3.55 | 0.73 | 9.93 |
| | 3 ft | 28066 | 13686 | 3256 | 6.99 | 3.41 | 0.81 | 9.95 |
| Infilt. | 0.5 ach | 27351 | 13568 | 2659 | 6.81 | 3.38 | 0.66 | 9.60 |
| | 2.0 ach | 29316 | 14355 | 3836 | 7.30 | 3.58 | 0.96 | 10.00 |
| Insul. | R0W,R4C | 24310 | 10822 | 2361 | 6.06 | 2.70 | 0.59 | 9.90 |
| | R5W,R11C | 21757 | 9009 | 1622 | 5.42 | 2.24 | 0.40 | 9.19 |
| | R11W,R19C | 20812 | 8376 | 1311 | 5.18 | 2.09 | 0.33 | 8.94 |
| | R11W,R19C** | 21453 | 9045 | 1283 | 5.34 | 2.25 | 0.32 | 8.82 |
| Roof | Light | 25620 | 10095 | 4400 | 6.38 | 2.51 | 1.10 | 9.98 |
| Color | Reflec. | 24256 | 8054 | 5077 | 6.04 | 2.01 | 1.26 | 9.93 |
| Wall C. | Light | 27767 | 13063 | 3578 | 6.92 | 3.25 | 0.89 | 9.86 |
| Eff. Lights | | 23845 | 13705 | 3263 | 5.94 | 3.41 | 0.81 | 9.37 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 4.5e. Summary of Simple Parametric Simulations for Prototypical Single-Family House in Peshawar (a=4014 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 26948 | 10326 | 5496 | 6.71 | 2.57 | 1.37 | 10.03 |
| AC Setting | 78 | 27121 | 10499 | 5496 | 6.76 | 2.62 | 1.37 | 10.01 |
| | 80 | 26770 | 10149 | 5496 | 6.67 | 2.53 | 1.37 | 9.91 |
| | 82 | 26420 | 9798 | 5496 | 6.58 | 2.44 | 1.37 | 9.59 |
| AC COP | 2.28 | 27855 | 11233 | 5496 | 6.94 | 2.80 | 1.37 | 10.77 |
| | 2.8 | 25939 | 9317 | 5496 | 6.46 | 2.32 | 1.37 | 9.20 |
| | 3.0 | 25379 | 8757 | 5496 | 6.32 | 2.18 | 1.37 | 8.73 |
| | 3.5 | 24259 | 7638 | 5496 | 6.04 | 1.90 | 1.37 | 8.54 |
| Adj. Shade | 2 Houses | 26913 | 9864 | 5925 | 6.70 | 2.46 | 1.48 | 9.99 |
| | 3 Houses | 26904 | 9688 | 6091 | 6.70 | 2.41 | 1.52 | 9.98 |
| Overhang | 1 ft | 27075 | 10636 | 5313 | 6.75 | 2.65 | 1.32 | 10.04 |
| | 3 ft | 26901 | 10128 | 5650 | 6.70 | 2.52 | 1.41 | 10.01 |
| Infilt. | 0.5 ach | 26152 | 10112 | 4915 | 6.52 | 2.52 | 1.22 | 9.81 |
| | 2.0 ach | 28152 | 10605 | 6422 | 7.01 | 2.64 | 1.60 | 10.25 |
| Insul. | R0W,R4C | 23180 | 7690 | 4365 | 5.77 | 1.92 | 1.09 | 9.78 |
| | R5W,R11C | 20854 | 6364 | 3365 | 5.20 | 1.59 | 0.84 | 9.19 |
| | R11W,R19C | 20006 | 5914 | 2967 | 4.98 | 1.47 | 0.74 | 8.96 |
| | R11W,R19C** | 20395 | 6389 | 2882 | 5.08 | 1.59 | 0.72 | 9.01 |
| Roof Color | Light | 25197 | 7073 | 6997 | 6.28 | 1.76 | 1.74 | 10.05 |
| | Reflec. | 24665 | 5685 | 7853 | 6.14 | 1.42 | 1.96 | 9.82 |
| Wall C. | Light | 26815 | 9584 | 6105 | 6.68 | 2.39 | 1.52 | 9.91 |
| Eff. Lights | | 22676 | 10130 | 5670 | 5.65 | 2.52 | 1.41 | 9.43 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 4.5f. Summary of Simple Parametric Simulations for Prototypical Single-Family House in Quetta (a=4014 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 27950 | 3055 | 13768 | 6.96 | 0.76 | 3.43 | 9.07 |
| AC Setting | 78 | 28079 | 3186 | 13768 | 7.00 | 0.79 | 3.43 | 9.31 |
| | 80 | 27822 | 2929 | 13768 | 6.93 | 0.73 | 3.43 | 8.84 |
| | 82 | 27580 | 2685 | 13768 | 6.87 | 0.67 | 3.43 | 8.67 |
| AC COP | 2.28 | 28127 | 3231 | 13768 | 7.01 | 0.80 | 3.43 | 9.73 |
| | 2.8 | 27754 | 2858 | 13768 | 6.91 | 0.71 | 3.43 | 8.67 |
| | 3.0 | 27644 | 2751 | 13768 | 6.89 | 0.69 | 3.43 | 8.67 |
| | 3.5 | 27428 | 2532 | 13768 | 6.83 | 0.63 | 3.43 | 8.67 |
| Adj. Shade | 2 Houses | 28312 | 2997 | 14188 | 7.05 | 0.75 | 3.53 | 9.03 |
| | 3 Houses | 28457 | 2974 | 14358 | 7.09 | 0.74 | 3.58 | 9.01 |
| Overhang | 1 ft | 27713 | 3099 | 13487 | 6.90 | 0.77 | 3.36 | 9.09 |
| | 3 ft | 28150 | 3033 | 13992 | 7.01 | 0.76 | 3.49 | 9.06 |
| Infilt. | 0.5 ach | 27074 | 2993 | 12954 | 6.74 | 0.75 | 3.23 | 8.71 |
| | 2.0 ach | 29386 | 3155 | 15104 | 7.32 | 0.79 | 3.76 | 9.68 |
| Insul. | R0W,R4C | 25469 | 2574 | 11770 | 6.35 | 0.64 | 2.93 | 8.67 |
| | R5W,R11C | 22900 | 2343 | 9430 | 5.71 | 0.58 | 2.35 | 8.59 |
| | R11W,R19C | 21996 | 2263 | 8606 | 5.48 | 0.56 | 2.14 | 8.59 |
| | R11W,R19C** | 22306 | 2370 | 8809 | 5.56 | 0.59 | 2.19 | 8.59 |
| Roof Color | Light | 29326 | 2561 | 15639 | 7.31 | 0.64 | 3.90 | 8.67 |
| | Reflec. | 30116 | 2375 | 16614 | 7.50 | 0.59 | 4.14 | 8.67 |
| Wall C. | Light | 28516 | 2924 | 14466 | 7.10 | 0.73 | 3.60 | 8.93 |
| Eff. Lights | | 23807 | 3069 | 13861 | 5.93 | 0.76 | 3.45 | 8.52 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 4.6a. Summary of Combined Parametric Simulations for Prototypical Single-Family House in Islamabad (a=4014 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 20522 | 4981 | 4418 | 5.11 | 1.24 | 1.10 | 9.31 |
| | | | 2.5 | 20154 | 4612 | 4418 | 5.02 | 1.15 | 1.10 | 8.69 |
| | | | 2.8 | 19743 | 4202 | 4418 | 4.92 | 1.05 | 1.10 | 8.00 |
| | | | 3.0 | 19517 | 3976 | 4418 | 4.86 | 0.99 | 1.10 | 7.62 |
| | | | 3.5 | 19062 | 3521 | 4418 | 4.75 | 0.88 | 1.10 | 7.62 |
| R0 | R4 | 1.0 ach | 2.28 | 21600 | 5157 | 5319 | 5.38 | 1.28 | 1.33 | 9.61 |
| | | | 2.5 | 21219 | 4775 | 5319 | 5.29 | 1.19 | 1.33 | 8.96 |
| | | | 2.8 | 20794 | 4351 | 5319 | 5.18 | 1.08 | 1.33 | 8.24 |
| | | | 3.0 | 20560 | 4115 | 5319 | 5.12 | 1.03 | 1.33 | 8.00 |
| | | | 3.5 | 20088 | 3645 | 5319 | 5.00 | 0.91 | 1.33 | 8.00 |
| R0 | R4 | 2.0 ach | 2.28 | 23168 | 5421 | 6621 | 5.77 | 1.35 | 1.65 | 10.10 |
| | | | 2.5 | 22768 | 5020 | 6621 | 5.67 | 1.25 | 1.65 | 9.41 |
| | | | 2.8 | 22321 | 4574 | 6621 | 5.56 | 1.14 | 1.65 | 8.65 |
| | | | 3.0 | 22073 | 4327 | 6621 | 5.50 | 1.08 | 1.65 | 8.59 |
| | | | 3.5 | 21578 | 3831 | 6621 | 5.38 | 0.95 | 1.65 | 8.59 |
| R5 | R11 | 0.5 ach | 2.28 | 18312 | 4107 | 3081 | 4.56 | 1.02 | 0.77 | 8.78 |
| | | | 2.5 | 18015 | 3809 | 3081 | 4.49 | 0.95 | 0.77 | 8.21 |
| | | | 2.8 | 17685 | 3479 | 3081 | 4.41 | 0.87 | 0.77 | 7.57 |
| | | | 3.0 | 17501 | 3296 | 3081 | 4.36 | 0.82 | 0.77 | 7.22 |
| | | | 3.5 | 17135 | 2929 | 3081 | 4.27 | 0.73 | 0.77 | 6.51 |
| R5 | R11 | 1.0 ach | 2.28 | 19498 | 4290 | 4083 | 4.86 | 1.07 | 1.02 | 9.08 |
| | | | 2.5 | 19188 | 3980 | 4083 | 4.78 | 0.99 | 1.02 | 8.48 |
| | | | 2.8 | 18842 | 3635 | 4083 | 4.69 | 0.91 | 1.02 | 7.81 |
| | | | 3.0 | 18651 | 3443 | 4083 | 4.65 | 0.86 | 1.02 | 7.62 |
| | | | 3.5 | 18268 | 3060 | 4083 | 4.55 | 0.76 | 1.02 | 7.62 |
| R5 | R11 | 2.0 ach | 2.28 | 21479 | 4583 | 5771 | 5.35 | 1.14 | 1.44 | 9.62 |
| | | | 2.5 | 21147 | 4251 | 5771 | 5.27 | 1.06 | 1.44 | 8.98 |
| | | | 2.8 | 20780 | 3884 | 5771 | 5.18 | 0.97 | 1.44 | 8.59 |
| | | | 3.0 | 20575 | 3679 | 5771 | 5.13 | 0.92 | 1.44 | 8.59 |
| | | | 3.5 | 20167 | 3270 | 5771 | 5.02 | 0.81 | 1.44 | 8.59 |
| Best | Case* | | | 17661 | 2821 | 3715 | 4.40 | 0.70 | 0.93 | 7.08 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 4.6b. Summary of Combined Parametric Simulations for Prototypical Single-Family House in Karachi (a=4014 ft²)**

| Insulation Walls | Roofs | Infilt | AC COP | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|---|---|
| R0 | R4 | 0.5 ach | 2.28 | 18299 | 6784 | 391 | 4.56 | 1.69 | 0.10 | 9.23 |
| | | | 2.5 | 17734 | 6219 | 391 | 4.42 | 1.55 | 0.10 | 8.61 |
| | | | 2.8 | 17107 | 5592 | 391 | 4.26 | 1.39 | 0.10 | 7.93 |
| | | | 3.0 | 16759 | 5244 | 391 | 4.18 | 1.31 | 0.10 | 7.56 |
| | | | 3.5 | 16063 | 4548 | 391 | 4.00 | 1.13 | 0.10 | 6.80 |
| R0 | R4 | 1.0 ach | 2.28 | 18819 | 7149 | 545 | 4.69 | 1.78 | 0.14 | 9.42 |
| | | | 2.5 | 18224 | 6552 | 545 | 4.54 | 1.63 | 0.14 | 8.79 |
| | | | 2.8 | 17561 | 5890 | 545 | 4.37 | 1.47 | 0.14 | 8.09 |
| | | | 3.0 | 17194 | 5523 | 545 | 4.28 | 1.38 | 0.14 | 7.70 |
| | | | 3.5 | 16459 | 4789 | 545 | 4.10 | 1.19 | 0.14 | 7.39 |
| R0 | R4 | 2.0 ach | 2.28 | 19546 | 7613 | 808 | 4.87 | 1.90 | 0.20 | 9.74 |
| | | | 2.5 | 18910 | 6977 | 808 | 4.71 | 1.74 | 0.20 | 9.08 |
| | | | 2.8 | 18204 | 6272 | 808 | 4.54 | 1.56 | 0.20 | 8.35 |
| | | | 3.0 | 17813 | 5880 | 808 | 4.44 | 1.46 | 0.20 | 7.95 |
| | | | 3.5 | 17029 | 5098 | 808 | 4.24 | 1.27 | 0.20 | 7.62 |
| R5 | R11 | 0.5 ach | 2.28 | 17126 | 5932 | 69 | 4.27 | 1.48 | 0.02 | 8.37 |
| | | | 2.5 | 16634 | 5440 | 69 | 4.14 | 1.36 | 0.02 | 7.84 |
| | | | 2.8 | 16087 | 4894 | 69 | 4.01 | 1.22 | 0.02 | 7.24 |
| | | | 3.0 | 15784 | 4591 | 69 | 3.93 | 1.14 | 0.02 | 6.91 |
| | | | 3.5 | 15177 | 3983 | 69 | 3.78 | 0.99 | 0.02 | 6.25 |
| R5 | R11 | 1.0 ach | 2.28 | 17586 | 6279 | 183 | 4.38 | 1.56 | 0.05 | 8.57 |
| | | | 2.5 | 17064 | 5757 | 183 | 4.25 | 1.43 | 0.05 | 8.02 |
| | | | 2.8 | 16485 | 5177 | 183 | 4.11 | 1.29 | 0.05 | 7.40 |
| | | | 3.0 | 16163 | 4855 | 183 | 4.03 | 1.21 | 0.05 | 7.05 |
| | | | 3.5 | 15519 | 4212 | 183 | 3.87 | 1.05 | 0.05 | 6.37 |
| R5 | R11 | 2.0 ach | 2.28 | 18361 | 6776 | 459 | 4.57 | 1.69 | 0.11 | 8.97 |
| | | | 2.5 | 17796 | 6212 | 459 | 4.43 | 1.55 | 0.11 | 8.38 |
| | | | 2.8 | 17170 | 5584 | 459 | 4.28 | 1.39 | 0.11 | 7.72 |
| | | | 3.0 | 16822 | 5237 | 459 | 4.19 | 1.30 | 0.11 | 7.36 |
| | | | 3.5 | 16126 | 4542 | 459 | 4.02 | 1.13 | 0.11 | 6.90 |
| Best | Case* | | | 15335 | 4083 | 127 | 3.82 | 1.02 | 0.03 | 6.78 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 4.6c. Summary of Combined Parametric Simulations for Prototypical Single-Family House in Lahore (a=4014 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 21764 | 9169 | 1470 | 5.42 | 2.28 | 0.37 | 10.07 |
| | | | 2.5 | 21013 | 8419 | 1470 | 5.23 | 2.10 | 0.37 | 9.38 |
| | | | 2.8 | 20177 | 7584 | 1470 | 5.03 | 1.89 | 0.37 | 8.62 |
| | | | 3.0 | 19715 | 7121 | 1470 | 4.91 | 1.77 | 0.37 | 8.20 |
| | | | 3.5 | 18790 | 6196 | 1470 | 4.68 | 1.54 | 0.37 | 7.35 |
| R0 | R4 | 1.0 ach | 2.28 | 22641 | 9549 | 1966 | 5.64 | 2.38 | 0.49 | 10.41 |
| | | | 2.5 | 21858 | 8767 | 1966 | 5.45 | 2.18 | 0.49 | 9.70 |
| | | | 2.8 | 20989 | 7898 | 1966 | 5.23 | 1.97 | 0.49 | 8.90 |
| | | | 3.0 | 20506 | 7415 | 1966 | 5.11 | 1.85 | 0.49 | 8.46 |
| | | | 3.5 | 19542 | 6450 | 1966 | 4.87 | 1.61 | 0.49 | 7.62 |
| R0 | R4 | 2.0 ach | 2.28 | 23954 | 10022 | 2809 | 5.97 | 2.50 | 0.70 | 10.63 |
| | | | 2.5 | 23135 | 9202 | 2809 | 5.76 | 2.29 | 0.70 | 9.89 |
| | | | 2.8 | 22222 | 8290 | 2809 | 5.54 | 2.07 | 0.70 | 9.07 |
| | | | 3.0 | 21716 | 7783 | 2809 | 5.41 | 1.94 | 0.70 | 8.62 |
| | | | 3.5 | 20705 | 6773 | 2809 | 5.16 | 1.69 | 0.70 | 7.72 |
| R5 | R11 | 0.5 ach | 2.28 | 19102 | 7304 | 673 | 4.76 | 1.82 | 0.17 | 9.25 |
| | | | 2.5 | 18510 | 6712 | 673 | 4.61 | 1.67 | 0.17 | 8.64 |
| | | | 2.8 | 17850 | 6053 | 673 | 4.45 | 1.51 | 0.17 | 7.95 |
| | | | 3.0 | 17486 | 5688 | 673 | 4.36 | 1.42 | 0.17 | 7.57 |
| | | | 3.5 | 16755 | 4957 | 673 | 4.17 | 1.23 | 0.17 | 6.81 |
| R5 | R11 | 1.0 ach | 2.28 | 20167 | 7742 | 1301 | 5.02 | 1.93 | 0.32 | 9.70 |
| | | | 2.5 | 19538 | 7114 | 1301 | 4.87 | 1.77 | 0.32 | 9.05 |
| | | | 2.8 | 18840 | 6415 | 1301 | 4.69 | 1.60 | 0.32 | 8.32 |
| | | | 3.0 | 18453 | 6027 | 1301 | 4.60 | 1.50 | 0.32 | 7.91 |
| | | | 3.5 | 17678 | 5253 | 1301 | 4.40 | 1.31 | 0.32 | 7.11 |
| R5 | R11 | 2.0 ach | 2.28 | 21834 | 8422 | 2286 | 5.44 | 2.10 | 0.57 | 10.28 |
| | | | 2.5 | 21149 | 7738 | 2286 | 5.27 | 1.93 | 0.57 | 9.58 |
| | | | 2.8 | 20388 | 6977 | 2286 | 5.08 | 1.74 | 0.57 | 8.80 |
| | | | 3.0 | 19967 | 6555 | 2286 | 4.97 | 1.63 | 0.57 | 8.36 |
| | | | 3.5 | 19123 | 5710 | 2286 | 4.76 | 1.42 | 0.57 | 7.62 |
| Best | Case* | | | 16883 | 4573 | 1185 | 4.21 | 1.14 | 0.30 | 7.41 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 4.6d. Summary of Combined Parametric Simulations for Prototypical Single-Family House in Multan (a=4014 ft$^2$)**

| Insulation | | | | Energy (kWh) | | | KWh/ft$^2$ | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 24171 | 11210 | 1837 | 6.02 | 2.79 | 0.46 | 10.27 |
| | | | 2.5 | 23243 | 10283 | 1837 | 5.79 | 2.56 | 0.46 | 9.56 |
| | | | 2.8 | 22214 | 9254 | 1837 | 5.53 | 2.31 | 0.46 | 8.78 |
| | | | 3.0 | 21643 | 8681 | 1837 | 5.39 | 2.16 | 0.46 | 8.35 |
| | | | 3.5 | 20501 | 7539 | 1837 | 5.11 | 1.88 | 0.46 | 7.48 |
| R0 | R4 | 1.0 ach | 2.28 | 25285 | 11798 | 2361 | 6.30 | 2.94 | 0.59 | 10.63 |
| | | | 2.5 | 24310 | 10822 | 2361 | 6.06 | 2.70 | 0.59 | 9.90 |
| | | | 2.8 | 23224 | 9738 | 2361 | 5.79 | 2.43 | 0.59 | 9.08 |
| | | | 3.0 | 22623 | 9136 | 2361 | 5.64 | 2.28 | 0.59 | 8.63 |
| | | | 3.5 | 21420 | 7933 | 2361 | 5.34 | 1.98 | 0.59 | 7.72 |
| R0 | R4 | 2.0 ach | 2.28 | 27031 | 12644 | 3260 | 6.73 | 3.15 | 0.81 | 11.19 |
| | | | 2.5 | 25984 | 11598 | 3260 | 6.47 | 2.89 | 0.81 | 10.40 |
| | | | 2.8 | 24822 | 10435 | 3260 | 6.18 | 2.60 | 0.81 | 9.53 |
| | | | 3.0 | 24176 | 9791 | 3260 | 6.02 | 2.44 | 0.81 | 9.05 |
| | | | 3.5 | 22888 | 8501 | 3260 | 5.70 | 2.12 | 0.81 | 8.08 |
| R5 | R11 | 0.5 ach | 2.28 | 21185 | 9117 | 943 | 5.28 | 2.27 | 0.23 | 9.43 |
| | | | 2.5 | 20435 | 8368 | 943 | 5.09 | 2.08 | 0.23 | 8.80 |
| | | | 2.8 | 19602 | 7536 | 943 | 4.88 | 1.88 | 0.23 | 8.10 |
| | | | 3.0 | 19141 | 7074 | 943 | 4.77 | 1.76 | 0.23 | 7.71 |
| | | | 3.5 | 18217 | 6150 | 943 | 4.54 | 1.53 | 0.23 | 6.93 |
| R5 | R11 | 1.0 ach | 2.28 | 22565 | 9817 | 1622 | 5.62 | 2.45 | 0.40 | 9.86 |
| | | | 2.5 | 21757 | 9009 | 1622 | 5.42 | 2.24 | 0.40 | 9.19 |
| | | | 2.8 | 20860 | 8112 | 1622 | 5.20 | 2.02 | 0.40 | 8.45 |
| | | | 3.0 | 20362 | 7614 | 1622 | 5.07 | 1.90 | 0.40 | 8.04 |
| | | | 3.5 | 19367 | 6619 | 1622 | 4.82 | 1.65 | 0.40 | 7.21 |
| R5 | R11 | 2.0 ach | 2.28 | 24695 | 10860 | 2708 | 6.15 | 2.71 | 0.67 | 10.54 |
| | | | 2.5 | 23800 | 9966 | 2708 | 5.93 | 2.48 | 0.67 | 9.81 |
| | | | 2.8 | 22806 | 8973 | 2708 | 5.68 | 2.24 | 0.67 | 9.00 |
| | | | 3.0 | 22255 | 8421 | 2708 | 5.54 | 2.10 | 0.67 | 8.55 |
| | | | 3.5 | 21152 | 7319 | 2708 | 5.27 | 1.82 | 0.67 | 7.65 |
| Best | Case* | | | 18473 | 5852 | 1497 | 4.60 | 1.46 | 0.37 | 7.56 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 4.6e. Summary of Combined Parametric Simulations for Prototypical Single-Family House in Peshawar (a=4014 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 22704 | 7935 | 3644 | 5.66 | 1.98 | 0.91 | 10.18 |
| | | | 2.5 | 22075 | 7305 | 3644 | 5.50 | 1.82 | 0.91 | 9.48 |
| | | | 2.8 | 21376 | 6607 | 3644 | 5.33 | 1.65 | 0.91 | 8.71 |
| | | | 3.0 | 20989 | 6220 | 3644 | 5.23 | 1.55 | 0.91 | 8.28 |
| | | | 3.5 | 20214 | 5444 | 3644 | 5.04 | 1.36 | 0.91 | 7.42 |
| R0 | R4 | 1.0 ach | 2.28 | 23843 | 8353 | 4365 | 5.94 | 2.08 | 1.09 | 10.50 |
| | | | 2.5 | 23180 | 7690 | 4365 | 5.77 | 1.92 | 1.09 | 9.78 |
| | | | 2.8 | 22443 | 6953 | 4365 | 5.59 | 1.73 | 1.09 | 8.97 |
| | | | 3.0 | 22035 | 6544 | 4365 | 5.49 | 1.63 | 1.09 | 8.53 |
| | | | 3.5 | 21217 | 5727 | 4365 | 5.29 | 1.43 | 1.09 | 7.64 |
| R0 | R4 | 2.0 ach | 2.28 | 25662 | 8965 | 5571 | 6.39 | 2.23 | 1.39 | 10.69 |
| | | | 2.5 | 24949 | 8252 | 5571 | 6.22 | 2.06 | 1.39 | 9.95 |
| | | | 2.8 | 24157 | 7461 | 5571 | 6.02 | 1.86 | 1.39 | 9.13 |
| | | | 3.0 | 23718 | 7022 | 5571 | 5.91 | 1.75 | 1.39 | 8.67 |
| | | | 3.5 | 22839 | 6142 | 5571 | 5.69 | 1.53 | 1.39 | 8.45 |
| R5 | R11 | 0.5 ach | 2.28 | 20032 | 6424 | 2484 | 4.99 | 1.60 | 0.62 | 9.49 |
| | | | 2.5 | 19531 | 5923 | 2484 | 4.87 | 1.48 | 0.62 | 8.85 |
| | | | 2.8 | 18972 | 5365 | 2484 | 4.73 | 1.34 | 0.62 | 8.15 |
| | | | 3.0 | 18663 | 5056 | 2484 | 4.65 | 1.26 | 0.62 | 7.75 |
| | | | 3.5 | 18044 | 4436 | 2484 | 4.50 | 1.11 | 0.62 | 6.97 |
| R5 | R11 | 1.0 ach | 2.28 | 21395 | 6906 | 3365 | 5.33 | 1.72 | 0.84 | 9.85 |
| | | | 2.5 | 20854 | 6364 | 3365 | 5.20 | 1.59 | 0.84 | 9.19 |
| | | | 2.8 | 20252 | 5763 | 3365 | 5.05 | 1.44 | 0.84 | 8.45 |
| | | | 3.0 | 19919 | 5429 | 3365 | 4.96 | 1.35 | 0.84 | 8.03 |
| | | | 3.5 | 19252 | 4761 | 3365 | 4.80 | 1.19 | 0.84 | 7.21 |
| R5 | R11 | 2.0 ach | 2.28 | 23623 | 7657 | 4841 | 5.89 | 1.91 | 1.21 | 10.13 |
| | | | 2.5 | 23021 | 7055 | 4841 | 5.74 | 1.76 | 1.21 | 9.44 |
| | | | 2.8 | 22351 | 6385 | 4841 | 5.57 | 1.59 | 1.21 | 8.67 |
| | | | 3.0 | 21980 | 6014 | 4841 | 5.48 | 1.50 | 1.21 | 8.24 |
| | | | 3.5 | 21237 | 5271 | 4841 | 5.29 | 1.31 | 1.21 | 7.62 |
| Best | Case* | | | 18527 | 4211 | 3191 | 4.62 | 1.05 | 0.79 | 7.60 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 4.6f. Summary of Combined Parametric Simulations for Prototypical Single-Family House in Quetta (a=4014 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 24474 | 2651 | 10696 | 6.10 | 0.66 | 2.66 | 8.59 |
| | | | 2.5 | 24339 | 2516 | 10696 | 6.06 | 0.63 | 2.66 | 8.59 |
| | | | 2.8 | 24188 | 2366 | 10696 | 6.03 | 0.59 | 2.66 | 8.59 |
| | | | 3.0 | 24105 | 2283 | 10696 | 6.01 | 0.57 | 2.66 | 8.59 |
| | | | 3.5 | 23939 | 2116 | 10696 | 5.96 | 0.53 | 2.66 | 8.59 |
| R0 | R4 | 1.0 ach | 2.28 | 25607 | 2711 | 11770 | 6.38 | 0.68 | 2.93 | 8.91 |
| | | | 2.5 | 25469 | 2574 | 11770 | 6.35 | 0.64 | 2.93 | 8.67 |
| | | | 2.8 | 25317 | 2422 | 11770 | 6.31 | 0.60 | 2.93 | 8.67 |
| | | | 3.0 | 25233 | 2337 | 11770 | 6.29 | 0.58 | 2.93 | 8.67 |
| | | | 3.5 | 25063 | 2168 | 11770 | 6.24 | 0.54 | 2.93 | 8.67 |
| R0 | R4 | 2.0 ach | 2.28 | 27430 | 2824 | 13478 | 6.83 | 0.70 | 3.36 | 9.62 |
| | | | 2.5 | 27288 | 2682 | 13478 | 6.80 | 0.67 | 3.36 | 8.97 |
| | | | 2.8 | 27129 | 2523 | 13478 | 6.76 | 0.63 | 3.36 | 8.67 |
| | | | 3.0 | 27041 | 2435 | 13478 | 6.74 | 0.61 | 3.36 | 8.67 |
| | | | 3.5 | 26865 | 2261 | 13478 | 6.69 | 0.56 | 3.36 | 8.67 |
| R5 | R11 | 0.5 ach | 2.28 | 21500 | 2387 | 7988 | 5.36 | 0.59 | 1.99 | 8.59 |
| | | | 2.5 | 21381 | 2267 | 7988 | 5.33 | 0.56 | 1.99 | 8.59 |
| | | | 2.8 | 21248 | 2135 | 7988 | 5.29 | 0.53 | 1.99 | 8.59 |
| | | | 3.0 | 21174 | 2061 | 7988 | 5.28 | 0.51 | 1.99 | 8.59 |
| | | | 3.5 | 21026 | 1913 | 7988 | 5.24 | 0.48 | 1.99 | 8.59 |
| R5 | R11 | 1.0 ach | 2.28 | 23021 | 2465 | 9430 | 5.74 | 0.61 | 2.35 | 8.59 |
| | | | 2.5 | 22900 | 2343 | 9430 | 5.71 | 0.58 | 2.35 | 8.59 |
| | | | 2.8 | 22762 | 2206 | 9430 | 5.67 | 0.55 | 2.35 | 8.59 |
| | | | 3.0 | 22688 | 2130 | 9430 | 5.65 | 0.53 | 2.35 | 8.59 |
| | | | 3.5 | 22537 | 1979 | 9430 | 5.61 | 0.49 | 2.35 | 8.59 |
| R5 | R11 | 2.0 ach | 2.28 | 25251 | 2589 | 11536 | 6.29 | 0.64 | 2.87 | 9.10 |
| | | | 2.5 | 25124 | 2461 | 11536 | 6.26 | 0.61 | 2.87 | 8.60 |
| | | | 2.8 | 24982 | 2320 | 11536 | 6.22 | 0.58 | 2.87 | 8.60 |
| | | | 3.0 | 24904 | 2241 | 11536 | 6.20 | 0.56 | 2.87 | 8.60 |
| | | | 3.5 | 24746 | 2084 | 11536 | 6.16 | 0.52 | 2.87 | 8.60 |
| Best | Case* | | | 21999 | 1960 | 8912 | 5.48 | 0.49 | 2.22 | 8.59 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

Figure 4.2a
SIMPLE PARAMETRICS OF COOLING ENERGY USE FOR A PROTOTYPICAL SINGLE-FAMILY HOUSE IN KARACHI

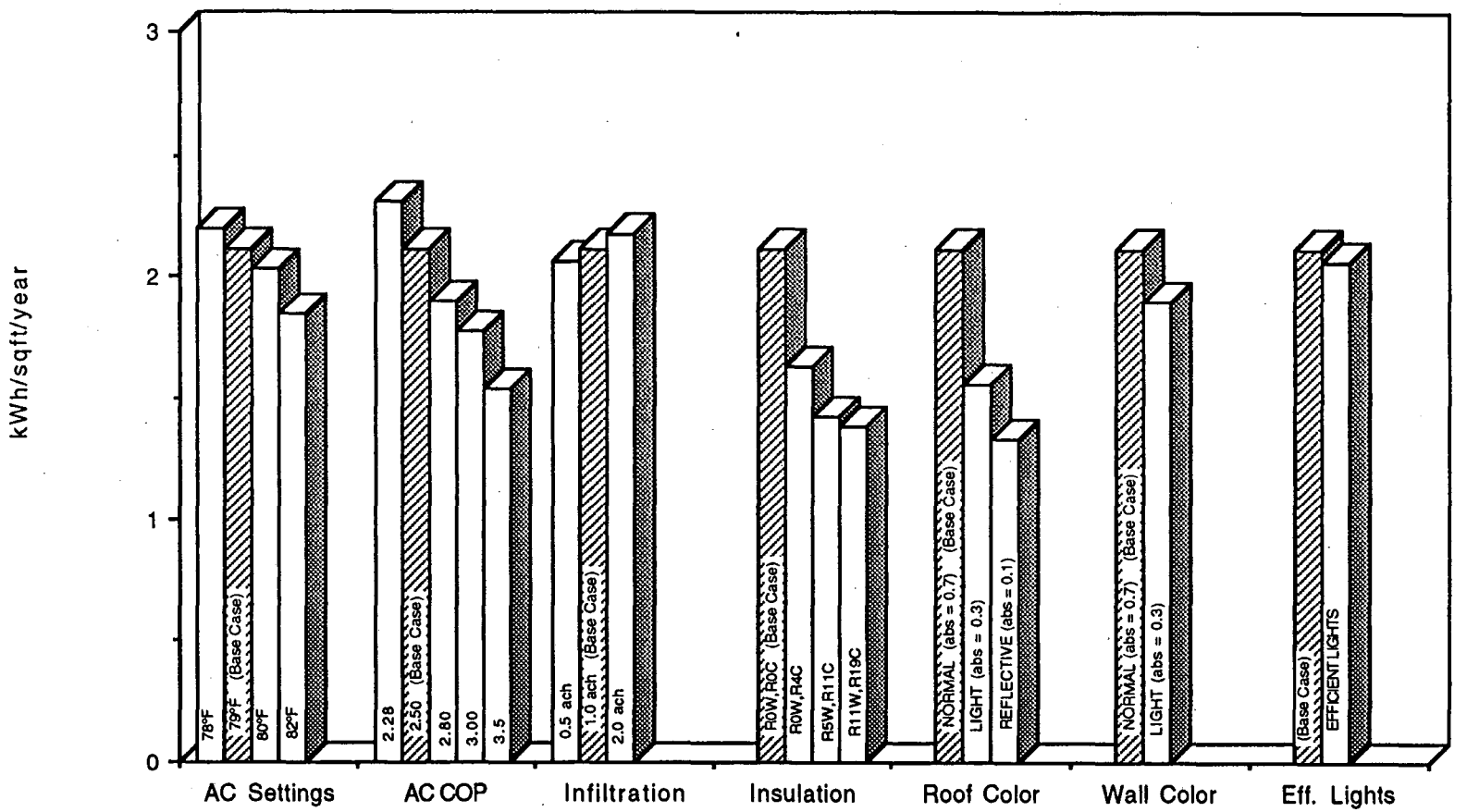


Figure 4.2b
SIMPLE PARAMETRICS OF HEATING ENERGY USE FOR A PROTOTYPICAL SINGLE-FAMILY HOUSE IN ISLAMABAD

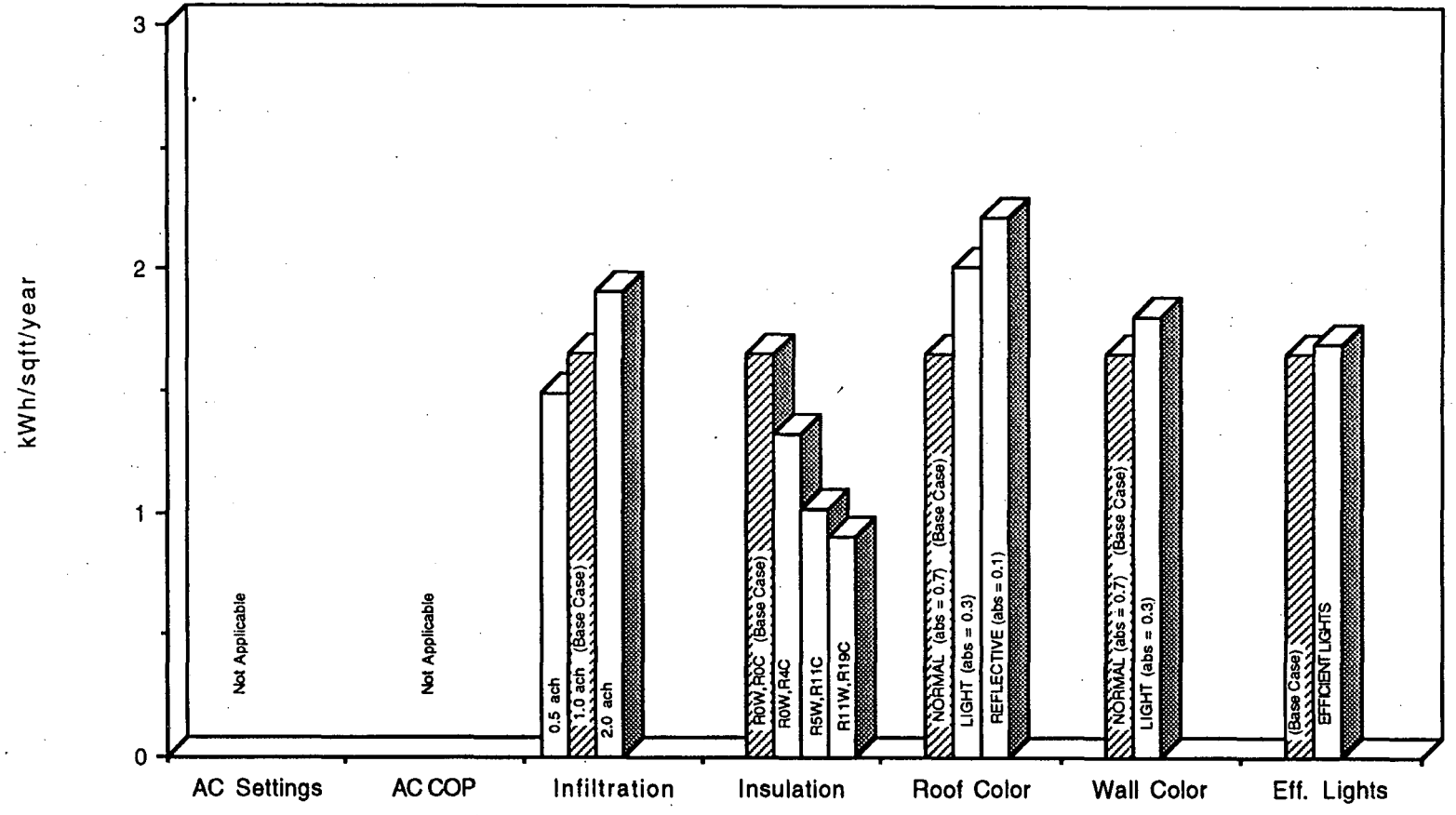
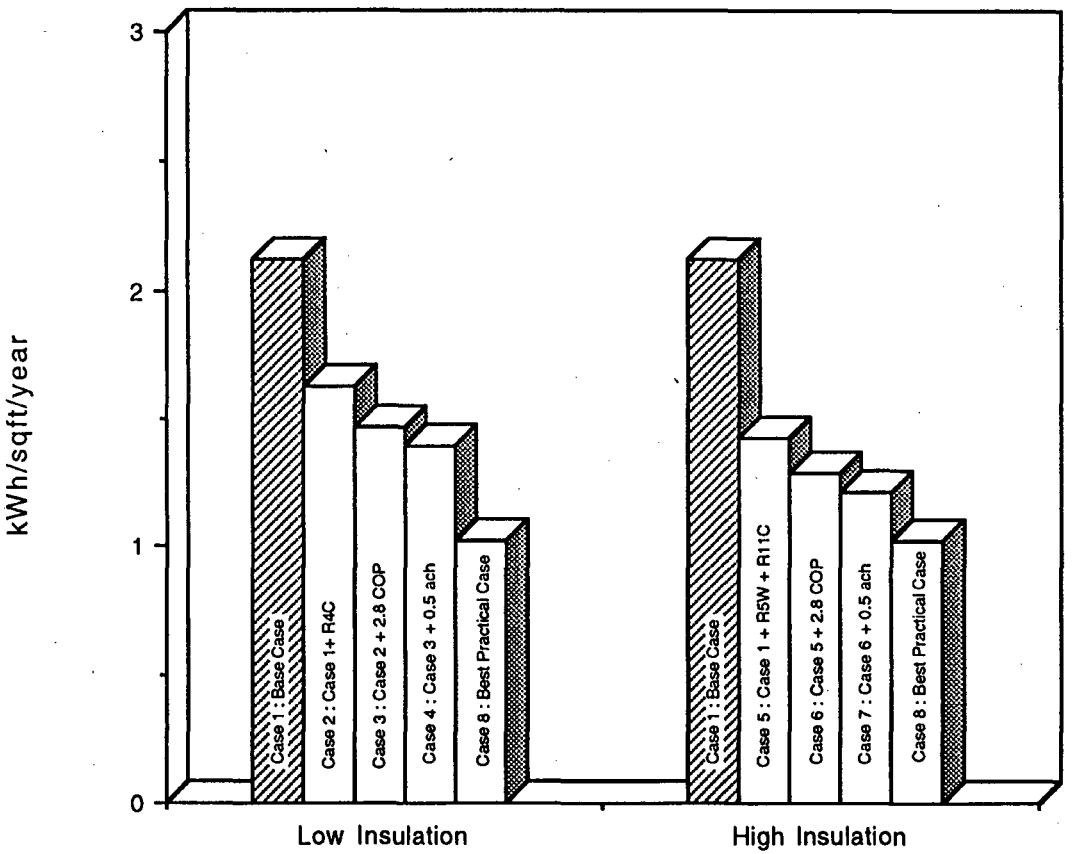
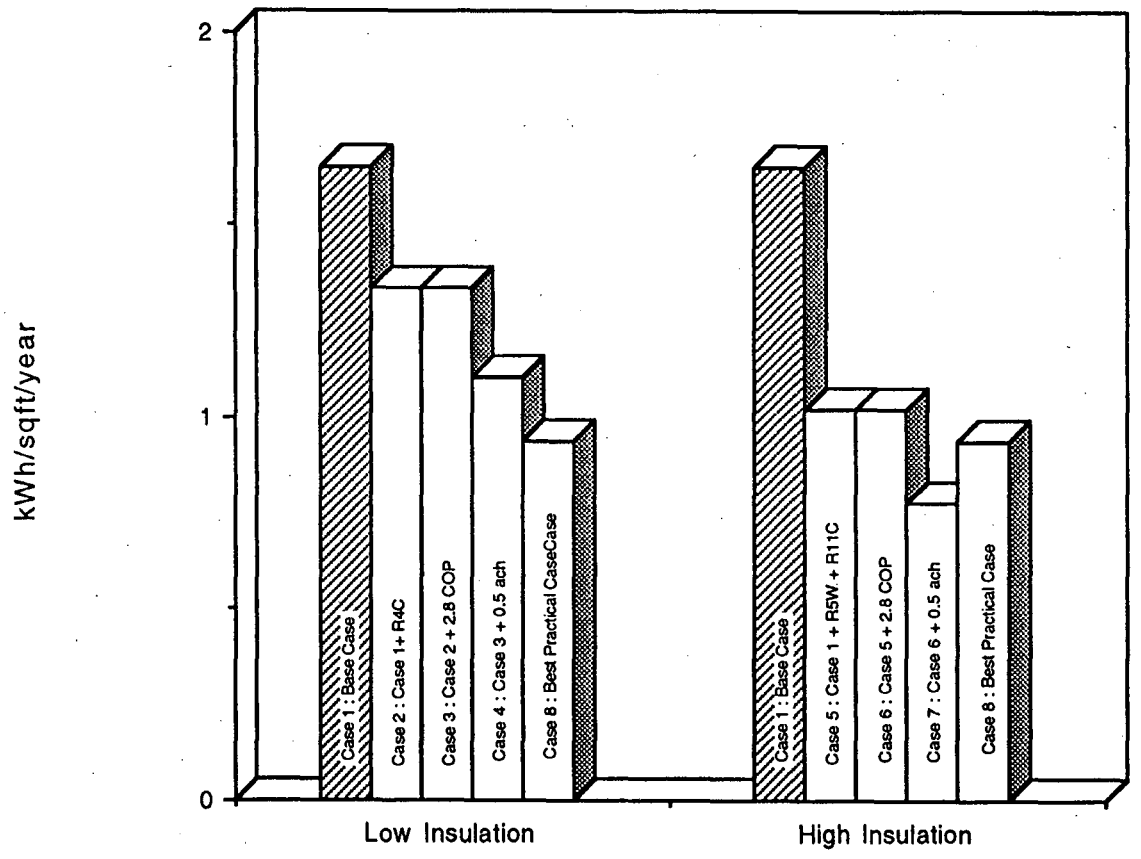


Figure 4.3a
COMBINED PARAMETRICS OF COOLING ENERGY USE FOR A PROTOTYPICAL SINGLE-FAMILY HOUSE IN KARACHI




Best Practical Case: AC setting:79F, AC COP: 3.0, Overhang:3ft, Infilt:0.5 ACH, Wall Colour: normal (0.7 abs), Roof Colour:Light (0.3 abs), Insul: R4 roof for low case and R11 roof and R5 walls for high case, Adj. Shade: none, Efficient Lighting: none

Figure 4.3b
COMBINED PARAMETRICS OF HEATING ENERGY USE FOR A PROTOTYPICAL SINGLE-FAMILY HOUSE IN ISLAMABAD




Best Practical Case: AC setting:79F, AC COP: 3.0, Overhang:3ft, Infilt: 0.5 ACH, Wall Colour: normal (0.7 abs), Roof Colour: Light (0.3 abs), Insul: R4 roof for low case and R11 roof and R5 walls for high case, Adj. Shade: none, Eff. Lighting: none

*Chapter 5*

# Office Building Converted from a Single-Family House in Pakistan

In Chapter 4, we discussed the detailed characteristics of a prototype residential building and presented DOE-2.1D simulation results for six climates showing the impacts of different conservation measures on the energy consumption. In this chapter, using the same methodology, the energy use of a prototypical office which is converted from a single family detached house will be analyzed. The main difference between the two analyses is the difference in their schedules of occupancy and use. The results of DOE-2.1D simulations for six climates (Karachi, Lahore, Islamabad, Quetta, Multan, and Peshawar) and for different energy conservation measures will be discussed.

The converted office prototype was defined based on surveys performed mainly in Islamabad, Karachi, and Lahore. In this chapter, parametric simulations for the three mentioned cities will be discussed in detail. For the other locations, namely, Multan, Peshawar, and Quetta, similar DOE-2 simulations using the prototype building models developed for Lahore and Islamabad were performed.

## Prototype Office Building Converted from a Single-Family Detached House

In this section, data obtained from the two sources in developing a prototype for the converted office were used. Three major factors were considered in development of the converted office prototype:

1. the physical layout of the building, floor plan, zones, and construction materials;
2. the internal loads and schedules for each zone; and
3. cooling and heating systems and schedules.

### *Floor plan, zones, and construction*

The recently surveyed converted offices were in the range of 1,800 to 4,900 $ft^2$. Consistent with the prototype single-family house, the floor area of the prototype converted office was assumed to be about about 3,800 $ft^2$. The building was divided into 7 zones. Six of these zones were offices and one zone included the corridors, kitchen and the common areas where secretaries and a receptionist are typically located. **Figures 5.1a&b** show the general floor plan of the prototype converted office building.

**Table 5.1** summarizes the highlights of the prototype. To avoid any directional bias in the simulation results, the external walls and windows were distributed equally in the four cardinal directions.

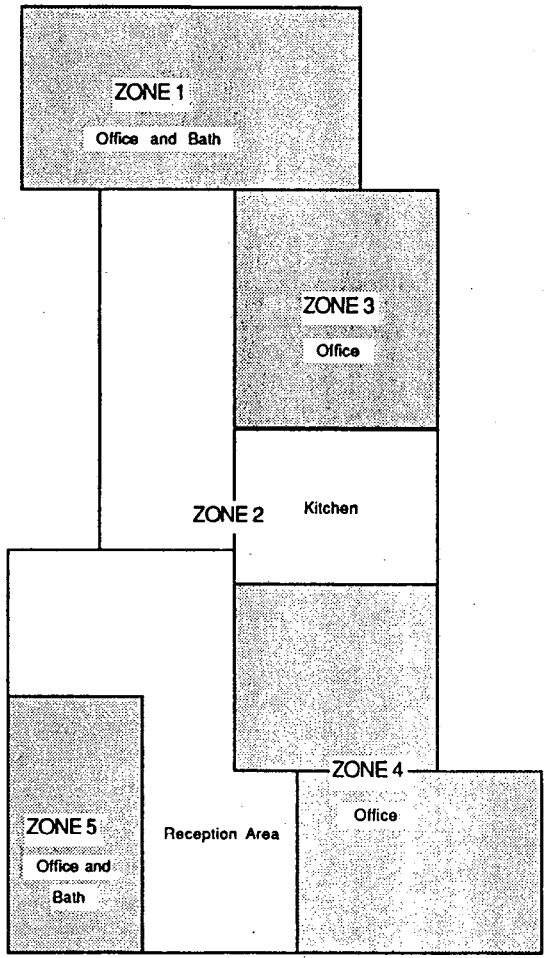



Figure 5.1 a General Floor Plan of the Prototype Converted Office Building (Ground Floor)

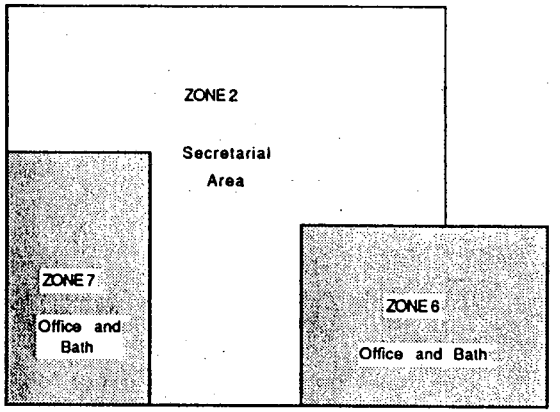



Figure 5.1 b General Floor Plan of the Prototype Converted Office Building (First Floor)

**Table 5.1.**
**Prototypical Converted Office Description in Pakistan**

| | |
|---|---|
| Number of stories: | 2 |
| Total floor area: | 3816 $ft^2$ |
| Total conditioned area: | 3816 $ft^2$ |
| Total window area: | 750 $ft^2$ |
| Window construction: | Single-pane glass, with 1.5-3.5 ft overhangs, no reflective film is used (reflective film will be used in the prototype models of regular office buildings) |
| Wall construction: | In Karachi, 6" concrete with 1/2" plaster on either side In Islamabad and Lahore, 9½ " brick with 1/2" plaster on either side |
| Roof construction: | 6" concrete with 1/2" plaster inside, 1/2" roofing outside |
| Number of occupants: | 15 |
| Lighting: | Fluorescent, 1 Watt/sqft, except for the central area |
| Lighting schedule: | 8.00 - 17.00 |
| Internal loads: | a refrigerator, a hot plate, one telephone exchange (150W), two computers (200W) each. |
| Air conditioning: | Nine 1.5 tons window units with 2.5 COP (one for each office, two for the central area and two for the large office which originally was the drawing and the dining room) |
| Fans: | One in each office room and three in the central area (a total of 9 fans 50W each) |
| Heating: | Electric resistance (no heating in Karachi) |
| Thermostat setting: | Cooling 79°F, heating 65°F |
| Others: | Roof and walls have an absorptivity of 0.7 |

*Internal loads and schedules*

The prototype house was simulated with a 100 Watts refrigerator, two computers (400 Watts), a hot plate (200 Watts), and a telephone exchange (150 Watts). Lighting was fluorescent with a peak usage of about 2600 watts. 15 people work in the office. Lighting and occupancy schedules were 8 a.m. to 5 p.m. while the rest of the equipment was assumed to operate all the time. **Table 5.1** also summarizes the internal loads of the converted office.

*Cooling and heating systems and schedules*

Data for cooling and heating equipment were obtained from the ENERCON reports (1987, 1990) and the recent survey.

The prototype building was simulated with seven air conditioned zones. The central zone (Zone 2) and the former dining-drawing room (Zone 4) were cooled by two 1.5 ton window units each. The other offices had one 1.5 ton units each. The building was simulated with nine 50 Watt fans operating during working hours. The air conditioning season was April through November.

The recent survey shows that no heating is done in the three buildings in Karachi. In the prototypical buildings, it is assumed that heating is done with electrical resistance heaters. The heating energy use was then estimated by gas heating equipment using an assumed efficiency for the heating equipment. This reduced the number of DOE-2 runs without loss of accuracy.

**DOE-2.1D Parametric Simulation**

A systematic series of DOE-2.1D simulations were performed to benchmark and validate the simulation results with monthly utility bills (on a kWh/sqft basis). These comparisons are shown in **Table 5.2.** Once the base case prototype has been benchmarked against measured utility bills, parametric simulations we performed in order to investigate the energy saving potentials of various conservation measures.

*Base Case*

The base case simulations were performed with the heating thermostat at 65°F between 8 a.m. and 5 p.m., and the cooling thermostat at 79°F from 8 a.m. to 5 p.m. Window conditions were assumed to be fixed (closed) at all times.

The window air-conditioners were assumed to have COPs of 2.5. The roofs and walls were assumed to be uninsulated, and the windows were single-pane clear glass. Shading from adjoining buildings was ignored for the base case, but analyzed in the parametric analysis of conservation measures.

*Energy conserving measures*

Once the base case prototype was simulated and validated, a series of parametric simulations were performed to estimate the energy saving potentials of conservation. Typical conservation measures usually considered for the converted office applications include envelope retrofit measures (to control heating and cooling loads of the building), energy efficient lighting, and energy efficient appliances (refrigerators, air conditioners etc.). **Table 5.3** shows a list of technologies that may be applicable to Pakistan buildings. Those technologies considered for our parametric analyses are printed in **boldface**.

*Parametric Simulations*

The parametric simulations were focussed around three subjects: envelope modification, efficient window air conditioners, and improved operational strategies. These parametrics include four levels of insulation in walls and roofs, two levels of overhang size, one level of wall

**Table 5.2.**
**Comparison of Measured Electricity Consumption of the Three Karachi and Lahore Offices and the Prototype Converted Offices**

| | Area | kWh/year | kWh/sqft.year |
|---|---|---|---|
| **Karachi** | | | |
| Building 10 | 2160 | 17594 | 8.14 |
| Building 12 | 4900 | 65270 | 13.32 |
| Building 17 | 1800 | 17000* | 9.44 |
| **Prototype** | **3816** | **31542** | **8.26** |
| **Lahore** | | | |
| Building 22 | 3521 | 37562† | 10.66 |
| Building 23 | 1996 | 28333† | 14.19 |
| Building 24 | 2430 | 26778† | 10.92 |
| **Prototype** | **3816** | **37582** | **9.84** |

* Interpolated values were used for the months for which bills are missing.

† Lahore building sizes were smaller than the prototype. Hence electricity intensities of Lahore buildings were higher than the prototype. Also, the sample Lahore buildings were in part heated with gas. Total gas heating cost, however, was less than 10% of the total energy bills.

color, two levels of roof colors, two levels of infiltration, four levels of air conditioning COPs, and three cooling thermostat settings. In addition, the effects of varying amounts of shading from adjoining houses was also investigated. See **Table 5.4** for details.

As for single-family detached house simulations, upon the completion of single parametric DOE-2 simulations, some complementary simulations on a combination of a few promising ECOs were performed. The methodology used to develop the combined parametrics was the same as in the residential buildings. The combined parametric simulations included simultaneous variations of insulation levels on walls and roofs, change in infiltration rate, and change in coefficient of performance of air conditioning unit.

**Table 5.3.**
**Converted Office Conservation Technologies**
(The impact of boldfaced ECOs were simulated in this study)

Cooling/Heating

1. **Ceiling insulation**
2. Floor insulation
3. **Wall insulation**
4. **Building color**
5. Multiple glazing
6. **Reduce infiltration** (weather stripping and caulking)
7. Movable window insulation
8. **Shading adjacent buildings**
9. Insulate ductwork
10. **High COP air conditioning units**
11. Evaporative coolers

Lighting

12. **Energy efficient fluorescent lamps**
13. Lighting controls
14. Selective switching

## Results

To a certain extend, the results of the parametric simulations for the converted office are comparable to those of the single family houses. Recall that the converted office prototype has the construction and structure of a house but with office equipment and schedules.

The simulation results for single and combined parametrics are presented in **Tables 5.5a-f** and **Tables 5.6a-f**, respectively. Parametrics for climates regions of Islamabad, Karachi, Lahore, Multan, Peshawar, and Quetta are denoted with letters **a** through **f**. Table 5.5 presents simulation results for total building, and cooling and heating end uses; both total energy use and normalized energy use ($kWh/ft^2$) are presented. These tables also provide data on peak electric demand on the building. For illustration and discussion purposes, the parametric results for Karachi (cooling dominated) and Islamabad (both cooling and heating are needed) are also plotted in **Figures 5.2** and **5.3**.

**Table 5.4: DOE-2.1D Parametric Simulations for Converted Prototype Office Building**

| Parametric simulation | Description |
|---|---|
| **Base Case** | R0 in walls and roofs; 1 ACH; A/C COP of 2.5; cooling thermostat setting of 79°F; roof and wall absorptivity 0.7; no shading from adjoining buildings. |
| **Simple Parametrics** | |
| Insulation | Four Cases: walls R0, roofs R4; walls R5, roof R11; walls R11 roofs R19 (insulation inside and outside) |
| Infiltration | Two Cases: 0.5, and 2.0 ACH |
| A/C COP | Four Cases: 2.28, 2.8, 3.0, and 3.5 |
| Cooling thermostat setting | Three Cooling Cases: 78, 80, and 82 °F |
| Overhangs | Two cases: 1-ft and 3-ft |
| Shading from adjoining buildings | Two Cases: two and three buildings |
| Wall color | One case: light (absorptivity 0.3) |
| Roof color | Two cases: light (abs 0.3), very light (abs 0.1) |
| Energy efficient lights and equipment | One case: Consumption is reduced by 50% |

*Simple Parametrics*

Cooling

The total simulated electricity use for the base case building was 31,542 kWh per year of which 18,416 kWh was for cooling. (See Table 5.5b and Figure 5.2a.) The heating electricity use was 1,162 kWh. Lighting, fans, refrigerators, and other miscellaneous end uses accounted for the rest of electricity use (11,964 kWh per year).

We discuss the impact of ECOs on cooling energy use only for Karachi. The conclusions made to Karachi buildings can be also extended to other climate zones. As Figure 5.2a indicates, the cooling energy use was very sensitive to thermostat setting, air conditioning COP, infiltration, roof and walls insulation, and roof color. The impact of overhang length, and efficient lighting systems on air conditioning use was fairly low. Increasing the air conditioning temperature set-point from 79°F to 82°F decreased the cooling energy use by 15% (~4% per °F) or 2,793 kWh per year.

The base case prototype converted office was simulated with no insulation on walls and roofs. Insulating the roofs of the building to meet the Pakistani proposed standards (no insulation on

walls and R4 total resistance of the roofs) decreased the cooling energy use of the building by 2,311 kWh per year (13%). Further increase on walls and roof insulation to [R5 on walls and R11 on roof] and [R11 on walls and R19 on roof] decreased the cooling energy use by 3,083 kWh (17%) and 3,294 kWh (18%), respectively.

All the simulations assume that the insulation on the walls and roof are on the outside. This would allow the building to take advantage of thermal mass in walls and ceilings. To analyze the impact of location of the insulation (inside or outside), the [R11 walls, R19 Roof] simulation was repeated with insulation on the inside. The results indicate a slight increase in both heating and cooling energy demand.

The cooling energy use, as it might be expected, was also very sensitive to the efficiency of the window air conditioning units. Increasing the COP of the window units from 2.5 (base case) to 3.5 resulted in a decrease of 4,995 kWh per year (27%). The Pakistani code suggests a minimum COP of 2.28 for window units. Changing the standards to the most efficient system (COP 3.5) in the market resulted in energy savings of 6,681 kWh (33%) per year per converted office.

Changing the color of the roof form the base case to a light color (absorptivity of 0.3) resulted in a 3,116 kWh (17%) reduction in air conditioning use. Further decrease in absorptivity of the roof color to 0.1 increaseed these savings to 4,399 kWh (24%). Note that changing the color of the roof is as effective as having R11 insulation on the roofs and R5 insulation on the walls. Obviously, changing colors of buildings will be probably much less costly than adding insulation on roofs and walls. Hence, we strongly recommend lighter building colors be included in the Pakistani codes and standards.

As we indicated in Chapter 4, horizontal surfaces (and to a certain extend, vertical surfaces) tend to collect dust and therefore dusty white roofs have lower reflectances than clean white roofs. Consequently, the energy savings potential of white colored roofs deteriorate with time. However, the reflectivity of a dusty white surface is still high and of order of 40 to 50%. Regular maintenance (clean up) of white roofs will insure the persistence of the cooling energy savings.

Changing the color of walls had less impact on cooling energy use, only 1,776 kWh (10%). It should be noticed that lightening the color of the roofs and walls had a negative impact on heating energy use. In Karachi, where the heating energy demand is fairly low, this change in color only increased the heating energy demand by less than 500 kWh per year. However, as we will discuss, the DOE-2 results for Islamabad showed that the impact of roof color on heating energy requirements may be fairly significant.

The cooling energy use of the converted office building was also sensitive to infiltration rate. Increasing the infiltration rate from 1 ACH (base case) to 2 ACH increased the cooling energy use by 1,766 kWh per year; about 10%. While, decreasing infiltration to 0.5 ACH reduced cooling energy use by 1,239 kWh (7%). Note that the impact of infiltration rate on cooling energy

consumption in a converted office was much more predominant than in single family houses. The main reason for this difference is the air conditioning schedules; in the converted office, the air conditioning is operating for longer hours and during the daytime where there is significant wind. In contrast, in the residential buildings, air conditioning is mainly operating for shorter hours during the nighttimes when wind speed is low and the outside temperature is also low.

There is no shading due to adjoining buildings in the base case. To estimate the shading impacts, the prototype building was simulated with adjacent buildings on **two** and **three** sides. Shading the building on two sides reduced the cooling energy use by 777 kWh per year (4%). The impact of the shading on the third side was an additional reduction of 311 kWh (2%).

Cooling energy use is fairly insensitive to overhang length. Increasing the overhang length from 2 feet to 3 feet reduced the cooling energy use by 329 kWh, while decreasing the length to 1 foot increased the cooling use by 494 kWh. The main reason for this behavior is the internal shades modeled for the prototypical building. Note that in the prototypical analysis, the windows are distributed equally in all orientations. Obviously the impact of the window shadings will be larger if the majority of the windows are positioned on the south and west of the building.

Also, the effects of efficient lighting and other appliances on cooling energy demand were fairly low.

Heating

As we discussed in the preceding section, some of the measures considered for reducing cooling energy use may have a negative impact on heating energy use (e.g., lighter roof color). Although, some other measures will result in heating and cooling energy savings (e.g., roof and wall insulation) and some other measures will not affect heating energy use at all (e.g., air conditioning set point temperature). We will review the impact of the proposed ECOs on heating energy use in Islamabad (Figure 5.2b). Data for all climate zones are presented in Tables 5.5.

Measures having the greatest impact on heating energy demand were roof and wall insulation (positive impact), roof color (negative impact), and control of infiltration (positive impact). The total building energy use for the Islamabad converted office was 35,059 kWh of that 13,890 kWh was for cooling and 9,201 kWh for heating.[1]

The effects of added insulation on roofs [R4] was to decrease heating energy use by 2,486 kWh (27%). Further increase in insulation of walls and roofs [R11 in walls, R19 in roofs] increased the energy savings to 5,782 kWh (63%). Note that having the same insulation on the interior side of the walls and roofs have slightly (245 kWh) increased heating energy savings of the

[1] Consumption data for heating are obtained with electric resistance heating. To estimate the heating energy use by in-room gas convective heater, divide the electric heating demands by the efficiency of the gas heater, usually in the range of 55 to 75%.

converted office building in Islamabad.

The impact of an increase in infiltration from 1.0 ACH to 2.0 ACH was an increase of 2,513 kWh (27%) in heating energy need. Decreasing infiltration form 1.0 ACH to 0.5 ACH resulted in a decrease of 1,332 kWh (14%) in heating energy use.

Changing the roof color to white or reflective colors increased heating energy use by 2,497 (27%) and 3,971 kWh (43%). The effect of wall colors on heating energy use was also significant (1,446 kWH or 16%).

Efficient appliances such as lights increased the heating energy use of the building by 880 KWh (10%).

*Combined Parametrics*

Through the simple parametric simulations, measures that have the highest impact on both heating and cooling energy requirements of prototypical converted office building in all climate regions were identified. The combined parametrics included variation in wall and roof insulation, COP, and air infiltration. Based on these combined parametrics, identified ECOs for a "best practical case" were identified. **Tables 5.6a-f** present the results of 31 parametric simulations for each of the climate zones (a total of 186 simulations).

In Figure 5.3a a selected group of combined parametrics for Karachi has been plotted. Two series of cases are presented: low insulation (Case 1) and high insulation (Case 5). The low insulation case considers R4 insulation on roofs and the high insulation case considers R11 insulation on roofs and R5 insulation on walls. To each case is progressively added the impact of COP increase from 2.5 to 2.8 (Cases 3 and 6) and the reduced infiltration (Cases 4 and 7). Finally, simulation results for "best practical case" (Case 8) are shown. The best case is defined as the case of A/C temperature setting of 79°F, A/C COP of 3.0; 3-foot overhang; 0.5 ACH, R5 insulation of walls, R11 insulation on roof, light roof color (abs 0.3), and efficient lighting.

As in the simple parametric simulations, the highest relative savings were still obtained by adding insulation on roofs and walls. The impact of roof insulation on reducing cooling energy use was much higher than that of the wall insulation. The cooling energy difference between the base case and the "best" case was 7,202 kWh per year (39%). In other words, – **40% of cooling energy use in converted office buildings in Karachi can be saved through simple, practical, and readily available measures and technologies in Pakistan.**

In the analysis of heating energy use for Islamabad (Figure 5.3b) similar results were obtained. The difference between the base case and best case heating energy use was 5,574 kWh per year (61%). Most of heating energy savings were realized through roof and wall insulation and control of infiltration.

In summary, the DOE-2 parametric simulations show that **savings on the order of 50% in both heating and cooling energy use in Pakistani converted office buildings, through use of some simple and available conservation measures such as insulating roofs and walls, control of infiltration, use of high COP air conditioning units, coloring the roofs white, are easily achievable.** An economic analysis is needed to evaluate the cost effectiveness of the proposed measures. This was not done due to the lack of cost data.

**Table 5.5a. Summary of Simple Parametric Simulations for Prototypical Converted Office Building in Islamabad (a=3816 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 35059 | 13890 | 9201 | 9.19 | 3.64 | 2.41 | 22.95 |
| AC Setting | 78 | 35595 | 14428 | 9201 | 9.33 | 3.78 | 2.41 | 22.97 |
| | 80 | 34525 | 13360 | 9201 | 9.05 | 3.50 | 2.41 | 22.95 |
| | 82 | 33477 | 12308 | 9201 | 8.77 | 3.23 | 2.41 | 22.95 |
| AC COP | 2.28 | 36219 | 15051 | 9201 | 9.49 | 3.94 | 2.41 | 24.40 |
| | 2.8 | 33770 | 12600 | 9201 | 8.85 | 3.30 | 2.41 | 22.95 |
| | 3.0 | 33052 | 11885 | 9201 | 8.66 | 3.11 | 2.41 | 22.95 |
| | 3.5 | 31623 | 10454 | 9201 | 8.29 | 2.74 | 2.41 | 22.95 |
| Adj. | 2 Houses | 35204 | 13312 | 9923 | 9.23 | 3.49 | 2.60 | 22.95 |
| Shade | 3 Houses | 35273 | 13084 | 10221 | 9.24 | 3.43 | 2.68 | 22.95 |
| Overhang | 1 ft | 35129 | 14259 | 8903 | 9.21 | 3.74 | 2.33 | 22.95 |
| | 3 ft | 35063 | 13652 | 9443 | 9.19 | 3.58 | 2.47 | 22.95 |
| Infilt. | 0.5 ach | 33042 | 13206 | 7869 | 8.66 | 3.46 | 2.06 | 22.95 |
| | 2.0 ach | 38587 | 14906 | 11714 | 10.11 | 3.91 | 3.07 | 24.67 |
| Insul. | R0W,R4C | 29774 | 11091 | 6715 | 7.80 | 2.91 | 1.76 | 22.95 |
| | R5W,R11C | 26478 | 10285 | 4224 | 6.94 | 2.70 | 1.11 | 22.93 |
| | R11W,R19C | 25356 | 9969 | 3419 | 6.64 | 2.61 | 0.90 | 22.78 |
| | R11W,R19C** | 25303 | 10160 | 3174 | 6.63 | 2.66 | 0.83 | 22.61 |
| Roof | Light | 33757 | 10092 | 11698 | 8.85 | 2.64 | 3.07 | 22.95 |
| Color | Reflec. | 33751 | 8607 | 13172 | 8.84 | 2.26 | 3.45 | 22.95 |
| Wall C. | Light | 35203 | 12590 | 10647 | 9.23 | 3.30 | 2.79 | 22.95 |
| Eff. Lights | | 29204 | 13138 | 10081 | 7.65 | 3.44 | 2.64 | 21.18 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 5.5b. Summary of Parametric Simulations for Prototypical Converted Office Building in Karachi (a=3816 ft$^2$)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft$^2$ Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 31542 | 18416 | 1162 | 8.27 | 4.83 | 0.30 | 22.95 |
| AC Setting | 78 | 32462 | 19333 | 1162 | 8.51 | 5.07 | 0.30 | 23.18 |
| | 80 | 30616 | 17485 | 1162 | 8.02 | 4.58 | 0.30 | 22.95 |
| | 82 | 28751 | 15623 | 1161 | 7.53 | 4.09 | 0.30 | 22.95 |
| AC COP | 2.28 | 33227 | 20102 | 1162 | 8.71 | 5.27 | 0.30 | 24.62 |
| | 2.8 | 29669 | 16541 | 1162 | 7.77 | 4.33 | 0.30 | 22.95 |
| | 3.0 | 28630 | 15501 | 1162 | 7.50 | 4.06 | 0.30 | 22.95 |
| | 3.5 | 26549 | 13421 | 1162 | 6.96 | 3.52 | 0.30 | 22.95 |
| Adj. Shade | 2 Houses | 30864 | 17639 | 1259 | 8.09 | 4.62 | 0.33 | 22.95 |
| | 3 Houses | 30596 | 17328 | 1301 | 8.02 | 4.54 | 0.34 | 22.95 |
| Overhang | 1 ft | 31986 | 18910 | 1108 | 8.38 | 4.96 | 0.29 | 22.95 |
| | 3 ft | 31263 | 18087 | 1206 | 8.19 | 4.74 | 0.32 | 22.95 |
| Infilt. | 0.5 ach | 30124 | 17177 | 981 | 7.89 | 4.50 | 0.26 | 22.95 |
| | 2.0 ach | 33652 | 20182 | 1504 | 8.82 | 5.29 | 0.39 | 25.50 |
| Insul. | R0W,R4C | 28761 | 16105 | 689 | 7.54 | 4.22 | 0.18 | 22.75 |
| | R5W,R11C | 27466 | 15333 | 166 | 7.20 | 4.02 | 0.04 | 20.52 |
| | R11W,R19C | 27174 | 15122 | 83 | 7.12 | 3.96 | 0.02 | 20.27 |
| | R11W,R19C** | 27426 | 15311 | 148 | 7.19 | 4.01 | 0.04 | 19.73 |
| Roof Color | Light | 28761 | 15300 | 1496 | 7.54 | 4.01 | 0.39 | 22.95 |
| | Reflec. | 27696 | 14017 | 1711 | 7.26 | 3.67 | 0.45 | 22.95 |
| Wall C. | Light | 30053 | 16640 | 1444 | 7.88 | 4.36 | 0.38 | 22.95 |
| Eff. Lights | | 24724 | 17415 | 1325 | 6.48 | 4.56 | 0.35 | 21.18 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 5.5c. Summary of Simple Parametric Simulations for Prototypical Converted Office Building in Lahore (a=3816 ft$^2$)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft$^2$ Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 37582 | 22686 | 2929 | 9.85 | 5.94 | 0.77 | 24.75 |
| AC Setting | 78 | 38125 | 23228 | 2929 | 9.99 | 6.09 | 0.77 | 25.12 |
| | 80 | 37022 | 22124 | 2929 | 9.70 | 5.80 | 0.77 | 24.35 |
| | 82 | 35925 | 21030 | 2929 | 9.41 | 5.51 | 0.77 | 23.54 |
| AC COP | 2.28 | 39626 | 24729 | 2929 | 10.38 | 6.48 | 0.77 | 26.76 |
| | 2.8 | 35308 | 20414 | 2929 | 9.25 | 5.35 | 0.77 | 22.79 |
| | 3.0 | 34047 | 19151 | 2929 | 8.92 | 5.02 | 0.77 | 22.79 |
| | 3.5 | 31528 | 16632 | 2929 | 8.26 | 4.36 | 0.77 | 22.79 |
| Adj. Shade | 2 Houses | 37119 | 21800 | 3352 | 9.73 | 5.71 | 0.88 | 24.63 |
| | 3 Houses | 36954 | 21454 | 3535 | 9.68 | 5.62 | 0.93 | 24.58 |
| Overhang | 1 ft | 37951 | 23224 | 2757 | 9.95 | 6.09 | 0.72 | 24.84 |
| | 3 ft | 37356 | 22314 | 3074 | 9.79 | 5.85 | 0.81 | 24.69 |
| Infilt. | 0.5 ach | 35751 | 21387 | 2396 | 9.37 | 5.60 | 0.63 | 22.82 |
| | 2.0 ach | 40407 | 24415 | 4022 | 10.59 | 6.40 | 1.05 | 26.94 |
| Insul. | R0W,R4C | 31538 | 17627 | 1942 | 8.26 | 4.62 | 0.51 | 23.06 |
| | R5W,R11C | 28204 | 15244 | 991 | 7.39 | 3.99 | 0.26 | 22.29 |
| | R11W,R19C | 27169 | 14502 | 699 | 7.12 | 3.80 | 0.18 | 22.01 |
| | R11W,R19C** | 27556 | 14936 | 654 | 7.22 | 3.91 | 0.17 | 21.45 |
| Roof Color | Light | 32853 | 16429 | 4457 | 8.61 | 4.31 | 1.17 | 23.55 |
| | Reflec. | 31192 | 13792 | 5430 | 8.17 | 3.61 | 1.42 | 22.92 |
| Wall C. | Light | 36266 | 20512 | 3786 | 9.50 | 5.38 | 0.99 | 24.41 |
| Eff. Lights | | 31056 | 21670 | 3404 | 8.14 | 5.68 | 0.89 | 22.65 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 5.5d. Summary of Simple Parametric Simulations for Prototypical Converted Office Building in Multan (a=3816 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 42387 | 26694 | 3724 | 11.11 | 7.00 | 0.98 | 25.45 |
| AC Setting | 78 | 42856 | 27164 | 3724 | 11.23 | 7.12 | 0.98 | 25.75 |
| | 80 | 41910 | 26219 | 3724 | 10.98 | 6.87 | 0.98 | 25.04 |
| | 82 | 40940 | 25247 | 3724 | 10.73 | 6.62 | 0.98 | 24.11 |
| AC COP | 2.28 | 44811 | 29120 | 3724 | 11.74 | 7.63 | 0.98 | 27.52 |
| | 2.8 | 39692 | 24002 | 3724 | 10.40 | 6.29 | 0.98 | 23.16 |
| | 3.0 | 38196 | 22508 | 3724 | 10.01 | 5.90 | 0.98 | 22.95 |
| | 3.5 | 35209 | 19518 | 3724 | 9.23 | 5.11 | 0.98 | 22.95 |
| Adj. | 2 Houses | 41947 | 25820 | 4159 | 10.99 | 6.77 | 1.09 | 25.36 |
| Shade | 3 Houses | 41786 | 25474 | 4343 | 10.95 | 6.68 | 1.14 | 25.31 |
| Overhang | 1 ft | 42781 | 27285 | 3529 | 11.21 | 7.15 | 0.92 | 25.51 |
| | 3 ft | 42158 | 26301 | 3888 | 11.05 | 6.89 | 1.02 | 25.41 |
| Infilt. | 0.5 ach | 39957 | 24935 | 3055 | 10.47 | 6.53 | 0.80 | 23.58 |
| | 2.0 ach | 46181 | 29153 | 5058 | 12.10 | 7.64 | 1.33 | 27.70 |
| Insul. | R0W,R4C | 35529 | 21053 | 2510 | 9.31 | 5.52 | 0.66 | 24.06 |
| | R5W,R11C | 31247 | 17894 | 1386 | 8.19 | 4.69 | 0.36 | 23.20 |
| | R11W,R19C | 29889 | 16899 | 1022 | 7.83 | 4.43 | 0.27 | 22.85 |
| | R11W,R19C** | 30505 | 17600 | 940 | 7.99 | 4.61 | 0.25 | 22.25 |
| Roof | Light | 37691 | 20371 | 5354 | 9.88 | 5.34 | 1.40 | 24.38 |
| Color | Reflec. | 35873 | 17547 | 6359 | 9.40 | 4.60 | 1.67 | 23.76 |
| Wall C. | Light | 41145 | 24542 | 4636 | 10.78 | 6.43 | 1.21 | 25.24 |
| Eff. Lights | | 35859 | 25635 | 4239 | 9.40 | 6.72 | 1.11 | 23.41 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 5.5e. Summary of Simple Parametric Simulations for Prototypical Converted Office Building in Peshawar (a=3816 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 38663 | 19542 | 7153 | 10.13 | 5.12 | 1.87 | 24.21 |
| AC Setting | 78 | 39129 | 20008 | 7153 | 10.25 | 5.24 | 1.87 | 24.62 |
| | 80 | 38194 | 19073 | 7153 | 10.01 | 5.00 | 1.87 | 23.80 |
| | 82 | 37279 | 18158 | 7153 | 9.77 | 4.76 | 1.87 | 22.96 |
| AC COP | 2.28 | 40371 | 21250 | 7153 | 10.58 | 5.57 | 1.87 | 26.16 |
| | 2.8 | 36762 | 17641 | 7153 | 9.63 | 4.62 | 1.87 | 22.95 |
| | 3.0 | 35709 | 16587 | 7153 | 9.36 | 4.35 | 1.87 | 22.95 |
| | 3.5 | 33602 | 14481 | 7153 | 8.81 | 3.79 | 1.87 | 22.95 |
| Adj. | 2 Houses | 38654 | 18834 | 7852 | 10.13 | 4.94 | 2.06 | 24.07 |
| Shade | 3 Houses | 38674 | 18563 | 8142 | 10.13 | 4.86 | 2.13 | 24.01 |
| Overhang | 1 ft | 38847 | 19997 | 6884 | 10.18 | 5.24 | 1.80 | 24.29 |
| | 3 ft | 38582 | 19241 | 7375 | 10.11 | 5.04 | 1.93 | 24.16 |
| Infilt. | 0.5 ach | 36353 | 18336 | 6048 | 9.53 | 4.81 | 1.58 | 22.95 |
| | 2.0 ach | 42520 | 21282 | 9272 | 11.14 | 5.58 | 2.43 | 26.60 |
| Insul. | R0W,R4C | 32541 | 15418 | 5156 | 8.53 | 4.04 | 1.35 | 22.95 |
| | R5W,R11C | 28640 | 13443 | 3232 | 7.51 | 3.52 | 0.85 | 22.61 |
| | R11W,R19C | 27416 | 12829 | 2616 | 7.18 | 3.36 | 0.69 | 22.18 |
| | R11W,R19C** | 27526 | 13228 | 2328 | 7.21 | 3.47 | 0.61 | 22.24 |
| Roof | Light | 36271 | 14740 | 9566 | 9.50 | 3.86 | 2.51 | 23.19 |
| Color | Reflec. | 35686 | 12711 | 11007 | 9.35 | 3.33 | 2.88 | 22.95 |
| Wall C. | Light | 38419 | 17893 | 8559 | 10.07 | 4.69 | 2.24 | 23.91 |
| Eff. Lights | | 32604 | 18661 | 7961 | 8.54 | 4.89 | 2.09 | 22.13 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 5.5f. Summary of Simple Parametric Simulations for Prototypical Converted Office Building in Quetta (a=3816 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat | Peak Elec(kW) |
|---|---|---|---|---|---|---|---|---|
| Base Case* | | 44822 | 6782 | 26071 | 11.75 | 1.78 | 6.83 | 22.95 |
| AC Setting | 78 | 45275 | 7235 | 26071 | 11.86 | 1.90 | 6.83 | 22.95 |
| | 80 | 44391 | 6348 | 26071 | 11.63 | 1.66 | 6.83 | 22.95 |
| | 82 | 43633 | 5596 | 26071 | 11.43 | 1.47 | 6.83 | 22.95 |
| AC COP | 2.28 | 45218 | 7180 | 26071 | 11.85 | 1.88 | 6.83 | 22.95 |
| | 2.8 | 44380 | 6340 | 26071 | 11.63 | 1.66 | 6.83 | 22.95 |
| | 3.0 | 44134 | 6094 | 26071 | 11.57 | 1.60 | 6.83 | 22.95 |
| | 3.5 | 43645 | 5604 | 26071 | 11.44 | 1.47 | 6.83 | 22.95 |
| Adj. Shade | 2 Houses | 45626 | 6622 | 27039 | 11.96 | 1.74 | 7.09 | 22.95 |
| | 3 Houses | 45954 | 6559 | 27429 | 12.04 | 1.72 | 7.19 | 22.95 |
| Overhang | 1 ft | 44427 | 6933 | 25522 | 11.64 | 1.82 | 6.69 | 22.95 |
| | 3 ft | 45157 | 6693 | 26496 | 11.83 | 1.75 | 6.94 | 22.95 |
| Infilt. | 0.5 ach | 42115 | 6646 | 23501 | 11.04 | 1.74 | 6.16 | 22.95 |
| | 2.0 ach | 49764 | 7122 | 30674 | 13.04 | 1.87 | 8.04 | 22.95 |
| Insul. | R0W,R4C | 39203 | 6124 | 21110 | 10.27 | 1.60 | 5.53 | 22.95 |
| | R5W,R11C | 32386 | 6074 | 14342 | 8.49 | 1.59 | 3.76 | 22.95 |
| | R11W,R19C | 30130 | 6056 | 12108 | 7.90 | 1.59 | 3.17 | 22.95 |
| | R11W,R19C** | 30451 | 6230 | 12254 | 7.98 | 1.63 | 3.21 | 22.95 |
| Roof Color | Light | 47150 | 5596 | 29587 | 12.36 | 1.47 | 7.75 | 22.95 |
| | Reflec. | 48509 | 5123 | 31416 | 12.71 | 1.34 | 8.23 | 22.95 |
| Wall C. | Light | 46326 | 6419 | 27940 | 12.14 | 1.68 | 7.32 | 22.95 |
| Eff. Lights | | 39589 | 6363 | 27241 | 10.37 | 1.67 | 7.14 | 21.18 |

* Base Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Efficient Lighting: none.

** Insulation applied to the interior surface.

**Table 5.6a. Summary of Combined Parametric Simulations for Prototypical Converted Office Building in Islamabad (a=3816 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 28649 | 11272 | 5407 | 7.51 | 2.95 | 1.42 | 22.95 |
| | | | 2.5 | 27804 | 10428 | 5407 | 7.29 | 2.73 | 1.42 | 22.95 |
| | | | 2.8 | 26865 | 9487 | 5407 | 7.04 | 2.49 | 1.42 | 22.95 |
| | | | 3.0 | 26344 | 8968 | 5407 | 6.90 | 2.35 | 1.42 | 22.95 |
| | | | 3.5 | 25302 | 7926 | 5407 | 6.63 | 2.08 | 1.42 | 22.95 |
| R0 | R4 | 1.0 ach | 2.28 | 30677 | 11995 | 6715 | 8.04 | 3.14 | 1.76 | 22.95 |
| | | | 2.5 | 29774 | 11091 | 6715 | 7.80 | 2.91 | 1.76 | 22.95 |
| | | | 2.8 | 28767 | 10088 | 6715 | 7.54 | 2.64 | 1.76 | 22.95 |
| | | | 3.0 | 28210 | 9529 | 6715 | 7.39 | 2.50 | 1.76 | 22.95 |
| | | | 3.5 | 27097 | 8415 | 6715 | 7.10 | 2.21 | 1.76 | 22.95 |
| R0 | R4 | 2.0 ach | 2.28 | 34491 | 13147 | 9378 | 9.04 | 3.45 | 2.46 | 25.27 |
| | | | 2.5 | 33494 | 12151 | 9378 | 8.78 | 3.18 | 2.46 | 23.40 |
| | | | 2.8 | 32388 | 11042 | 9378 | 8.49 | 2.89 | 2.46 | 22.95 |
| | | | 3.0 | 31773 | 10427 | 9378 | 8.33 | 2.73 | 2.46 | 22.95 |
| | | | 3.5 | 30544 | 9199 | 9378 | 8.00 | 2.41 | 2.46 | 22.95 |
| R5 | R11 | 0.5 ach | 2.28 | 25406 | 10469 | 2969 | 6.66 | 2.74 | 0.78 | 22.47 |
| | | | 2.5 | 24625 | 9686 | 2969 | 6.45 | 2.54 | 0.78 | 22.47 |
| | | | 2.8 | 23754 | 8817 | 2969 | 6.22 | 2.31 | 0.78 | 22.47 |
| | | | 3.0 | 23273 | 8334 | 2969 | 6.10 | 2.18 | 0.78 | 22.47 |
| | | | 3.5 | 22308 | 7370 | 2969 | 5.85 | 1.93 | 0.78 | 22.47 |
| R5 | R11 | 1.0 ach | 2.28 | 27312 | 11120 | 4224 | 7.16 | 2.91 | 1.11 | 22.93 |
| | | | 2.5 | 26478 | 10285 | 4224 | 6.94 | 2.70 | 1.11 | 22.93 |
| | | | 2.8 | 25548 | 9354 | 4224 | 6.69 | 2.45 | 1.11 | 22.93 |
| | | | 3.0 | 25034 | 8840 | 4224 | 6.56 | 2.32 | 1.11 | 22.93 |
| | | | 3.5 | 24003 | 7811 | 4224 | 6.29 | 2.05 | 1.11 | 22.93 |
| R5 | R11 | 2.0 ach | 2.28 | 31077 | 12192 | 6918 | 8.14 | 3.19 | 1.81 | 24.58 |
| | | | 2.5 | 30155 | 11271 | 6918 | 7.90 | 2.95 | 1.81 | 22.95 |
| | | | 2.8 | 29132 | 10246 | 6918 | 7.63 | 2.69 | 1.81 | 22.95 |
| | | | 3.0 | 28563 | 9678 | 6918 | 7.49 | 2.54 | 1.81 | 22.95 |
| | | | 3.5 | 27430 | 8543 | 6918 | 7.19 | 2.24 | 1.81 | 22.95 |
| Best | Case* | | | 23169 | 7575 | 3627 | 6.07 | 1.99 | 0.95 | 22.63 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 5.6b. Summary of Combined Parametric Simulations for Prototypical Converted Office Building in Karachi (a=3816 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 28730 | 16248 | 515 | 7.53 | 4.26 | 0.13 | 22.41 |
| | | | 2.5 | 27374 | 14893 | 515 | 7.17 | 3.90 | 0.13 | 22.41 |
| | | | 2.8 | 25869 | 13387 | 515 | 6.78 | 3.51 | 0.13 | 22.41 |
| | | | 3.0 | 25033 | 12553 | 515 | 6.56 | 3.29 | 0.13 | 22.41 |
| | | | 3.5 | 23362 | 10880 | 515 | 6.12 | 2.85 | 0.13 | 22.41 |
| R0 | R4 | 1.0 ach | 2.28 | 30231 | 17574 | 689 | 7.92 | 4.61 | 0.18 | 23.27 |
| | | | 2.5 | 28761 | 16105 | 689 | 7.54 | 4.22 | 0.18 | 22.75 |
| | | | 2.8 | 27127 | 14471 | 689 | 7.11 | 3.79 | 0.18 | 22.75 |
| | | | 3.0 | 26220 | 13564 | 689 | 6.87 | 3.55 | 0.18 | 22.75 |
| | | | 3.5 | 24408 | 11752 | 689 | 6.40 | 3.08 | 0.18 | 22.75 |
| R0 | R4 | 2.0 ach | 2.28 | 32545 | 19552 | 1025 | 8.53 | 5.12 | 0.27 | 26.54 |
| | | | 2.5 | 30907 | 17912 | 1025 | 8.10 | 4.69 | 0.27 | 24.55 |
| | | | 2.8 | 29085 | 16091 | 1025 | 7.62 | 4.22 | 0.27 | 22.95 |
| | | | 3.0 | 28074 | 15079 | 1025 | 7.36 | 3.95 | 0.27 | 22.95 |
| | | | 3.5 | 26053 | 13057 | 1025 | 6.83 | 3.42 | 0.27 | 22.95 |
| R5 | R11 | 0.5 ach | 2.28 | 27546 | 15519 | 60 | 7.22 | 4.07 | 0.02 | 19.97 |
| | | | 2.5 | 26253 | 14225 | 60 | 6.88 | 3.73 | 0.02 | 18.56 |
| | | | 2.8 | 24816 | 12789 | 60 | 6.50 | 3.35 | 0.02 | 16.98 |
| | | | 3.0 | 24018 | 11990 | 60 | 6.29 | 3.14 | 0.02 | 16.11 |
| | | | 3.5 | 22425 | 10396 | 60 | 5.88 | 2.72 | 0.02 | 14.36 |
| R5 | R11 | 1.0 ach | 2.28 | 28865 | 16731 | 166 | 7.56 | 4.38 | 0.04 | 22.13 |
| | | | 2.5 | 27466 | 15333 | 166 | 7.20 | 4.02 | 0.04 | 20.52 |
| | | | 2.8 | 25912 | 13779 | 166 | 6.79 | 3.61 | 0.04 | 18.74 |
| | | | 3.0 | 25051 | 12916 | 166 | 6.56 | 3.38 | 0.04 | 17.75 |
| | | | 3.5 | 23326 | 11192 | 166 | 6.11 | 2.93 | 0.04 | 16.44 |
| R5 | R11 | 2.0 ach | 2.28 | 31034 | 18608 | 460 | 8.13 | 4.88 | 0.12 | 25.05 |
| | | | 2.5 | 29475 | 17048 | 460 | 7.72 | 4.47 | 0.12 | 23.19 |
| | | | 2.8 | 27742 | 15315 | 460 | 7.27 | 4.01 | 0.12 | 21.99 |
| | | | 3.0 | 26780 | 14353 | 460 | 7.02 | 3.76 | 0.12 | 21.99 |
| | | | 3.5 | 24859 | 12430 | 460 | 6.51 | 3.26 | 0.12 | 21.99 |
| Best | Case* | | | 23283 | 11217 | 101 | 6.10 | 2.94 | 0.03 | 15.75 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 5.6c. Summary of Combined Parametric Simulations for Prototypical Converted Office Building in Lahore (a=3816 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 31255 | 17853 | 1434 | 8.19 | 4.68 | 0.38 | 22.92 |
| | | | 2.5 | 29800 | 16398 | 1434 | 7.81 | 4.30 | 0.38 | 21.26 |
| | | | 2.8 | 28183 | 14781 | 1434 | 7.39 | 3.87 | 0.38 | 21.26 |
| | | | 3.0 | 27284 | 13884 | 1434 | 7.15 | 3.64 | 0.38 | 21.26 |
| | | | 3.5 | 25491 | 12088 | 1434 | 6.68 | 3.17 | 0.38 | 21.26 |
| R0 | R4 | 1.0 ach | 2.28 | 33109 | 19198 | 1942 | 8.68 | 5.03 | 0.51 | 24.91 |
| | | | 2.5 | 31538 | 17627 | 1942 | 8.26 | 4.62 | 0.51 | 23.06 |
| | | | 2.8 | 29794 | 15882 | 1942 | 7.81 | 4.16 | 0.51 | 22.56 |
| | | | 3.0 | 28824 | 14913 | 1942 | 7.55 | 3.91 | 0.51 | 22.56 |
| | | | 3.5 | 26889 | 12976 | 1942 | 7.05 | 3.40 | 0.51 | 22.56 |
| R0 | R4 | 2.0 ach | 2.28 | 36176 | 21262 | 2948 | 9.48 | 5.57 | 0.77 | 27.58 |
| | | | 2.5 | 34432 | 19516 | 2948 | 9.02 | 5.11 | 0.77 | 25.51 |
| | | | 2.8 | 32491 | 17575 | 2948 | 8.51 | 4.61 | 0.77 | 23.20 |
| | | | 3.0 | 31418 | 16499 | 2948 | 8.23 | 4.32 | 0.77 | 22.95 |
| | | | 3.5 | 29263 | 14347 | 2948 | 7.67 | 3.76 | 0.77 | 22.95 |
| R5 | R11 | 0.5 ach | 2.28 | 27735 | 15287 | 481 | 7.27 | 4.01 | 0.13 | 22.12 |
| | | | 2.5 | 26499 | 14052 | 481 | 6.94 | 3.68 | 0.13 | 20.52 |
| | | | 2.8 | 25127 | 12677 | 481 | 6.58 | 3.32 | 0.13 | 18.74 |
| | | | 3.0 | 24364 | 11916 | 481 | 6.38 | 3.12 | 0.13 | 17.75 |
| | | | 3.5 | 22839 | 10391 | 481 | 5.99 | 2.72 | 0.13 | 16.93 |
| R5 | R11 | 1.0 ach | 2.28 | 29552 | 16592 | 991 | 7.74 | 4.35 | 0.26 | 24.06 |
| | | | 2.5 | 28204 | 15244 | 991 | 7.39 | 3.99 | 0.26 | 22.29 |
| | | | 2.8 | 26706 | 13746 | 991 | 7.00 | 3.60 | 0.26 | 20.35 |
| | | | 3.0 | 25875 | 12914 | 991 | 6.78 | 3.38 | 0.26 | 20.35 |
| | | | 3.5 | 24212 | 11253 | 991 | 6.34 | 2.95 | 0.26 | 20.35 |
| R5 | R11 | 2.0 ach | 2.28 | 32683 | 18713 | 2003 | 8.56 | 4.90 | 0.52 | 26.98 |
| | | | 2.5 | 31156 | 17185 | 2003 | 8.16 | 4.50 | 0.52 | 24.96 |
| | | | 2.8 | 29456 | 15487 | 2003 | 7.72 | 4.06 | 0.52 | 22.90 |
| | | | 3.0 | 28516 | 14546 | 2003 | 7.47 | 3.81 | 0.52 | 22.90 |
| | | | 3.5 | 26632 | 12661 | 2003 | 6.98 | 3.32 | 0.52 | 22.90 |
| Best | Case* | | | 23419 | 10631 | 821 | 6.14 | 2.79 | 0.22 | 18.48 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 5.6d. Summary of Combined Parametric Simulations for Prototypical Converted Office Building in Multan (a=3816 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 34961 | 21082 | 1912 | 9.16 | 5.52 | 0.50 | 23.59 |
| | | | 2.5 | 33226 | 19345 | 1912 | 8.71 | 5.07 | 0.50 | 21.90 |
| | | | 2.8 | 31296 | 17417 | 1912 | 8.20 | 4.56 | 0.50 | 21.90 |
| | | | 3.0 | 30227 | 16347 | 1912 | 7.92 | 4.28 | 0.50 | 21.90 |
| | | | 3.5 | 28086 | 14206 | 1912 | 7.36 | 3.72 | 0.50 | 21.90 |
| R0 | R4 | 1.0 ach | 2.28 | 37425 | 22948 | 2510 | 9.81 | 6.01 | 0.66 | 25.99 |
| | | | 2.5 | 35529 | 21053 | 2510 | 9.31 | 5.52 | 0.66 | 24.06 |
| | | | 2.8 | 33422 | 18946 | 2510 | 8.76 | 4.96 | 0.66 | 22.81 |
| | | | 3.0 | 32254 | 17778 | 2510 | 8.45 | 4.66 | 0.66 | 22.81 |
| | | | 3.5 | 29917 | 15440 | 2510 | 7.84 | 4.05 | 0.66 | 22.81 |
| R0 | R4 | 2.0 ach | 2.28 | 41574 | 25843 | 3763 | 10.89 | 6.77 | 0.99 | 28.81 |
| | | | 2.5 | 39433 | 23703 | 3763 | 10.33 | 6.21 | 0.99 | 26.63 |
| | | | 2.8 | 37053 | 21323 | 3763 | 9.71 | 5.59 | 0.99 | 24.20 |
| | | | 3.0 | 35732 | 20003 | 3763 | 9.36 | 5.24 | 0.99 | 22.95 |
| | | | 3.5 | 33093 | 17360 | 3763 | 8.67 | 4.55 | 0.99 | 22.95 |
| R5 | R11 | 0.5 ach | 2.28 | 30340 | 17603 | 770 | 7.95 | 4.61 | 0.20 | 22.53 |
| | | | 2.5 | 28903 | 16165 | 770 | 7.57 | 4.24 | 0.20 | 20.90 |
| | | | 2.8 | 27305 | 14568 | 770 | 7.16 | 3.82 | 0.20 | 19.08 |
| | | | 3.0 | 26420 | 13681 | 770 | 6.92 | 3.59 | 0.20 | 18.07 |
| | | | 3.5 | 24645 | 11908 | 770 | 6.46 | 3.12 | 0.20 | 17.56 |
| R5 | R11 | 1.0 ach | 2.28 | 32846 | 19494 | 1386 | 8.61 | 5.11 | 0.36 | 25.05 |
| | | | 2.5 | 31247 | 17894 | 1386 | 8.19 | 4.69 | 0.36 | 23.20 |
| | | | 2.8 | 29468 | 16117 | 1386 | 7.72 | 4.22 | 0.36 | 21.50 |
| | | | 3.0 | 28482 | 15130 | 1386 | 7.46 | 3.96 | 0.36 | 21.50 |
| | | | 3.5 | 26509 | 13158 | 1386 | 6.95 | 3.45 | 0.36 | 21.50 |
| R5 | R11 | 2.0 ach | 2.28 | 37127 | 22557 | 2601 | 9.73 | 5.91 | 0.68 | 28.08 |
| | | | 2.5 | 35265 | 20697 | 2601 | 9.24 | 5.42 | 0.68 | 25.97 |
| | | | 2.8 | 33197 | 18630 | 2601 | 8.70 | 4.88 | 0.68 | 23.61 |
| | | | 3.0 | 32049 | 17483 | 2601 | 8.40 | 4.58 | 0.68 | 22.95 |
| | | | 3.5 | 29756 | 15187 | 2601 | 7.80 | 3.98 | 0.68 | 22.95 |
| Best | Case* | | | 25432 | 12301 | 1164 | 6.66 | 3.22 | 0.31 | 19.25 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 5.6e. Summary of Combined Parametric Simulations for Prototypical Converted Office Building in Peshawar (a=3816 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 31592 | 15495 | 4131 | 8.28 | 4.06 | 1.08 | 22.74 |
| | | | 2.5 | 30372 | 14274 | 4131 | 7.96 | 3.74 | 1.08 | 22.74 |
| | | | 2.8 | 29016 | 12917 | 4131 | 7.60 | 3.38 | 1.08 | 22.74 |
| | | | 3.0 | 28263 | 12165 | 4131 | 7.41 | 3.19 | 1.08 | 22.74 |
| | | | 3.5 | 26759 | 10661 | 4131 | 7.01 | 2.79 | 1.08 | 22.74 |
| R0 | R4 | 1.0 ach | 2.28 | 33866 | 16745 | 5156 | 8.87 | 4.39 | 1.35 | 24.68 |
| | | | 2.5 | 32541 | 15418 | 5156 | 8.53 | 4.04 | 1.35 | 22.95 |
| | | | 2.8 | 31068 | 13945 | 5156 | 8.14 | 3.65 | 1.35 | 22.95 |
| | | | 3.0 | 30251 | 13126 | 5156 | 7.93 | 3.44 | 1.35 | 22.95 |
| | | | 3.5 | 28614 | 11492 | 5156 | 7.50 | 3.01 | 1.35 | 22.95 |
| R0 | R4 | 2.0 ach | 2.28 | 38037 | 18767 | 7304 | 9.97 | 4.92 | 1.91 | 27.30 |
| | | | 2.5 | 36543 | 17272 | 7304 | 9.58 | 4.53 | 1.91 | 25.25 |
| | | | 2.8 | 34882 | 15610 | 7304 | 9.14 | 4.09 | 1.91 | 22.97 |
| | | | 3.0 | 33959 | 14688 | 7304 | 8.90 | 3.85 | 1.91 | 22.95 |
| | | | 3.5 | 32118 | 12845 | 7304 | 8.42 | 3.37 | 1.91 | 22.95 |
| R5 | R11 | 0.5 ach | 2.28 | 27545 | 13378 | 2201 | 7.22 | 3.51 | 0.58 | 21.37 |
| | | | 2.5 | 26504 | 12335 | 2201 | 6.95 | 3.23 | 0.58 | 21.13 |
| | | | 2.8 | 25345 | 11177 | 2201 | 6.64 | 2.93 | 0.58 | 21.13 |
| | | | 3.0 | 24702 | 10535 | 2201 | 6.47 | 2.76 | 0.58 | 21.13 |
| | | | 3.5 | 23416 | 9250 | 2201 | 6.14 | 2.42 | 0.58 | 21.13 |
| R5 | R11 | 1.0 ach | 2.28 | 29784 | 14586 | 3232 | 7.81 | 3.82 | 0.85 | 23.82 |
| | | | 2.5 | 28640 | 13443 | 3232 | 7.51 | 3.52 | 0.85 | 22.61 |
| | | | 2.8 | 27368 | 12168 | 3232 | 7.17 | 3.19 | 0.85 | 22.61 |
| | | | 3.0 | 26661 | 11465 | 3232 | 6.99 | 3.00 | 0.85 | 22.61 |
| | | | 3.5 | 25251 | 10051 | 3232 | 6.62 | 2.63 | 0.85 | 22.61 |
| R5 | R11 | 2.0 ach | 2.28 | 33912 | 16613 | 5330 | 8.89 | 4.35 | 1.40 | 26.49 |
| | | | 2.5 | 32597 | 15300 | 5330 | 8.54 | 4.01 | 1.40 | 24.51 |
| | | | 2.8 | 31137 | 13839 | 5330 | 8.16 | 3.63 | 1.40 | 22.95 |
| | | | 3.0 | 30326 | 13028 | 5330 | 7.95 | 3.41 | 1.40 | 22.95 |
| | | | 3.5 | 28706 | 11408 | 5330 | 7.52 | 2.99 | 1.40 | 22.95 |
| Best | Case* | | | 24361 | 9581 | 2813 | 6.38 | 2.51 | 0.74 | 21.65 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

**Table 5.6f. Summary of Combined Parametric Simulations for Prototypical Converted Office Building in Quetta (a=3816 ft²)**

| Insulation | | | | Energy (kWh) | | | KWh/ft² | | | Peak |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Total | Cool | Heat | Total | Cool | Heat | Elec(kW) |
| R0 | R4 | 0.5 ach | 2.28 | 36343 | 6363 | 18010 | 9.52 | 1.67 | 4.72 | 22.95 |
| | | | 2.5 | 35993 | 6013 | 18010 | 9.43 | 1.58 | 4.72 | 22.95 |
| | | | 2.8 | 35606 | 5623 | 18010 | 9.33 | 1.47 | 4.72 | 22.95 |
| | | | 3.0 | 35389 | 5408 | 18010 | 9.27 | 1.42 | 4.72 | 22.95 |
| | | | 3.5 | 34957 | 4978 | 18010 | 9.16 | 1.30 | 4.72 | 22.95 |
| R0 | R4 | 1.0 ach | 2.28 | 39553 | 6474 | 21110 | 10.37 | 1.70 | 5.53 | 22.95 |
| | | | 2.5 | 39203 | 6124 | 21110 | 10.27 | 1.60 | 5.53 | 22.95 |
| | | | 2.8 | 38813 | 5732 | 21110 | 10.17 | 1.50 | 5.53 | 22.95 |
| | | | 3.0 | 38598 | 5516 | 21110 | 10.11 | 1.45 | 5.53 | 22.95 |
| | | | 3.5 | 38164 | 5084 | 21110 | 10.00 | 1.33 | 5.53 | 22.95 |
| R0 | R4 | 2.0 ach | 2.28 | 45348 | 6790 | 26591 | 11.88 | 1.78 | 6.97 | 22.95 |
| | | | 2.5 | 44985 | 6429 | 26591 | 11.79 | 1.68 | 6,97 | 22.95 |
| | | | 2.8 | 44583 | 6025 | 26591 | 11.68 | 1.58 | 6.97 | 22.95 |
| | | | 3.0 | 44358 | 5800 | 26591 | 11.62 | 1.52 | 6.97 | 22.95 |
| | | | 3.5 | 43911 | 5351 | 26591 | 11.51 | 1.40 | 6.97 | 22.95 |
| R5 | R11 | 0.5 ach | 2.28 | 29355 | 6443 | 10941 | 7.69 | 1.69 | 2.87 | 22.95 |
| | | | 2.5 | 28978 | 6066 | 10941 | 7.59 | 1.59 | 2.87 | 22.95 |
| | | | 2.8 | 28559 | 5647 | 10941 | 7.48 | 1.48 | 2.87 | 22.95 |
| | | | 3.0 | 28328 | 5416 | 10941 | 7.42 | 1.42 | 2.87 | 22.95 |
| | | | 3.5 | 27866 | 4955 | 10941 | 7.30 | 1.30 | 2.87 | 22.95 |
| R5 | R11 | 1.0 ach | 2.28 | 32750 | 6441 | 14342 | 8.58 | 1.69 | 3.76 | 22.95 |
| | | | 2.5 | 32386 | 6074 | 14342 | 8.49 | 1.59 | 3.76 | 22.95 |
| | | | 2.8 | 31977 | 5669 | 14342 | 8.38 | 1.49 | 3.76 | 22.95 |
| | | | 3.0 | 31752 | 5443 | 14342 | 8.32 | 1.43 | 3.76 | 22.95 |
| | | | 3.5 | 31302 | 4991 | 14342 | 8.20 | 1.31 | 3.76 | 22.95 |
| R5 | R11 | 2.0 ach | 2.28 | 39308 | 6671 | 20671 | 10.30 | 1.75 | 5.42 | 22.95 |
| | | | 2.5 | 38941 | 6303 | 20671 | 10.20 | 1.65 | 5.42 | 22.95 |
| | | | 2.8 | 38532 | 5894 | 20671 | 10.10 | 1.54 | 5.42 | 22.95 |
| | | | 3.0 | 38304 | 5665 | 20671 | 10.04 | 1.48 | 5.42 | 22.95 |
| | | | 3.5 | 37849 | 5210 | 20671 | 9.92 | 1.37 | 5.42 | 22.95 |
| Best | Case* | | | 29286 | 5035 | 12286 | 7.67 | 1.32 | 3.22 | 22.95 |

* Best Case is for the prototype model with the following properties: AC setting: 79°F, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Efficient Lighting: none.

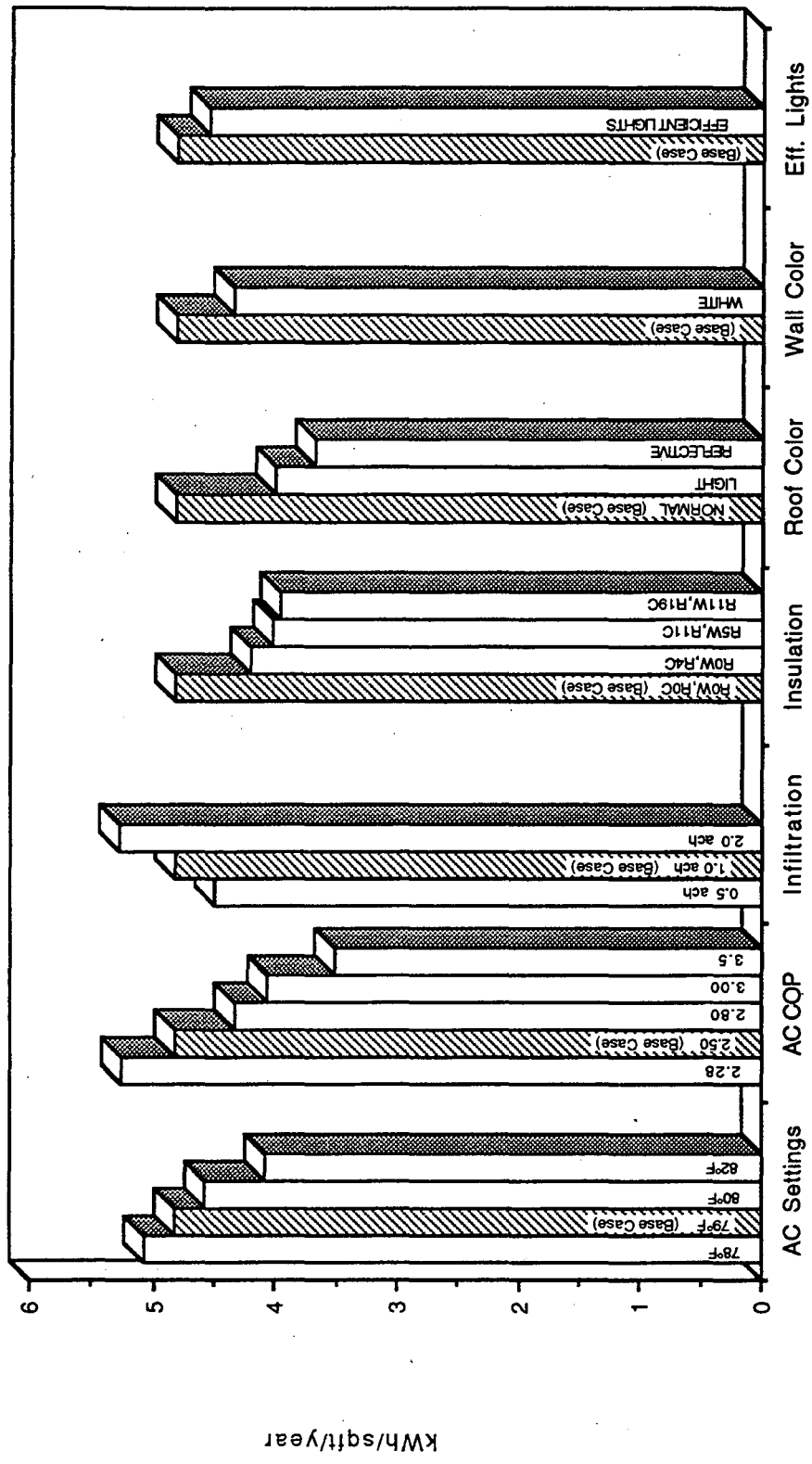



Figure 5.2a
SIMPLE PARAMETRICS OF COOLING ENERGY USE FOR A PROTOTYPICAL CONVERTED OFFICE BUILDING IN KARACHI

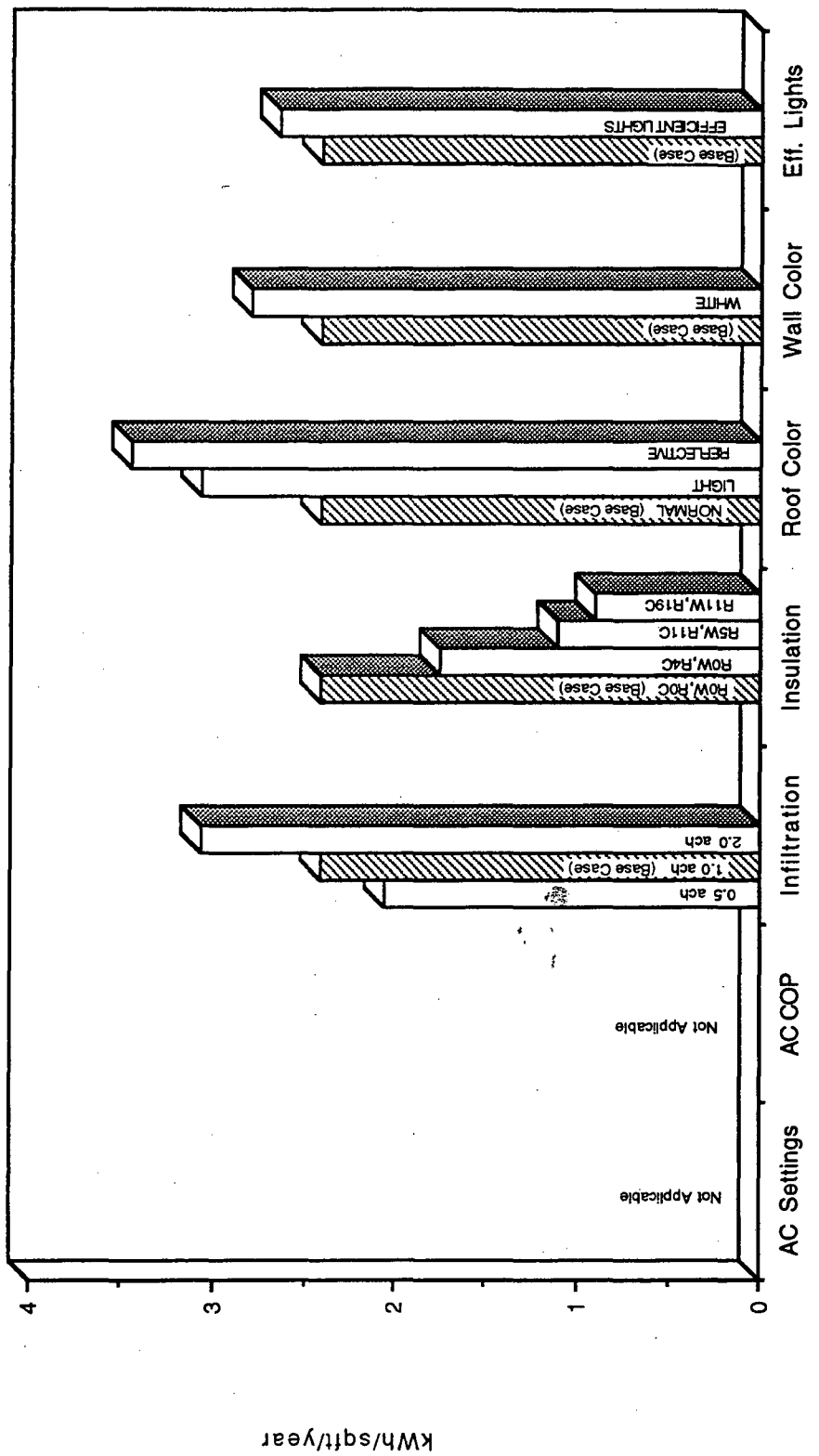
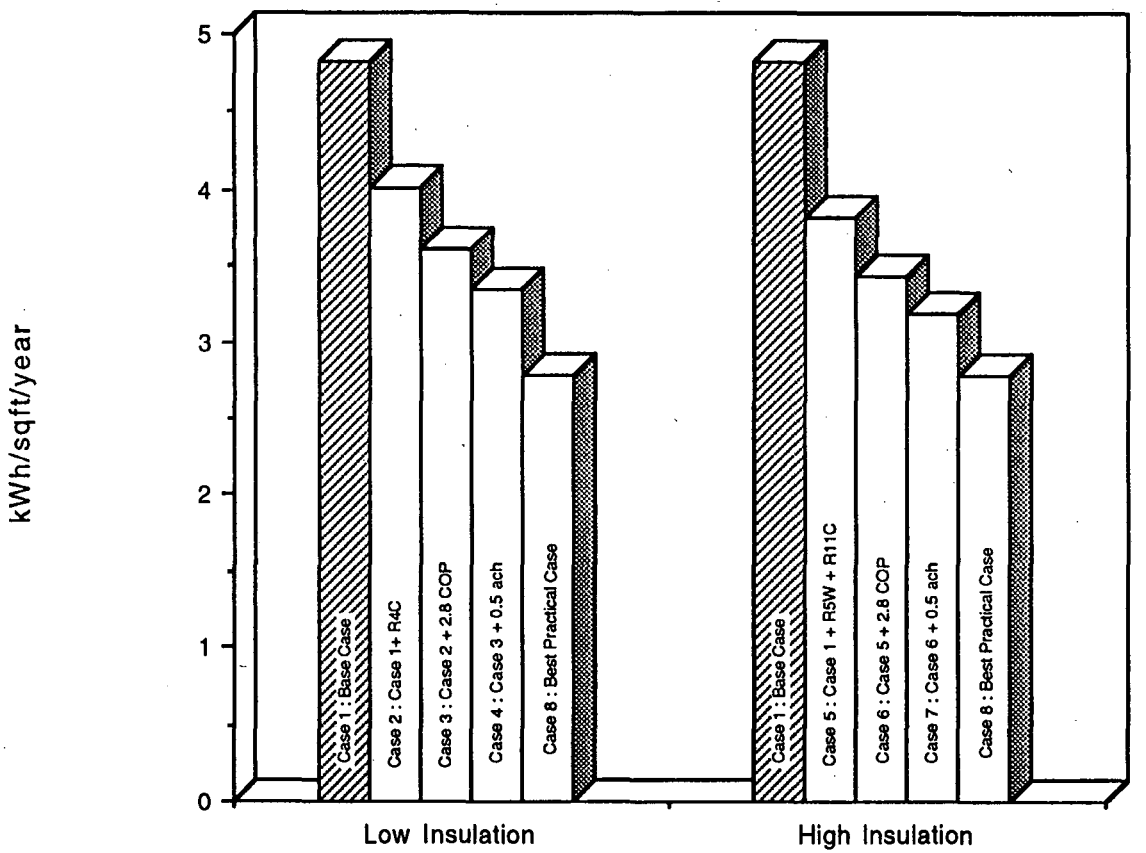


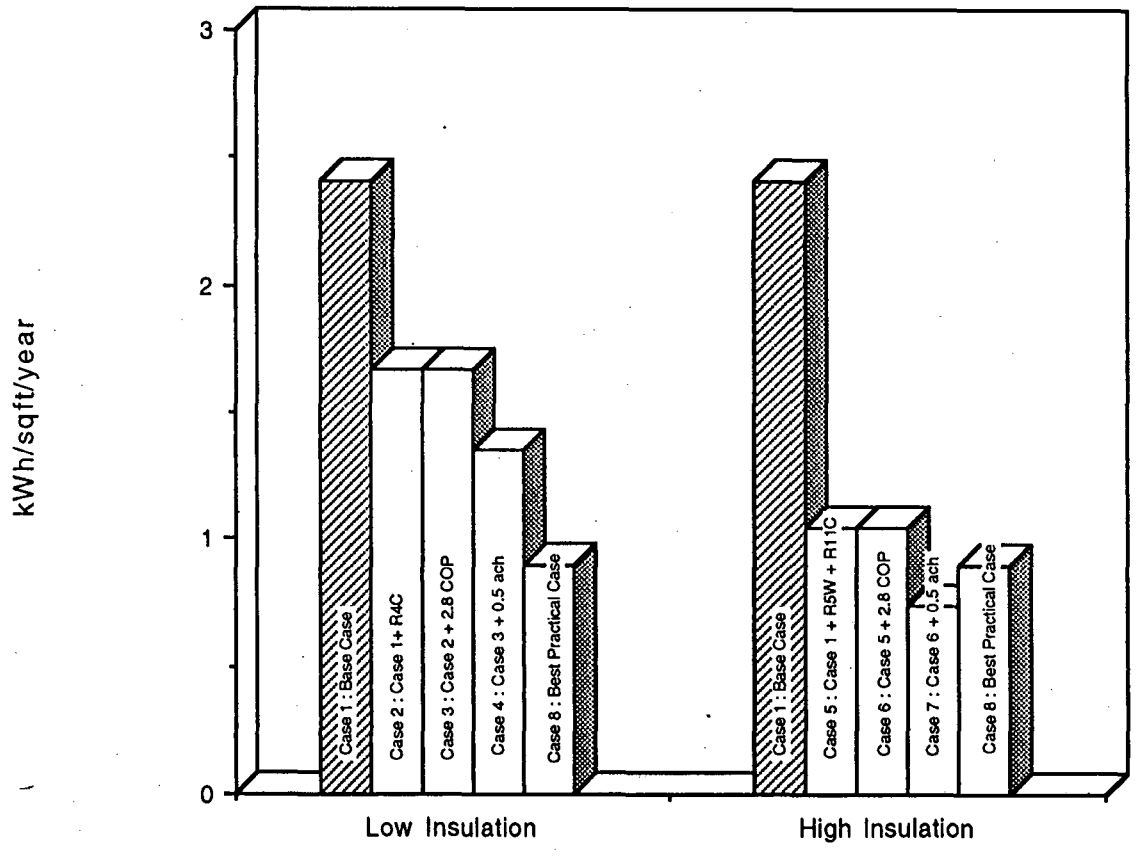

Figure 5.2b
SIMPLE PARAMETRICS OF HEATING ENERGY USE FOR A PROTOTYPICAL CONVERTED OFFICE BUILDING IN ISLAMABAD

Figure 5.3a
COMBINED PARAMETRICS OF COOLING ENERGY USE FOR A PROTOTYPICAL CONVERTED OFFICE BUILDING IN KARACHI




Best Practical Case: AC setting:79F, AC COP:3.0, Overhang: 3ft, Infilt: 0.5 ACH, Wall Colour: normal (0.7 abs), Roof Colour: Light (0.3 abs), Insul: R4 roof for low case and R11 roof and R5 walls for high case, Adj. Shade: none, Eff. Lighting: none

Figure 5.3b
COMBINED PARAMETRICS OF HEATING ENERGY USE FOR A PROTOTYPICAL CONVERTED OFFICE BUILDING IN ISLAMABAD




Best Practical Case: AC setting:79F, AC COP: 3.0, Overhang: 3ft, Infilt: 0.5 ACH, Wall Colour: normal (0.7 abs), Roof Colour: Light (0.3 abs), Insul: R4 roof for low case and R11 roof and R5 walls for high case, Adj. Shade: none, Eff. Lighting: none

*Chapter 6*

# Office Building

In Chapter 5, the detailed characteristics of a prototype residential building converted and used as an office were discussed and DOE-2.1D simulations results for six climate conditions showing the effects of different conservation measures on energy consumption were presented. In this chapter, a different methodology will be used to develop several prototype room models for a variety of offices located in different sides of a multi-story office building. The results of DOE-2.1D simulation for six climate conditions (Karachi, Lahore, Islamabad, Quetta, Multan, and Peshawar) and for different energy conservation measures will be given and discussed.

The office prototypes are defined based on surveys performed mainly in Islamabad, Karachi, and Lahore. In this chapter, parametric simulations for the three cities will be discussed in detail. For the other locations, i.e., Multan, Peshawar, and Quetta, similar DOE-2 simulations using the prototypes developed for Lahore and Islamabad were performed.

## Prototype Office Buildings

Three major factors are considered in developing office prototype:

1. the physical layout of the building, floor plan, zones, and construction materials;
2. the internal loads and schedules for each zone; and
3. cooling and heating systems and schedules.

### *Floor plan, zones, and construction*

Since most offices included in the 1989 survey have window air conditioning units, the orientation of each office will have a significant effect on cooling and heating energy consumption of the office. In addition to office orientation, other factors, such as whether the office is located on the corner of the building (two exterior walls rather than one) or the top floor (that is, it has roofs), will also significantly affect office energy consumption.

To account for all these variations, 32 prototypical office units were developed to simulate energy use of all possible configurations. Three office types were considered: top floor with roof in direct contact with unconditioned environment, middle floor, ground floor with floor in direct contact with unconditioned environment, and one story offices. For each floor conditions, eight possible office configurations were considered: North, Northeast, East, Southeast, South, Southwest, West, and Northwest.

Each prototype office was assumed to be square in shape with a floor area of 225 $ft^2$, conditioned by an individual window air conditioning unit. In some centrally air conditioned offices, the eight zones (one room per zone) on each floor were combined into one big zone depending

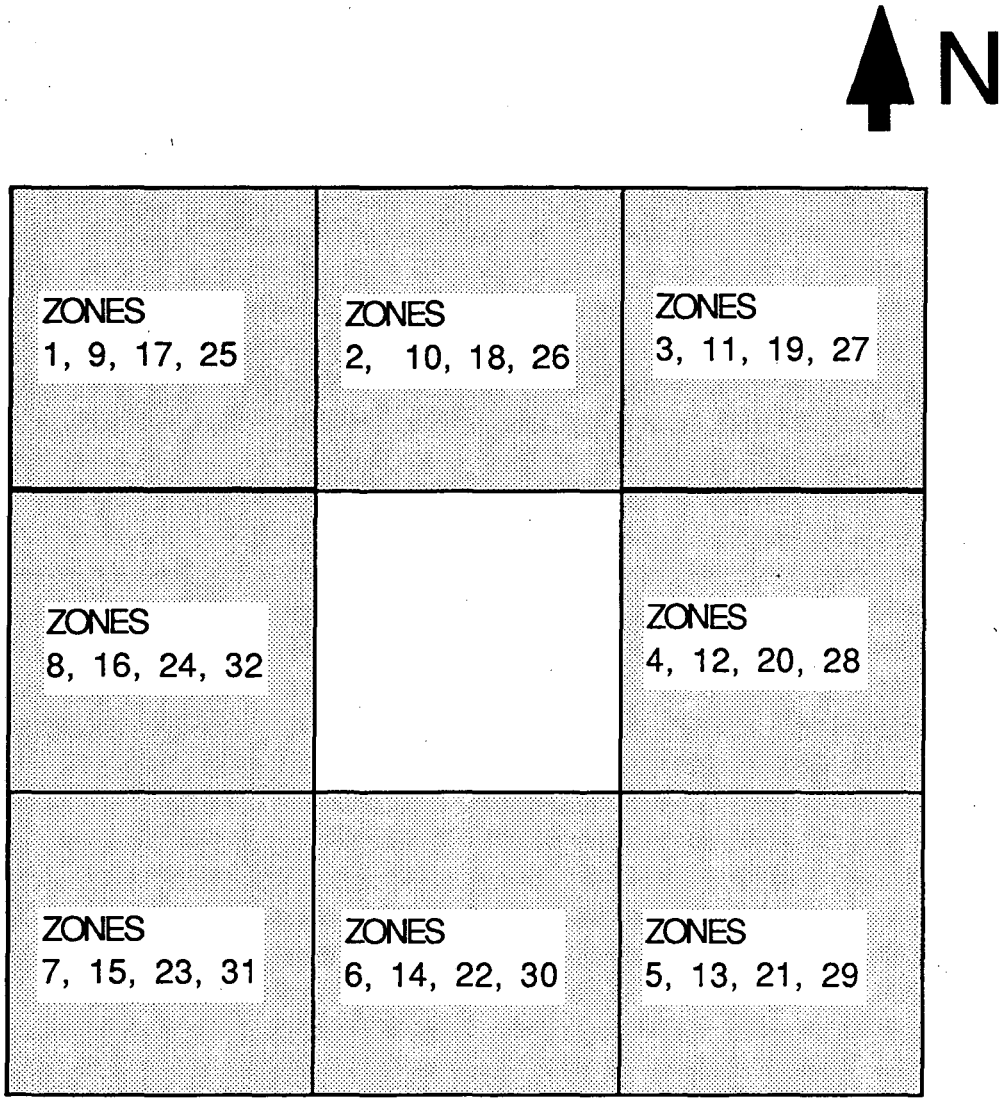
on the type of HVAC equipment used. **Figure 6.1** shows the general floor plan layout of the prototype offices.

**Table 6.1** summarizes the highlights of the prototype office room and **Table 6.2** summarizes the highlights of the prototype office building.

**Table 6.1.**
**Prototypical Single Office Room Description in Pakistan**

| | |
|---|---|
| Total floor area: | 225 $ft^2$ |
| Total conditioned area: | 225 $ft^2$ |
| Total window area: | 60 $ft^2$ for central offices and 120 $ft^2$ for corner offices |
| Window construction: | Single-pane glass with reflective film, with 1.5-3.5 ft overhangs |
| Wall construction: | In Karachi, 6" concrete with 1/2" plaster on either side In Islamabad and Lahore, 9½ " brick with 1/2" plaster on either side |
| Roof construction: | 6" concrete with 1/2" plaster inside, 1/2" roofing outside (note that middle floor offices do not have external roofs) |
| Number of occupants: | 2 |
| Lighting: | Fluorescent, 1 Watt/sqft |
| Lighting schedule: | 8.00 - 17.00 |
| Air conditioning: | 1.5 tons window units with 2.5 COP (one for each office) |
| Fans: | One in each room (50W) |
| Heating: | Electric resistance |
| Thermostat setting: | Cooling 79°F, Heating 70°F |

Figure 6.1 General Floor Plan of the Prototype Office Building




Top Floor: Zones 1,2,3,,4,5,6,7 and 8
Middle Floor: Zones 9,10,11,12,13,14,15 and 16
Ground Floor: Zones 17,18,19,20,21,22,23 and 24
Single Story: Zones 25,26,27,28,29,30,31 and 32

**Table 6.2.**
**Prototypical Office Building Description in Pakistan**

| | |
|---|---|
| Number of stories: | 3 |
| Total floor area: | 7200 $ft^2$ |
| Total conditioned area: | 7200 $ft^2$ |
| Total window area: | 2880 $ft^2$ |
| Window construction: | Single-pane glass with reflective film, with 2-ft overhangs |
| Wall construction: | In Karachi, 6" concrete with 1/2" plaster on either side In Islamabad and Lahore, 9½ " brick with 1/2" plaster on either side |
| Roof construction: | 6" concrete with 1/2" plaster inside, 1/2" roofing outside |
| Number of occupants: | 64 |
| Lighting: | Fluorescent, 1 Watt/sqft |
| Lighting schedule: | 8.00 - 17.00 |
| Air conditioning: | Central single zone package rooftop unit with 2.5 COP |
| Fans: | One in each room (50W) |
| Heating: | Electric resistance (no heating in Karachi) |
| Thermostat setting: | Cooling 79°F, Heating 70°F |

*Internal loads and schedules*

Each room was simulated with a 50 Watt fan operating during working hours. Lighting was fluorescent with an intensity of $1W/ft^2$. Each person approximately occupied 110 $ft^2$. Lighting and occupancy schedules were 8 a.m. to 5 p.m.. **Tables 6.1&2** also summarize the internal loads of the prototypical office buildings.

*Cooling and heating systems and schedules*

Data for cooling and heating equipment were obtained from the ENERCOM reports (1987, 1990) and the recent survey.

The prototype single offices were simulated with window air conditioners. The prototype office building was also simulated with central package air conditioning units and central fan coil systems.

The recent survey showed that no heating was done in the seven buildings in Karachi. In Lahore, out of the three samples one had no heating system and the other two used electric resistance heaters. In Islamabad, out of the sample of four buildings (all of which had heating systems), one used single zone packaged units, one used a fan-coil system, one used a room gas heater, and one used a combination of a room gas and electric resistance heater for heating.

**DOE-2.1D Parametric Simulation**

A systematic series of DOE-2.1D simulations were performed to benchmark and validate the simulation results with monthly utility bills (on a kWh/sqft basis). These comparisons are shown in **Table 6.3.** Once the base case prototype were benchmarked against measured utility bills, parametric simulations were performed in order to investigate the energy saving potentials of various conservation measures.

*Base Case*

The base case simulations were performed with the heating thermostat at 70°F between 8 a.m. and 5 p.m., and the cooling thermostat at 79°F from 8 a.m. to 5 p.m. The windows were assumed closed at all times.

The window air-conditioners were assumed to have COPs of 2.5. The roofs and walls were assumed to be uninsulated, and the windows were single-pane clear glass. Shading from adjoining buildings was ignored for the base case, but analyzed in the parametric simulations of conservation measures.

*Base Case Office Orientation*

One of the factors that significantly affected the heating and cooling energy use of individually conditioned offices is the office's orientation. For centrally conditioned offices, the impact of building orientation, once it is averaged is not that significant. Before performing the parametric simulations, the impact of office orientation was analyzed by simulating the heating and cooling energy use of 32 offices. Two building conditions were envisioned: single-story buildings and multi-story office buildings. For multi-story office buildings, three possible floors were considered: top floor, middle floor(s), and ground floor. Eight offices for each floor were simulated. Parametric simulations were performed on all 32 base cases. Although, all simulated data was included on the electronic data base, we only discuss the results of parametric simulations of the average of the four-side offices for each floor type will be discussed.

*Energy conserving measures*

Once the base case prototype was simulated and validated, we performed a series of parametric simulations were performed to estimate the energy saving potentials of conservation measures. Typical conservation measures usually considered for the office applications include

**Table 6.3.**
**Comparison of Measured Electricity Consumption of the Offices in Karachi, Lahore, and Islamabad and the Prototype Converted Offices**

| | Area | kWh/year | kWh/sqft.year |
|---|---|---|---|
| **Karachi** | | | |
| Building 11 | 3200 | N/A | |
| Building 13 | 801 | 6533 | 8.15 |
| Building 14 | 1890 | 363580[a] | 153.67 |
| Building 15 | 6200 | 109492[b] | 17.66 |
| Building 16 | 1444 | 20269 | 14.04 |
| Building 18 | 955 | N/A | |
| Building 19 | 2989 | 23973 | 8.02 |
| **Prototype** | **7200** | **102276** | **14.2** |
| **Lahore** | | | |
| Building 20 | 2436 | N/A | |
| Building 21 | 1929 | 35445 | 18.37 |
| Building 25 | 2007 | 37186 | 18.52 |
| **Prototype** | **7200** | **112077** | **15.5** |
| **Islamabad** | | | |
| Building 30 | 2436 | N/A | |
| Building 31 | 2436 | 59098 | 18.94 |
| Building 32 | 2436 | 55801 | 15.70 |
| Building 33 | 2436 | 22119 | 9.25 |
| **Prototype** | **7200** | **98617** | **13.7** |

N/A Utility data unavailable.

a. Very high value (This building is a hospital!)

b. Bills for the entire building.

envelop retrofit measures (to control heating and cooling loads of the building), energy efficient lighting, daylighting, and energy efficient systems and appliances (refrigerators, air conditioners etc.). **Table 6.4** shows a list of technologies that may be applicable to Pakistan buildings. Those technologies considered for our parametric analyses were printed in **boldface**.

**Table 6.4.**
**Office Conservation Technologies**

Cooling/Heating

1. **Ceiling insulation**
2. Floor insulation
3. **Wall insulation**
4. **Building color**
5. Multiple glazing
6. **Reduce infiltration** (weather stripping and caulking)
7. Movable window insulation
8. **Shading modifications (solar screens, reflective films)**
9. Insulate ductwork
10. **High COP air conditioning units**
11. Evaporative coolers
12. **Reduced internal loads including daylighting**

Lighting

12. **Energy efficient fluorescent lamps**
13. **Lighting controls/daylighting**
14. Selective switching

*Parametric Simulations*

The parametric simulations were focussed on three subjects: envelope modification, efficient window air conditioners, and improved operational strategies (daylighting). These parametrics included three levels of insulation in walls and roofs, two levels of infiltration, four levels of air conditioning COPs, two levels of overhangs, one level of wall color, two levels of roof color, two levels of film on windows, and one level of daylighting. In addition, the effects of varying amounts of shading from adjoining buildings was also investigated. The effects of natural ventilation were not examined. (See **Table 6.5** for details.)

As mentioned earlier, the parametric simulations were performed for all 32 base case offices. However, the impact of ECOs for the weighted average of offices on the North, South, East, and West sides of the buildings will be discussed only.

Just like for the case the single family detached house and converted office simulations, upon the completion of the single parametric DOE-2 simulations, some complementary simulations on a combination of a few promising ECOs were performed. The methodology we used to

develop the various combinations of parametrics was the same as for the residential case. The parametric combinations included simultaneous variations in insulation levels on walls and roofs, change in infiltration rate, change in coefficient of performance of air conditioning units and the roof color.

Large office buildings can be conditioned with both in-room or central units. For offices, and in addition to all parametric simulations mentioned above, also simulated was the heating and cooling energy use of the building for two central systems: packaged and two-pipe fan coil.

**Table 6.5: DOE-2.1D Parametric Simulations for Prototype Office Building**

| Parametric simulation | Description |
|---|---|
| **32 Base Cases** | R0 in walls and roofs; 1 ACH; A/C COP of 2.5; cooling thermostat setting of 79°F; 2-ft overhangs; roof and wall absorptivity 0.7; no shading from adjoining buildings. |
| **Simple Parametrics** | |
| Insulation | Three Cases: walls R0, roofs R4; walls R5, roof R11; walls R11 roofs R19 (insulation inside)<br>For locations other than Karachi, two more cases are simulated: tile roof with 1½ " polystrene insulation, and mud covered roof |
| Infiltration | Two Cases: 0.5, and 2.0 ACH |
| A/C COP | Four Cases: 2.28, 2.8, 3.0, and 3.5 |
| Overhangs | Two cases: 1-ft and 3-ft |
| Shading from adjoining buildings | Two Cases: two and three buildings |
| Wall color | One case: light (absorptivity 0.3) |
| Roof color | Two cases: light (abs 0.3), very light (abs 0.1) |
| Day lighting | One case |
| Central systems | Three cases: packaged single with and without reheat, 2-pipe fan coil |

**Results**

We will discuss the simulation results in three sections: office orientations, energy conservation options, and central HVAC systems vs. window and in-room units. The total number of simulations performed for office buildings is approximately
32 (offices) x 50 (ECO parametrics) x 6 (locations) = 9,600 .

*The Impact of Office Orientation*

Heating, cooling, and total energy use for each office and for all climate zones for the base case simulations are shown in **Tables 6.6a-f** and plotted for Islamabad on **Figures 6.2a&b**. Note that all the prototypes had the same area so that the energy per unit area is comparable. In Islamabad, the difference in cooling energy use between the office with the lowest load (North) and the office with the highest load (South East) were 951, 1307, 875, and 701 kWh per year for the "top", "middle", "ground" floor, and "single story" offices, respectively. The difference in the heating energy use between the offices of lowest (South) load and highest load (either North or NorthWest) were 908, 782, 756, and 818 kWh per year for the "top", "middle", "ground" floor, and "single story" offices, respectively. Usually offices with the lowest cooling loads have the highest heating energy demand. The total office energy use for the South facing offices were lowest. The main reasons being: 1) during the summer, the windows in South facing offices are shaded with two-feet overhangs and 2) during the winter, South-facing offices have the greatest solar gains because of lower solar angle. It was found that the effect of office orientation on total heating and cooling energy use in Islamabad is about 800 to 1,000 kWh per year. For other locations, differences of the same order of magnitude were observed.

To further investigate the effect of location of offices on heating and cooling energy use, the average of energy use for corner offices was calculated and compared them with the corresponding averages for side offices and the average for the entire floor. The average heating energy use for the corner offices were about the same as the side offices. However, the average cooling energy use was about 400-700 kWh/year larger in corner offices than those of the side offices. This difference can be readily traced back to larger widow areas for corner offices.

In proposing energy conservation options, hence, one should carefully take into the account the location and orientation of the office. **Figure 6.1** is intended to show the orientations of the prototypical rooms, however, we are not restricted in this analysis to a square floor-plan. Any floor-plan can be modeled using the room models. While some measures such as wall and roof insulation and infiltration have a clear impact on the energy use for all offices, measures such as window films and overhangs will have greater impacts on some offices compared to others. Although, the parametric simulations were performed for all configurations, the discussion will be limited to the parametrics for the average energy use for the side offices. The main reason for selecting side offices for the parametric discussion is that there can be more offices located

on the sides of the buildings than their corners.

*Parametric Simulation Results*

The simulation results for single and combined parametrics are presented in **Tables 6.7a-f(i-iii)** and **Tables 6.8a-f(i-iii)**, respectively. Parametrics for climate regions of Islamabad, Karachi, Lahore, Multan, Peshawar, and Quetta are denoted with letters **a** through **f**. Greek numerals **i, ii, and iii** refers to simulation results for "top", "middle" floor, and "single story" buildings. Although the database for the simulation results include results for all rooms types, for presentation purposes only Tables 6.7 have been included in this report. These present simulation results, averaged for 4-side offices for each floor type configurations, for total office, and cooling and heating end uses; both total energy use and normalized energy use ($kWh/ft^2$) are presented. For illustration and discussion purposes, the parametric results for Karachi (cooling dominated) and Islamabad (both cooling and heating are needed) for single story office (data corresponding to Tables 6.7b.iii and 6.7a.iii, and Tables 6.8b.iii and 6.8a.iii) are plotted in **Figures 6.3a&b** and **6.4a&b**, respectively.

*Simple Parametrics*

Cooling

The total simulated electricity use for the single story base case office was 2,850 kWh per year (12.67 $kWh/ft^2$) of that 2,167 kWh (76%) was for cooling. (See Table 6.7b.iii and Figure 6.3a.) Lighting, fans, and other miscellaneous end uses accounted for the rest of electricity use.

The impact of ECOs on cooling energy use for Karachi will be discussed only. The conclusions made for Karachi office can be extended to other climate zones. As Figure 6.3a indicates, the cooling energy use was very sensitive to air conditioning COP, window film, roof and walls insulation, and roof color. The impact of overhang length, wall color, efficient lighting systems, day lighting, and infiltration on air conditioning use was fairly low.

The base case prototype office was simulated with no insulation on walls and roofs. Insulating the roofs to meet the Pakistani proposed standards (no insulation on walls and R4 total resistance of the roofs) decreased the cooling energy use of the building by 229 kWh per year per side office (11%). Further increase on walls and roof insulation to [R5 on walls and R11 on roof] and [R11 on walls and R19 on roof] did not result in significant energy savings.

The cooling energy use, as it might be expected, was also very sensitive to the efficiency of the window air conditioning units. Increasing the COP of the window units form 2.5 (base case) to 3.5 resulted in a decrease of 586 kWh per year (27%). The Pakistani code suggests a minimum COP of 2.28 for window units. Changing the standards to the most efficient system (COP 3.5) in the market will result in energy savings of 784 kWh (33%) per year per office.

Changing the color of the roof (absorptivity of 0.7) to a light color (absorptivity of 0.3) resulted in a 430 kWh (20%) reduction in air conditioning use. Further decrease in absorptivity of the roof color to 0.1 increased these savings to 609 kWh (28%). Note that changing the color of the roof white for the single story office building in Karachi is more effective than having R11 insulation on the roofs and R5 insulation on the walls. Also, changing colors of buildings will be probably much less costly than adding insulation on roofs and walls. Hence, we strongly recommend lighter building colors be included in the Pakistani codes and standards.

Changing the color of walls had a small impact on cooling energy use, only 84 kWh (4%). It should be noticed that lightening the color of the roofs and walls had a negative impact on heating energy use. In Karachi, where the heating energy demand is fairly low, this change in the color only increased the heating energy demand by a negligible amount. In fact, the heating energy use for Karachi was not simulated at all. However, as will be discussed later with the the DOE-2 results for of Islamabad simulations, the impact of roof color on heating energy requirement may be fairly significant.

The cooling energy use of the single-story office building was moderately sensitive to infiltration rate. Increasing the infiltration rate from 1 ACH (base case) to 2 ACH increased the cooling energy use by 115 kWh per year; about 5%. While, decreasing infiltration to 0.5 ACH reduced cooling energy use by 71 kWh (3%).

To estimate the shading impacts of adjacent buildings, buildings on **two** and **three** sides of the prototype building were simulated. Shading the building on two randomly picked sides reduced the cooling energy use by 289 kWh per year (13%). The impact of the shading on the third randomly picked side was an additional reduction of 112 kWh (5%).

Window films also have a significant potential for energy savings. Simulating the office building with window films of 80% transmissivity resulted in reducing the cooling energy consumption by 194 kWh (9%). A further decrease in the film transmissivity to 0.6 resulted in an additional savings of 191 kWh (9%).

Cooling energy use was fairly insensitive to the overhang length. Increasing the overhang length from 2 feet to 3 feet reduced the cooling energy use per side office by only 19 kWh, while decreasing the length to 1 foot increased the cooling use by 29 kWh for the office.

Also, the effects of efficient lighting, daylighting, and other equipment on cooling energy demand were fairly low.

Heating

As was discussed in the preceding section, some of the measures considered for reducing cooling energy use may have a negative impact on heating energy use (e.g., roof color). Although, some other measures will result in heating and cooling energy savings (e.g., roof and wall

insulations) and some other measures will not affect heating energy use at all (e.g., air conditioning set point temperature). The impact of the proposed ECOs on heating energy use in Islamabad (**Figure 6.3b**) will be discussed. Data for all climate zones are presented in Tables 6.7.

Measures having the greatest impact on heating energy demand were roof and wall insulations (positive impact), roof color (negative impact), and control of infiltration (positive impact). The total building energy use for the Islamabad office was 3,143 kWh of that 1,596 kWh was for cooling and 863 kWh for heating.[1]

The effects of added insulation on roofs [R4] was to decrease heating energy use by 290 kWh (34%). Further increase in insulation of walls and roofs [R11 in walls, R19 in roofs] increased the energy savings to 473 kWh (57%). The prototype office building was also simulated with tile roofing plus insulation and mud roof with no insulation. The total heating energy use for the tile-roof case was 475 kWh, a saving of 388 kWh (45%). For the mud roof case there were no significant change in heating and cooling energy use from the base case.

The impact of an increase in infiltration from 1.0 ACH to 2.0 ACH was an increase of 208 kWh (24%) in heating energy need. Decreasing infiltration form 1.0 ACH to 0.5 ACH resulted in a decrease of 105 kWh (12%) in heating energy use.

Changing the roof color to white or reflective colors increased heating energy use by 248 (29%) and 396 kWh (46%), respectively. The effect of wall colors on heating energy use was fairly insignificant (35 kWH or 4%).

Efficient lighting and daylighting also slightly increased the heating energy use of the building. Use of window films also increased heating energy use by 85 to 182 kWh (10 to 21%).

*Combined Parametrics*

Through the simple parametric simulations measures that have the highest impact on both heating and cooling energy requirements of prototypical office building in all climate regions were identified. The combined parametrics included variation in walls and roof insulation, roof color, air conditioning COP, and air infiltration. Based on these combined parametric simulations, ECOs for a "best practical case" were identified. **Tables 6.8a-f(i-iii)** present the results of 33 parametric simulations (averaged for four side offices) for each floor type and each climate zones.

[1] Consumption data for heating are obtained with electric resistance heating. To estimate the heating energy use by in-room gas convective heater, divide the electric heating demands by the efficiency of the gas heater, usually in the range of 55 to 75%.

A selected group of combined parametric simulation results for Karachi is plotted in **Figure 6.4a**. Case 1 is the base case. Two series of cases are presented: low insulation (Case 2) and high insulation (Case 6). The low insulation case considers R4 insulation on roofs and the high insulation case considers R11 insulation on roofs and R5 insulation on walls. To each case has progressively been added the impact of COP increase from 2.5 to 2.8 (Cases 3 and 7), reduced infiltration (Cases 4 and 8), and light color roof (Cases 5 and 9). Finally, simulation results for "best practical case" (Case 10) ared presented. The best case has the following characteristics: A/C COP 3.0, 3-ft overhang, 0.5 ACH, R5 wall and R11 roof insulation.

As in the simple parametric simulations, the highest relative savings are obtained by adding insulations on roofs and walls. The impact of roof insulation on reducing cooling energy use was much higher than that of wall insulation. The cooling energy difference between the base case and the "best" case was 639 kWh per year (29%). In other words, **~30% of cooling energy use in office buildings in Karachi can be saved through simple, practical, and readily available measures and technologies in Pakistani market.**

The analysis of heating energy use for Islamabad (**Figure 6.4b**) gives similar results . The difference between the base case and best case heating energy use was 501 kWh per year (58%). Most of heating energy savings were realized through roof and wall insulations and control of infiltration.

In summary, the DOE-2 parametrics show that **savings in the order of 30 to 60% in both heating and cooling energy use in Pakistani office buildings are achievable, through use of some simple and available conservation measures such as insulating roofs and walls, control of infiltration, use of high COP air conditioning units, and coloring the roofs white.** An economic analysis is needed to evaluate the cost effectiveness of the proposed measures.

*Central versus Window Air Conditioning Systems*

The recent survey of 1989 shows that the most common HVAC setup is window air-conditioners together with room gas heaters. This setup is compared to the two other central systems which are also used by some office buildings according to the same survey.

The two central systems examined are the 'Two Pipe Fan Coil system' (TPFC) and the 'Packaged Single Zone system' (PSZ). The prototype office with TPFC system uses a single central system for all of the four floors. When examining the PSZ system a separate system is assumed for each floor.

The PSZ system may be controlled in more than one way. Two of these implementations are analyzed. In one, during the cooling season, each of the office rooms has its own thermostat control and the supply temperature out of the unit is controlled by the thermostat in the room

with the highest cooling load. The supply air into the other rooms are electrically reheated to maintain comfort. This case is called 'Packaged Single Zone unit with Reheat' (PSZ/RH). In the other implementation, one thermostat in the middle of the office floor controls the supply temperature. This case is called simply the 'Packaged Single Zone system'. During the heating season both types are controlled by a thermostat at the center of the floor.

DOE-2 simulations were done for the base case values for all of the above HVAC systems and the results are tabulated in **Table 6.9.** The electricity consumption is shown in **Figures 6.5a-f** for Islamabad, Lahore, Multan, Peshawar and Quetta respectively. Gas consumption is shown in **Figure 6.6.**

*Packaged Single Zone Systems*

For cooling, as far as electricity consumption is concerned, central packaged units are not as good as window units because of the additional fan power requirements to transport the cool air to the zones (see Figures 6.5a-f). Naturally if there is reheat in the zones the electricity consumption further increases. On the other hand, during the heating season the gas consumption of the packaged single zone system is less than the setup where each office is individually heated by a room gas heater(see Figure 6.6). This is because of the fact that the central system is controlled by the average temperature of the floor and this allows the heat from the offices facing south to warm up the offices facing north. Hence the energy consumption for heating is less than the case where the rooms are individually heated by room gas heaters.

*Two Pipe Fan Coil Systems*

It can be seen from Figures 6.5.a-f and Figure 6.6 that both electricity and gas consumption of the central fan coil system is lower than the other systems considered. There are several reasons for this.

During the heating season the efficiency of the boiler is higher than the efficiency of typical gas heaters. Also, although zones are individually controlled, the offices facing south still help warm up the offices facing north and this reduces gas consumption.

During the cooling season the seasonal efficiency of the central fan coil system is better than of the heat pump in the window air conditioner. Therefore the energy consumption is less for the central system. This advantage diminishes when the cooling load reduces as can be seen from Figure 6.5.f for Quetta.

It should be noted that although the TPFC system is the least expensive system to operate, it is the most expensive system to install and maintain. Before one can determine the optimal system configuration, an economic analysis considering the equipment, installation and maintenance costs must be performed. Such price information was not available at this point but in

future, such a study can be performed using the data in this section to estimate operating costs.

Figure 6.2a
The impact of Orientation of Single Story Office Building on Cooling and Heating Energy Use in Islamabad

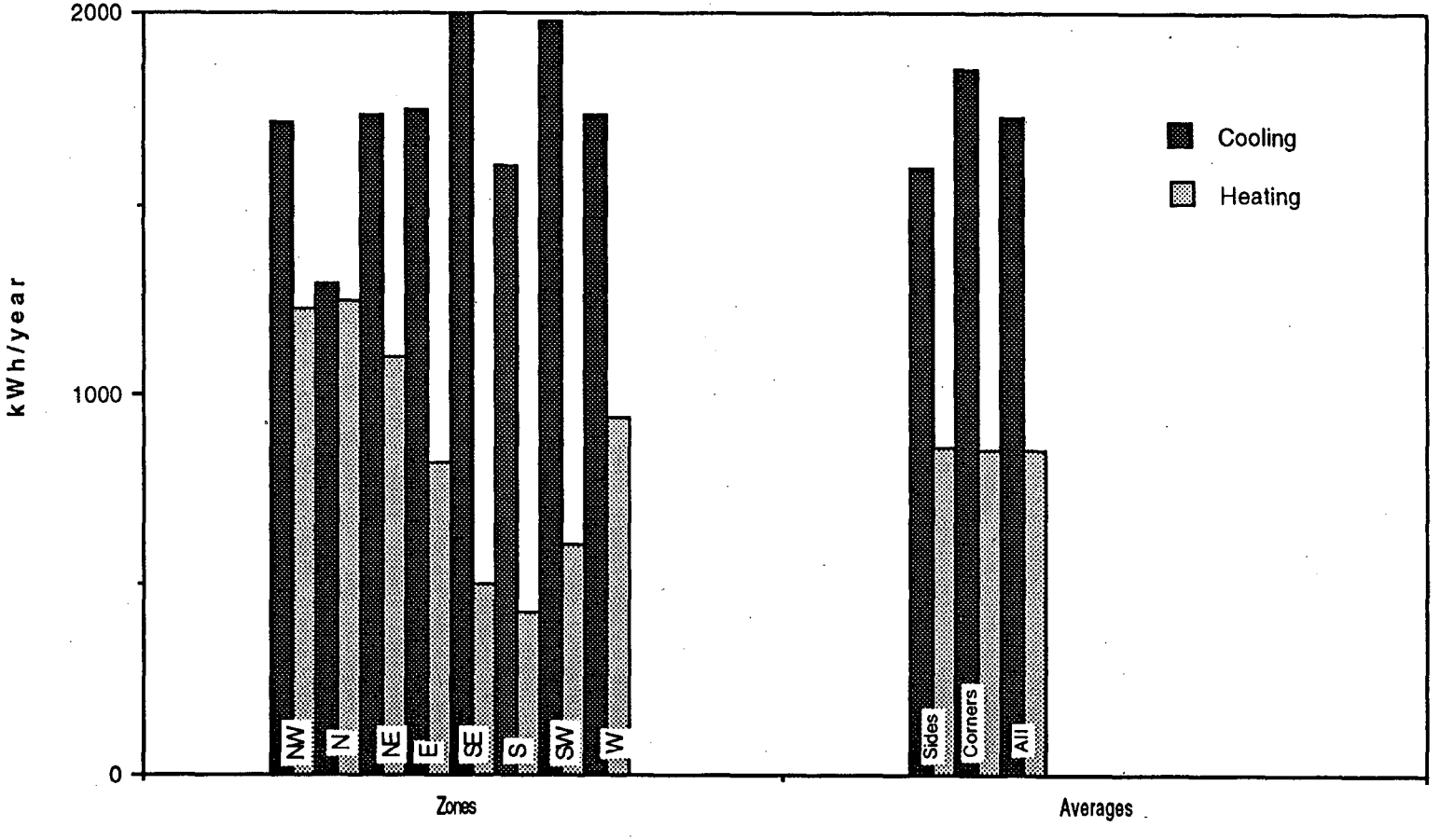


Figure 6.2b
The impact of Orientation of a Middle Floor Office on Cooling and Heating Energy Use in Islamabad

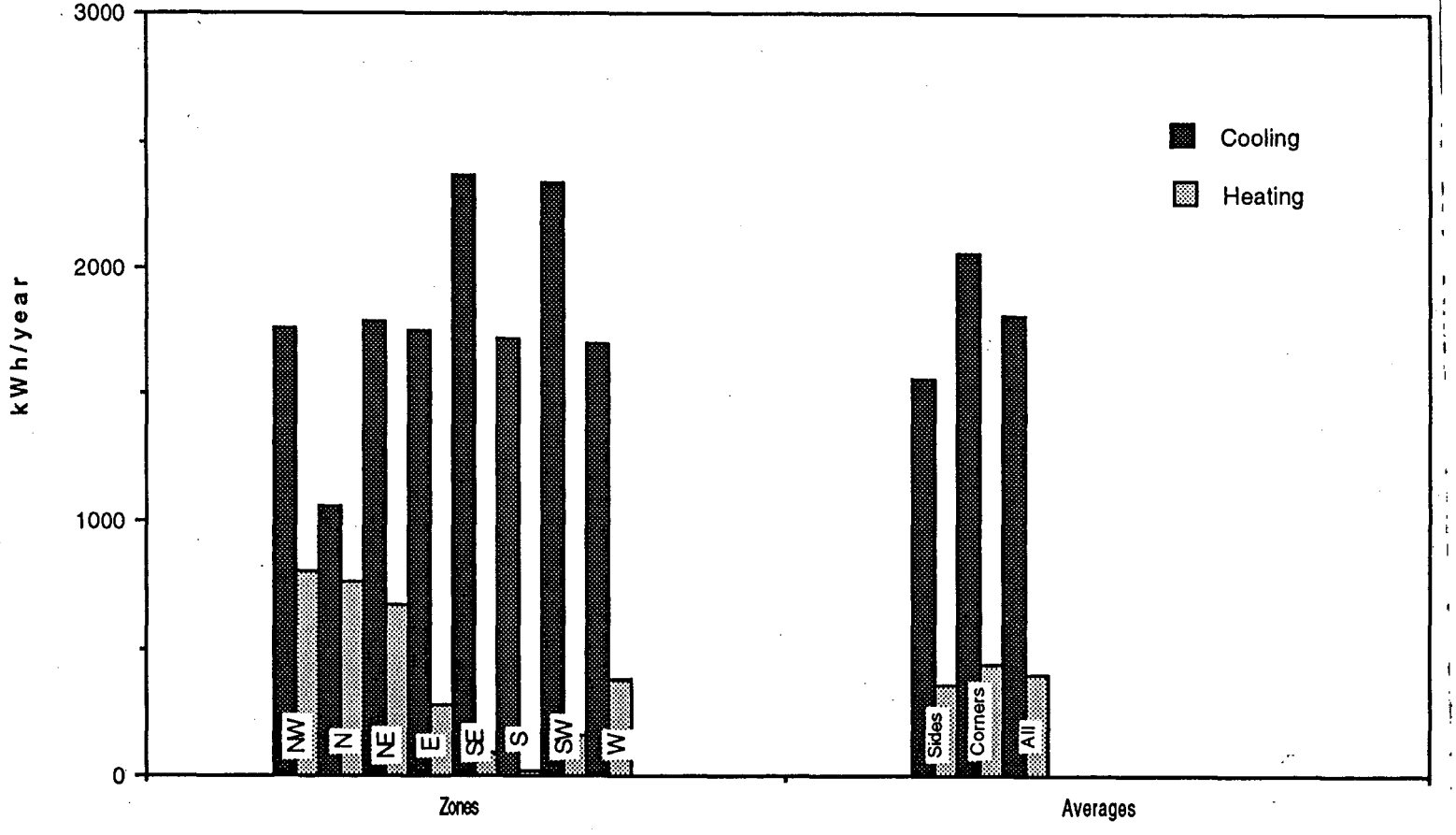
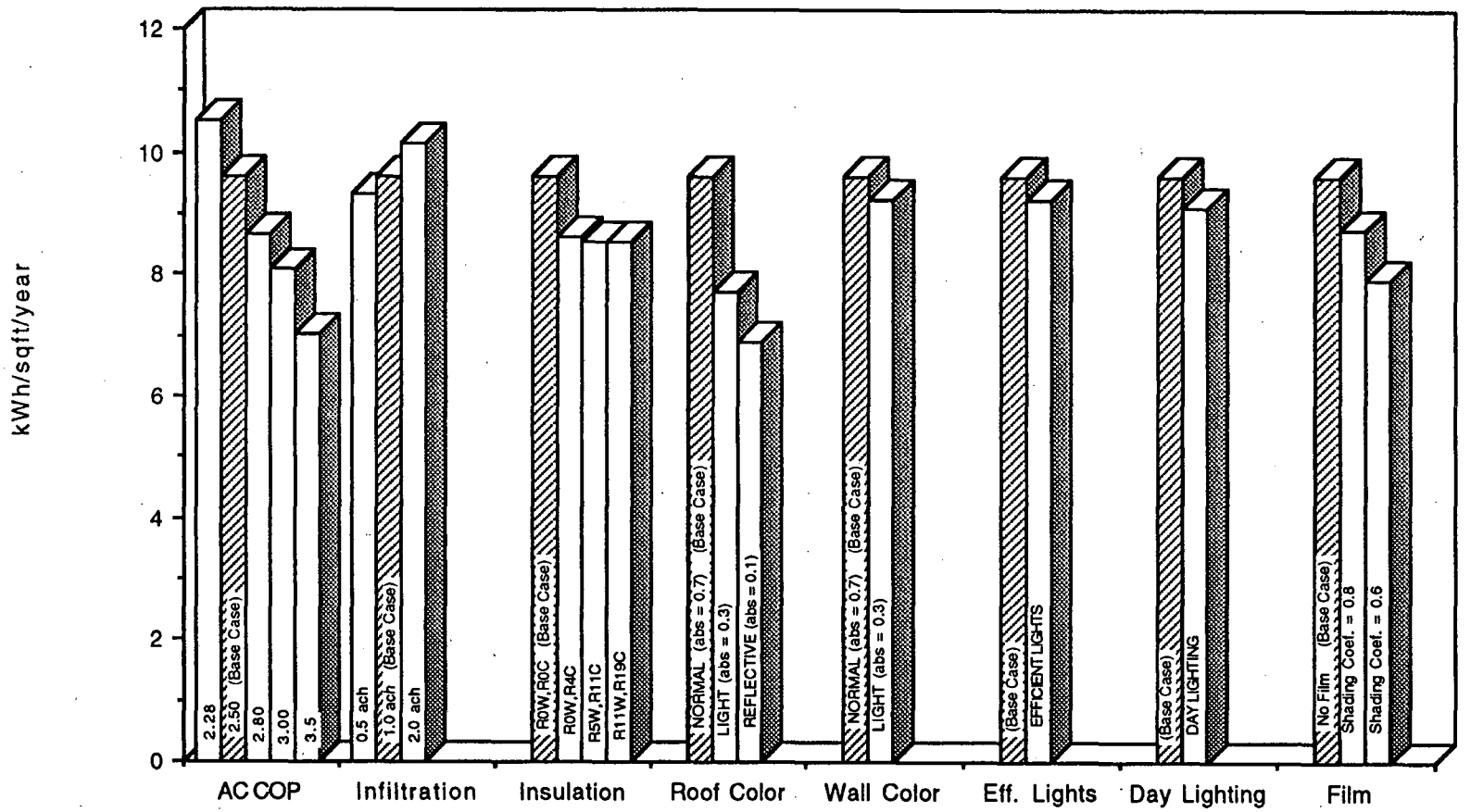


Figure 6.3a
SIMPLE PARAMETRICS OF COOLING ENERGY USE FOR A PROTOTYPICAL OFFICE BUILDING IN KARACHI



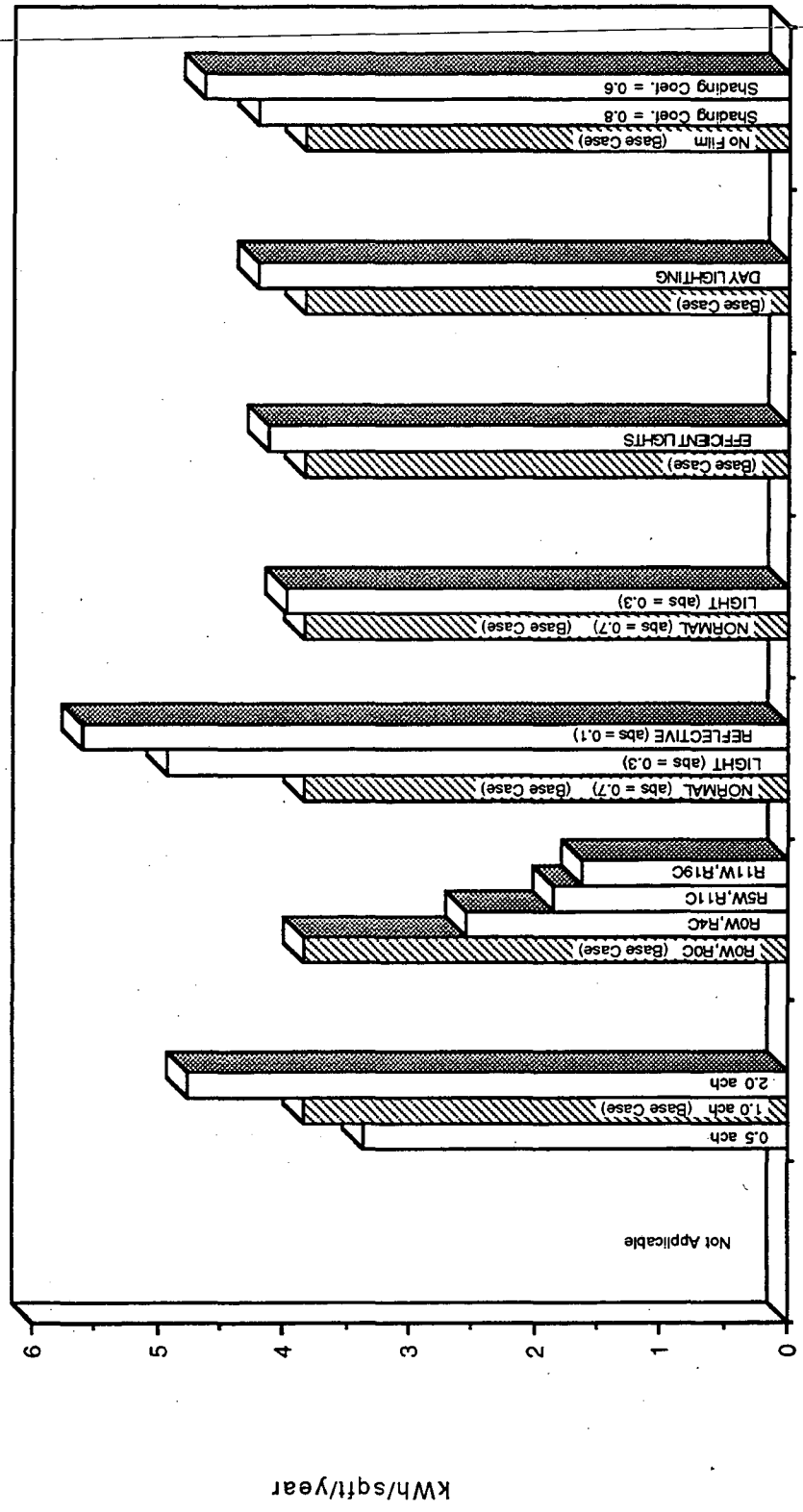
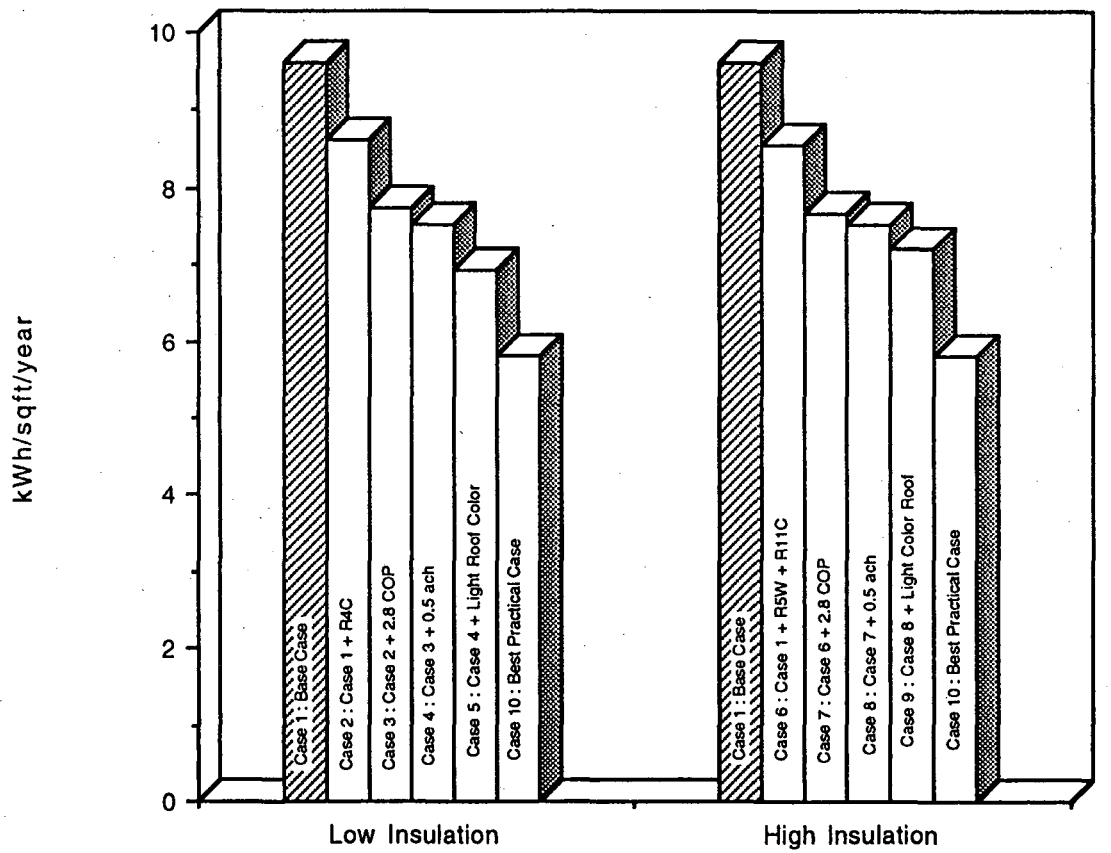


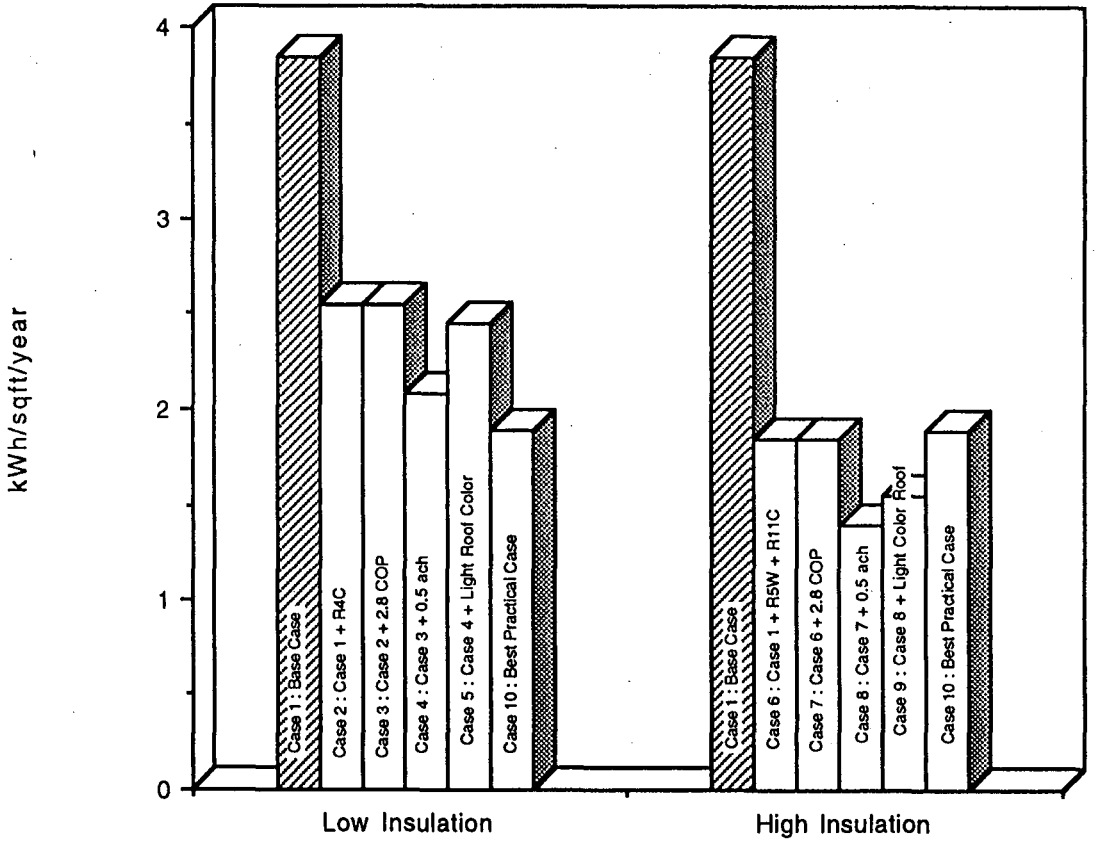

Figure 6.3b
SIMPLE PARAMETRICS OF HEATING ENERGY USE FOR A PROTOTYPICAL
OFFICE BUILDING IN ISLAMABAD

Figure 6.4a
COMBINED PARAMETRICS OF COOLING ENERGY USE FOR A PROTOTYPICAL OFFICE BUILDING IN KARACHI




Best Practical Case: AC setting:79F, AC COP: 3.0, Overhang: 3ft, Infilt: 0.5 ACH, Wall Colour: normal (0.7 abs), Roof Colour: Light (0.3 abs), Film Shading Coeff: 0.8, Insul: R4 roof for the low case and R11 roof and R5 walls for the high case

Figure 6.4b
COMBINED PARAMETRICS OF HEATING ENERGY USE FOR A PROTOTYPICAL OFFICE BUILDING IN ISLAMABAD




Best Practical Case: AC setting:79F, AC COP: 3.0, Overhang: 3ft, Infilt: 0.5 ACH, Wall Colour: normal (0.7 abs), Roof Colour: Light (0.3 abs), Film Shading Coeff: 0.8, Insul: R4 roof for low case and R11 roof and R5 walls for the high case

**Table 6.6a**
**The Impact of Office Orientation on Cooling and Heating Energy Use for Islamabad.**
All figures are in kWh per year.

| | Top Floor | | | Middle Floor | | | Ground Floor | | | Single Story | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Office | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating |
| NW | 4086 | 2099 | 1304 | 3243 | 1763 | 798 | 2830 | 1363 | 785 | 3627 | 1719 | 1226 |
| N | 3500 | 1548 | 1270 | 2507 | 1059 | 765 | 2375 | 888 | 804 | 3230 | 1297 | 1249 |
| NE | 3957 | 2121 | 1153 | 3149 | 1791 | 675 | 2755 | 1399 | 673 | 3518 | 1733 | 1102 |
| E | 3573 | 2087 | 803 | 2719 | 1757 | 279 | 2434 | 1403 | 349 | 3260 | 1750 | 827 |
| SE | 3654 | 2499 | 472 | 3143 | 2366 | 94 | 2580 | 1763 | 134 | 3183 | 1998 | 503 |
| S | 3031 | 1953 | 396 | 2425 | 1726 | 16 | 2059 | 1328 | 48 | 2716 | 1602 | 431 |
| SW | 3742 | 2471 | 589 | 3175 | 2334 | 159 | 2628 | 1740 | 205 | 3266 | 1977 | 606 |
| W | 3691 | 2063 | 945 | 2759 | 1699 | 377 | 2436 | 1304 | 449 | 3366 | 1737 | 946 |
| Avg. Sides | 3449 | 1913 | 854 | 2103 | 1560 | 359 | 2326 | 1231 | 413 | 3143 | 1597 | 863 |
| Avg. Corners | 3860 | 2298 | 880 | 3178 | 2064 | 432 | 2698 | 1917 | 449 | 3399 | 1857 | 859 |
| Avg. All | 3655 | 2106 | 867 | 2641 | 1812 | 396 | 2512 | 1574 | 431 | 3271 | 1727 | 861 |

**Table 6.6b**
**The Impact of Office Orientation on Cooling and Heating Energy Use for Karachi.**
All figures are in kWh per year.

| Office | Top Floor | | | Middle Floor | | | Ground Floor | | | Single Story | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating |
| NW | 3533 | 2850 | 0 | 3349 | 2666 | 0 | 2872 | 2190 | 0 | 3062 | 2379 | 0 |
| N | 2590 | 1907 | 0 | 2162 | 1479 | 0 | 2022 | 1339 | 0 | 2365 | 1682 | 0 |
| NE | 3484 | 2801 | 0 | 3331 | 2648 | 0 | 2853 | 2170 | 0 | 3009 | 2326 | 0 |
| E | 3323 | 2641 | 0 | 3139 | 2457 | 0 | 2838 | 2156 | 0 | 3005 | 2323 | 0 |
| SE | 4145 | 3462 | 0 | 4145 | 3463 | 0 | 3465 | 2782 | 0 | 3490 | 2807 | 0 |
| S | 3316 | 2633 | 0 | 3149 | 2466 | 0 | 2797 | 2114 | 0 | 2953 | 2270 | 0 |
| SW | 4173 | 3491 | 0 | 4209 | 3526 | 0 | 3501 | 2819 | 0 | 3516 | 2833 | 0 |
| W | 3401 | 2719 | 0 | 3208 | 2526 | 0 | 2794 | 2110 | 0 | 3077 | 2394 | 0 |
| Avg. Sides | 3158 | 2475 | 0 | 2915 | 2232 | 0 | 2613 | 1930 | 0 | 2850 | 2167 | 0 |
| Avg. Corners | 3834 | 3151 | 0 | 3759 | 3076 | 0 | 3173 | 2490 | 0 | 3269 | 2586 | 0 |
| Avg. All | 3496 | 2813 | 0 | 3337 | 2654 | 0 | 2893 | 2210 | 0 | 3060 | 2377 | 0 |

**Table 6.6c**
**The Impact of Office Orientation on Cooling and Heating Energy Use for Lahore.**
All figures are in kWh per year.

| | Top Floor | | | Middle Floor | | | Ground Floor | | | Single Story | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Office | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating |
| NW | 4334 | 3037 | 613 | 3534 | 2478 | 373 | 3029 | 2022 | 323 | 3812 | 2599 | 531 |
| N | 3612 | 2293 | 637 | 2467 | 1373 | 412 | 2260 | 1202 | 375 | 3309 | 2040 | 586 |
| NE | 4250 | 3075 | 492 | 3458 | 2507 | 268 | 2968 | 2048 | 237 | 3740 | 2626 | 431 |
| E | 4034 | 3040 | 312 | 3100 | 2353 | 64 | 2734 | 1986 | 66 | 3693 | 2711 | 300 |
| SE | 4431 | 3628 | 121 | 3992 | 3304 | 4 | 3329 | 2638 | 8 | 3831 | 3027 | 121 |
| S | 3697 | 2899 | 115 | 3003 | 2321 | 0 | 2629 | 1946 | 0 | 3333 | 2541 | 109 |
| SW | 4484 | 3603 | 198 | 3991 | 3287 | 20 | 3327 | 2615 | 29 | 3879 | 3008 | 188 |
| W | 4108 | 2992 | 433 | 3192 | 2374 | 136 | 2753 | 1930 | 140 | 3764 | 2676 | 405 |
| Avg. Sides | 3863 | 2806 | 374 | 2941 | 2105 | 153 | 2594 | 1766 | 145 | 3525 | 2492 | 350 |
| Avg. Corners | 4375 | 3336 | 356 | 3744 | 2894 | 166 | 3163 | 2331 | 149 | 3816 | 2815 | 318 |
| Avg. All | 4119 | 3071 | 365 | 3342 | 2500 | 160 | 2879 | 2048 | 147 | 3670 | 2654 | 334 |

**Table 6.6d**

**The Impact of Office Orientation on Cooling and Heating Energy Use for Multan.**

All figures are in kWh per year.

| | Top Floor | | | Middle Floor | | | Ground Floor | | | Single Story | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Office | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating |
| NW | 4858 | 3477 | 698 | 4007 | 2906 | 419 | 3481 | 2444 | 355 | 4302 | 3019 | 600 |
| N | 4005 | 2602 | 720 | 2722 | 1582 | 457 | 2473 | 1389 | 402 | 3683 | 2355 | 645 |
| NE | 4749 | 3471 | 595 | 3885 | 2871 | 331 | 3368 | 2405 | 280 | 4214 | 3015 | 516 |
| E | 4463 | 3393 | 387 | 3416 | 2638 | 95 | 3038 | 2265 | 89 | 4130 | 3090 | 357 |
| SE | 4850 | 3993 | 174 | 4334 | 3636 | 15 | 3677 | 2974 | 20 | 4246 | 3395 | 169 |
| S | 4020 | 3178 | 159 | 3175 | 2492 | 0 | 2798 | 2115 | 0 | 3675 | 2844 | 149 |
| SW | 4948 | 4012 | 252 | 4413 | 3693 | 37 | 3745 | 3016 | 46 | 4328 | 3411 | 234 |
| W | 4565 | 3391 | 491 | 3602 | 2763 | 156 | 3157 | 2321 | 153 | 4216 | 3087 | 446 |
| Avg. Sides | 4263 | 3141 | 439 | 3229 | 2369 | 177 | 2867 | 2023 | 161 | 3926 | 2844 | 399 |
| Avg. Corners | 4851 | 3738 | 430 | 4160 | 3277 | 201 | 3568 | 2710 | 175 | 4273 | 3210 | 380 |
| Avg. All | 4557 | 3440 | 435 | 3694 | 2823 | 189 | 3217 | 2366 | 168 | 4099 | 3027 | 390 |

**Table 6.6e**
**The Impact of Office Orientation on Cooling and Heating Energy Use for Peshawar.**
All figures are in kWh per year.

| | Top Floor | | | Middle Floor | | | Ground Floor | | | Single Story | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Office | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating |
| NW | 4454 | 2671 | 1101 | 3592 | 2221 | 688 | 3119 | 1788 | 648 | 3942 | 2254 | 1005 |
| N | 3773 | 2001 | 1089 | 2644 | 1279 | 682 | 2464 | 1094 | 687 | 3479 | 1756 | 1041 |
| NE | 4377 | 2721 | 974 | 3565 | 2293 | 588 | 3082 | 1842 | 557 | 3877 | 2294 | 900 |
| E | 4029 | 2676 | 670 | 3069 | 2156 | 230 | 2728 | 1774 | 271 | 3692 | 2339 | 670 |
| SE | 4218 | 3179 | 356 | 3691 | 2946 | 63 | 3076 | 2304 | 89 | 3670 | 2621 | 366 |
| S | 3496 | 2507 | 307 | 2748 | 2058 | 7 | 2352 | 1648 | 21 | 3166 | 2156 | 328 |
| SW | 4265 | 3121 | 462 | 3684 | 2886 | 116 | 3086 | 2252 | 150 | 3717 | 2577 | 458 |
| W | 4077 | 2607 | 788 | 3104 | 2105 | 316 | 2709 | 1666 | 360 | 3729 | 2277 | 770 |
| Avg. Sides | 3844 | 2448 | 714 | 2891 | 1900 | 309 | 2563 | 1546 | 335 | 3517 | 2132 | 702 |
| Avg. Corners | 4329 | 2923 | 723 | 3633 | 2587 | 364 | 3091 | 2047 | 361 | 3802 | 2437 | 682 |
| Avg. All | 4086 | 2685 | 718 | 3262 | 2243 | 336 | 2827 | 1796 | 348 | 3659 | 2284 | 692 |

**Table 6.6f**
**The Impact of Office Orientation on Cooling and Heating Energy Use for Quette.**
All figures are in kWh per year.

| | Top Floor | | | Middle Floor | | | Ground Floor | | | Single Story | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Office | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating | Total | Cooling | Heating |
| NW | 4885 | 1247 | 2955 | 3824 | 1230 | 1911 | 3635 | 901 | 2051 | 4648 | 980 | 2985 |
| N | 4305 | 861 | 2762 | 3045 | 758 | 1604 | 3106 | 600 | 1823 | 4256 | 709 | 2864 |
| NE | 4787 | 1309 | 2796 | 3761 | 1342 | 1736 | 3573 | 996 | 1894 | 4548 | 1022 | 2843 |
| E | 3967 | 1275 | 2009 | 2818 | 1360 | 775 | 2726 | 1023 | 1020 | 3866 | 1013 | 2169 |
| SE | 3725 | 1426 | 1617 | 2783 | 1571 | 530 | 2561 | 1116 | 761 | 3576 | 1087 | 1806 |
| S | 2973 | 950 | 1339 | 1950 | 1054 | 212 | 1875 | 757 | 435 | 2973 | 769 | 1521 |
| SW | 3865 | 1382 | 1800 | 2840 | 1481 | 677 | 2613 | 1026 | 904 | 3698 | 1051 | 1965 |
| W | 4063 | 1192 | 2187 | 2889 | 1267 | 939 | 2749 | 883 | 1183 | 3927 | 927 | 2318 |
| Avg. Sides | 3827 | 1070 | 2074 | 2676 | 1110 | 883 | 2614 | 816 | 1115 | 3756 | 855 | 2218 |
| Avg. Corners | 4316 | 1341 | 2292 | 3302 | 1406 | 1214 | 3096 | 1010 | 1403 | 4118 | 1035 | 2400 |
| Avg. All | 4071 | 1205 | 2183 | 2989 | 1258 | 1048 | 2855 | 913 | 1259 | 3937 | 945 | 2309 |

**Table 6.7a(i). Summary of Simple Parametric Simulations for Prototypical Office in Islamabad on Top Floor (a=225 ft$^2$)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft$^2$ Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3448 | 1912 | 853 | 15.33 | 8.50 | 3.79 |
| AC COP | 2.28 | 3609 | 2073 | 853 | 16.04 | 9.22 | 3.79 |
| | 2.8 | 3270 | 1734 | 853 | 14.53 | 7.71 | 3.79 |
| | 3.0 | 3171 | 1635 | 853 | 14.10 | 7.27 | 3.79 |
| | 3.5 | 2973 | 1437 | 853 | 13.22 | 6.39 | 3.79 |
| Adj. | 2 Houses | 3438 | 1894 | 861 | 15.28 | 8.42 | 3.83 |
| Shade | 3 Houses | 3434 | 1887 | 863 | 15.26 | 8.39 | 3.84 |
| Overhang | 1 ft | 3463 | 1934 | 846 | 15.39 | 8.60 | 3.76 |
| | 3 ft | 3437 | 1895 | 859 | 15.28 | 8.43 | 3.82 |
| Infilt. | 0.5 ach | 3309 | 1884 | 742 | 14.71 | 8.38 | 3.30 |
| | 2.0 ach | 3710 | 1952 | 1074 | 16.49 | 8.68 | 4.78 |
| Insul. | R0W,R4C | 2858 | 1651 | 524 | 12.70 | 7.34 | 2.33 |
| | R5W,R11C | 2656 | 1616 | 356 | 11.81 | 7.18 | 1.59 |
| | R11W,R19C | 2595 | 1609 | 302 | 11.53 | 7.15 | 1.35 |
| | R0W,TileR** | 2685 | 1582 | 420 | 11.94 | 7.03 | 1.87 |
| | R0W,MudR | 3453 | 1902 | 867 | 15.34 | 8.45 | 3.86 |
| Wall C. | Light | 3419 | 1845 | 891 | 15.20 | 8.20 | 3.96 |
| Roof | Light | 3145 | 1353 | 1109 | 13.98 | 6.01 | 4.93 |
| Color | Reflec. | 3069 | 1123 | 1262 | 13.64 | 4.99 | 5.61 |
| Film | 0.8 | 3382 | 1757 | 942 | 15.03 | 7.81 | 4.19 |
| | 0.6 | 3334 | 1607 | 1044 | 14.82 | 7.14 | 4.64 |
| Eff. Lights | | 3103 | 1845 | 917 | 13.79 | 8.20 | 4.07 |
| Day Lighting | | 2985 | 1822 | 935 | 13.27 | 8.10 | 4.16 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft; Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7a(ii). Summary of Simple Parametric Simulations for Prototypical Office in Islamabad on Middle Floor (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 2602 | 1560 | 359 | 11.57 | 6.94 | 1.60 |
| AC COP | 2.28 | 2731 | 1689 | 359 | 12.14 | 7.51 | 1.60 |
| | 2.8 | 2459 | 1417 | 359 | 10.93 | 6.30 | 1.60 |
| | 3.0 | 2380 | 1338 | 359 | 10.58 | 5.95 | 1.60 |
| | 3.5 | 2221 | 1179 | 359 | 9.87 | 5.24 | 1.60 |
| Adj. | 2 Houses | 2543 | 1474 | 385 | 11.30 | 6.55 | 1.71 |
| Shade | 3 Houses | 2520 | 1441 | 397 | 11.20 | 6.40 | 1.77 |
| Overhang | 1 ft | 2629 | 1592 | 354 | 11.68 | 7.07 | 1.57 |
| | 3 ft | 2583 | 1538 | 362 | 11.48 | 6.84 | 1.61 |
| Infilt. | 0.5 ach | 2528 | 1584 | 261 | 11.24 | 7.04 | 1.16 |
| | 2.0 ach | 2795 | 1548 | 564 | 12.43 | 6.88 | 2.51 |
| Insul. | R0W,R4C | 2602 | 1560 | 359 | 11.57 | 6.94 | 1.60 |
| | R5W,R11C | 2555 | 1593 | 279 | 11.36 | 7.08 | 1.24 |
| | R11W,R19C | 2542 | 1604 | 256 | 11.30 | 7.13 | 1.14 |
| | R0W,TileR** | 2602 | 1560 | 359 | 11.57 | 6.94 | 1.60 |
| | R0W,MudR | 2602 | 1560 | 359 | 11.57 | 6.94 | 1.60 |
| Wall C. | Light | 2544 | 1475 | 386 | 11.31 | 6.56 | 1.72 |
| Roof | Light | 2602 | 1560 | 359 | 11.57 | 6.94 | 1.60 |
| Color | Reflec. | 2602 | 1560 | 359 | 11.57 | 6.94 | 1.60 |
| Film | 0.8 | 2452 | 1341 | 428 | 10.90 | 5.96 | 1.91 |
| | 0.6 | 2350 | 1145 | 521 | 10.45 | 5.09 | 2.32 |
| Eff. Lights | | 2235 | 1477 | 417 | 9.94 | 6.57 | 1.86 |
| Day Lighting | | 2109 | 1448 | 434 | 9.38 | 6.44 | 1.93 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7a(iii). Summary of Simple Parametric Simulations for Prototypical Office in Islamabad in a Single-Story Building (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3143 | 1596 | 863 | 13.97 | 7.09 | 3.84 |
| AC COP | 2.28 | 3273 | 1727 | 863 | 14.55 | 7.68 | 3.84 |
| | 2.8 | 2997 | 1451 | 863 | 13.32 | 6.45 | 3.84 |
| | 3.0 | 2917 | 1370 | 863 | 12.97 | 6.09 | 3.84 |
| | 3.5 | 2756 | 1209 | 863 | 12.25 | 5.38 | 3.84 |
| Adj. Shade | 2 Houses | 3091 | 1405 | 1002 | 13.74 | 6.25 | 4.46 |
| | 3 Houses | 3083 | 1332 | 1068 | 13.70 | 5.92 | 4.75 |
| Overhang | 1 ft | 3154 | 1616 | 856 | 14.02 | 7.18 | 3.81 |
| | 3 ft | 3136 | 1584 | 869 | 13.94 | 7.04 | 3.86 |
| Infilt. | 0.5 ach | 2998 | 1556 | 758 | 13.32 | 6.92 | 3.37 |
| | 2.0 ach | 3416 | 1662 | 1071 | 15.18 | 7.39 | 4.76 |
| Insul. | R0W,R4C | 2582 | 1325 | 573 | 11.48 | 5.89 | 2.55 |
| | R5W,R11C | 2367 | 1269 | 415 | 10.52 | 5.64 | 1.85 |
| | R11W,R19C | 2300 | 1253 | 363 | 10.23 | 5.57 | 1.62 |
| | R0W,TileR** | 2413 | 1255 | 475 | 10.73 | 5.58 | 2.11 |
| | R0W,MudR | 3150 | 1585 | 882 | 14.00 | 7.05 | 3.92 |
| Wall C. | Light | 3123 | 1542 | 898 | 13.88 | 6.86 | 3.99 |
| Roof Color | Light | 2934 | 1140 | 1111 | 13.04 | 5.07 | 4.94 |
| | Reflec. | 2906 | 964 | 1259 | 12.92 | 4.28 | 5.60 |
| Film | 0.8 | 3100 | 1469 | 948 | 13.78 | 6.53 | 4.22 |
| | 0.6 | 3073 | 1346 | 1045 | 13.66 | 5.98 | 4.64 |
| Eff. Lights | | 2806 | 1537 | 927 | 12.47 | 6.83 | 4.12 |
| Day Lighting | | 2692 | 1517 | 947 | 11.97 | 6.74 | 4.22 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7b(i). Summary of Simple Parametric Simulations for Prototypical Office in Karachi on Top Floor (a=225 ft$^2$)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft$^2$ Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3157 | 2475 | 0 | 14.03 | 11.00 | 0.00 |
| AC COP | 2.28 | 3384 | 2702 | 0 | 15.04 | 12.01 | 0.00 |
| | 2.8 | 2905 | 2222 | 0 | 12.91 | 9.88 | 0.00 |
| | 3.0 | 2765 | 2082 | 0 | 12.29 | 9.26 | 0.00 |
| | 3.5 | 2485 | 1802 | 0 | 11.05 | 8.01 | 0.00 |
| Adj. | 2 Houses | 3132 | 2449 | 0 | 13.92 | 10.89 | 0.00 |
| Shade | 3 Houses | 3122 | 2439 | 0 | 13.88 | 10.84 | 0.00 |
| Overhang | 1 ft | 3190 | 2508 | 0 | 14.18 | 11.15 | 0.00 |
| | 3 ft | 3133 | 2451 | 0 | 13.93 | 10.90 | 0.00 |
| Infilt. | 0.5 ach | 3085 | 2402 | 0 | 13.71 | 10.68 | 0.00 |
| | 2.0 ach | 3262 | 2580 | 0 | 14.50 | 11.47 | 0.00 |
| Insul. | R0W,R4C | 2926 | 2243 | 0 | 13.01 | 9.97 | 0.00 |
| | R5W,R11C | 2941 | 2258 | 0 | 13.07 | 10.04 | 0.00 |
| | R11W,R19C | 2948 | 2265 | 0 | 13.10 | 10.07 | 0.00 |
| Wall C. | Light | 3063 | 2380 | 0 | 13.61 | 10.58 | 0.00 |
| Roof | Light | 2664 | 1980 | 0 | 11.84 | 8.80 | 0.00 |
| Color | Reflec. | 2441 | 1758 | 0 | 10.85 | 7.82 | 0.00 |
| Film | 0.8 | 2931 | 2248 | 0 | 13.03 | 9.99 | 0.00 |
| | 0.6 | 2708 | 2025 | 0 | 12.04 | 9.00 | 0.00 |
| Eff. Lights | | 2723 | 2381 | 0 | 12.10 | 10.59 | 0.00 |
| Day Lighting | | 2576 | 2349 | 0 | 11.45 | 10.44 | 0.00 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

**Table 6.7b(ii). Summary of Simple Parametric Simulations for Prototypical Office in Karachi on Middle Floor (a=225 ft$^2$)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft$^2$ Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 2914 | 2232 | 0 | 12.95 | 9.92 | 0.00 |
| AC COP | 2.28 | 3118 | 2436 | 0 | 13.86 | 10.83 | 0.00 |
| | 2.8 | 2687 | 2005 | 0 | 11.95 | 8.91 | 0.00 |
| | 3.0 | 2562 | 1879 | 0 | 11.39 | 8.35 | 0.00 |
| | 3.5 | 2310 | 1628 | 0 | 10.27 | 7.24 | 0.00 |
| Adj. | 2 Houses | 2800 | 2117 | 0 | 12.44 | 9.41 | 0.00 |
| Shade | 3 Houses | 2755 | 2072 | 0 | 12.25 | 9.21 | 0.00 |
| Overhang | 1 ft | 2954 | 2271 | 0 | 13.13 | 10.10 | 0.00 |
| | 3 ft | 2884 | 2201 | 0 | 12.82 | 9.79 | 0.00 |
| Infilt. | 0.5 ach | 2875 | 2192 | 0 | 12.78 | 9.74 | 0.00 |
| | 2.0 ach | 2984 | 2301 | 0 | 13.26 | 10.23 | 0.00 |
| Insul. | R0W,R4C | 2914 | 2232 | 0 | 12.95 | 9.92 | 0.00 |
| | R5W,R11C | 2963 | 2280 | 0 | 13.17 | 10.13 | 0.00 |
| | R11W,R19C | 2977 | 2294 | 0 | 13.23 | 10.20 | 0.00 |
| Wall C. | Light | 2801 | 2118 | 0 | 12.45 | 9.41 | 0.00 |
| Roof | Light | 2914 | 2232 | 0 | 12.95 | 9.92 | 0.00 |
| Color | Reflec. | 2914 | 2232 | 0 | 12.95 | 9.92 | 0.00 |
| Film | 0.8 | 2631 | 1948 | 0 | 11.70 | 8.66 | 0.00 |
| | 0.6 | 2346 | 1663 | 0 | 10.43 | 7.39 | 0.00 |
| Eff. Lights | | 2463 | 2122 | 0 | 10.95 | 9.43 | 0.00 |
| Day Lighting | | 2313 | 2085 | 0 | 10.28 | 9.27 | 0.00 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

**Table 6.7b(iii). Summary of Simple Parametric Simulations for Prototypical Office in Karachi in a Single-Story Building (a=225 ft²)**

| Measure | Case | Energy (kWh) | | | KWh/ft² | | |
|---|---|---|---|---|---|---|---|
| | | Total | Cool | Heat | Total | Cool | Heat |
| Base Case* | | 2850 | 2167 | 0 | 12.67 | 9.63 | 0.00 |
| AC COP | 2.28 | 3048 | 2365 | 0 | 13.55 | 10.51 | 0.00 |
| | 2.8 | 2630 | 1947 | 0 | 11.69 | 8.66 | 0.00 |
| | 3.0 | 2507 | 1825 | 0 | 11.15 | 8.11 | 0.00 |
| | 3.5 | 2263 | 1581 | 0 | 10.06 | 7.03 | 0.00 |
| Adj. Shade | 2 Houses | 2561 | 1878 | 0 | 11.38 | 8.35 | 0.00 |
| | 3 Houses | 2449 | 1766 | 0 | 10.89 | 7.85 | 0.00 |
| Overhang | 1 ft | 2879 | 2196 | 0 | 12.80 | 9.76 | 0.00 |
| | 3 ft | 2830 | 2148 | 0 | 12.58 | 9.55 | 0.00 |
| Infilt. | 0.5 ach | 2778 | 2096 | 0 | 12.35 | 9.32 | 0.00 |
| | 2.0 ach | 2965 | 2282 | 0 | 13.18 | 10.14 | 0.00 |
| Insul. | R0W,R4C | 2621 | 1938 | 0 | 11.65 | 8.61 | 0.00 |
| | R5W,R11C | 2607 | 1924 | 0 | 11.59 | 8.56 | 0.00 |
| | R11W,R19C | 2606 | 1923 | 0 | 11.59 | 8.55 | 0.00 |
| Wall C. | Light | 2765 | 2083 | 0 | 12.29 | 9.26 | 0.00 |
| Roof Color | Light | 2420 | 1737 | 0 | 10.76 | 7.72 | 0.00 |
| | Reflec. | 2241 | 1558 | 0 | 9.96 | 6.92 | 0.00 |
| Film | 0.8 | 2656 | 1973 | 0 | 11.81 | 8.77 | 0.00 |
| | 0.6 | 2465 | 1782 | 0 | 10.96 | 7.92 | 0.00 |
| Eff. Lights | | 2420 | 2079 | 0 | 10.76 | 9.24 | 0.00 |
| Day Lighting | | 2276 | 2048 | 0 | 10.12 | 9.11 | 0.00 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

**Table 6.7c(i). Summary of Simple Parametric Simulations for Prototypical Office in Lahore on Top Floor (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3862 | 2806 | 374 | 17.17 | 12.47 | 1.66 |
| AC COP | 2.28 | 4114 | 3057 | 374 | 18.28 | 13.59 | 1.66 |
| | 2.8 | 3583 | 2526 | 374 | 15.93 | 11.23 | 1.66 |
| | 3.0 | 3428 | 2371 | 374 | 15.24 | 10.54 | 1.66 |
| | 3.5 | 3118 | 2061 | 374 | 13.86 | 9.16 | 1.66 |
| Adj. Shade | 2 Houses | 3845 | 2784 | 378 | 17.09 | 12.37 | 1.68 |
| | 3 Houses | 3838 | 2775 | 380 | 17.06 | 12.33 | 1.69 |
| Overhang | 1 ft | 3887 | 2834 | 370 | 17.28 | 12.59 | 1.65 |
| | 3 ft | 3845 | 2785 | 377 | 17.09 | 12.38 | 1.68 |
| Infilt. | 0.5 ach | 3727 | 2724 | 320 | 16.56 | 12.11 | 1.42 |
| | 2.0 ach | 4087 | 2926 | 479 | 18.17 | 13.00 | 2.13 |
| Insul. | R0W,R4C | 3281 | 2374 | 223 | 14.59 | 10.56 | 1.00 |
| | R5W,R11C | 3045 | 2216 | 145 | 13.53 | 9.85 | 0.65 |
| | R11W,R19C | 2967 | 2163 | 120 | 13.19 | 9.61 | 0.54 |
| | R0W,TileR** | 3075 | 2215 | 177 | 13.67 | 9.85 | 0.79 |
| | R0W,MudR | 3894 | 2834 | 377 | 17.31 | 12.60 | 1.68 |
| Wall C. | Light | 3794 | 2714 | 396 | 16.86 | 12.07 | 1.77 |
| Roof Color | Light | 3246 | 2021 | 542 | 14.43 | 8.98 | 2.41 |
| | Reflec. | 2984 | 1652 | 648 | 13.26 | 7.35 | 2.88 |
| Film | 0.8 | 3713 | 2607 | 423 | 16.51 | 11.59 | 1.88 |
| | 0.6 | 3579 | 2415 | 481 | 15.91 | 10.73 | 2.14 |
| Eff. Lights | | 3479 | 2725 | 413 | 15.47 | 12.11 | 1.84 |
| Day Lighting | | 3347 | 2696 | 423 | 14.88 | 11.99 | 1.88 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7c(ii). Summary of Simple Parametric Simulations for Prototypical Office in Lahore on Middle Floor (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 2940 | 2105 | 153 | 13.07 | 9.36 | 0.68 |
| AC COP | 2.28 | 3126 | 2291 | 153 | 13.89 | 10.18 | 0.68 |
| | 2.8 | 2734 | 1898 | 153 | 12.15 | 8.44 | 0.68 |
| | 3.0 | 2619 | 1784 | 153 | 11.64 | 7.93 | 0.68 |
| | 3.5 | 2390 | 1554 | 153 | 10.62 | 6.91 | 0.68 |
| Adj. | 2 Houses | 2840 | 1987 | 170 | 12.62 | 8.83 | 0.75 |
| Shade | 3 Houses | 2802 | 1943 | 177 | 12.46 | 8.64 | 0.78 |
| Overhang | 1 ft | 2978 | 2145 | 151 | 13.24 | 9.53 | 0.67 |
| | 3 ft | 2912 | 2075 | 154 | 12.94 | 9.22 | 0.69 |
| Infilt. | 0.5 ach | 2864 | 2075 | 106 | 12.73 | 9.22 | 0.47 |
| | 2.0 ach | 3106 | 2173 | 250 | 13.81 | 9.66 | 1.11 |
| Insul. | R0W,R4C | 2940 | 2105 | 153 | 13.07 | 9.36 | 0.68 |
| | R5W,R11C | 2894 | 2098 | 113 | 12.87 | 9.33 | 0.50 |
| | R11W,R19C | 2882 | 2097 | 102 | 12.81 | 9.33 | 0.45 |
| | R0W,TileR** | 2940 | 2105 | 153 | 13.07 | 9.36 | 0.68 |
| | R0W,MudR | 2940 | 2105 | 153 | 13.07 | 9.36 | 0.68 |
| Wall C. | Light | 2833 | 1981 | 169 | 12.59 | 8.81 | 0.75 |
| Roof | Light | 2940 | 2105 | 153 | 13.07 | 9.36 | 0.68 |
| Color | Reflec. | 2940 | 2105 | 153 | 13.07 | 9.36 | 0.68 |
| Film | 0.8 | 2701 | 1828 | 191 | 12.01 | 8.12 | 0.85 |
| | 0.6 | 2478 | 1556 | 239 | 11.02 | 6.92 | 1.06 |
| Eff. Lights | | 2529 | 2001 | 187 | 11.25 | 8.89 | 0.83 |
| Day Lighting | | 2393 | 1969 | 196 | 10.64 | 8.75 | 0.88 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7c(iii). Summary of Simple Parametric Simulations for Prototypical Office in Lahore in a Single-Story Building (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3524 | 2492 | 350 | 15.66 | 11.07 | 1.55 |
| AC COP | 2.28 | 3746 | 2714 | 350 | 16.65 | 12.06 | 1.55 |
| | 2.8 | 3278 | 2245 | 350 | 14.57 | 9.98 | 1.55 |
| | 3.0 | 3141 | 2109 | 350 | 13.96 | 9.38 | 1.55 |
| | 3.5 | 2868 | 1835 | 350 | 12.75 | 8.16 | 1.55 |
| Adj. | 2 Houses | 3333 | 2223 | 426 | 14.81 | 9.88 | 1.89 |
| Shade | 3 Houses | 3264 | 2119 | 462 | 14.51 | 9.42 | 2.06 |
| Overhang | 1 ft | 3546 | 2517 | 346 | 15.76 | 11.19 | 1.54 |
| | 3 ft | 3510 | 2475 | 353 | 15.60 | 11.00 | 1.57 |
| Infilt. | 0.5 ach | 3390 | 2407 | 299 | 15.07 | 10.70 | 1.33 |
| | 2.0 ach | 3758 | 2627 | 447 | 16.70 | 11.68 | 1.99 |
| Insul. | R0W,R4C | 2896 | 1997 | 215 | 12.87 | 8.88 | 0.96 |
| | R5W,R11C | 2665 | 1841 | 141 | 11.85 | 8.18 | 0.63 |
| | R11W,R19C | 2593 | 1792 | 117 | 11.53 | 7.97 | 0.52 |
| | R0W,TileR** | 2700 | 1847 | 170 | 12.00 | 8.21 | 0.76 |
| | R0W,MudR | 3558 | 2518 | 357 | 15.81 | 11.19 | 1.59 |
| Wall C. | Light | 3460 | 2407 | 370 | 15.38 | 10.70 | 1.64 |
| Roof | Light | 2954 | 1768 | 503 | 13.13 | 7.86 | 2.24 |
| Color | Reflec. | 2744 | 1461 | 601 | 12.20 | 6.49 | 2.67 |
| Film | 0.8 | 3394 | 2315 | 395 | 15.09 | 10.29 | 1.76 |
| | 0.6 | 3279 | 2146 | 449 | 14.57 | 9.54 | 2.00 |
| Eff. Lights | | 3145 | 2414 | 388 | 13.98 | 10.73 | 1.73 |
| Day Lighting | | 3015 | 2387 | 399 | 13.40 | 10.61 | 1.77 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7d(i). Summary of Simple Parametric Simulations for Prototypical Office in Multan on Top Floor (a=225 ft$^2$)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft$^2$ Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 4263 | 3141 | 439 | 18.95 | 13.96 | 1.95 |
| AC COP | 2.28 | 4546 | 3424 | 439 | 20.20 | 15.22 | 1.95 |
| | 2.8 | 3948 | 2825 | 439 | 17.55 | 12.56 | 1.95 |
| | 3.0 | 3773 | 2651 | 439 | 16.77 | 11.78 | 1.95 |
| | 3.5 | 3424 | 2301 | 439 | 15.22 | 10.23 | 1.95 |
| Adj. | 2 Houses | 4244 | 3117 | 444 | 18.86 | 13.86 | 1.97 |
| Shade | 3 Houses | 4236 | 3108 | 446 | 18.83 | 13.82 | 1.98 |
| Overhang | 1 ft | 4288 | 3170 | 435 | 19.06 | 14.09 | 1.93 |
| | 3 ft | 4244 | 3119 | 442 | 18.87 | 13.86 | 1.97 |
| Infilt. | 0.5 ach | 4084 | 3024 | 376 | 18.15 | 13.44 | 1.67 |
| | 2.0 ach | 4567 | 3325 | 559 | 20.30 | 14.78 | 2.49 |
| Insul. | R0W,R4C | 3605 | 2659 | 263 | 16.02 | 11.82 | 1.17 |
| | R5W,R11C | 3330 | 2474 | 173 | 14.81 | 11.00 | 0.77 |
| | R11W,R19C | 3240 | 2413 | 144 | 14.40 | 10.73 | 0.64 |
| | R0W,TileR** | 3386 | 2498 | 205 | 15.05 | 11.10 | 0.91 |
| | R0W,MudR | 4311 | 3193 | 434 | 19.17 | 14.20 | 1.93 |
| Wall C. | Light | 4201 | 3056 | 462 | 18.67 | 13.59 | 2.05 |
| Roof | Light | 3676 | 2382 | 610 | 16.34 | 10.59 | 2.71 |
| Color | Reflec. | 3417 | 2015 | 718 | 15.18 | 8.96 | 3.19 |
| Film | 0.8 | 4112 | 2938 | 491 | 18.27 | 13.06 | 2.18 |
| | 0.6 | 3978 | 2741 | 553 | 17.68 | 12.19 | 2.46 |
| Eff. Lights | | 3878 | 3058 | 479 | 17.24 | 13.59 | 2.13 |
| Day Lighting | | 3746 | 3028 | 490 | 16.65 | 13.46 | 2.18 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7d(ii). Summary of Simple Parametric Simulations for Prototypical Office in Multan on Middle Floor (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3228 | 2368 | 177 | 14.35 | 10.53 | 0.79 |
| AC COP | 2.28 | 3439 | 2580 | 177 | 15.28 | 11.47 | 0.79 |
| | 2.8 | 2993 | 2134 | 177 | 13.31 | 9.48 | 0.79 |
| | 3.0 | 2863 | 2003 | 177 | 12.73 | 8.91 | 0.79 |
| | 3.5 | 2603 | 1743 | 177 | 11.57 | 7.75 | 0.79 |
| Adj. | 2 Houses | 3123 | 2245 | 195 | 13.88 | 9.98 | 0.87 |
| Shade | 3 Houses | 3081 | 2196 | 203 | 13.69 | 9.76 | 0.90 |
| Overhang | 1 ft | 3267 | 2410 | 174 | 14.52 | 10.72 | 0.78 |
| | 3 ft | 3201 | 2339 | 178 | 14.23 | 10.40 | 0.80 |
| Infilt. | 0.5 ach | 3111 | 2305 | 123 | 13.83 | 10.25 | 0.55 |
| | 2.0 ach | 3473 | 2502 | 288 | 15.44 | 11.12 | 1.28 |
| Insul. | R0W,R4C | 3228 | 2368 | 177 | 14.35 | 10.53 | 0.79 |
| | R5W,R11C | 3156 | 2340 | 134 | 14.03 | 10.40 | 0.59 |
| | R11W,R19C | 3139 | 2335 | 121 | 13.95 | 10.38 | 0.54 |
| | R0W,TileR** | 3228 | 2368 | 177 | 14.35 | 10.53 | 0.79 |
| | R0W,MudR | 3228 | 2368 | 177 | 14.35 | 10.53 | 0.79 |
| Wall C. | Light | 3129 | 2252 | 194 | 13.90 | 10.01 | 0.86 |
| Roof | Light | 3228 | 2368 | 177 | 14.35 | 10.53 | 0.79 |
| Color | Reflec. | 3228 | 2368 | 177 | 14.35 | 10.53 | 0.79 |
| Film | 0.8 | 2982 | 2081 | 218 | 13.25 | 9.25 | 0.97 |
| | 0.6 | 2740 | 1786 | 271 | 12.18 | 7.94 | 1.21 |
| Eff. Lights | | 2820 | 2265 | 213 | 12.53 | 10.07 | 0.94 |
| Day Lighting | | 2682 | 2231 | 223 | 11.92 | 9.92 | 1.00 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7d(iii). Summary of Simple Parametric Simulations for Prototypical Office in Multan in a Single-Story Building (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3926 | 2844 | 399 | 17.45 | 12.64 | 1.77 |
| AC COP | 2.28 | 4181 | 3099 | 399 | 18.58 | 13.78 | 1.77 |
| | 2.8 | 3642 | 2560 | 399 | 16.19 | 11.38 | 1.77 |
| | 3.0 | 3484 | 2402 | 399 | 15.49 | 10.68 | 1.77 |
| | 3.5 | 3169 | 2087 | 399 | 14.09 | 9.28 | 1.77 |
| Adj. Shade | 2 Houses | 3732 | 2576 | 473 | 16.59 | 11.45 | 2.10 |
| | 3 Houses | 3663 | 2471 | 508 | 16.28 | 10.98 | 2.26 |
| Overhang | 1 ft | 3948 | 2870 | 395 | 17.55 | 12.76 | 1.76 |
| | 3 ft | 3909 | 2824 | 402 | 17.37 | 12.55 | 1.79 |
| Infilt. | 0.5 ach | 3749 | 2725 | 341 | 16.67 | 12.11 | 1.52 |
| | 2.0 ach | 4228 | 3036 | 509 | 18.79 | 13.49 | 2.26 |
| Insul. | R0W,R4C | 3217 | 2289 | 244 | 14.30 | 10.18 | 1.09 |
| | R5W,R11C | 2944 | 2100 | 161 | 13.09 | 9.34 | 0.72 |
| | R11W,R19C | 2858 | 2041 | 133 | 12.71 | 9.07 | 0.59 |
| | R0W,TileR** | 3003 | 2130 | 190 | 13.35 | 9.47 | 0.84 |
| | R0W,MudR | 3982 | 2899 | 400 | 17.70 | 12.89 | 1.78 |
| Wall C. | Light | 3867 | 2764 | 419 | 17.19 | 12.28 | 1.86 |
| Roof Color | Light | 3357 | 2121 | 552 | 14.92 | 9.43 | 2.46 |
| | Reflec. | 3131 | 1801 | 647 | 13.92 | 8.01 | 2.88 |
| Film | 0.8 | 3792 | 2662 | 447 | 16.86 | 11.83 | 1.99 |
| | 0.6 | 3669 | 2483 | 502 | 16.31 | 11.04 | 2.23 |
| Eff. Lights | | 3545 | 2765 | 438 | 15.76 | 12.29 | 1.95 |
| Day Lighting | | 3415 | 2736 | 450 | 15.18 | 12.16 | 2.00 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7e(i). Summary of Simple Parametric Simulations for Prototypical Office in Peshawar on Top Floor (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3843 | 2447 | 713 | 17.09 | 10.88 | 3.17 |
| AC COP | 2.28 | 4056 | 2660 | 713 | 18.03 | 11.83 | 3.17 |
| | 2.8 | 3607 | 2211 | 713 | 16.03 | 9.83 | 3.17 |
| | 3.0 | 3476 | 2079 | 713 | 15.45 | 9.24 | 3.17 |
| | 3.5 | 3213 | 1817 | 713 | 14.28 | 8.08 | 3.17 |
| Adj. | 2 Houses | 3830 | 2428 | 720 | 17.02 | 10.79 | 3.20 |
| Shade | 3 Houses | 3825 | 2420 | 722 | 17.01 | 10.76 | 3.21 |
| Overhang | 1 ft | 3863 | 2472 | 707 | 17.17 | 10.99 | 3.14 |
| | 3 ft | 3829 | 2428 | 718 | 17.02 | 10.79 | 3.19 |
| Infilt. | 0.5 ach | 3679 | 2377 | 619 | 16.35 | 10.57 | 2.75 |
| | 2.0 ach | 4140 | 2556 | 901 | 18.40 | 11.36 | 4.01 |
| Insul. | R0W,R4C | 3225 | 2100 | 441 | 14.34 | 9.34 | 1.96 |
| | R5W,R11C | 2965 | 1980 | 302 | 13.18 | 8.80 | 1.34 |
| | R11W,R19C | 2884 | 1944 | 258 | 12.82 | 8.64 | 1.15 |
| | R0W,TileR** | 3017 | 1975 | 359 | 13.41 | 8.78 | 1.60 |
| | R0W,MudR | 3870 | 2460 | 728 | 17.20 | 10.93 | 3.24 |
| Wall C. | Light | 3806 | 2375 | 748 | 16.92 | 10.56 | 3.33 |
| Roof | Light | 3474 | 1829 | 962 | 15.44 | 8.13 | 4.28 |
| Color | Reflec. | 3337 | 1539 | 1115 | 14.83 | 6.84 | 4.96 |
| Film | 0.8 | 3749 | 2276 | 790 | 16.66 | 10.12 | 3.51 |
| | 0.6 | 3672 | 2109 | 880 | 16.32 | 9.38 | 3.91 |
| Eff. Lights | | 3489 | 2375 | 771 | 15.51 | 10.56 | 3.43 |
| Day Lighting | | 3369 | 2352 | 789 | 14.97 | 10.45 | 3.51 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7e(ii). Summary of Simple Parametric Simulations for Prototypical Office in Peshawar on Middle Floor (a=225 ft²)**

| Measure | Case | Energy (kWh) | | | KWh/ft² | | |
|---|---|---|---|---|---|---|---|
| | | Total | Cool | Heat | Total | Cool | Heat |
| Base Case* | | 2891 | 1899 | 308 | 12.85 | 8.44 | 1.37 |
| AC COP | 2.28 | 3053 | 2062 | 308 | 13.57 | 9.16 | 1.37 |
| | 2.8 | 2711 | 1719 | 308 | 12.05 | 7.64 | 1.37 |
| | 3.0 | 2610 | 1619 | 308 | 11.60 | 7.20 | 1.37 |
| | 3.5 | 2410 | 1419 | 308 | 10.72 | 6.31 | 1.37 |
| Adj. | 2 Houses | 2815 | 1799 | 334 | 12.51 | 8.00 | 1.49 |
| Shade | 3 Houses | 2784 | 1757 | 344 | 12.38 | 7.81 | 1.53 |
| Overhang | 1 ft | 2924 | 1937 | 304 | 13.00 | 8.61 | 1.36 |
| | 3 ft | 2868 | 1873 | 312 | 12.75 | 8.32 | 1.39 |
| Infilt. | 0.5 ach | 2794 | 1888 | 223 | 12.42 | 8.40 | 0.99 |
| | 2.0 ach | 3128 | 1958 | 487 | 13.90 | 8.71 | 2.16 |
| Insul. | R0W,R4C | 2891 | 1899 | 308 | 12.85 | 8.44 | 1.37 |
| | R5W,R11C | 2824 | 1902 | 239 | 12.55 | 8.45 | 1.07 |
| | R11W,R19C | 2805 | 1903 | 219 | 12.47 | 8.46 | 0.97 |
| | R0W,TileR** | 2891 | 1899 | 308 | 12.85 | 8.44 | 1.37 |
| | R0W,MudR | 2891 | 1899 | 308 | 12.85 | 8.44 | 1.37 |
| Wall C. | Light | 2817 | 1799 | 335 | 12.52 | 8.00 | 1.49 |
| Roof | Light | 2891 | 1899 | 308 | 12.85 | 8.44 | 1.37 |
| Color | Reflec. | 2891 | 1899 | 308 | 12.85 | 8.44 | 1.37 |
| Film | 0.8 | 2705 | 1651 | 370 | 12.02 | 7.34 | 1.64 |
| | 0.6 | 2551 | 1416 | 453 | 11.34 | 6.30 | 2.01 |
| Eff. Lights | | 2514 | 1809 | 363 | 11.17 | 8.05 | 1.62 |
| Day Lighting | | 2386 | 1779 | 380 | 10.61 | 7.90 | 1.69 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7e(iii). Summary of Simple Parametric Simulations for Prototypical Office in Peshawar in a Single-Story Building (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3516 | 2132 | 702 | 15.63 | 9.48 | 3.12 |
| AC COP | 2.28 | 3700 | 2315 | 702 | 16.44 | 10.29 | 3.12 |
| | 2.8 | 3313 | 1928 | 702 | 14.73 | 8.57 | 3.12 |
| | 3.0 | 3200 | 1815 | 702 | 14.23 | 8.07 | 3.12 |
| | 3.5 | 2974 | 1589 | 702 | 13.22 | 7.07 | 3.12 |
| Adj. | 2 Houses | 3423 | 1915 | 824 | 15.21 | 8.51 | 3.67 |
| Shade | 3 Houses | 3396 | 1830 | 883 | 15.09 | 8.14 | 3.92 |
| Overhang | 1 ft | 3533 | 2154 | 696 | 15.70 | 9.58 | 3.09 |
| | 3 ft | 3506 | 2115 | 706 | 15.58 | 9.40 | 3.14 |
| Infilt. | 0.5 ach | 3352 | 2055 | 613 | 14.90 | 9.14 | 2.73 |
| | 2.0 ach | 3820 | 2260 | 877 | 16.98 | 10.04 | 3.90 |
| Insul. | R0W,R4C | 2865 | 1718 | 464 | 12.73 | 7.63 | 2.07 |
| | R5W,R11C | 2611 | 1595 | 333 | 11.61 | 7.09 | 1.48 |
| | R11W,R19C | 2534 | 1560 | 291 | 11.27 | 6.94 | 1.29 |
| | R0W,TileR** | 2669 | 1599 | 386 | 11.86 | 7.11 | 1.72 |
| | R0W,MudR | 3546 | 2142 | 721 | 15.76 | 9.52 | 3.21 |
| Wall C. | Light | 3485 | 2067 | 734 | 15.49 | 9.19 | 3.27 |
| Roof | Light | 3189 | 1569 | 937 | 14.17 | 6.98 | 4.17 |
| Color | Reflec. | 3088 | 1324 | 1081 | 13.73 | 5.89 | 4.81 |
| Film | 0.8 | 3441 | 1983 | 774 | 15.30 | 8.82 | 3.44 |
| | 0.6 | 3379 | 1839 | 857 | 15.02 | 8.18 | 3.81 |
| Eff. Lights | | 3167 | 2066 | 760 | 14.08 | 9.18 | 3.38 |
| Day Lighting | | 3050 | 2043 | 779 | 13.56 | 9.09 | 3.46 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7f(i). Summary of Simple Parametric Simulations for Prototypical Office in Quetta on Top Floor (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3827 | 1069 | 2074 | 17.01 | 4.76 | 9.22 |
| AC COP | 2.28 | 3898 | 1140 | 2074 | 17.32 | 5.07 | 9.22 |
| | 2.8 | 3747 | 990 | 2074 | 16.66 | 4.40 | 9.22 |
| | 3.0 | 3703 | 946 | 2074 | 16.46 | 4.21 | 9.22 |
| | 3.5 | 3615 | 858 | 2074 | 16.07 | 3.81 | 9.22 |
| Adj. Shade | 2 Houses | 3828 | 1058 | 2087 | 17.02 | 4.70 | 9.28 |
| | 3 Houses | 3829 | 1053 | 2093 | 17.02 | 4.68 | 9.30 |
| Overhang | 1 ft | 3825 | 1084 | 2058 | 17.00 | 4.82 | 9.15 |
| | 3 ft | 3829 | 1059 | 2087 | 17.02 | 4.71 | 9.28 |
| Infilt. | 0.5 ach | 3611 | 1086 | 1842 | 16.05 | 4.83 | 8.19 |
| | 2.0 ach | 4271 | 1060 | 2528 | 18.98 | 4.71 | 11.24 |
| Insul. | R0W,R4C | 3015 | 1062 | 1269 | 13.40 | 4.72 | 5.64 |
| | R5W,R11C | 2676 | 1124 | 868 | 11.90 | 5.00 | 3.86 |
| | R11W,R19C | 2581 | 1151 | 745 | 11.47 | 5.12 | 3.31 |
| | R0W,TileR** | 2791 | 1073 | 1035 | 12.41 | 4.77 | 4.60 |
| | R0W,MudR | 3866 | 1035 | 2147 | 17.18 | 4.60 | 9.55 |
| Wall C. | Light | 3857 | 1044 | 2130 | 17.15 | 4.64 | 9.47 |
| Roof Color | Light | 3981 | 833 | 2465 | 17.69 | 3.70 | 10.96 |
| | Reflec. | 4104 | 736 | 2685 | 18.24 | 3.27 | 11.93 |
| Film | 0.8 | 3889 | 965 | 2240 | 17.29 | 4.29 | 9.96 |
| | 0.6 | 3976 | 873 | 2420 | 17.67 | 3.88 | 10.76 |
| Eff. Lights | | 3524 | 1020 | 2162 | 15.66 | 4.53 | 9.61 |
| Day Lighting | | 3424 | 1003 | 2192 | 15.22 | 4.46 | 9.75 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7f(ii). Summary of Simple Parametric Simulations for Prototypical Office in Quetta on Middle Floor (a=225 ft²)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft² Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 2675 | 1109 | 882 | 11.89 | 4.93 | 3.92 |
| AC COP | 2.28 | 2753 | 1188 | 882 | 12.24 | 5.28 | 3.92 |
| | 2.8 | 2588 | 1022 | 882 | 11.50 | 4.55 | 3.92 |
| | 3.0 | 2539 | 974 | 882 | 11.28 | 4.33 | 3.92 |
| | 3.5 | 2443 | 877 | 882 | 10.86 | 3.90 | 3.92 |
| Adj. | 2 Houses | 2660 | 1044 | 933 | 11.82 | 4.64 | 4.15 |
| Shade | 3 Houses | 2656 | 1019 | 954 | 11.81 | 4.53 | 4.24 |
| Overhang | 1 ft | 2686 | 1133 | 870 | 11.94 | 5.03 | 3.87 |
| | 3 ft | 2666 | 1091 | 891 | 11.85 | 4.85 | 3.96 |
| Infilt. | 0.5 ach | 2534 | 1180 | 670 | 11.26 | 5.24 | 2.98 |
| | 2.0 ach | 3047 | 1038 | 1326 | 13.55 | 4.62 | 5.90 |
| Insul. | R0W,R4C | 2675 | 1109 | 882 | 11.89 | 4.93 | 3.92 |
| | R5W,R11C | 2548 | 1171 | 693 | 11.33 | 5.21 | 3.08 |
| | R11W,R19C | 2516 | 1191 | 642 | 11.19 | 5.30 | 2.85 |
| | R0W,TileR** | 2675 | 1109 | 882 | 11.89 | 4.93 | 3.92 |
| | R0W,MudR | 2675 | 1109 | 882 | 11.89 | 4.93 | 3.92 |
| Wall C. | Light | 2677 | 1067 | 927 | 11.90 | 4.74 | 4.12 |
| Roof | Light | 2675 | 1109 | 882 | 11.89 | 4.93 | 3.92 |
| Color | Reflec. | 2675 | 1109 | 882 | 11.89 | 4.93 | 3.92 |
| Film | 0.8 | 2664 | 949 | 1032 | 11.84 | 4.22 | 4.59 |
| | 0.6 | 2715 | 816 | 1216 | 12.07 | 3.62 | 5.41 |
| Eff. Lights | | 2353 | 1043 | 969 | 10.46 | 4.64 | 4.31 |
| Day Lighting | | 2247 | 1024 | 995 | 9.99 | 4.55 | 4.43 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.7f(iii). Summary of Simple Parametric Simulations for Prototypical Office in Quetta in a Single-Story Building (a=225 ft$^2$)**

| Measure | Case | Energy (kWh) Total | Cool | Heat | KWh/ft$^2$ Total | Cool | Heat |
|---|---|---|---|---|---|---|---|
| Base Case* | | 3755 | 854 | 2218 | 16.69 | 3.80 | 9.86 |
| AC COP | 2.28 | 3806 | 905 | 2218 | 16.92 | 4.03 | 9.86 |
| | 2.8 | 3699 | 798 | 2218 | 16.44 | 3.55 | 9.86 |
| | 3.0 | 3667 | 767 | 2218 | 16.30 | 3.41 | 9.86 |
| | 3.5 | 3605 | 704 | 2218 | 16.03 | 3.13 | 9.86 |
| Adj. Shade | 2 Houses | 3893 | 766 | 2443 | 17.30 | 3.41 | 10.86 |
| | 3 Houses | 3954 | 734 | 2538 | 17.58 | 3.27 | 11.28 |
| Overhang | 1 ft | 3750 | 865 | 2201 | 16.67 | 3.84 | 9.78 |
| | 3 ft | 3760 | 846 | 2231 | 16.71 | 3.76 | 9.91 |
| Infilt. | 0.5 ach | 3535 | 859 | 1993 | 15.72 | 3.82 | 8.86 |
| | 2.0 ach | 4201 | 863 | 2654 | 18.67 | 3.84 | 11.80 |
| Insul. | R0W,R4C | 2980 | 818 | 1479 | 13.25 | 3.64 | 6.57 |
| | R5W,R11C | 2620 | 828 | 1108 | 11.64 | 3.68 | 4.93 |
| | R11W,R19C | 2507 | 832 | 991 | 11.14 | 3.70 | 4.41 |
| | R0W,TileR** | 2756 | 810 | 1263 | 12.25 | 3.60 | 5.61 |
| | R0W,MudR | 3803 | 829 | 2291 | 16.91 | 3.69 | 10.18 |
| Wall C. | Light | 3793 | 836 | 2273 | 16.86 | 3.72 | 10.10 |
| Roof Color | Light | 3976 | 683 | 2609 | 17.67 | 3.04 | 11.60 |
| | Reflec. | 4123 | 615 | 2825 | 18.33 | 2.74 | 12.55 |
| Film | 0.8 | 3845 | 783 | 2379 | 17.09 | 3.48 | 10.58 |
| | 0.6 | 3952 | 719 | 2550 | 17.56 | 3.19 | 11.34 |
| Eff. Lights | | 3461 | 813 | 2305 | 15.38 | 3.62 | 10.25 |
| Day Lighting | | 3364 | 800 | 2336 | 14.95 | 3.55 | 10.39 |

* Base Case is for the prototype model with the following properties: AC setting: 79, AC COP: 2.5, Adj. Shade: none, Overhang: 2ft, Infilt: 1.0 ach, Insul: R0, Wall Color: normal(0.7 absorbtance), Roof Color: normal(0.7 absorbtance), Film Shading Coef.: none, Day Lighting: none, Efficient Lighting: none.

** There is 1 1/2 " polystyrene insulation under tile roof.

**Table 6.8a(i). Summary of Combined Parametric Simulations for Prototypical Office in Islamabad on Top Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2896 | 1791 | 421 | 12.87 | 7.96 | 1.88 |
| | | | 2.28 | Light | 2716 | 1529 | 505 | 12.08 | 6.80 | 2.25 |
| | | | 2.5 | Normal | 2758 | 1654 | 421 | 12.26 | 7.35 | 1.88 |
| | | | 2.5 | Light | 2602 | 1414 | 505 | 11.57 | 6.29 | 2.25 |
| | | | 2.8 | Normal | 2606 | 1501 | 421 | 11.58 | 6.67 | 1.88 |
| | | | 2.8 | Light | 2475 | 1287 | 505 | 11.00 | 5.72 | 2.25 |
| | | | 3.0 | Normal | 2521 | 1416 | 421 | 11.20 | 6.30 | 1.88 |
| | | | 3.0 | Light | 2404 | 1216 | 505 | 10.69 | 5.40 | 2.25 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 2995 | 1787 | 524 | 13.31 | 7.94 | 2.33 |
| | | | 2.28 | Light | 2835 | 1540 | 612 | 12.60 | 6.85 | 2.72 |
| | | | 2.5 | Normal | 2858 | 1651 | 524 | 12.70 | 7.34 | 2.33 |
| | | | 2.5 | Light | 2720 | 1425 | 612 | 12.09 | 6.34 | 2.72 |
| | | | 2.8 | Normal | 2706 | 1499 | 524 | 12.03 | 6.66 | 2.33 |
| | | | 2.8 | Light | 2592 | 1297 | 612 | 11.52 | 5.77 | 2.72 |
| | | | 3.0 | Normal | 2622 | 1414 | 524 | 11.65 | 6.29 | 2.33 |
| | | | 3.0 | Light | 2521 | 1226 | 612 | 11.21 | 5.45 | 2.72 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2720 | 1778 | 259 | 12.09 | 7.90 | 1.15 |
| | | | 2.28 | Light | 2619 | 1642 | 293 | 11.64 | 7.30 | 1.31 |
| | | | 2.5 | Normal | 2583 | 1641 | 259 | 11.48 | 7.30 | 1.15 |
| | | | 2.5 | Light | 2495 | 1518 | 293 | 11.09 | 6.74 | 1.31 |
| | | | 2.8 | Normal | 2431 | 1490 | 259 | 10.81 | 6.62 | 1.15 |
| | | | 2.8 | Light | 2356 | 1379 | 293 | 10.47 | 6.13 | 1.31 |
| | | | 3.0 | Normal | 2347 | 1405 | 259 | 10.43 | 6.25 | 1.15 |
| | | | 3.0 | Light | 2279 | 1302 | 293 | 10.13 | 5.79 | 1.31 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2790 | 1750 | 356 | 12.40 | 7.78 | 1.59 |
| | | | 2.28 | Light | 2702 | 1625 | 394 | 12.01 | 7.22 | 1.75 |
| | | | 2.5 | Normal | 2656 | 1616 | 356 | 11.81 | 7.18 | 1.59 |
| | | | 2.5 | Light | 2579 | 1502 | 394 | 11.46 | 6.68 | 1.75 |
| | | | 2.8 | Normal | 2507 | 1467 | 356 | 11.15 | 6.52 | 1.59 |
| | | | 2.8 | Light | 2442 | 1365 | 394 | 10.85 | 6.07 | 1.75 |
| | | | 3.0 | Normal | 2424 | 1385 | 356 | 10.78 | 6.15 | 1.59 |
| | | | 3.0 | Light | 2366 | 1289 | 394 | 10.51 | 5.73 | 1.75 |
| Best | Case* | | | | 2140 | 1095 | 362 | 9.51 | 4.87 | 1.61 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8a(ii). Summary of Combined Parametric Simulations for Prototypical Office in Islamabad on Middle Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2659 | 1716 | 261 | 11.82 | 7.63 | 1.16 |
| | | | 2.28 | Light | 2659 | 1716 | 261 | 11.82 | 7.63 | 1.16 |
| | | | 2.5 | Normal | 2528 | 1584 | 261 | 11.24 | 7.04 | 1.16 |
| | | | 2.5 | Light | 2528 | 1584 | 261 | 11.24 | 7.04 | 1.16 |
| | | | 2.8 | Normal | 2382 | 1438 | 261 | 10.58 | 6.39 | 1.16 |
| | | | 2.8 | Light | 2382 | 1438 | 261 | 10.58 | 6.39 | 1.16 |
| | | | 3.0 | Normal | 2301 | 1357 | 261 | 10.23 | 6.03 | 1.16 |
| | | | 3.0 | Light | 2301 | 1357 | 261 | 10.23 | 6.03 | 1.16 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 2731 | 1689 | 359 | 12.14 | 7.51 | 1.60 |
| | | | 2.28 | Light | 2731 | 1689 | 359 | 12.14 | 7.51 | 1.60 |
| | | | 2.5 | Normal | 2602 | 1560 | 359 | 11.57 | 6.94 | 1.60 |
| | | | 2.5 | Light | 2602 | 1560 | 359 | 11.57 | 6.94 | 1.60 |
| | | | 2.8 | Normal | 2459 | 1417 | 359 | 10.93 | 6.30 | 1.60 |
| | | | 2.8 | Light | 2459 | 1417 | 359 | 10.93 | 6.30 | 1.60 |
| | | | 3.0 | Normal | 2380 | 1338 | 359 | 10.58 | 5.95 | 1.60 |
| | | | 3.0 | Light | 2380 | 1338 | 359 | 10.58 | 5.95 | 1.60 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2635 | 1769 | 183 | 11.71 | 7.86 | 0.81 |
| | | | 2.28 | Light | 2635 | 1769 | 183 | 11.71 | 7.86 | 0.81 |
| | | | 2.5 | Normal | 2499 | 1633 | 183 | 11.11 | 7.26 | 0.81 |
| | | | 2.5 | Light | 2499 | 1633 | 183 | 11.11 | 7.26 | 0.81 |
| | | | 2.8 | Normal | 2348 | 1481 | 183 | 10.43 | 6.58 | 0.81 |
| | | | 2.8 | Light | 2348 | 1481 | 183 | 10.43 | 6.58 | 0.81 |
| | | | 3.0 | Normal | 2264 | 1398 | 183 | 10.06 | 6.21 | 0.81 |
| | | | 3.0 | Light | 2264 | 1398 | 183 | 10.06 | 6.21 | 0.81 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2688 | 1725 | 279 | 11.95 | 7.67 | 1.24 |
| | | | 2.28 | Light | 2688 | 1725 | 279 | 11.95 | 7.67 | 1.24 |
| | | | 2.5 | Normal | 2555 | 1593 | 279 | 11.36 | 7.08 | 1.24 |
| | | | 2.5 | Light | 2555 | 1593 | 279 | 11.36 | 7.08 | 1.24 |
| | | | 2.8 | Normal | 2409 | 1446 | 279 | 10.70 | 6.43 | 1.24 |
| | | | 2.8 | Light | 2409 | 1446 | 279 | 10.70 | 6.43 | 1.24 |
| | | | 3.0 | Normal | 2327 | 1365 | 279 | 10.35 | 6.07 | 1.24 |
| | | | 3.0 | Light | 2327 | 1365 | 279 | 10.35 | 6.07 | 1.24 |
| Best | Case* | | | | 2091 | 1171 | 237 | 9.30 | 5.20 | 1.06 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8a(iii). Summary of Combined Parametric Simulations for Prototypical Office in Islamabad in a Single-Story Building (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2554 | 1402 | 470 | 11.35 | 6.23 | 2.09 |
| | | | 2.28 | Light | 2449 | 1214 | 551 | 10.89 | 5.40 | 2.45 |
| | | | 2.5 | Normal | 2451 | 1298 | 470 | 10.90 | 5.77 | 2.09 |
| | | | 2.5 | Light | 2361 | 1127 | 551 | 10.50 | 5.01 | 2.45 |
| | | | 2.8 | Normal | 2336 | 1183 | 470 | 10.39 | 5.26 | 2.09 |
| | | | 2.8 | Light | 2264 | 1030 | 551 | 10.07 | 4.58 | 2.45 |
| | | | 3.0 | Normal | 2272 | 1119 | 470 | 10.10 | 4.97 | 2.09 |
| | | | 3.0 | Light | 2210 | 976 | 551 | 9.83 | 4.34 | 2.45 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 2688 | 1431 | 573 | 11.95 | 6.36 | 2.55 |
| | | | 2.28 | Light | 2593 | 1252 | 658 | 11.53 | 5.56 | 2.93 |
| | | | 2.5 | Normal | 2582 | 1325 | 573 | 11.48 | 5.89 | 2.55 |
| | | | 2.5 | Light | 2503 | 1161 | 658 | 11.13 | 5.16 | 2.93 |
| | | | 2.8 | Normal | 2465 | 1208 | 573 | 10.95 | 5.37 | 2.55 |
| | | | 2.8 | Light | 2403 | 1061 | 658 | 10.68 | 4.72 | 2.93 |
| | | | 3.0 | Normal | 2399 | 1142 | 573 | 10.66 | 5.08 | 2.55 |
| | | | 3.0 | Light | 2347 | 1006 | 658 | 10.43 | 4.47 | 2.93 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2350 | 1353 | 314 | 10.44 | 6.01 | 1.40 |
| | | | 2.28 | Light | 2290 | 1259 | 348 | 10.18 | 5.60 | 1.55 |
| | | | 2.5 | Normal | 2250 | 1253 | 314 | 10.00 | 5.57 | 1.40 |
| | | | 2.5 | Light | 2198 | 1167 | 348 | 9.77 | 5.19 | 1.55 |
| | | | 2.8 | Normal | 2139 | 1142 | 314 | 9.51 | 5.08 | 1.40 |
| | | | 2.8 | Light | 2096 | 1066 | 348 | 9.32 | 4.74 | 1.55 |
| | | | 3.0 | Normal | 2077 | 1081 | 314 | 9.23 | 4.80 | 1.40 |
| | | | 3.0 | Light | 2040 | 1009 | 348 | 9.07 | 4.49 | 1.55 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2468 | 1370 | 415 | 10.97 | 6.09 | 1.85 |
| | | | 2.28 | Light | 2416 | 1281 | 452 | 10.74 | 5.70 | 2.02 |
| | | | 2.5 | Normal | 2367 | 1269 | 415 | 10.52 | 5.64 | 1.85 |
| | | | 2.5 | Light | 2323 | 1187 | 452 | 10.33 | 5.28 | 2.02 |
| | | | 2.8 | Normal | 2255 | 1156 | 415 | 10.02 | 5.14 | 1.85 |
| | | | 2.8 | Light | 2219 | 1084 | 452 | 9.86 | 4.82 | 2.02 |
| | | | 3.0 | Normal | 2192 | 1094 | 415 | 9.74 | 4.86 | 1.85 |
| | | | 3.0 | Light | 2161 | 1026 | 452 | 9.61 | 4.56 | 2.02 |
| Best | Case* | | | | 1980 | 873 | 424 | 8.80 | 3.88 | 1.89 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8b(i). Summary of Combined Parametric Simulations for Prototypical Office in Karachi on Top Floor (a=225 ft$^2$)**

| Insulation Walls | Roofs | Infilt | AC COP | Roof Color | Energy (kWh) Total | Cool | Heat | KWh/ft$^2$ Total | Cool | Heat |
|---|---|---|---|---|---|---|---|---|---|---|
| R0 | R4 | 0.5 ach | 2.28 | Normal | 3085 | 2402 | 0 | 13.71 | 10.68 | 0.00 |
| | | | 2.28 | Light | 2878 | 2194 | 0 | 12.79 | 9.75 | 0.00 |
| | | | 2.5 | Normal | 2884 | 2201 | 0 | 12.82 | 9.78 | 0.00 |
| | | | 2.5 | Light | 2694 | 2011 | 0 | 11.98 | 8.94 | 0.00 |
| | | | 2.8 | Normal | 2660 | 1977 | 0 | 11.82 | 8.79 | 0.00 |
| | | | 2.8 | Light | 2491 | 1808 | 0 | 11.07 | 8.04 | 0.00 |
| | | | 3.0 | Normal | 2536 | 1853 | 0 | 11.27 | 8.24 | 0.00 |
| | | | 3.0 | Light | 2378 | 1695 | 0 | 10.57 | 7.53 | 0.00 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3131 | 2448 | 0 | 13.92 | 10.89 | 0.00 |
| | | | 2.28 | Light | 2937 | 2254 | 0 | 13.06 | 10.02 | 0.00 |
| | | | 2.5 | Normal | 2926 | 2243 | 0 | 13.01 | 9.97 | 0.00 |
| | | | 2.5 | Light | 2748 | 2065 | 0 | 12.22 | 9.18 | 0.00 |
| | | | 2.8 | Normal | 2698 | 2015 | 0 | 11.99 | 8.96 | 0.00 |
| | | | 2.8 | Light | 2539 | 1856 | 0 | 11.28 | 8.25 | 0.00 |
| | | | 3.0 | Normal | 2571 | 1889 | 0 | 11.43 | 8.40 | 0.00 |
| | | | 3.0 | Light | 2423 | 1740 | 0 | 10.77 | 7.74 | 0.00 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 3124 | 2441 | 0 | 13.89 | 10.85 | 0.00 |
| | | | 2.28 | Light | 3015 | 2332 | 0 | 13.40 | 10.37 | 0.00 |
| | | | 2.5 | Normal | 2919 | 2237 | 0 | 12.98 | 9.94 | 0.00 |
| | | | 2.5 | Light | 2820 | 2137 | 0 | 12.54 | 9.50 | 0.00 |
| | | | 2.8 | Normal | 2692 | 2009 | 0 | 11.97 | 8.93 | 0.00 |
| | | | 2.8 | Light | 2603 | 1921 | 0 | 11.57 | 8.54 | 0.00 |
| | | | 3.0 | Normal | 2566 | 1884 | 0 | 11.41 | 8.37 | 0.00 |
| | | | 3.0 | Light | 2483 | 1800 | 0 | 11.04 | 8.00 | 0.00 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 3147 | 2464 | 0 | 13.99 | 10.95 | 0.00 |
| | | | 2.28 | Light | 3045 | 2362 | 0 | 13.53 | 10.50 | 0.00 |
| | | | 2.5 | Normal | 2941 | 2258 | 0 | 13.07 | 10.04 | 0.00 |
| | | | 2.5 | Light | 2847 | 2164 | 0 | 12.65 | 9.62 | 0.00 |
| | | | 2.8 | Normal | 2711 | 2029 | 0 | 12.05 | 9.02 | 0.00 |
| | | | 2.8 | Light | 2627 | 1945 | 0 | 11.68 | 8.64 | 0.00 |
| | | | 3.0 | Normal | 2584 | 1901 | 0 | 11.48 | 8.45 | 0.00 |
| | | | 3.0 | Light | 2505 | 1823 | 0 | 11.14 | 8.10 | 0.00 |
| Best | Case* | | | | 2211 | 1528 | 0 | 9.82 | 6.79 | 0.00 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8b(ii). Summary of Combined Parametric Simulations for Prototypical Office in Karachi on Middle Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 3075 | 2393 | 0 | 13.67 | 10.64 | 0.00 |
| | | | 2.28 | Light | 3075 | 2393 | 0 | 13.67 | 10.64 | 0.00 |
| | | | 2.5 | Normal | 2875 | 2192 | 0 | 12.78 | 9.74 | 0.00 |
| | | | 2.5 | Light | 2875 | 2192 | 0 | 12.78 | 9.74 | 0.00 |
| | | | 2.8 | Normal | 2653 | 1970 | 0 | 11.79 | 8.76 | 0.00 |
| | | | 2.8 | Light | 2653 | 1970 | 0 | 11.79 | 8.76 | 0.00 |
| | | | 3.0 | Normal | 2529 | 1846 | 0 | 11.24 | 8.21 | 0.00 |
| | | | 3.0 | Light | 2529 | 1846 | 0 | 11.24 | 8.21 | 0.00 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3118 | 2436 | 0 | 13.86 | 10.83 | 0.00 |
| | | | 2.28 | Light | 3118 | 2436 | 0 | 13.86 | 10.83 | 0.00 |
| | | | 2.5 | Normal | 2914 | 2232 | 0 | 12.95 | 9.92 | 0.00 |
| | | | 2.5 | Light | 2914 | 2232 | 0 | 12.95 | 9.92 | 0.00 |
| | | | 2.8 | Normal | 2687 | 2005 | 0 | 11.95 | 8.91 | 0.00 |
| | | | 2.8 | Light | 2687 | 2005 | 0 | 11.95 | 8.91 | 0.00 |
| | | | 3.0 | Normal | 2562 | 1879 | 0 | 11.39 | 8.35 | 0.00 |
| | | | 3.0 | Light | 2562 | 1879 | 0 | 11.39 | 8.35 | 0.00 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 3150 | 2468 | 0 | 14.00 | 10.97 | 0.00 |
| | | | 2.28 | Light | 3150 | 2468 | 0 | 14.00 | 10.97 | 0.00 |
| | | | 2.5 | Normal | 2944 | 2261 | 0 | 13.08 | 10.05 | 0.00 |
| | | | 2.5 | Light | 2944 | 2261 | 0 | 13.08 | 10.05 | 0.00 |
| | | | 2.8 | Normal | 2714 | 2031 | 0 | 12.06 | 9.03 | 0.00 |
| | | | 2.8 | Light | 2714 | 2031 | 0 | 12.06 | 9.03 | 0.00 |
| | | | 3.0 | Normal | 2587 | 1904 | 0 | 11.50 | 8.47 | 0.00 |
| | | | 3.0 | Light | 2587 | 1904 | 0 | 11.50 | 8.47 | 0.00 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 3171 | 2488 | 0 | 14.09 | 11.06 | 0.00 |
| | | | 2.28 | Light | 3171 | 2488 | 0 | 14.09 | 11.06 | 0.00 |
| | | | 2.5 | Normal | 2963 | 2280 | 0 | 13.17 | 10.13 | 0.00 |
| | | | 2.5 | Light | 2963 | 2280 | 0 | 13.17 | 10.13 | 0.00 |
| | | | 2.8 | Normal | 2731 | 2048 | 0 | 12.14 | 9.11 | 0.00 |
| | | | 2.8 | Light | 2731 | 2048 | 0 | 12.14 | 9.11 | 0.00 |
| | | | 3.0 | Normal | 2602 | 1919 | 0 | 11.57 | 8.53 | 0.00 |
| | | | 3.0 | Light | 2602 | 1919 | 0 | 11.57 | 8.53 | 0.00 |
| Best | Case* | | | | 2306 | 1623 | 0 | 10.25 | 7.22 | 0.00 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8b(iii). Summary of Combined Parametric Simulations for Prototypical Office in Karachi in a Single-Story Building (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2735 | 2052 | 0 | 12.16 | 9.12 | 0.00 |
| | | | 2.28 | Light | 2571 | 1889 | 0 | 11.43 | 8.40 | 0.00 |
| | | | 2.5 | Normal | 2564 | 1882 | 0 | 11.40 | 8.36 | 0.00 |
| | | | 2.5 | Light | 2415 | 1732 | 0 | 10.74 | 7.70 | 0.00 |
| | | | 2.8 | Normal | 2374 | 1692 | 0 | 10.56 | 7.52 | 0.00 |
| | | | 2.8 | Light | 2241 | 1558 | 0 | 9.96 | 6.93 | 0.00 |
| | | | 3.0 | Normal | 2269 | 1586 | 0 | 10.09 | 7.05 | 0.00 |
| | | | 3.0 | Light | 2144 | 1461 | 0 | 9.53 | 6.49 | 0.00 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 2797 | 2114 | 0 | 12.43 | 9.40 | 0.00 |
| | | | 2.28 | Light | 2640 | 1957 | 0 | 11.74 | 8.70 | 0.00 |
| | | | 2.5 | Normal | 2621 | 1938 | 0 | 11.65 | 8.61 | 0.00 |
| | | | 2.5 | Light | 2477 | 1794 | 0 | 11.01 | 7.97 | 0.00 |
| | | | 2.8 | Normal | 2425 | 1742 | 0 | 10.78 | 7.74 | 0.00 |
| | | | 2.8 | Light | 2296 | 1613 | 0 | 10.21 | 7.18 | 0.00 |
| | | | 3.0 | Normal | 2316 | 1634 | 0 | 10.30 | 7.26 | 0.00 |
| | | | 3.0 | Light | 2196 | 1513 | 0 | 9.76 | 6.73 | 0.00 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2739 | 2057 | 0 | 12.18 | 9.14 | 0.00 |
| | | | 2.28 | Light | 2654 | 1971 | 0 | 11.80 | 8.76 | 0.00 |
| | | | 2.5 | Normal | 2568 | 1885 | 0 | 11.41 | 8.38 | 0.00 |
| | | | 2.5 | Light | 2490 | 1807 | 0 | 11.07 | 8.03 | 0.00 |
| | | | 2.8 | Normal | 2378 | 1695 | 0 | 10.57 | 7.54 | 0.00 |
| | | | 2.8 | Light | 2308 | 1626 | 0 | 10.26 | 7.22 | 0.00 |
| | | | 3.0 | Normal | 2272 | 1590 | 0 | 10.10 | 7.07 | 0.00 |
| | | | 3.0 | Light | 2207 | 1524 | 0 | 9.81 | 6.78 | 0.00 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2782 | 2099 | 0 | 12.37 | 9.33 | 0.00 |
| | | | 2.28 | Light | 2701 | 2018 | 0 | 12.01 | 8.97 | 0.00 |
| | | | 2.5 | Normal | 2607 | 1924 | 0 | 11.59 | 8.56 | 0.00 |
| | | | 2.5 | Light | 2533 | 1850 | 0 | 11.26 | 8.22 | 0.00 |
| | | | 2.8 | Normal | 2412 | 1730 | 0 | 10.72 | 7.69 | 0.00 |
| | | | 2.8 | Light | 2346 | 1664 | 0 | 10.43 | 7.40 | 0.00 |
| | | | 3.0 | Normal | 2305 | 1622 | 0 | 10.24 | 7.21 | 0.00 |
| | | | 3.0 | Light | 2243 | 1560 | 0 | 9.97 | 6.93 | 0.00 |
| Best | Case* | | | | 1989 | 1306 | 0 | 8.84 | 5.81 | 0.00 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8c(i). Summary of Combined Parametric Simulations for Prototypical Office in Lahore on Top Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 3399 | 2541 | 175 | 15.11 | 11.29 | 0.78 |
| | | | 2.28 | Light | 3071 | 2156 | 231 | 13.65 | 9.58 | 1.03 |
| | | | 2.5 | Normal | 3191 | 2333 | 175 | 14.19 | 10.37 | 0.78 |
| | | | 2.5 | Light | 2897 | 1982 | 231 | 12.87 | 8.81 | 1.03 |
| | | | 2.8 | Normal | 2961 | 2103 | 175 | 13.16 | 9.35 | 0.78 |
| | | | 2.8 | Light | 2703 | 1788 | 231 | 12.02 | 7.95 | 1.03 |
| | | | 3.0 | Normal | 2833 | 1975 | 175 | 12.59 | 8.78 | 0.78 |
| | | | 3.0 | Light | 2596 | 1681 | 231 | 11.54 | 7.47 | 1.03 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3493 | 2585 | 223 | 15.52 | 11.49 | 1.00 |
| | | | 2.28 | Light | 3179 | 2213 | 282 | 14.13 | 9.84 | 1.25 |
| | | | 2.5 | Normal | 3281 | 2374 | 223 | 14.59 | 10.56 | 1.00 |
| | | | 2.5 | Light | 2999 | 2034 | 282 | 13.33 | 9.04 | 1.25 |
| | | | 2.8 | Normal | 3046 | 2139 | 223 | 13.54 | 9.51 | 1.00 |
| | | | 2.8 | Light | 2801 | 1835 | 282 | 12.45 | 8.16 | 1.25 |
| | | | 3.0 | Normal | 2916 | 2009 | 223 | 12.96 | 8.93 | 1.00 |
| | | | 3.0 | Light | 2690 | 1725 | 282 | 11.96 | 7.67 | 1.25 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 3162 | 2380 | 99 | 14.05 | 10.58 | 0.44 |
| | | | 2.28 | Light | 2990 | 2185 | 121 | 13.29 | 9.72 | 0.54 |
| | | | 2.5 | Normal | 2968 | 2186 | 99 | 13.20 | 9.72 | 0.44 |
| | | | 2.5 | Light | 2813 | 2008 | 121 | 12.50 | 8.93 | 0.54 |
| | | | 2.8 | Normal | 2753 | 1971 | 99 | 12.24 | 8.76 | 0.44 |
| | | | 2.8 | Light | 2616 | 1812 | 121 | 11.63 | 8.06 | 0.54 |
| | | | 3.0 | Normal | 2633 | 1851 | 99 | 11.70 | 8.23 | 0.44 |
| | | | 3.0 | Light | 2507 | 1703 | 121 | 11.14 | 7.57 | 0.54 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 3241 | 2413 | 145 | 14.40 | 10.72 | 0.65 |
| | | | 2.28 | Light | 3077 | 2224 | 171 | 13.68 | 9.89 | 0.76 |
| | | | 2.5 | Normal | 3045 | 2216 | 145 | 13.53 | 9.85 | 0.65 |
| | | | 2.5 | Light | 2897 | 2044 | 171 | 12.88 | 9.08 | 0.76 |
| | | | 2.8 | Normal | 2827 | 1998 | 145 | 12.57 | 8.88 | 0.65 |
| | | | 2.8 | Light | 2697 | 1844 | 171 | 11.99 | 8.20 | 0.76 |
| | | | 3.0 | Normal | 2705 | 1877 | 145 | 12.03 | 8.35 | 0.65 |
| | | | 3.0 | Light | 2586 | 1733 | 171 | 11.50 | 7.70 | 0.76 |
| Best | Case* | | | | 2291 | 1448 | 160 | 10.18 | 6.44 | 0.71 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8c(ii). Summary of Combined Parametric Simulations for Prototypical Office in Lahore on Middle Floor (a=225 ft²)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft² | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 3047 | 2258 | 106 | 13.55 | 10.04 | 0.47 |
| | | | 2.28 | Light | 3047 | 2258 | 106 | 13.55 | 10.04 | 0.47 |
| | | | 2.5 | Normal | 2864 | 2075 | 106 | 12.73 | 9.22 | 0.47 |
| | | | 2.5 | Light | 2864 | 2075 | 106 | 12.73 | 9.22 | 0.47 |
| | | | 2.8 | Normal | 2660 | 1871 | 106 | 11.82 | 8.32 | 0.47 |
| | | | 2.8 | Light | 2660 | 1871 | 106 | 11.82 | 8.32 | 0.47 |
| | | | 3.0 | Normal | 2547 | 1759 | 106 | 11.32 | 7.82 | 0.47 |
| | | | 3.0 | Light | 2547 | 1759 | 106 | 11.32 | 7.82 | 0.47 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3126 | 2291 | 153 | 13.89 | 10.18 | 0.68 |
| | | | 2.28 | Light | 3126 | 2291 | 153 | 13.89 | 10.18 | 0.68 |
| | | | 2.5 | Normal | 2940 | 2105 | 153 | 13.07 | 9.36 | 0.68 |
| | | | 2.5 | Light | 2940 | 2105 | 153 | 13.07 | 9.36 | 0.68 |
| | | | 2.8 | Normal | 2734 | 1898 | 153 | 12.15 | 8.44 | 0.68 |
| | | | 2.8 | Light | 2734 | 1898 | 153 | 12.15 | 8.44 | 0.68 |
| | | | 3.0 | Normal | 2619 | 1784 | 153 | 11.64 | 7.93 | 0.68 |
| | | | 3.0 | Light | 2619 | 1784 | 153 | 11.64 | 7.93 | 0.68 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 3017 | 2263 | 70 | 13.41 | 10.06 | 0.31 |
| | | | 2.28 | Light | 3017 | 2263 | 70 | 13.41 | 10.06 | 0.31 |
| | | | 2.5 | Normal | 2833 | 2080 | 70 | 12.59 | 9.24 | 0.31 |
| | | | 2.5 | Light | 2833 | 2080 | 70 | 12.59 | 9.24 | 0.31 |
| | | | 2.8 | Normal | 2629 | 1876 | 70 | 11.69 | 8.34 | 0.31 |
| | | | 2.8 | Light | 2629 | 1876 | 70 | 11.69 | 8.34 | 0.31 |
| | | | 3.0 | Normal | 2516 | 1763 | 70 | 11.18 | 7.84 | 0.31 |
| | | | 3.0 | Light | 2516 | 1763 | 70 | 11.18 | 7.84 | 0.31 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 3079 | 2283 | 113 | 13.69 | 10.15 | 0.50 |
| | | | 2.28 | Light | 3079 | 2283 | 113 | 13.69 | 10.15 | 0.50 |
| | | | 2.5 | Normal | 2894 | 2098 | 113 | 12.87 | 9.33 | 0.50 |
| | | | 2.5 | Light | 2894 | 2098 | 113 | 12.87 | 9.33 | 0.50 |
| | | | 2.8 | Normal | 2688 | 1892 | 113 | 11.95 | 8.41 | 0.50 |
| | | | 2.8 | Light | 2688 | 1892 | 113 | 11.95 | 8.41 | 0.50 |
| | | | 3.0 | Normal | 2574 | 1778 | 113 | 11.44 | 7.90 | 0.50 |
| | | | 3.0 | Light | 2574 | 1778 | 113 | 11.44 | 7.90 | 0.50 |
| Best | Case* | | | | 2269 | 1490 | 96 | 10.09 | 6.62 | 0.42 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8c(iii). Summary of Combined Parametric Simulations for Prototypical Office in Lahore in a Single-Story Building (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2957 | 2107 | 167 | 13.14 | 9.36 | 0.74 |
| | | | 2.28 | Light | 2694 | 1794 | 217 | 11.98 | 7.97 | 0.97 |
| | | | 2.5 | Normal | 2787 | 1937 | 167 | 12.39 | 8.61 | 0.74 |
| | | | 2.5 | Light | 2551 | 1652 | 217 | 11.34 | 7.34 | 0.97 |
| | | | 2.8 | Normal | 2598 | 1748 | 167 | 11.55 | 7.77 | 0.74 |
| | | | 2.8 | Light | 2393 | 1493 | 217 | 10.64 | 6.63 | 0.97 |
| | | | 3.0 | Normal | 2493 | 1643 | 167 | 11.08 | 7.30 | 0.74 |
| | | | 3.0 | Light | 2305 | 1405 | 217 | 10.24 | 6.24 | 0.97 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3072 | 2173 | 215 | 13.66 | 9.66 | 0.96 |
| | | | 2.28 | Light | 2818 | 1867 | 267 | 12.53 | 8.30 | 1.19 |
| | | | 2.5 | Normal | 2896 | 1997 | 215 | 12.87 | 8.88 | 0.96 |
| | | | 2.5 | Light | 2669 | 1719 | 267 | 11.87 | 7.64 | 1.19 |
| | | | 2.8 | Normal | 2701 | 1802 | 215 | 12.01 | 8.01 | 0.96 |
| | | | 2.8 | Light | 2503 | 1553 | 267 | 11.13 | 6.90 | 1.19 |
| | | | 3.0 | Normal | 2593 | 1694 | 215 | 11.52 | 7.53 | 0.96 |
| | | | 3.0 | Light | 2411 | 1461 | 267 | 10.72 | 6.49 | 1.19 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2724 | 1947 | 95 | 12.11 | 8.65 | 0.43 |
| | | | 2.28 | Light | 2597 | 1799 | 115 | 11.54 | 8.00 | 0.51 |
| | | | 2.5 | Normal | 2568 | 1791 | 95 | 11.41 | 7.96 | 0.43 |
| | | | 2.5 | Light | 2453 | 1655 | 115 | 10.91 | 7.36 | 0.51 |
| | | | 2.8 | Normal | 2394 | 1617 | 95 | 10.64 | 7.19 | 0.43 |
| | | | 2.8 | Light | 2294 | 1496 | 115 | 10.20 | 6.65 | 0.51 |
| | | | 3.0 | Normal | 2298 | 1520 | 95 | 10.22 | 6.76 | 0.43 |
| | | | 3.0 | Light | 2206 | 1408 | 115 | 9.80 | 6.26 | 0.51 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2826 | 2002 | 141 | 12.56 | 8.90 | 0.63 |
| | | | 2.28 | Light | 2706 | 1859 | 164 | 12.02 | 8.26 | 0.73 |
| | | | 2.5 | Normal | 2665 | 1841 | 141 | 11.85 | 8.18 | 0.63 |
| | | | 2.5 | Light | 2557 | 1711 | 164 | 11.36 | 7.61 | 0.73 |
| | | | 2.8 | Normal | 2486 | 1661 | 141 | 11.05 | 7.39 | 0.63 |
| | | | 2.8 | Light | 2392 | 1545 | 164 | 10.64 | 6.87 | 0.73 |
| | | | 3.0 | Normal | 2387 | 1563 | 141 | 10.61 | 6.94 | 0.63 |
| | | | 3.0 | Light | 2300 | 1454 | 164 | 10.23 | 6.46 | 0.73 |
| Best | Case* | | | | 2040 | 1207 | 150 | 9.07 | 5.37 | 0.67 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8d(i). Summary of Combined Parametric Simulations for Prototypical Office in Multan on Top Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 3703 | 2813 | 207 | 16.46 | 12.50 | 0.92 |
| | | | 2.28 | Light | 3395 | 2448 | 263 | 15.09 | 10.88 | 1.17 |
| | | | 2.5 | Normal | 3472 | 2581 | 207 | 15.43 | 11.48 | 0.92 |
| | | | 2.5 | Light | 3195 | 2249 | 263 | 14.20 | 9.99 | 1.17 |
| | | | 2.8 | Normal | 3214 | 2324 | 207 | 14.29 | 10.33 | 0.92 |
| | | | 2.8 | Light | 2973 | 2026 | 263 | 13.21 | 9.01 | 1.17 |
| | | | 3.0 | Normal | 3072 | 2181 | 207 | 13.65 | 9.69 | 0.92 |
| | | | 3.0 | Light | 2850 | 1903 | 263 | 12.66 | 8.46 | 1.17 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3843 | 2897 | 263 | 17.08 | 12.88 | 1.17 |
| | | | 2.28 | Light | 3548 | 2544 | 321 | 15.77 | 11.31 | 1.43 |
| | | | 2.5 | Normal | 3605 | 2659 | 263 | 16.02 | 11.82 | 1.17 |
| | | | 2.5 | Light | 3340 | 2336 | 321 | 14.85 | 10.38 | 1.43 |
| | | | 2.8 | Normal | 3340 | 2394 | 263 | 14.84 | 10.64 | 1.17 |
| | | | 2.8 | Light | 3109 | 2105 | 321 | 13.82 | 9.35 | 1.43 |
| | | | 3.0 | Normal | 3193 | 2247 | 263 | 14.19 | 9.98 | 1.17 |
| | | | 3.0 | Light | 2981 | 1976 | 321 | 13.25 | 8.79 | 1.43 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 3425 | 2622 | 119 | 15.22 | 11.65 | 0.53 |
| | | | 2.28 | Light | 3264 | 2438 | 142 | 14.51 | 10.84 | 0.63 |
| | | | 2.5 | Normal | 3210 | 2407 | 119 | 14.27 | 10.70 | 0.53 |
| | | | 2.5 | Light | 3064 | 2239 | 142 | 13.62 | 9.95 | 0.63 |
| | | | 2.8 | Normal | 2971 | 2168 | 119 | 13.20 | 9.64 | 0.53 |
| | | | 2.8 | Light | 2843 | 2018 | 142 | 12.64 | 8.97 | 0.63 |
| | | | 3.0 | Normal | 2838 | 2035 | 119 | 12.61 | 9.05 | 0.53 |
| | | | 3.0 | Light | 2720 | 1895 | 142 | 12.09 | 8.43 | 0.63 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 3552 | 2695 | 173 | 15.79 | 11.98 | 0.77 |
| | | | 2.28 | Light | 3400 | 2519 | 198 | 15.11 | 11.19 | 0.88 |
| | | | 2.5 | Normal | 3330 | 2474 | 173 | 14.81 | 11.00 | 0.77 |
| | | | 2.5 | Light | 3194 | 2313 | 198 | 14.20 | 10.28 | 0.88 |
| | | | 2.8 | Normal | 3085 | 2228 | 173 | 13.71 | 9.90 | 0.77 |
| | | | 2.8 | Light | 2965 | 2084 | 198 | 13.18 | 9.27 | 0.88 |
| | | | 3.0 | Normal | 2948 | 2092 | 173 | 13.10 | 9.30 | 0.77 |
| | | | 3.0 | Light | 2838 | 1957 | 198 | 12.61 | 8.70 | 0.88 |
| Best | Case* | | | | 2496 | 1629 | 184 | 11.10 | 7.24 | 0.82 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8d(ii). Summary of Combined Parametric Simulations for Prototypical Office in Multan on Middle Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 3317 | 2511 | 123 | 14.74 | 11.16 | 0.55 |
| | | | 2.28 | Light | 3317 | 2511 | 123 | 14.74 | 11.16 | 0.55 |
| | | | 2.5 | Normal | 3111 | 2305 | 123 | 13.83 | 10.25 | 0.55 |
| | | | 2.5 | Light | 3111 | 2305 | 123 | 13.83 | 10.25 | 0.55 |
| | | | 2.8 | Normal | 2883 | 2077 | 123 | 12.82 | 9.24 | 0.55 |
| | | | 2.8 | Light | 2883 | 2077 | 123 | 12.82 | 9.24 | 0.55 |
| | | | 3.0 | Normal | 2756 | 1951 | 123 | 12.25 | 8.67 | 0.55 |
| | | | 3.0 | Light | 2756 | 1951 | 123 | 12.25 | 8.67 | 0.55 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3439 | 2580 | 177 | 15.28 | 11.47 | 0.79 |
| | | | 2.28 | Light | 3439 | 2580 | 177 | 15.28 | 11.47 | 0.79 |
| | | | 2.5 | Normal | 3228 | 2368 | 177 | 14.35 | 10.53 | 0.79 |
| | | | 2.5 | Light | 3228 | 2368 | 177 | 14.35 | 10.53 | 0.79 |
| | | | 2.8 | Normal | 2993 | 2134 | 177 | 13.31 | 9.48 | 0.79 |
| | | | 2.8 | Light | 2993 | 2134 | 177 | 13.31 | 9.48 | 0.79 |
| | | | 3.0 | Normal | 2863 | 2003 | 177 | 12.73 | 8.91 | 0.79 |
| | | | 3.0 | Light | 2863 | 2003 | 177 | 12.73 | 8.91 | 0.79 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 3261 | 2493 | 84 | 14.50 | 11.08 | 0.38 |
| | | | 2.28 | Light | 3261 | 2493 | 84 | 14.50 | 11.08 | 0.38 |
| | | | 2.5 | Normal | 3057 | 2290 | 84 | 13.59 | 10.18 | 0.38 |
| | | | 2.5 | Light | 3057 | 2290 | 84 | 13.59 | 10.18 | 0.38 |
| | | | 2.8 | Normal | 2830 | 2063 | 84 | 12.58 | 9.17 | 0.38 |
| | | | 2.8 | Light | 2830 | 2063 | 84 | 12.58 | 9.17 | 0.38 |
| | | | 3.0 | Normal | 2704 | 1937 | 84 | 12.02 | 8.61 | 0.38 |
| | | | 3.0 | Light | 2704 | 1937 | 84 | 12.02 | 8.61 | 0.38 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 3365 | 2548 | 134 | 14.96 | 11.32 | 0.59 |
| | | | 2.28 | Light | 3365 | 2548 | 134 | 14.96 | 11.32 | 0.59 |
| | | | 2.5 | Normal | 3156 | 2340 | 134 | 14.03 | 10.40 | 0.59 |
| | | | 2.5 | Light | 3156 | 2340 | 134 | 14.03 | 10.40 | 0.59 |
| | | | 2.8 | Normal | 2925 | 2108 | 134 | 13.00 | 9.37 | 0.59 |
| | | | 2.8 | Light | 2925 | 2108 | 134 | 13.00 | 9.37 | 0.59 |
| | | | 3.0 | Normal | 2796 | 1979 | 134 | 12.43 | 8.80 | 0.59 |
| | | | 3.0 | Light | 2796 | 1979 | 134 | 12.43 | 8.80 | 0.59 |
| Best | Case* | | | | 2444 | 1648 | 112 | 10.86 | 7.33 | 0.50 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8d(iii). Summary of Combined Parametric Simulations for Prototypical Office in Multan in a Single-Story Building (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 3265 | 2392 | 190 | 14.51 | 10.63 | 0.85 |
| | | | 2.28 | Light | 3002 | 2081 | 238 | 13.34 | 9.25 | 1.06 |
| | | | 2.5 | Normal | 3070 | 2197 | 190 | 13.64 | 9.77 | 0.85 |
| | | | 2.5 | Light | 2834 | 1913 | 238 | 12.60 | 8.51 | 1.06 |
| | | | 2.8 | Normal | 2853 | 1980 | 190 | 12.68 | 8.80 | 0.85 |
| | | | 2.8 | Light | 2647 | 1727 | 238 | 11.77 | 7.68 | 1.06 |
| | | | 3.0 | Normal | 2733 | 1860 | 190 | 12.15 | 8.27 | 0.85 |
| | | | 3.0 | Light | 2544 | 1623 | 238 | 11.31 | 7.21 | 1.06 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3420 | 2493 | 244 | 15.20 | 11.08 | 1.09 |
| | | | 2.28 | Light | 3169 | 2191 | 295 | 14.08 | 9.74 | 1.31 |
| | | | 2.5 | Normal | 3217 | 2289 | 244 | 14.30 | 10.18 | 1.09 |
| | | | 2.5 | Light | 2991 | 2014 | 295 | 13.30 | 8.95 | 1.31 |
| | | | 2.8 | Normal | 2990 | 2063 | 244 | 13.29 | 9.17 | 1.09 |
| | | | 2.8 | Light | 2794 | 1817 | 295 | 12.42 | 8.07 | 1.31 |
| | | | 3.0 | Normal | 2865 | 1937 | 244 | 12.74 | 8.61 | 1.09 |
| | | | 3.0 | Light | 2685 | 1707 | 295 | 11.94 | 7.59 | 1.31 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2985 | 2194 | 108 | 13.27 | 9.75 | 0.48 |
| | | | 2.28 | Light | 2859 | 2048 | 128 | 12.71 | 9.10 | 0.57 |
| | | | 2.5 | Normal | 2807 | 2016 | 108 | 12.48 | 8.96 | 0.48 |
| | | | 2.5 | Light | 2694 | 1882 | 128 | 11.98 | 8.36 | 0.57 |
| | | | 2.8 | Normal | 2609 | 1818 | 108 | 11.60 | 8.08 | 0.48 |
| | | | 2.8 | Light | 2510 | 1699 | 128 | 11.15 | 7.55 | 0.57 |
| | | | 3.0 | Normal | 2499 | 1708 | 108 | 11.11 | 7.60 | 0.48 |
| | | | 3.0 | Light | 2408 | 1597 | 128 | 10.70 | 7.10 | 0.57 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 3130 | 2286 | 161 | 13.91 | 10.16 | 0.72 |
| | | | 2.28 | Light | 3006 | 2140 | 183 | 13.36 | 9.51 | 0.81 |
| | | | 2.5 | Normal | 2944 | 2100 | 161 | 13.09 | 9.34 | 0.72 |
| | | | 2.5 | Light | 2833 | 1967 | 183 | 12.59 | 8.74 | 0.81 |
| | | | 2.8 | Normal | 2738 | 1894 | 161 | 12.17 | 8.42 | 0.72 |
| | | | 2.8 | Light | 2640 | 1774 | 183 | 11.74 | 7.89 | 0.81 |
| | | | 3.0 | Normal | 2623 | 1779 | 161 | 11.66 | 7.91 | 0.72 |
| | | | 3.0 | Light | 2533 | 1668 | 183 | 11.26 | 7.41 | 0.81 |
| Best | Case* | | | | 2219 | 1371 | 165 | 9.86 | 6.09 | 0.73 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8e(i). Summary of Combined Parametric Simulations for Prototypical Office in Peshawar on Top Floor (a=225 ft²)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft² | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 3278 | 2242 | 353 | 14.57 | 9.97 | 1.57 |
| | | | 2.28 | Light | 3046 | 1928 | 435 | 13.54 | 8.57 | 1.93 |
| | | | 2.5 | Normal | 3100 | 2064 | 353 | 13.78 | 9.18 | 1.57 |
| | | | 2.5 | Light | 2896 | 1778 | 435 | 12.87 | 7.90 | 1.93 |
| | | | 2.8 | Normal | 2903 | 1867 | 353 | 12.90 | 8.30 | 1.57 |
| | | | 2.8 | Light | 2729 | 1611 | 435 | 12.13 | 7.16 | 1.93 |
| | | | 3.0 | Normal | 2793 | 1757 | 353 | 12.42 | 7.81 | 1.57 |
| | | | 3.0 | Light | 2636 | 1518 | 435 | 11.72 | 6.74 | 1.93 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3406 | 2281 | 441 | 15.14 | 10.14 | 1.96 |
| | | | 2.28 | Light | 3195 | 1984 | 528 | 14.20 | 8.81 | 2.35 |
| | | | 2.5 | Normal | 3225 | 2100 | 441 | 14.34 | 9.34 | 1.96 |
| | | | 2.5 | Light | 3040 | 1829 | 528 | 13.51 | 8.13 | 2.35 |
| | | | 2.8 | Normal | 3024 | 1900 | 441 | 13.44 | 8.44 | 1.96 |
| | | | 2.8 | Light | 2868 | 1656 | 528 | 12.75 | 7.37 | 2.35 |
| | | | 3.0 | Normal | 2912 | 1788 | 441 | 12.95 | 7.95 | 1.96 |
| | | | 3.0 | Light | 2772 | 1561 | 528 | 12.32 | 6.94 | 2.35 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 3034 | 2134 | 217 | 13.48 | 9.48 | 0.97 |
| | | | 2.28 | Light | 2911 | 1976 | 252 | 12.94 | 8.78 | 1.12 |
| | | | 2.5 | Normal | 2865 | 1965 | 217 | 12.73 | 8.73 | 0.97 |
| | | | 2.5 | Light | 2756 | 1821 | 252 | 12.25 | 8.10 | 1.12 |
| | | | 2.8 | Normal | 2678 | 1777 | 217 | 11.90 | 7.90 | 0.97 |
| | | | 2.8 | Light | 2584 | 1649 | 252 | 11.48 | 7.33 | 1.12 |
| | | | 3.0 | Normal | 2574 | 1673 | 217 | 11.44 | 7.44 | 0.97 |
| | | | 3.0 | Light | 2488 | 1553 | 252 | 11.06 | 6.90 | 1.12 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 3135 | 2149 | 302 | 13.93 | 9.55 | 1.34 |
| | | | 2.28 | Light | 3021 | 1999 | 339 | 13.43 | 8.88 | 1.51 |
| | | | 2.5 | Normal | 2965 | 1980 | 302 | 13.18 | 8.80 | 1.34 |
| | | | 2.5 | Light | 2864 | 1842 | 339 | 12.73 | 8.19 | 1.51 |
| | | | 2.8 | Normal | 2776 | 1791 | 302 | 12.34 | 7.96 | 1.34 |
| | | | 2.8 | Light | 2690 | 1668 | 339 | 11.96 | 7.41 | 1.51 |
| | | | 3.0 | Normal | 2671 | 1686 | 302 | 11.88 | 7.49 | 1.34 |
| | | | 3.0 | Light | 2593 | 1571 | 339 | 11.53 | 6.98 | 1.51 |
| Best | Case* | | | | 2313 | 1317 | 313 | 10.28 | 5.86 | 1.39 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8e(ii). Summary of Combined Parametric Simulations for Prototypical Office in Peshawar on Middle Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2956 | 2050 | 223 | 13.14 | 9.11 | 0.99 |
| | | | 2.28 | Light | 2956 | 2050 | 223 | 13.14 | 9.11 | 0.99 |
| | | | 2.5 | Normal | 2794 | 1888 | 223 | 12.42 | 8.40 | 0.99 |
| | | | 2.5 | Light | 2794 | 1888 | 223 | 12.42 | 8.40 | 0.99 |
| | | | 2.8 | Normal | 2615 | 1709 | 223 | 11.62 | 7.60 | 0.99 |
| | | | 2.8 | Light | 2615 | 1709 | 223 | 11.62 | 7.60 | 0.99 |
| | | | 3.0 | Normal | 2515 | 1609 | 223 | 11.18 | 7.15 | 0.99 |
| | | | 3.0 | Light | 2515 | 1609 | 223 | 11.18 | 7.15 | 0.99 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3053 | 2062 | 308 | 13.57 | 9.16 | 1.37 |
| | | | 2.28 | Light | 3053 | 2062 | 308 | 13.57 | 9.16 | 1.37 |
| | | | 2.5 | Normal | 2891 | 1899 | 308 | 12.85 | 8.44 | 1.37 |
| | | | 2.5 | Light | 2891 | 1899 | 308 | 12.85 | 8.44 | 1.37 |
| | | | 2.8 | Normal | 2711 | 1719 | 308 | 12.05 | 7.64 | 1.37 |
| | | | 2.8 | Light | 2711 | 1719 | 308 | 12.05 | 7.64 | 1.37 |
| | | | 3.0 | Normal | 2610 | 1619 | 308 | 11.60 | 7.20 | 1.37 |
| | | | 3.0 | Light | 2610 | 1619 | 308 | 11.60 | 7.20 | 1.37 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2898 | 2060 | 155 | 12.88 | 9.16 | 0.69 |
| | | | 2.28 | Light | 2898 | 2060 | 155 | 12.88 | 9.16 | 0.69 |
| | | | 2.5 | Normal | 2735 | 1898 | 155 | 12.16 | 8.44 | 0.69 |
| | | | 2.5 | Light | 2735 | 1898 | 155 | 12.16 | 8.44 | 0.69 |
| | | | 2.8 | Normal | 2555 | 1717 | 155 | 11.35 | 7.63 | 0.69 |
| | | | 2.8 | Light | 2555 | 1717 | 155 | 11.35 | 7.63 | 0.69 |
| | | | 3.0 | Normal | 2455 | 1617 | 155 | 10.91 | 7.19 | 0.69 |
| | | | 3.0 | Light | 2455 | 1617 | 155 | 10.91 | 7.19 | 0.69 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2987 | 2065 | 239 | 13.27 | 9.18 | 1.07 |
| | | | 2.28 | Light | 2987 | 2065 | 239 | 13.27 | 9.18 | 1.07 |
| | | | 2.5 | Normal | 2824 | 1902 | 239 | 12.55 | 8.45 | 1.07 |
| | | | 2.5 | Light | 2824 | 1902 | 239 | 12.55 | 8.45 | 1.07 |
| | | | 2.8 | Normal | 2643 | 1721 | 239 | 11.75 | 7.65 | 1.07 |
| | | | 2.8 | Light | 2643 | 1721 | 239 | 11.75 | 7.65 | 1.07 |
| | | | 3.0 | Normal | 2543 | 1621 | 239 | 11.30 | 7.20 | 1.07 |
| | | | 3.0 | Light | 2543 | 1621 | 239 | 11.30 | 7.20 | 1.07 |
| Best | Case* | | | | 2258 | 1371 | 204 | 10.04 | 6.10 | 0.90 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8e(iii). Summary of Combined Parametric Simulations for Prototypical Office in Peshawar in a Single-Story Building (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2856 | 1798 | 375 | 12.69 | 7.99 | 1.67 |
| | | | 2.28 | Light | 2696 | 1562 | 452 | 11.99 | 6.94 | 2.01 |
| | | | 2.5 | Normal | 2717 | 1658 | 375 | 12.07 | 7.37 | 1.67 |
| | | | 2.5 | Light | 2578 | 1443 | 452 | 11.46 | 6.41 | 2.01 |
| | | | 2.8 | Normal | 2562 | 1504 | 375 | 11.39 | 6.68 | 1.67 |
| | | | 2.8 | Light | 2446 | 1311 | 452 | 10.87 | 5.83 | 2.01 |
| | | | 3.0 | Normal | 2476 | 1418 | 375 | 11.01 | 6.30 | 1.67 |
| | | | 3.0 | Light | 2373 | 1238 | 452 | 10.55 | 5.50 | 2.01 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3010 | 1862 | 464 | 13.38 | 8.28 | 2.07 |
| | | | 2.28 | Light | 2861 | 1632 | 545 | 12.72 | 7.26 | 2.43 |
| | | | 2.5 | Normal | 2865 | 1718 | 464 | 12.73 | 7.63 | 2.07 |
| | | | 2.5 | Light | 2736 | 1508 | 545 | 12.16 | 6.70 | 2.43 |
| | | | 2.8 | Normal | 2704 | 1557 | 464 | 12.02 | 6.92 | 2.07 |
| | | | 2.8 | Light | 2597 | 1369 | 545 | 11.55 | 6.09 | 2.43 |
| | | | 3.0 | Normal | 2615 | 1468 | 464 | 11.62 | 6.53 | 2.07 |
| | | | 3.0 | Light | 2521 | 1292 | 545 | 11.20 | 5.75 | 2.43 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2611 | 1682 | 246 | 11.60 | 7.48 | 1.10 |
| | | | 2.28 | Light | 2527 | 1565 | 279 | 11.24 | 6.95 | 1.24 |
| | | | 2.5 | Normal | 2482 | 1552 | 246 | 11.03 | 6.90 | 1.10 |
| | | | 2.5 | Light | 2408 | 1445 | 279 | 10.70 | 6.43 | 1.24 |
| | | | 2.8 | Normal | 2337 | 1408 | 246 | 10.39 | 6.26 | 1.10 |
| | | | 2.8 | Light | 2275 | 1313 | 279 | 10.11 | 5.84 | 1.24 |
| | | | 3.0 | Normal | 2258 | 1328 | 246 | 10.03 | 5.90 | 1.10 |
| | | | 3.0 | Light | 2201 | 1239 | 279 | 9.78 | 5.51 | 1.24 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2745 | 1728 | 333 | 12.20 | 7.68 | 1.48 |
| | | | 2.28 | Light | 2670 | 1618 | 369 | 11.87 | 7.20 | 1.64 |
| | | | 2.5 | Normal | 2611 | 1595 | 333 | 11.61 | 7.09 | 1.48 |
| | | | 2.5 | Light | 2547 | 1494 | 369 | 11.32 | 6.64 | 1.64 |
| | | | 2.8 | Normal | 2463 | 1446 | 333 | 10.95 | 6.43 | 1.48 |
| | | | 2.8 | Light | 2409 | 1357 | 369 | 10.71 | 6.03 | 1.64 |
| | | | 3.0 | Normal | 2381 | 1364 | 333 | 10.58 | 6.07 | 1.48 |
| | | | 3.0 | Light | 2333 | 1280 | 369 | 10.37 | 5.69 | 1.64 |
| Best | Case* | | | | 2094 | 1069 | 342 | 9.31 | 4.75 | 1.52 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8f(i). Summary of Combined Parametric Simulations for Prototypical Office in Quetta on Top Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2913 | 1183 | 1046 | 12.95 | 5.26 | 4.65 |
| | | | 2.28 | Light | 2918 | 1061 | 1175 | 12.97 | 4.72 | 5.22 |
| | | | 2.5 | Normal | 2835 | 1105 | 1046 | 12.60 | 4.91 | 4.65 |
| | | | 2.5 | Light | 2851 | 994 | 1175 | 12.67 | 4.42 | 5.22 |
| | | | 2.8 | Normal | 2748 | 1019 | 1046 | 12.22 | 4.53 | 4.65 |
| | | | 2.8 | Light | 2777 | 920 | 1175 | 12.34 | 4.09 | 5.22 |
| | | | 3.0 | Normal | 2700 | 971 | 1046 | 12.00 | 4.32 | 4.65 |
| | | | 3.0 | Light | 2736 | 878 | 1175 | 12.16 | 3.91 | 5.22 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3088 | 1135 | 1269 | 13.72 | 5.05 | 5.64 |
| | | | 2.28 | Light | 3114 | 1025 | 1405 | 13.84 | 4.56 | 6.25 |
| | | | 2.5 | Normal | 3015 | 1062 | 1269 | 13.40 | 4.72 | 5.64 |
| | | | 2.5 | Light | 3050 | 962 | 1405 | 13.56 | 4.28 | 6.25 |
| | | | 2.8 | Normal | 2934 | 981 | 1269 | 13.04 | 4.36 | 5.64 |
| | | | 2.8 | Light | 2980 | 892 | 1405 | 13.25 | 3.97 | 6.25 |
| | | | 3.0 | Normal | 2888 | 936 | 1269 | 12.84 | 4.16 | 5.64 |
| | | | 3.0 | Light | 2942 | 853 | 1405 | 13.07 | 3.79 | 6.25 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2619 | 1279 | 658 | 11.65 | 5.68 | 2.93 |
| | | | 2.28 | Light | 2602 | 1209 | 710 | 11.56 | 5.38 | 3.16 |
| | | | 2.5 | Normal | 2532 | 1192 | 658 | 11.26 | 5.30 | 2.93 |
| | | | 2.5 | Light | 2521 | 1128 | 710 | 11.21 | 5.01 | 3.16 |
| | | | 2.8 | Normal | 2436 | 1095 | 658 | 10.83 | 4.87 | 2.93 |
| | | | 2.8 | Light | 2431 | 1038 | 710 | 10.81 | 4.61 | 3.16 |
| | | | 3.0 | Normal | 2382 | 1042 | 658 | 10.59 | 4.63 | 2.93 |
| | | | 3.0 | Light | 2382 | 988 | 710 | 10.59 | 4.39 | 3.16 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2756 | 1204 | 868 | 12.25 | 5.35 | 3.86 |
| | | | 2.28 | Light | 2750 | 1140 | 926 | 12.22 | 5.07 | 4.12 |
| | | | 2.5 | Normal | 2676 | 1124 | 868 | 11.90 | 5.00 | 3.86 |
| | | | 2.5 | Light | 2676 | 1066 | 926 | 11.89 | 4.74 | 4.12 |
| | | | 2.8 | Normal | 2587 | 1035 | 868 | 11.50 | 4.61 | 3.86 |
| | | | 2.8 | Light | 2593 | 983 | 926 | 11.52 | 4.37 | 4.12 |
| | | | 3.0 | Normal | 2538 | 986 | 868 | 11.28 | 4.39 | 3.86 |
| | | | 3.0 | Light | 2547 | 938 | 926 | 11.32 | 4.17 | 4.12 |
| Best | Case* | | | | 2380 | 837 | 860 | 10.58 | 3.72 | 3.82 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8f(ii). Summary of Combined Parametric Simulations for Prototypical Office in Quetta on Middle Floor (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2620 | 1266 | 670 | 11.65 | 5.63 | 2.98 |
| | | | 2.28 | Light | 2620 | 1266 | 670 | 11.65 | 5.63 | 2.98 |
| | | | 2.5 | Normal | 2534 | 1180 | 670 | 11.26 | 5.24 | 2.98 |
| | | | 2.5 | Light | 2534 | 1180 | 670 | 11.26 | 5.24 | 2.98 |
| | | | 2.8 | Normal | 2438 | 1085 | 670 | 10.84 | 4.82 | 2.98 |
| | | | 2.8 | Light | 2438 | 1085 | 670 | 10.84 | 4.82 | 2.98 |
| | | | 3.0 | Normal | 2385 | 1032 | 670 | 10.60 | 4.59 | 2.98 |
| | | | 3.0 | Light | 2385 | 1032 | 670 | 10.60 | 4.59 | 2.98 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 2753 | 1188 | 882 | 12.24 | 5.28 | 3.92 |
| | | | 2.28 | Light | 2753 | 1188 | 882 | 12.24 | 5.28 | 3.92 |
| | | | 2.5 | Normal | 2675 | 1109 | 882 | 11.89 | 4.93 | 3.92 |
| | | | 2.5 | Light | 2675 | 1109 | 882 | 11.89 | 4.93 | 3.92 |
| | | | 2.8 | Normal | 2588 | 1022 | 882 | 11.50 | 4.55 | 3.92 |
| | | | 2.8 | Light | 2588 | 1022 | 882 | 11.50 | 4.55 | 3.92 |
| | | | 3.0 | Normal | 2539 | 974 | 882 | 11.28 | 4.33 | 3.92 |
| | | | 3.0 | Light | 2539 | 974 | 882 | 11.28 | 4.33 | 3.92 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2537 | 1361 | 492 | 11.27 | 6.05 | 2.19 |
| | | | 2.28 | Light | 2537 | 1361 | 492 | 11.27 | 6.05 | 2.19 |
| | | | 2.5 | Normal | 2442 | 1267 | 492 | 10.85 | 5.63 | 2.19 |
| | | | 2.5 | Light | 2442 | 1267 | 492 | 10.85 | 5.63 | 2.19 |
| | | | 2.8 | Normal | 2337 | 1162 | 492 | 10.39 | 5.16 | 2.19 |
| | | | 2.8 | Light | 2337 | 1162 | 492 | 10.39 | 5.16 | 2.19 |
| | | | 3.0 | Normal | 2279 | 1103 | 492 | 10.13 | 4.91 | 2.19 |
| | | | 3.0 | Light | 2279 | 1103 | 492 | 10.13 | 4.91 | 2.19 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2633 | 1256 | 693 | 11.70 | 5.58 | 3.08 |
| | | | 2.28 | Light | 2633 | 1256 | 693 | 11.70 | 5.58 | 3.08 |
| | | | 2.5 | Normal | 2548 | 1171 | 693 | 11.33 | 5.21 | 3.08 |
| | | | 2.5 | Light | 2548 | 1171 | 693 | 11.33 | 5.21 | 3.08 |
| | | | 2.8 | Normal | 2454 | 1077 | 693 | 10.91 | 4.79 | 3.08 |
| | | | 2.8 | Light | 2454 | 1077 | 693 | 10.91 | 4.79 | 3.08 |
| | | | 3.0 | Normal | 2402 | 1025 | 693 | 10.68 | 4.56 | 3.08 |
| | | | 3.0 | Light | 2402 | 1025 | 693 | 10.68 | 4.56 | 3.08 |
| Best | Case* | | | | 2206 | 912 | 611 | 9.80 | 4.06 | 2.72 |

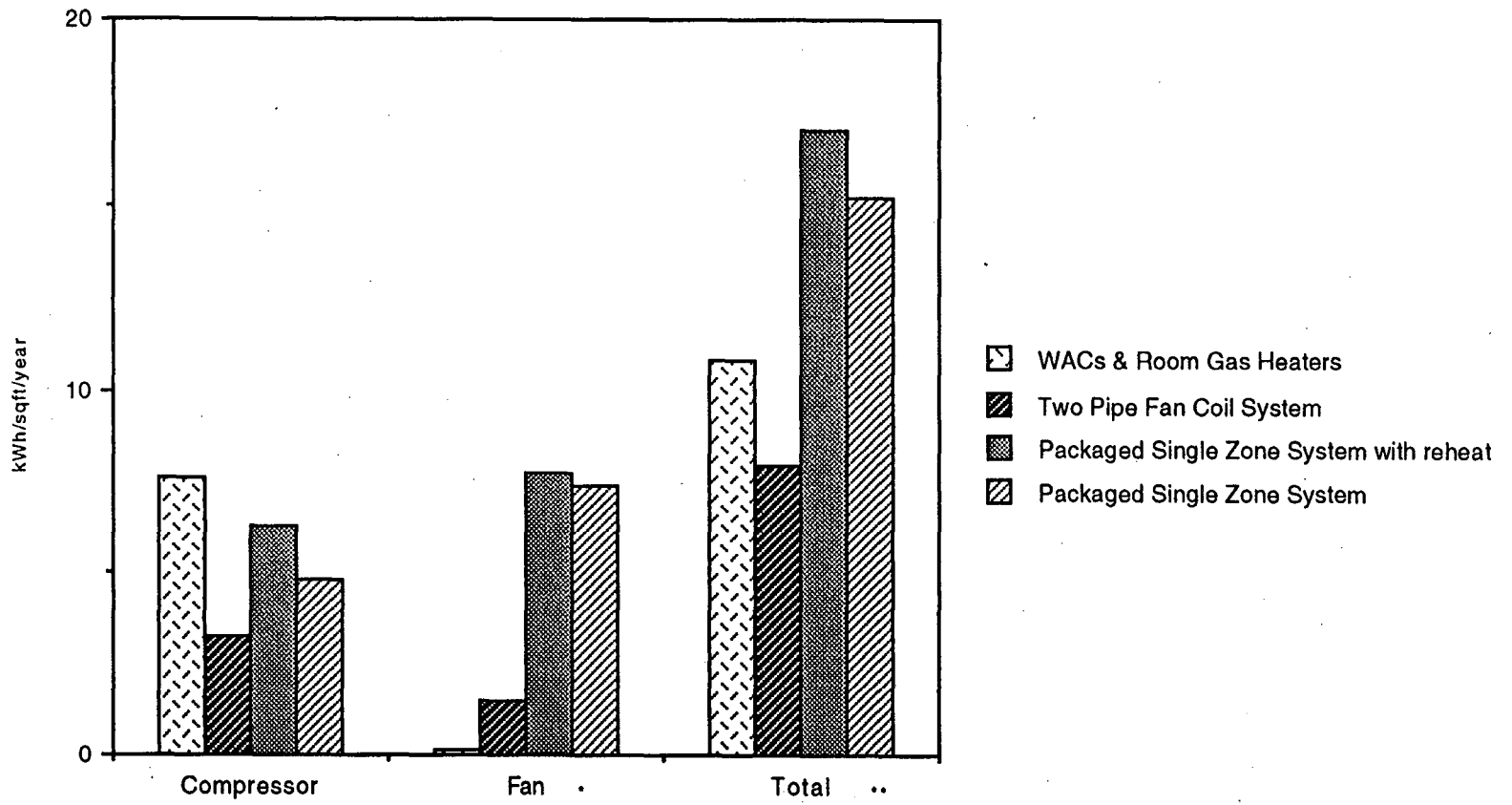
* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

**Table 6.8f(iii). Summary of Combined Parametric Simulations for Prototypical Office in Quetta in a Single-Story Building (a=225 ft$^2$)**

| Insulation | | | | | Energy (kWh) | | | KWh/ft$^2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Roofs | Infilt | AC COP | Roof Color | Total | Cool | Heat | Total | Cool | Heat |
| R0 | R4 | 0.5 ach | 2.28 | Normal | 2826 | 885 | 1258 | 12.56 | 3.94 | 5.60 |
| | | | 2.28 | Light | 2877 | 803 | 1391 | 12.79 | 3.57 | 6.18 |
| | | | 2.5 | Normal | 2775 | 833 | 1258 | 12.33 | 3.71 | 5.60 |
| | | | 2.5 | Light | 2833 | 759 | 1391 | 12.59 | 3.37 | 6.18 |
| | | | 2.8 | Normal | 2718 | 776 | 1258 | 12.08 | 3.45 | 5.60 |
| | | | 2.8 | Light | 2784 | 710 | 1391 | 12.37 | 3.16 | 6.18 |
| | | | 3.0 | Normal | 2686 | 744 | 1258 | 11.94 | 3.31 | 5.60 |
| | | | 3.0 | Light | 2757 | 683 | 1391 | 12.25 | 3.03 | 6.18 |
| R0 | R4 | 1.0 ach | 2.28 | Normal | 3030 | 867 | 1479 | 13.47 | 3.86 | 6.57 |
| | | | 2.28 | Light | 3089 | 790 | 1616 | 13.73 | 3.51 | 7.18 |
| | | | 2.5 | Normal | 2980 | 818 | 1479 | 13.25 | 3.64 | 6.57 |
| | | | 2.5 | Light | 3047 | 747 | 1616 | 13.54 | 3.32 | 7.18 |
| | | | 2.8 | Normal | 2925 | 763 | 1479 | 13.00 | 3.39 | 6.57 |
| | | | 2.8 | Light | 3000 | 700 | 1616 | 13.34 | 3.11 | 7.18 |
| | | | 3.0 | Normal | 2895 | 732 | 1479 | 12.87 | 3.26 | 6.57 |
| | | | 3.0 | Light | 2974 | 674 | 1616 | 13.22 | 3.00 | 7.18 |
| R5 | R11 | 0.5 ach | 2.28 | Normal | 2480 | 906 | 890 | 11.02 | 4.03 | 3.96 |
| | | | 2.28 | Light | 2492 | 861 | 948 | 11.08 | 3.83 | 4.22 |
| | | | 2.5 | Normal | 2426 | 852 | 890 | 10.78 | 3.79 | 3.96 |
| | | | 2.5 | Light | 2442 | 811 | 948 | 10.86 | 3.61 | 4.22 |
| | | | 2.8 | Normal | 2365 | 792 | 890 | 10.51 | 3.52 | 3.96 |
| | | | 2.8 | Light | 2386 | 755 | 948 | 10.61 | 3.36 | 4.22 |
| | | | 3.0 | Normal | 2332 | 758 | 890 | 10.36 | 3.37 | 3.96 |
| | | | 3.0 | Light | 2355 | 724 | 948 | 10.47 | 3.22 | 4.22 |
| R5 | R11 | 1.0 ach | 2.28 | Normal | 2671 | 880 | 1108 | 11.87 | 3.91 | 4.93 |
| | | | 2.28 | Light | 2691 | 839 | 1168 | 11.96 | 3.73 | 5.20 |
| | | | 2.5 | Normal | 2620 | 828 | 1108 | 11.64 | 3.68 | 4.93 |
| | | | 2.5 | Light | 2643 | 792 | 1168 | 11.75 | 3.52 | 5.20 |
| | | | 2.8 | Normal | 2563 | 771 | 1108 | 11.39 | 3.43 | 4.93 |
| | | | 2.8 | Light | 2590 | 738 | 1168 | 11.51 | 3.28 | 5.20 |
| | | | 3.0 | Normal | 2531 | 740 | 1108 | 11.25 | 3.29 | 4.93 |
| | | | 3.0 | Light | 2560 | 709 | 1168 | 11.38 | 3.15 | 5.20 |
| Best | Case* | | | | 2436 | 635 | 1117 | 10.83 | 2.83 | 4.97 |

* Best Case is for the prototype model with the following properties: AC setting: 79, AC COP: 3.0, Adj. Shade: none, Overhang: 3ft, Infilt: 0.5 ach, Insul: R5W and R11C, Wall Color: normal(0.7 absorbtance), Roof Color: light(0.3 absorbtance), Film Shading Coef.: 0.8 Day Lighting: none, Efficient Lighting: none.

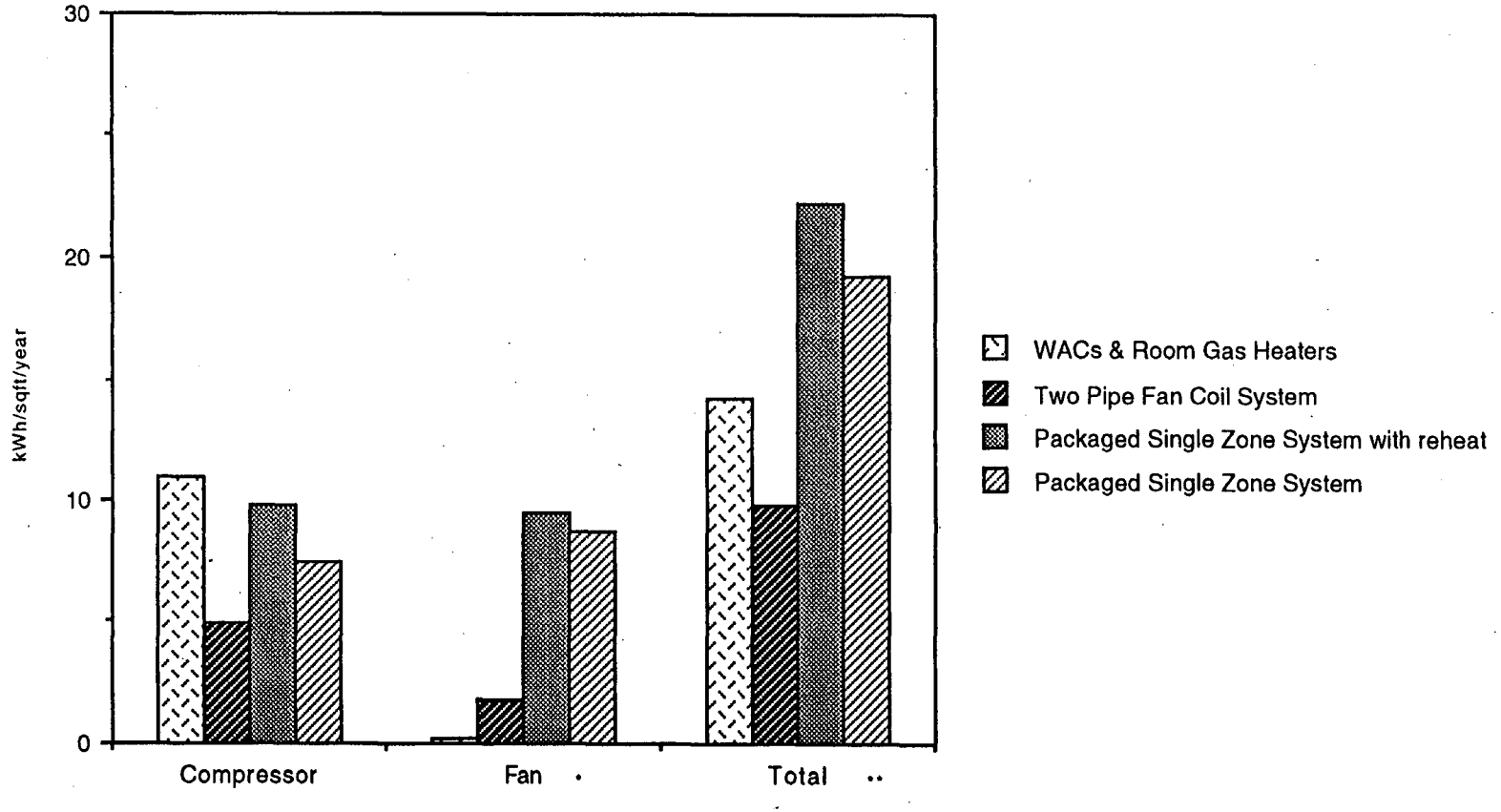
Figure 6.5a
THE IMPACT OF HVAC SYSTEM TYPES ON ELECTRICITY CONSUMPTION IN ISLAMABAD




* Fan energy use covers both cooling and heating,whenever applicable

** Total includes 3.04kWh/sqft for lighting and equipment

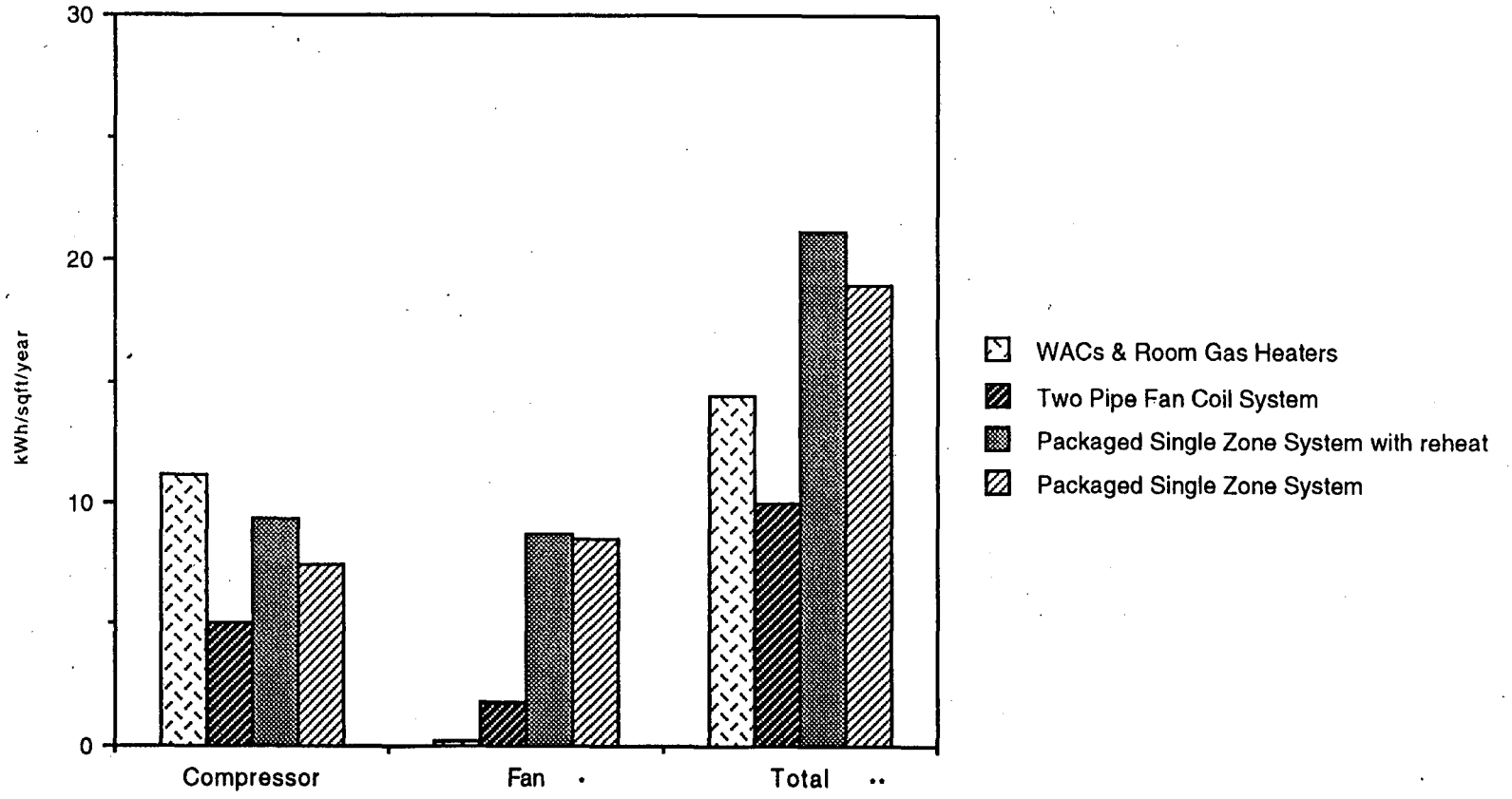
Figure 6.5b
THE IMPACT OF HVAC SYSTEM TYPES ON ELECTRICITY CONSUMPTION IN KARACHI




* Fan energy use covers both cooling and heating,whenever applicable

** Total includes 3.04kWh/sqft for lighting and equipment

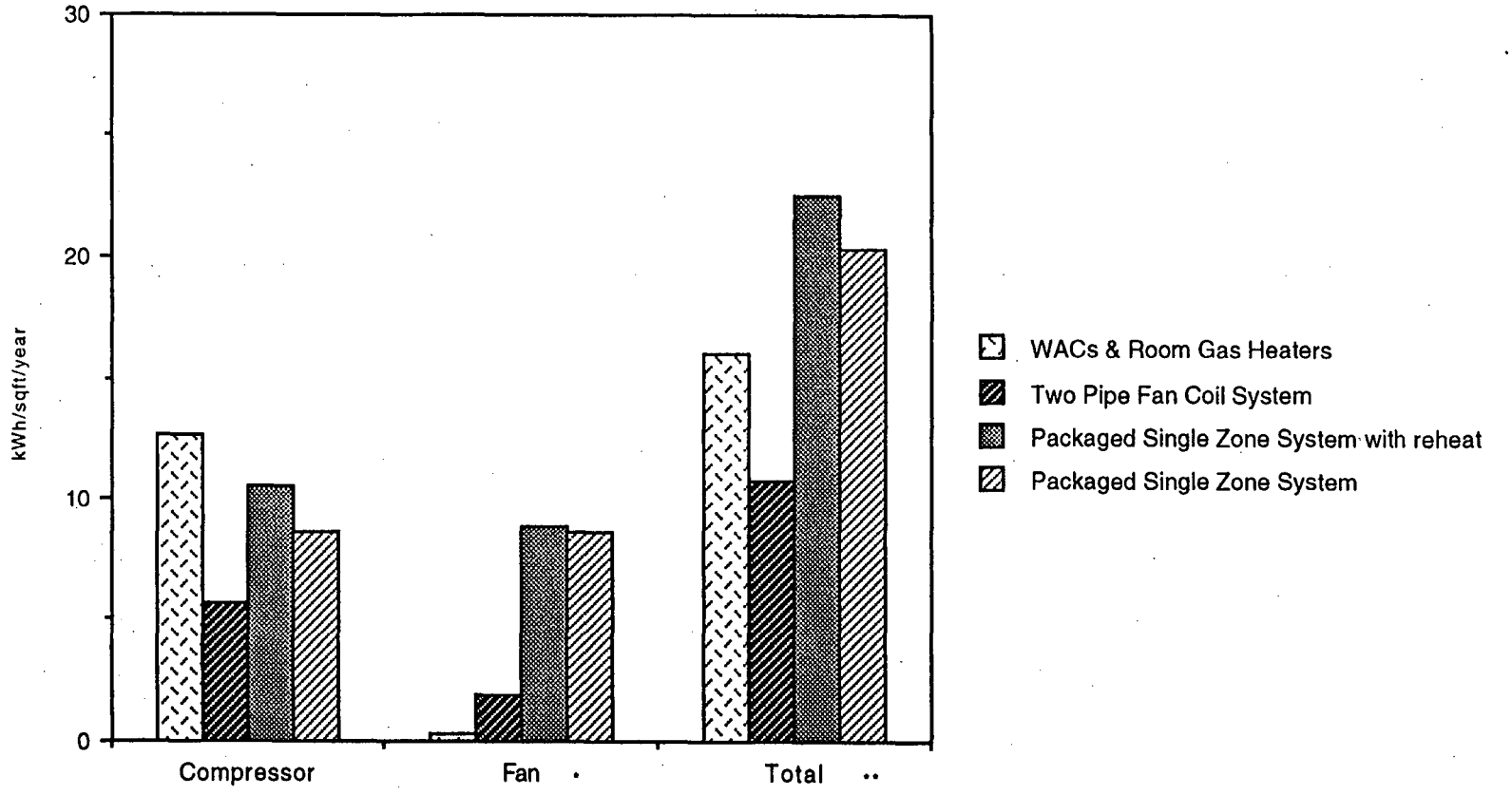
Figure 6.5c
THE IMPACT OF HVAC SYSTEM TYPES ON ELECTRICITY CONSUMPTION IN LAHORE




* Fan energy use covers both cooling and heating,whenever applicable

** Total includes 3.04kWh/sqft for lighting and equipment

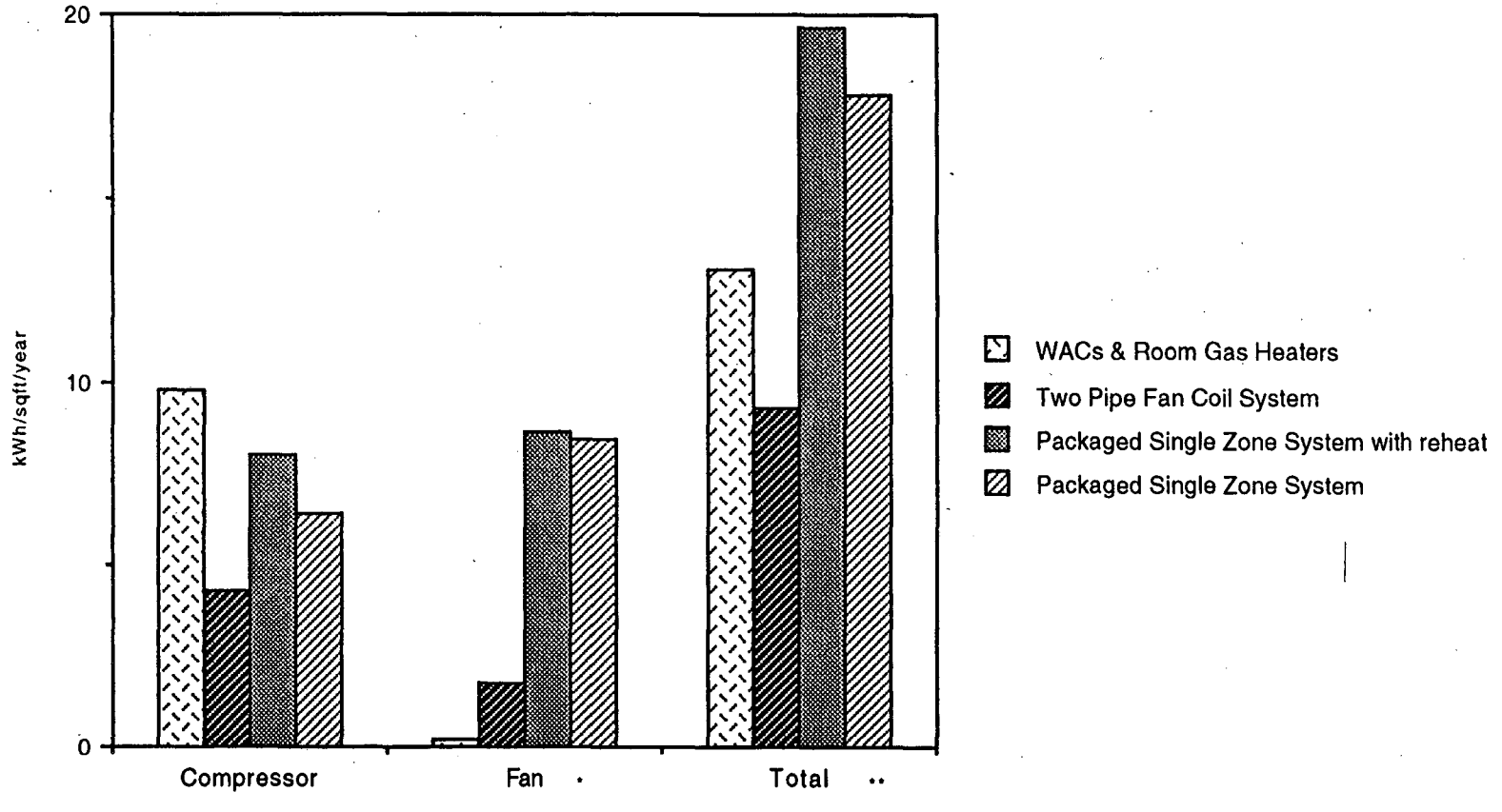
Figure 6.5d
THE IMPACT OF HVAC SYSTEM TYPES ON ELECTRICITY CONSUMPTION IN MULTAN




* Fan energy use covers both cooling and heating,whenever applicable

** Total includes 3.04kWh/sqft for lighting and equipment

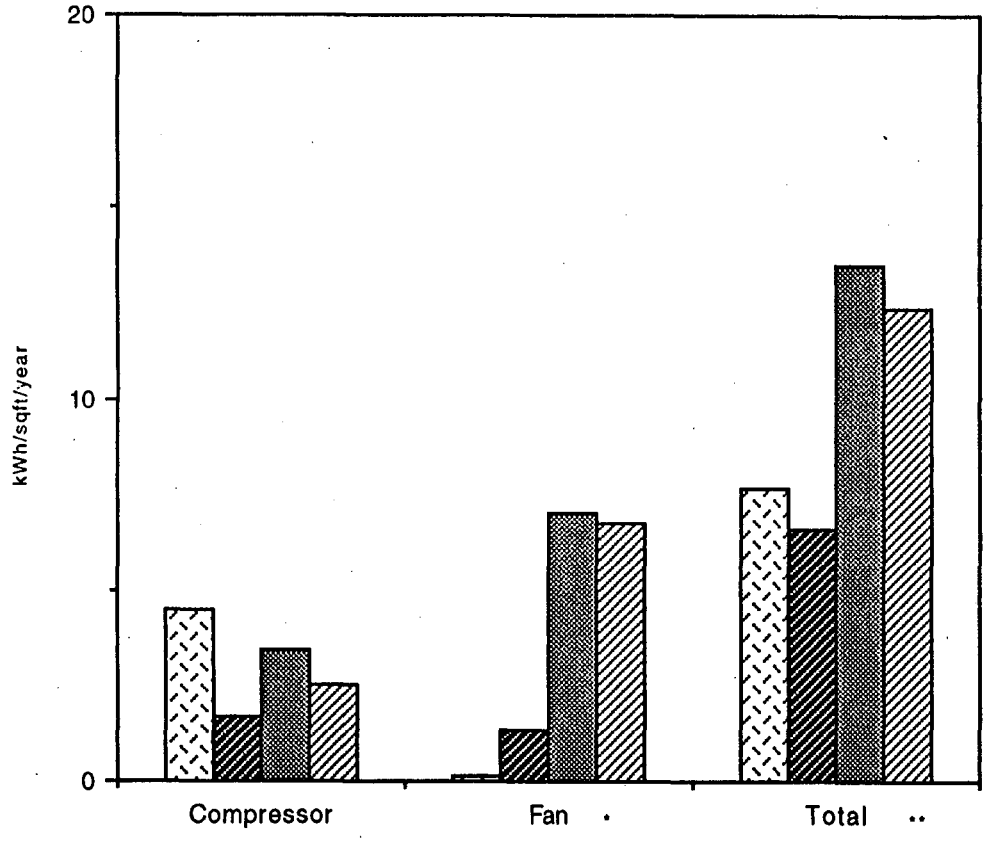
Figure 6.5e
THE IMPACT OF HVAC SYSTEM TYPES ON ELECTRICITY CONSUMPTION IN PESHAWAR

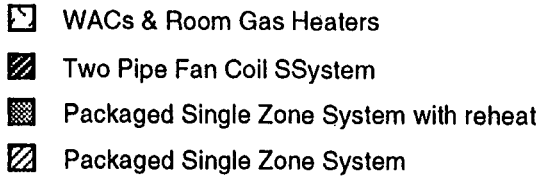



* Fan energy use covers both cooling and heating,whenever applicable

** Total includes 3.04kWh/sqft for lighting and equipment

Figure 6.5f
THE IMPACT OF HVAC SYSTEM TYPES ON ELECTRICITY CONSUMPTION IN QUETTA




* Fan energy use covers both cooling and heating,whenever applicable

** Total includes 3.04kWh/sqft for lighting and equipment

Figure 6.6
THE IMPACT OF HVAC SYSTEM TYPES ON GAS CONSUMPTION IN PAKISTAN

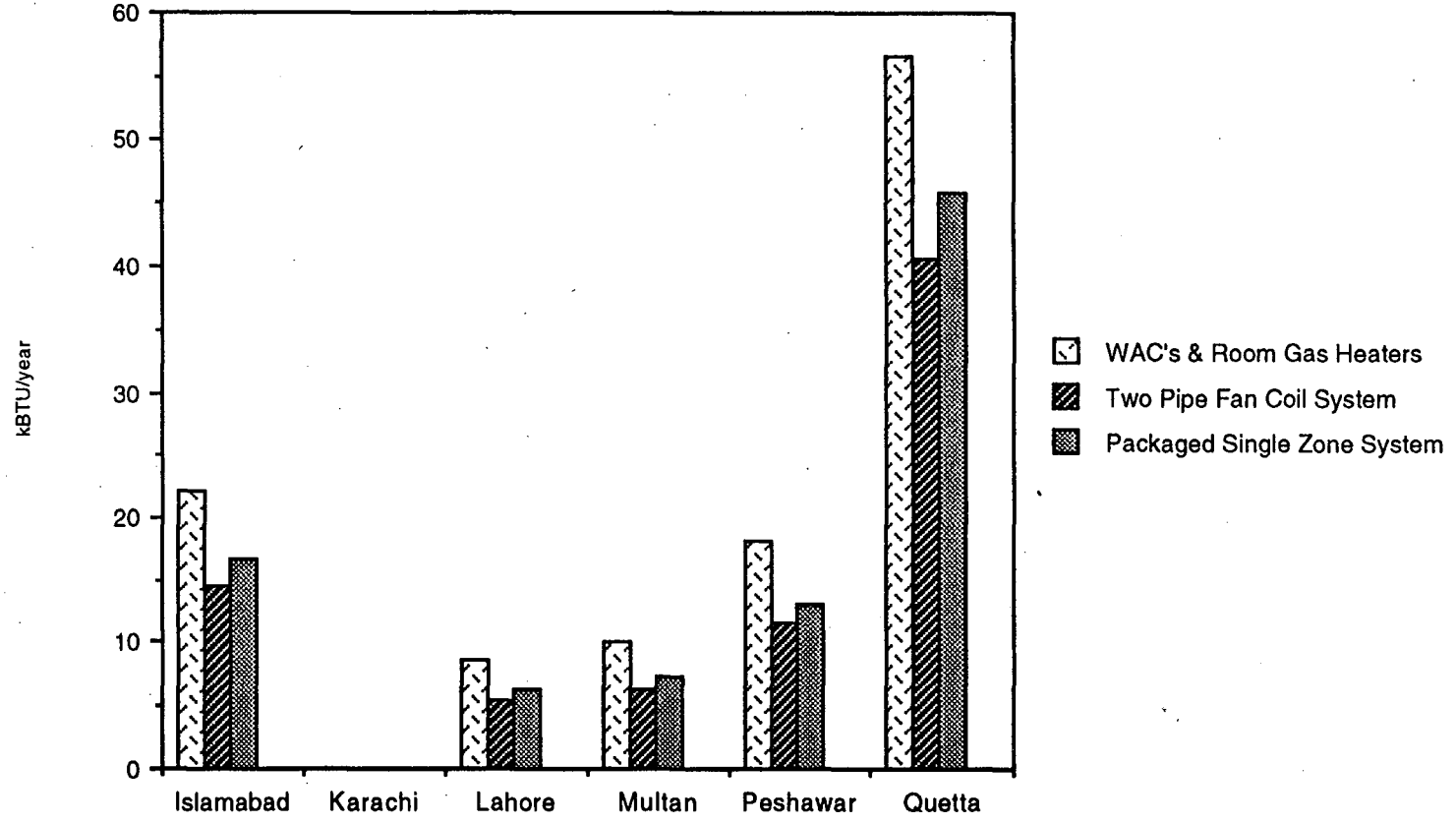


**Table 6.9. The Effect of the HVAC System Types on Electricity and Gas Consumption in Pakistan**

| | Heating | | Cooling | | Total Elec. | Total Gas |
|---|---|---|---|---|---|---|
| | Gas(kBTU) | Pumps(kWh) | Compressors(kWh) | Fans(kWh)* | (kWh) | (kBTU) |
| **Islamabad** | | | | | | |
| WACs & Room Gas Heaters | 22.11 | N/A | 7.59 | 0.17 | 10.82 | 22.11 |
| Two Pipe Fan Coil System | 14.53 | 0.18 | 3.20 | 1.50 | 7.92 | 14.53 |
| Packaged Single Zone System with Reheat | N/A | N/A | 6.26 | 7.75 | 17.07 | N/A |
| Packaged Single Zone System | 16.64 | N/A | 4.80 | 7.37 | 15.22 | 16.64 |
| **Karachi** | | | | | | |
| WACs & Room Gas Heaters | | | 10.93 | 0.24 | 14.22 | 0.00 |
| Two Pipe Fan Coil System | No | Heating | 4.97 | 1.82 | 9.82 | 0.00 |
| Packaged Single Zone System with Reheat | | | 9.77 | 9.44 | 22.26 | N/A |
| Packaged Single Zone System | | | 7.48 | 8.77 | 19.30 | 0.00 |
| **Lahore** | | | | | | |
| WACs & Room Gas Heaters | 8.72 | N/A | 11.15 | 0.25 | 14.23 | 8.72 |
| Two Pipe Fan Coil System | 5.44 | 0.07 | 5.06 | 1.83 | 10.00 | 5.44 |
| Packaged Single Zone System with Reheat | N/A | N/A | 9.42 | 8.69 | 21.14 | N/A |
| Packaged Single Zone System | 6.34 | N/A | 7.43 | 8.50 | 18.97 | 6.34 |
| **Multan** | | | | | | |
| WACs & Room Gas Heaters | 10.12 | N/A | 12.65 | 0.27 | 15.98 | 10.12 |
| Two Pipe Fan Coil System | 6.39 | 0.08 | 5.69 | 1.93 | 10.73 | 6.39 |
| Packaged Single Zone System with Reheat | N/A | N/A | 10.58 | 8.88 | 22.49 | N/A |
| Packaged Single Zone System | 7.29 | N/A | 8.59 | 8.65 | 20.29 | 7.29 |
| **Peshawar** | | | | | | |
| WACs & Room Gas Heaters | 18.17 | N/A | 9.74 | 0.22 | 13.02 | 18.17 |
| Two Pipe Fan Coil System | 11.63 | 0.14 | 4.30 | 1.76 | 9.24 | 11.63 |
| Packaged Single Zone System with Reheat | N/A | N/A | 8.02 | 8.60 | 19.68 | N/A |
| Packaged Single Zone System | 12.97 | N/A | 6.36 | 8.39 | 17.80 | 12.97 |
| **Quetta** | | | | | | |
| WACs & Room Gas Heaters | 56.63 | N/A | 4.48 | 0.16 | 7.68 | 56.63 |
| Two Pipe Fan Coil System | 40.64 | 0.51 | 1.70 | 1.33 | 6.57 | 40.64 |
| Packaged Single Zone System with Reheat | N/A | N/A | 3.43 | 7.02 | 13.48 | N/A |
| Packaged Single Zone System | 45.81 | N/A | 2.56 | 6.77 | 12.38 | 45.81 |

N/A Not applicable

* Fans do not account for ceiling fans

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