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SOLERAS

Saudi University Solar Cooling Laboratories Project

DESIGN ANALYSIS STUDY

King Faisal University

Volume 1
Design Review Report, Data Acquisition Plan and Experimental Plan

Midwest Research Institute, Operating Agent

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FOREWORD

THE SOLERAS PROGRAM: A UNIQUE EFFORT IN COOPERATIVE SOLAR ENERGY RESEARCH

In October 1977, Saudi Arabia and the United States signed a Program Agreement for Cooperation in the Field of Solar Energy. The Program, named SOLERAS, is the first of its kind in purpose, funding, organization, and results. It is based on the respective commitments of the United States and Saudi Arabia to advance the development of solar energy as a viable cost-competitive energy alternative, by combining the technical and other unique resources of each country. SOLERAS has made significant progress in demonstrating the effectiveness of solar energy—progress that would have been difficult for either country to achieve on its own.

SOLERAS is sponsored by the government agencies responsible for energy research and development in each country: the Saudi Arabian National Center for Science and Technology (SANCST) and the United States Department of Energy. The Program is under the auspices of the United States-Saudi Arabian Joint Commission on Economic Cooperation, formed in 1974 by the Saudi Arabian Ministry of Finance and National Economy and the United States Department of the Treasury.

Although SOLERAS is only one of more than 30 such projects under the direction of the Joint Commission, it is the only one that is funded by both countries. All other projects are funded completely by Saudi Arabia. This jointly funded program is evidence, therefore, that both countries recognize the mutually beneficial results expected to be generated by the cooperative research projects undertaken by SOLERAS.

The administration of SOLERAS also reflects the philosophy of cooperation underlying this unique Program. Senior officials from SANCST, the Ministry of Finance and National Economy, the U.S. Department of Energy, and the U.S. Department of the Treasury comprise an eight-member Executive Board which governs all aspects of the SOLERAS Program. The Board establishes the goals, objectives, and policies of SOLERAS and oversees the technical and financial management of the projects undertaken to implement those goals and objectives.

A four-member Project Selection Committee, with two members from each government, assists the Executive Board in selecting and evaluating projects. Its members combine their technical expertise and experience in renewable energy technologies and demonstration projects to review proposals, designs, plans, reports, operations, and data for the various projects.

The daily technical and administrative management of the SOLERAS projects is the responsibility of Midwest Research Institute, an independent, not-for-profit research organization, which has been designated as the SOLERAS Operating Agent. MRI utilizes technical and managerial personnel from both countries in fulfilling its responsibility for implementing the decisions of the Executive Board and in managing the individual technical projects. This includes contracting with various companies and research organizations in both countries to design and install state-of-the-art solar systems. SOLERAS program offices are located at MRI's Kansas City, Missouri, headquarters, and in Riyadh and Yanbu, Saudi Arabia.

SOLERAS has initiated several major research projects: converting solar energy into electricity for everyday use by the inhabitants of several rural villages; testing solar energy as a source for space cooling and water treatment; developing agricultural systems using solar energy to control the entire growing environment; undertaking fundamental photovoltaic and solar thermal research; establishing high technology laboratories for advanced solar research at Saudi Arabian universities; and sponsoring basic solar energy research in universities in the United States.

In addition, SOLERAS has contributed to the dissemination of scientific and technical solar information through its sponsorship of technology workshops, short courses, and the publication of technical reports. These have provided an important means of informing the scientific research community about the solar energy technologies developed under SOLERAS and other relevant projects throughout the world.

تقـديم

«البرنامج السعودي الامريكي المشترك»
للتعاون في ميدان أبحاث الطاقة الشمسية

وقّعت المملكة العربية السعودية والولايات المتحدة الأمريكية في عام ١٩٧٧م اتفاقية برنامج التعاون في ميدان أبحاث الطاقة الشمسية . وكان هذا البرنامج الذي سُمِّي «سوليراس» الاوّل من نوعه من حيث الغرض والتمويل والتنظيم والنتائج . وهو معتمد على الالتزام المتبادل بين الولايات المتحدة الأمريكية والمملكة العربية السعودية بالعمل على تنمية الطاقة الشمسية ، بوصفها طاقة بديلة متجدّدة وذات كلفة منافسة ، عن طريق الجمع للموارد الفنية وغيرها من المصادر الطبيعية لكل من البلدين . ولقد حقّق برنامج «سوليراس» تقدّما ملحوظا ببيان فعالية الطاقة الشمسية ، وهو تقدّم قد يكون من الصعب تحقيقه على أي من البلدين منفردا .

يتم انجاز برنامج «سوليراس» تحت رعاية الهيئات الحكومية المسؤولة عن أبحاث وتنمية الطاقة في كل من البلدين ، أي المركز الوطني السعودي للعلوم والتكنولوجيا ووزارة الطاقة الأمريكية . وتشرف على البرنامج اللجنة الأمريكية السعودية المشتركة للتعاون الاقتصادي المكوّنة عام ١٩٧٤م من قبل وزارة المالية والاقتصاد الوطني في المملكة العربية السعودية ووزارة المالية في الولايات المتحدة الأمريكية .

بالرغم من أن برنامج «سوليراس» هو واحد من بين ما يزيد عن ٣٠ مشروعا تديرها اللجنة المشتركة فانه البرنامج الوحيد الذي يموّله البلدان ، في حين أن جميع البرامج الأخرى تموّلها المملكة العربية السعودية كليا . فيبرهن هذا البرنامج ، المشترك التمويل ، على أن كلا البلدين يعترفان بالفوائد المتبادلة المتوقّع تحقيقها من خلال مشاريع البحث التعاوني التي يتداولها برنامج «سوليراس» .

وتعكس إدارة «سوليراس» أيضا فلسفة التعاون التي يستند عليها هذا البرنامج . فيشكّل مسؤولون من المركز الوطني السعودي للعلوم والتكنولوجيا ومن وزارة المالية والاقتصاد الوطني ومن وزارة الطاقة الأمريكية ووزارة المالية الأمريكية مجلسا تنفيذيا يضمّ ثمانية أعضاء ويدير جميع جوانب برنامج «سوليراس» . فيحدّد هذا المجلس أهداف وغايات وسياسة «سوليراس» كما يشرف على الادارة الفنية والمالية للمشاريع المباشَرة لتحقيق هذه الأهداف والغايات .

تقوم لجنة اختيار المشاريع المتكوّنة من أربعة أعضاء ، اثنان من كل جانب بمساعدة المجلس التنفيذي في اختيار وتقييم المشاريع . فيجمع أعضاء هذه اللجنة خبرتهم الفنية وتجربتهم في مجال تكنولوجيا الطاقة المتجدّدة والمشاريع النموذجية لمراجعة المقترحات والتصاميم والمخططات والتقارير والعمليات والبيانات المتعلقة بالمشاريع المتنوّعة .

أمّا الادارة الفنيّة والادارية اليوميّة لمشاريع «سوليراس» فهي تحت مسؤوولية «مدوست ريسيرتش انستيتيوت» (معهد «مدوست» للابحاث) . وهو معهد أبحاث مستقل ليس ذا صبغة تجارية ، تم تعيينه كوكيل تشغيل لبرنامج «سوليراس» . ويستخدم معهد «مدوست للأبحاث» فنييّن واداريين من كلا البلدين للقيام بمسؤولية تنفيذ قرارات المجلس التنفيذي وإدارة المشاريع الفنية الفردية . ويشمل ذلك التعاقد مع مختلف الشركات ومعاهد الابحاث في كلا البلدين لتصميم وتركيب أنظمة طاقة شمسية من أحدث تكنولوجيا . وتقع مكاتب برنامج «سوليراس» في المقرّ الرئيسي لمعهد «مدوست للأبحاث» بمدينة كنساس سيتي بولاية ميسوري وكذلك في الرياض وينبع بالمملكة العربية السعودية .

انبعث من برنامج «سوليراس» العديد من مشاريع الابحاث الكبرى ، منها تحويل الطاقة الشمسية الى كهرباء للاستعمال اليومي لسكّان العديد من القرى الريفية واختبار الطاقة الشمسية كمصدر طاقة للتبريد والتدفئة وتحلية المياه وتطوير أنظمة زراعية باستعمال الطاقة الشمسية للتحكّم في كامل بيئة الانماء ، والقيام بأبحاث نظرية حول الخلايا الكهروضوئية والحرارة الشمسية وانشاء مختبرات تكنولوجيا عالية للابحاث الشمسية المتقدّمة في الجامعات السعودية ورعاية أبحاث أساسية في الطاقة الشمسية في جامعات بالولايات المتحدة الأمريكية .

كما أن برنامج « سوليراس» ساهم في نشر المعلومات العلمية والفنية المتعلقة بالطاقة الشمسية من خلال رعايته للندوات العلمية والدورات القصيرة ونشر التقارير الفنية . ولقد كان ذلك وسيلة لنقل معلومات هامّة لمجموعة الباحثين العلميين حول تكنولوجيا الطاقة الشمسية المطوّرة من خلال برنامج «سوليراس» والمشاريع الأخرى المرتبطة به عبر بلدان العالم .

1.0 INTRODUCTION

The objectives of the SOLERAS program are to foster the development of solar energy technology for the mutual benefit of the two countries, to stimulate the development of solar industries, and to facilitate the transfer between the two countries of technology developed under the agreement. To achieve these objectives, SOLERAS projects are carried out in accordance with a technical plan which covers a diverse set of technologies and applications. The plan is intended to allow participation by a large group of industrial, academic, and research institutions in both countries, and to overlap the interests of many agencies of both governments. To provide guidelines for project planning and selection, four major program areas have been designated. The four program areas are:

- Urban Solar Applications
- Rural/Agricultural Solar Applications
- Industrial Solar Applications
- Resource Development Activities

Within the area of Urban Solar Applications, SOLERAS aimed to assist and enhance the research capabilities of universities in the area of solar energy technology. Solar Cooling Laboratory Research Projects have been proposed to be conducted at four Saudi universities to accomplish this goal. The projects were divided into three phases: Phase 1, to prepare the design of the proposed project; Phase 2, for installation of the system; and Phase 3, for operation of the system.

As part of this program, an agreement was signed in January, 1981, between King Faisal University and the Saudi Arabian National Center for Science and Technology (SANCST), acting on behalf of SOLERAS, for the university to prepare a preliminary design of the proposed solar cooling research laboratory. In response to that agreement, the university submitted the design for a passively cooled house to be constructed on the campus of King Faisal University in Dammam. In the summer of 1984, a partnership was established between King Faisal University (KFU) and the University of Arizona Environmental Research Laboratory (ERL), wherein ERL would provide engineering support for KFU's architectural work. The preliminary design was subsequently developed, refined, and specified so that construction could proceed. It resulted in funding for Phase 2 through December, 1985.

2.0 KING FAISAL UNIVERSITY PASSIVE SOLAR COOLING PROJECT

VOLUME SUMMARY

Four preliminary passive solar dwelling design concepts were developed at King Faisal University based upon previously established climatic design criteria (Report 82-1), and an identification of applicable passive cooling strategies was made. These were quantitatively compared for their thermal performance based upon a computer program (Report 82-2). The selected concept was optimized and preliminary construction drawings and details were submitted for review by SOLERAS (Report 83-3).

This report, prepared by King Faisal University and the University of Arizona Energy Research Laboratory, deals with the further refinement and development of the design concept and improvements of the performance of the selected passive elements. The final design has been detailed for actual construction and monitoring at the King Faisal University Dammam campus. This report also addresses the comparative evaluation of the previous design concepts utilizing more rigorous computer simulation methods.

The report was prepared in three volumes: Design Review Report, Data Acquisition Plan, and Experimental Plan. Separate volumes of appendices provide data to support the research.

Volume 1: Design Review Report

The proposed passive solar cooling project is a two-story house with a total floor area of 265 square meters, including walls, but excluding the garage and terrace. The length to width ratio of the main building, excluding garage, is 1.45:1, with longer sides oriented predominantly north and south. There are no openings on the east and west walls. The internal layout of the house is based upon considerations of the local climate as well as the Saudi cultural requirement of privacy, with a folding door allowing the male visitor's area (majlis) to be visually cut off from the rest of the house. There are three bedrooms on the second floor, one bathroom downstairs and two upstairs, an outside patio, upstairs balconies, and an aluminum louver-shaded roof area. The garage, which further protects the west wall, will house most of the monitoring equipment for the facility.

The objective has been to keep the house as conventional in construction as possible. The walls are load-bearing cavity walls with inner and outer skins of 10 cm and 20 cm respectively. The 10 cm cavity is filled with polystyrene insulation; thus, the walls have an overall thickness of 40 cm. All structural elements are fabricated of reinforced concrete.

The primary passive cooling features are ventilation, high mass, and a wind tower. There is a backup air-conditioning system, which will be monitored to ascertain cooling needs. Landscaping is proposed as a means of controlling dust, rather than as a significant source of shade.

The final King Faisal Passive Cooling Experimental Facility design was evaluated by three different computer models. Two of the codes utilize finite difference calculation techniques, and the other utilizes conduction transfer function techniques. The three codes are: The Building Loads Analysis and System Thermodynamics (BLAST), conduction transfer functions; MICROPAS, finite difference; and ERL PASSCOOL, finite difference. Section III of the Design Review Report presents in detail the computer simulation procedures and results.

Section IV of the report analyzes ventilation/wind tower strategies for all areas of the house. The proposed design is based on the use of five distinct ventilation strategies: cross-ventilation, both conventional and innovative; wind tower/"wind-driven" mode (given sufficient wind speeds); wind tower/"density-driven" mode (under calm or no wind conditions), powered by density differences between evaporatively cooled (heavier) air in the upper part of the tower and warmer (lighter) ambient air in the lower part of the tower; "mixed mode," employing a combination of cross-ventilation air for "upwind" rooms and wind tower air for "downwind" rooms; and ceiling fans, to achieve air movement when windows are closed and for heating season destratification. The strategies are developed in a ventilation zoning program and the design of the wind tower.

Section V describes the solar water heating system designed for the house. Section VI discusses the multi-zone heat pump selected as a backup air-conditioning system. Section VII is devoted to a baseline comparison of the final design with five other proposed designs. Section VIII sets forth a two-fold research approach to landscaping and lists recommended plant species.

Volume 2: Data Acquisition Plan

The data acquisition plan provides for a sensor field capable of measuring ambient weather and conditions, comfort conditions, heat flow, cooling effectiveness, power usage, and water usage. The data acquisition system comprises the HP 3497A programmable scanner, IBM PC/XT data acquisition computer, IBM PC/XT analysis computer, IBM PC display computer, SOLA power conditioner, Optima cabinets, and appropriate software to be collected, the instruments selected, and the sensor plan. It also discusses calibration of instruments and equipment specifications.

Volume 3: Experimental Plan

Thirty experiments are proposed to measure the essential passive cooling features of the structure with regard to variables that affect comfort; i.e. the dry-bulb temperature, the wet-bulb temperature, the mean radiant temperature, and the air velocity. The experiments are summarized in Table X.D.1.

Table X.D.1. Summary of Experiments

Exp. No.	Description
1	RECONFIGURABLE WALLS/DRUM LOUVER TESTS: To determine the effectiveness of a drum-louver type of inlet/outlet device in directing, maintaining and controlling wind-driven cross-ventilation.
2	RECONFIGURABLE WALLS, DOUBLE-HUNG WINDOWS PLUS DEFLECTOR LOUVER TESTS: To determine the effectiveness of deflector louvers when used in conjunction with standard double-hung windows, in directing, maintaining and controlling wind-driven cross-ventilation.
3	WING-WALL TESTS: To determine the effectiveness of wing-walls in directing, maintaining and controlling wind-driven cross-ventilation.
4	CHEVRON LOUVER TESTS: To determine the effectiveness of a "chevron" louver type inlet/outlet device in creating potential wind-driven cross-ventilation through two adjacent single-orientation rooms.
5	LOUVERED TRANSOMS & DOORS TEST: To determine the effectiveness of fixed louver-transomed doorways plus louvered folding doors as inlet/outlet devices in creating potential wind-driven cross-ventilation through two adjacent single-orientation rooms.
6	WIND TOWER DUCTED-SUPPLY VENTILATION/INLET ALTERNATE #1/YEAR 1: To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.
7	WIND TOWER DIRECT-SUPPLY VENTILATION/INLET ALTERNATE #1/YEAR 1: To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.
8	WIND TOWER DUCTED-SUPPLY EVAPORATIVE COOLING MODE/INLET ALTERNATE #1/YEAR 1: To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.
9	WIND TOWER DIRECT-SUPPLY EVAPORATIVE COOLING MODE/INLET ALTERNATE #1/YEAR 1: To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.

10 WIND TOWER DUCTED-SUPPLY VENTILATION/INLET ALTERNATE #2/YEAR 2: To determine the effectiveness of a 2-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.

11 WIND TOWER DIRECT-SUPPLY VENTILATION/INLET ALTERNATE #2/YEAR 2: To determine the effectiveness of a 2-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.

12 WIND TOWER DUCTED-SUPPLY 2-STAGE EVAPORATIVE COOLING MODE/INLET ALTERNATE #2/YEAR 2: To determine the effectiveness of a wind tower in maintaining wind-driven 2-stage evaporative cooling and thermal comfort in the occupied zone.

13 WIND TOWER DIRECT-SUPPLY 2-STAGE EVAPORATIVE COOLING MODE/INLET ALTERNATE #2/YEAR 2: To determine the effectiveness of a wind tower in maintaining wind-driven 2-stage evaporative cooling and thermal comfort in the occupied zone.

14 BUILDING LOSS COEFFICIENT: This experiment determines the Building loss coefficient. This is the building envelope transmission and infiltration loss coefficient not including the passive apertures.

15 OVERALL LOSS COEFFICIENT: This experiment determines the Overall loss coefficient (L). Simultaneously the infiltration rate should be measured (see Exp. 16)

16 AIR INFILTRATION: Measurement of the air infiltration rate utilizing a tracer gas technique (SF6).

17 BASELINE THERMAL PERFORMANCE (as built): This experiment establishes the baseline thermal performance of the building during the overheated period (i.e. air conditioning required).

18 AIR FLOW RATE MEASUREMENTS: Measure the volumetric air flow rate for discharge vents, circulation fans, appliance exhaust fans, etc..

19 PASSIVE SOLAR BATCH TYPE WATER HEATER COLLECTOR EFFICIENCY PERFORMANCE (#2): This experiment determines the Batch type water heater collector efficiency utilizing the "drain down" method.

20 PASSIVE SOLAR BATCH TYPE WATER HEATER COLLECTOR EFFICIENCY PERFORMANCE (#2): This experiment determines the Batch type water heater collector efficiency utilizing the BTU meter method.

21 ENERGY STORAGE EFFICIENCY OF THE SOLAR WATER HEATERS: To determine the 24-hour heat loss rate of the batch type solar water heating system.

22 THE EFFECT OF CHANGING THE THERMOSTAT SETPOINT ON ENERGY CONSUMPTION: The objective of the experiment is to study the effect of changing the thermostat on energy consumption of the HVAC system.

23 DUTY CYCLING OF AIR CONDITIONING EQUIPMENT, OPTIMUM START-STOP & BUILDING TIME CONSTANT: To evaluate the energy savings realized by shutting off the cooling system for 10-15 minutes every hour.

24 ROOM TEMPERATURE RESPONSE TO A SUDDEN HEAT DISTURBANCE INPUT: The objective of the experiment is to study the reaction of the control system to a sudden application of load (i.e. people, lights, etc).

25 OFF-PEAK COOLING: The objective is to compare energy requirements, energy cost, comfort levels of off-peak cooling to full-day cooling.

26 DE-RATED AIR CONDITIONING CAPACITY: The objective is to run the air conditioning equipment at a reduced capacity to determine if the cooling energy requirement will be reduced.

27 WINDOW FILMS: The objective is to compare the HVAC energy consumption of the building with and without reflective window films.

28 THE EFFECT OF COOLING THERMOSTAT HYSTERESIS ON REQUIRED COOLING ENERGY: To evaluate the cooling system energy requirements with different amounts of hysteresis on the cooling thermostat.

29 ROOM TEMPERATURE RESPONSE OF BUILDING WITH SYSTEM OFF ("FLOAT TEMPERATURE"): To determine the steady-state temperature response of the building with no cooling provided.

30 EFFECTS OF LOUVERED ROOF SHADING: To determine the effectiveness of the louvered roof shading system for both building load reduction and increased comfort of the roof terrace.

١ ـ مقدمــة

يهـدف البرنـامج السعودى الامريكى المشترك للتعاون فى مجـال الطـاقـــة الشمسية (سوليراس) الى تنميـــة التقنيـــة فـــى مجـــال الطـاقة الشمسية بمـا يعود بالفـائـدة علـــــى البلدين • كما يهـدف الى دفـع عجلة التطور فى مجالات الصناعات الشمسية وتسهيل تبـــــادل الخبرات التقنية التـى تكتسب خـلال البرنـامج بيـن البلدين • ولتحقيق الاهـداف المنشـودة يتم تنفيذ البرنـامج من خـلال خطـة مدروسـة تشمل الصناعات والتقنيات المختلفة •

ولقد روعى عند اعداد الخطة أن يشارك فى البرنـامج عددا كبيـرا مـــن المهتمـــين بالصنـاعـة والتعليم والبحث العلمى فى كلا البلدين بالاضافة الـــى الهيئات الحكومية المختلفة • وقدقسم العمل فى البرنـامج الى أربعة نشاطات تشـتمـل على :ـ

تطبيقات الطاقة الشمسية لخدمة مجتمع المدينة
تطبيقات الطاقة الشمسية فى الزراعة والمجتمعات النائيـة
تطبيقات الطاقة الشمسية فى الصناعة
النواحى المتعلقة بتنمية المـوارد البشـرية

ويهـدف البرنـامج المشترك الى المساهمة فى دعم الابحاث فى تطبيقات الطاقـــــة الشـمسيـة لخدمة مجتمع المدينة والتى تقوم بها الجامعات فى البلدين • وقد اقترح ان تقـوم اربـــع جامعات سعودية بأبحاث التبريد باستخدام الطاقة الشـمسيـة ، على أن يتم العمـل فـى هـذه الابحاث على ثلاث مراحل :

المرحلة الاولـى : للتصميم
المرحلة الثانية : للتركيـب
المرحلة الثالثة : للتشـغيل

وفى شهر ينـاير عام ١٩٨١ وقع المركز الوطنى للعلوم والتكنولوجيـا ، نـائبا عن سـوليراس ، اتفاقية مع جامعة الملك فيصل ، تقوم بمقتضاه باعـداد التصميمات المبدئيـــة لمختبر التبريد الشمسي • وعليه فقد قامت الجامعة باعـداد تصميم لمنزل مبرد سلبيا يجرى انشائه فى المدينة الجامعية لجامعـة الملـك فيصـــل بالدمـام • وفى صيف عام ١٩٨٤ اتفقت جامعة الملك فيصل ومعهد أبحاث البيئة بجامعة اريزونـا الامريكية على ان يقـوم المعهـــد بامـداد العون الهندسى للتصميمات المعمارية التى تتكفل بها جامعة الملك فيصل • وعليه فقد تم تطوير وتحسين التصميم المبدئى الى الحـد الذى يسمح ببدء الانشـاء ، وعليه فقد ووفـــق على دعم المشروع ماديا فى شهر ديسمبر ١٩٨٥م لاتمام المرحلة الثـانية والثـالثة من العمل •

٢ ـ مشـروع جامعة الملك فيصل للتبريد الشمسى السـلبى

" ملخص "

قامت جامعة الملك فيصل باعداد أربعة تصميمات مختلفة للمساكن آخذة فى الاعتبار التصميمات المناخية (التقرير ٨٢ ـ ١) وتم التوصل الى طرق التصميم الهندسية للتبريد الشمسي • قورنت هذه الطرق مقارنة كمية باستخدام برنامج الحاسب الآلى لتحديد خواصها الحرارية (التقرير ٨٢ ـ ٢)• أخيرا اختير التصميم الافضل وتم تعديله ليصبح فى الوضع الامثل وأعدت الرسومات المبدئية للانشاء مع التفصيلات اللازمة وقدمت الى سوليراس لمراجعتها (التقرير ٨٢ ـ ٣) •

ويتعرض هذا التقرير الذى أعدته جامعة الملك فيصل بالاشتراك مع مختبر أبحاث الطاقة بجامعة اريزونا ، للتحسينات والتطوير الذى أدخل على التصميم الاولى وماتبعه من تحسن فى مستوى اداء النظم السابقة المختارة • هذا وقد أعد التصميم النهائى الذى سوف يستخدم للانشاء فى جامعة الملك فيصل بالدمام • كما يتطرق التقرير الى مقارنة التصميم المذكور آنفا باستخدام طرق المحاكاة بالحاسب الآلى • وقد أخرج التقرير فى ثلاثة أجزاء :

تقرير مراجعة التصميم وخطة اكتساب المعلومات وخطة التجارب بالاضافة الى مجلدات الملحقات التى تحتوى البيانات اللازمة للتصميم والبحث •

الجزء الاول : تقرير مراجعة التصميمات

يشتمل المشروع المقترح للتبريد الشمسي السالب على انشاء منزل من طابقين بمساحة ٢٥٦ مترا مربعا بما فيها الجدران ولا تشتمل على التراس والجراج • وتبلغ نسبة الطول الى العرض للمبنى ، باستثناء الجراج ١٫٤٥ : ١ وفيه الاوجه الطويله متجهه نحو الشمال والجنوب ولا تحتوى الجدران الشرقية والغربية على أية فتحات • وفى التصميم الداخلى للمبنى ، روعيت اعتبارات الطقس والعادات والتقاليد السعودية وأهمها الخصوصية حيث زود المجلس الرجالى بابواب منطبقة بحجمها عن باقى المنزل • ويحتوى المنزل على ثلاث غرف للنوم وحمامين بالطابق الاعلى كما يوجد حمام بالدور الاسفل ويحتوى الطابق العلوى على تراس • اما الجراج والذى يساهم ايضا فى حماية الجدار الغربى فيحتوى على معدات القياس المختلفة • ولقد روعى أن يبقى تصميم المنزل تصميما اعتياديا بقدر المستطاع ولذلك استخدمت الحوائط الحاملة بسماكه داخلية وخارجية تبلغ ١٠ ، ٢٠ سم • اما التجويف الداخلى البالغ ١٠ سم فقد ملأ بمادة بوليسترين العازلة ولذا فقد بلغ سمك الجدار الكلى ٤٠ سم وفيما عدا ذلك فكل الانشاءات من الخرسانة المسلحة •

ومن أهم السمات المميزة للتبريد السالب هى التهوية وبرج الرياح • كما يوجد نظام تكييف هواء اعتيادى مساعد يمكن التبوء بكمية التبريد اللازمة عن طريق رصده • وتستخدم الشجيرات والاشجار لحجب الاتربة أساسا وليس للظلال •

ولقد تم التصميم النهائى للتبريد السالب الذى أعدته جامعة الملك فيصل باستخدام ثلاثة برامج مختلفة للحاسب الآلى • واستخدمت طريقة الفروق المحدودة فى اثنين منها اما الثالثة فاستخدمت طرق دالة الانتقال بالتوصيل •

واما شفرات برامج الحاسب الثلاث المستخدم فهى : الديناميكية الحرارية وتحليل احمال المبانى (بلاست) - انتقال الحرارة بالتوصيل (ميكروباس) - الفروق المحدودة (باسكوك) • ويقدم الفصل الثالث من تقرير التصميم طرق المحاكاة باستخدام الحاسب الآلى بالنتائج التى تم التوصل اليها • ويقدم الفصل الرابع تحليلا للتهوية وخطط برج التهوية لكل مساحة بالمنزل• ويعتمد التصميم المقترح على الاستفادة من خمسة خطط محددة للتهوية :

التهوية المعاكسة بالطرق التقليدية والحديثة ، برج الرياح " بدفع الرياح - فى حالة توفر سرعة رياح مناسبة " ، برج الرياح/ بدفع الكثافة - فى حالة سكون الرياح وسرعة الرياح القليلة " ، حيث تمتد الطاقة من فرق الكثافة بين البارد والهواء الساخن فى أعلى البرج وفى أسفل البرج على التوالى ، " الاسلوب المختلط " والذى تستخدم التهوية المتعاكسة للغرف " اعلى الرياح " كما يستخدم برج التهوية للغرف " اسفل الرياح" ، ومراوح السقف لتحريك الهواء فى حالة قفل النوافذ وفى الفصل الحار من السنة • ولقد طورت هذه الخطط من خلال برنامج تقسيم مناطق التهوية وتصميم برج الرياح •

وفى الفصل الخامس وصف لتسخين المياه بالطاقة الشمسية والذى صمم للمنزل • كما يناقش الفصل السادس الفتحه الحرارية للمناطق المتعددة والتى اختيرت كنظام تكييف هواء مساعد • ولقد خصص الفصل السابع لمقارنة التصميم النهائى مع خمسة تصميمات أخرى مقترحة ويقدم الفصل الثامن خطة بحث ثنائية للتشجير والنباتات المفضلة •

الجزء الثانى - خطة اكتساب المعلومات

تعتمد خطة اكتساب البيانات والمعلومات على حقل من أدوات الاستشعار ، قادرة على قياس حالة الطقس - ظروف الطقس المريحه - سريان الحرارة - مدى فاعلية التبريد - الطاقة المستخدمة - وكمية المياه المستهلكة • ويتكون نظام اكتساب المعلومات اساسا من ماسح مبرمج من طراز هيولت باركارد رقم ٣٤٩٧أ ، جهاز حاسب أى • بى • ام شخصي للتحليل ، جهاز حاسب أى • بى • ام شخصي للعرض مكيف لطاقة الشمس ، كبائن مثلى - ومجموعة برامج الحاسب المناسبة أجهزة القياس المختارة بلاضافة الى اداوات الاستشعار • كما يناقش طرق معايرة الاجهزة وقائمة بمواصفاتها •

الجزء الثالث - خطة التجربة العملية

هناك ثلاثون تجربة مقترحة لقياس الخواص الاساسية للتبريد السالب فيما يتعلق بالراحه - درجة حرارة البصيلة الجافة - درجة حرارة البصيلة المبتلة - متوسط درجة الحرارة المشعة وسرعة الريح • ويحتوى الجدول X.D.I. على ملخص لهذه التجارب •

جدول X.D.I. ملخص التجارب

رقم التجربة	وصفها
١	اختبارات الجدران المتغيره الشكل / اسطوانة فتحة التهوية : لتحديد مدى فعالية نوع فتحات التهوية الاسطوانية الشكل لجهاز السحب والتفريغ فى عملية توجيه ، صيانة وضبط نظام التهوية المتداخلة ذات الرياح المنساقة .
٢	اختبارات الجدران المتغيرة الشكل ، نوافذ ثنائية التعليق ، بالاضافة الى فتحات التهوية الجارفة : لتحديد مدى فعالية فتحات التهوية الجارفة عندما تستعمل بالاشتراك مع نوافذ ثنائية التعليق القياسية فى توجيه ، صيانة التهوية المتداخلة ذات الرياح المنساقة .
٣	اختبارات جدار الدعم الجانبى : لتحديد مدى فعالية جدران الدعم الجانبية فى توجيه ، صيانة وضبط التهوية المتداخلة ذات الرياح المنساقة .
٤	اختبارات فتحات سشيفرون للتهوية : لتحديد مدى فعالية نوع فتحات التهوية " سشيفرون " لجهاز السحب والتفريغ فى عملية تكوين تهوية متداخلة ذات الرياح المنساقة من خلال استخدام غرفتين ملحقتين وذو وجهه واحده .
٥	اختبار رافدات التهوية والابواب : لتحديد مدى فعالية المداخل ذات روافد التهوية الثابته بالاضافة الى الابواب المنطبقة ذات فتحات التهوية ، كما هو الحال فى أجهزة السحب والتفريغ ، وذلك فى عمليات تكوين تهوية متداخلة ذات الرياح المنساقة من خلال استخدام غرفتين ملحقتين وذو وجهه واحده .
٦	تهوية برج الرياح والتى تمد عن طريق الانابيب / مدخل دورى رقم ١/ سنة اولى : لتحديد مدى فعالية برج رياح ذو ثلاثة جوانب فى المحافظة على هواء الرياح المنساقة ومدى الراحة الحرارية فى منطقة مشغوله .
٧	تهوية برج رياح والتى تمد بطريقة مباشرة / مدخل دورى رقم ١/سنة اولى: لتحديد مدى فعالية برج رياح ذو ثلاثة جوانب فى المحافظة على حركة هواء الرياح المنساقة ومدى الراحه الحرارية فى منطقة مشغوله .

٨ اسلوب التبريد البخرى لبرج الرياح والذى يمد بالتهوية عن طريق الانابيب/ ثلاثة جوانب فى المحافظة على حركة هواء الرياح المنساقه والراحه الحرارية فى منطقة مشغوله ٠

٩ اسلوب التبريد البخرى لبرج الرياح والذى يمد بتهوية مباشرة / مدخل دورى رقم ١/ سنة أولى : لتحديد مدى فعالية برج الرياح ذو ثلاثة جوانب فى المحافظة على حركة هواء الرياح المنساقة والراحة الحرارية فى منطقة مشغولة ٠

١٠ تهوية برج الرياح والتى تمد عن طريق الانابيب / مدخل دورى رقم ٢/ سنةثانية : لتحديد مدى فعالية برج الرياح ذو جانبين فى المحافظة على حركة هواء الرياح المنساقة والراحه الحرارية فى منطقة مشغوله ٠

١١ تهوية برج الرياح ذو التهوية المباشرة/ مدخل دورى رقم ٢/ سنة ثانية : لتحديد مدى فعالية برج الرياح ذو جانبين فى المحافظة على حركة هواء الرياح المنساقة والراحه الحرارية فى منطقة مشغوله ٠

١٢ اسلوب التبريد الجزئى ذو المرحلتين لبرج الرياح والذى يمون عن طريق الانابيب / مدخل دورى رقم ٢ / سنة ثانية : لتحديد مدى فعالية برج الرياح فى المحافظة على نظام التبريد الجزئى ذو المرحلتين للرياح المنساقة والراحه الحرارية فى منطقة مشغوله ٠

١٣ اسلوب التبريد الجزئى ذو المرحلتين لبرج الرياح ذو التهوية المباشرة / مدخل دورى رقم ٢/ سنة ثانية : لتحديد مدى فعالية برج الرياح فى المحافظة على نظام التبريد الجزئى ذو المرحلتين للرياح المنساقة والراحه الحرارية فى منطقة مشغوله ٠

١٤ معامل الفقد من المبانى : هذه التجربه تحدد معامل الفقد بين المبانى ٠ وهذا هو منحنى التغير لمعامل الفقد فى التوصيل والترشيح للمبنى ولا يشتمل على الفتحات السلبيه ٠

١٥ معامل الفقد الكلى : هذه التجربه تحدد معامل الفقد الكلى (ل) ٠ ولابد من قياس معدل التنقية بطريقة آنيه (انظر تجربه ١٦) ٠

١٦ ترشيح الهواء : قياسات لمعدل ترشيح الهواء عن طريق استخدام اسلوب كاشف غازى (SF6) ٠

١٧ اداء الخط القاعدى الحرارى (كما هو مبنى) : تؤسس هذه التجربه اداء الخط القاعدى الحرارى للمبنى خلال الفترة التى تكون فيها الحرارة الساخنة اكثر مما ينبغى (ملحوظة : لابد من وجود جهاز تكييف) .

١٨ قياسات معدل انسياب الهواء : قياس معدل انسياب الهواء الحجمى لفتحات التفريغ ، مراوح التوزيع ، مراوح جهاز العادم ، الخ ..

١٩ اداء مجمع مائى حرارى فعال ذو الكمية الشمسية السلبية (رقم ٢) : تحدد هذه التجربة مدى فعالية المجمع المائى الحرارى ذو الكمية الشمسية باستخدام طريقة " التصريف " .

٢٠ اداء مجمع مائى حرارى فعال ذو الكمية الشمسية السلبية (رقم ٢) : تحدد هذه التجربة مدى فعالية المجمع المائى الحرارة ذو الكمية الشمسية باستخدام طريقة بى . تى . يو المتريه .

٢١ فعالية مخزون الطاقة لسخانات الماء الشمسية : لتحديد معدل الفقد لنظام التسخين المائى الشمسي على مدى ٢٤ ساعه .

٢٢ تأثير تغيير نقطة التحديد للترموستات عى استهلاك الطاقة : الهدف من التجربه هو دراسة التأثير الذى يحدث عند تغيير الترماستات عند استهلاك طاقة جهاز اتش فى ايه سى (HVAC) .

٢٣ دورة التشغيل لمعدات التكييف ، بدايه ـ توقف ـ مثلى والثابت الزمنى للمبنى لتقدير مدخر الطاقة والذى تم الحصول عليه عن طريق غلق جهاز التبريد لمدة ١٠ ـ ١٥ دقيقة كل ساعه ،.

٢٤ رد فعل درجة حرارة الغرفة عند استخدام تشويش حرارى مفاجىء : الهدف من هذه التجربه هو دراسة رد فعل نظام التبريد عند (استخدام حمل مفاجىء (مثل افراد، انوار ، الخ ..) .

٢٥ تبريد دون الذروة : الهدف هو المقارنة بين متطلبات الطاقة ، تكلفة الطاقة ، مستويات الراحه لتبريد دون الذروة وبين تبريد اليوم الكامل .

٢٦ سعة التكييف المخفضة : الهدف هو استعمال جهاز التكييف بسعة منخفضة لتحديد ما اذا كانت الطاقة المطلوبة واللازمة لعملية التبريد ستنخفض أيضا

٢٧ الطبقات الرقيقة للنوافذ : الهدف هو المقارنة عند استهلاك المبنى لطاقة (HVAC) بين حالتى وجود أو عدم وجود طبقات رقيقة عاكسة للنوافذ ٠

٢٨ تأثير ترموستات التبريد ذو التخلف المغناطيسي على طاقة التبريد المطلوبه :
هذه التجربه هى لتقدير متطلبات طاقة نظام التبريد بكميات مختلفة من التخلف المغناطيسى على ترموستات التبريد ٠

٢٩ رد فعل درجة الحرارة لغرفة فى مبنى مزود بجهاز مغلق (" درجة حرارة عامة ") : لتحديد رد فعل درجة الحرارة ذو الحالة المستقرة فى مبنى غير مزود بنظام تبريد ٠

٣٠ تأثيرات حجب السطح ذو الفتحات الهوائية : لتحديد مدى فعالية نظام حجب أو تظليل السطح المزود بفتحات تهوية عند محاولة تخفيف الحمل على المبنى وكذلك عند محاولة زيادة الراحة المطلوبه فى شرفة السطح ٠

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PREFACE

The Kingdom of Saudi Arabia and the United States of America have an Agreement of Cooperation in the field of Solar Energy (SOLERAS) under the auspices of the United States-Saudi Arabian Joint Commission on Economic Cooperation. Under the SOLERAS Agreement, the Saudi Arabian National Center for Science and Technology (SANCST) was authorized and has awarded a research contract to the King Faisal University (K.F.U.) which, in part, includes the design and construction of a house utilizing passive solar cooling for research purposes.

Also, under the SOLERAS Agreement, Midwest Research Institute (MRI) the operating Agent for SOLERAS was authorized to issue contracts as required, to support the research work that was being performed by the K.F.U. MRI SOLERAS has consequently assisted the K.F.U. research efforts by arranging support in areas of specialized consultancy from The University of Arizona, Environmental Research Laboratory (ERL), U.S.A. The Saudi Engineering Group (SEG), Al-Khobar, Saudi Arabia was similarly contracted for the preparation of construction documents. During all the ERL and SEG activities, members of the K.F.U. research team continued to be fully involved. A K.F.U. team member visited ERL early in this phase to coordinate the K.F.U. and ERL efforts.

In addition K.F.U. team members were actively involved with SEG in Al-Khobar, Saudi Arabia.

SUMMARY

Four preliminary passive solar dwelling design concepts were developed based upon previously established climatic design criteria (Report 82-1) and an identification of applicable passive cooling strategies was made. These were quantitatively compared for their thermal performance based upon a computer program (Report 82-2). The selected concept was optimized and preliminary construction drawings and details were submitted for review by SOLERAS (Report 83-3).

This report deals with the further refinement and development of the design concept and improvements of the performance of the selected passive elements. The final design has been detailed for actual construction and monitoring at the King Faisal University University Dammam Campus. In addition this report addresses the comparative evaluation of the previous design concepts utilizing more rigorous computer simulation methods.

ACKNOWLEDGEMENTS

The King Faisal University Research Team wishes to express its gratitude to the Joint United States - Saudi Arabian Program for Cooperation in the field of Solar Energy (SOLERAS) for its continued and generous support for this project in a vital area of research. Dr. Bakr H. Khoshaim, Saudi Programs Director and Mr. James S. Williamson, U.S. Programs Director are particularly thanked for taking a keen and personal interest and for providing valuable guidance at every stage of the project.

The Research Team also wishes to acknowledge the invaluable assistance and encouragement provided by the King Faisal University through His Excellency Dr. Abdullatif Al-Faraidy, the Vice President, and his predecessor H. E. Dr. Mohammad T. Altorki.

There are several persons, although no longer affiliated with the project, who have made contributions at one stage or another. These include Prof. Peter Greenwood, Mr. J. J. Boon, Dr. M. T. Hedaya, Dr. Paul K. Woods, and Mr. Joseph M. Galea.

I. INTRODUCTION

The following design review report is a joint effort between the King Faisal University Research Design Team and the researchers at the University of Arizona, Environmental Research Laboratory. The report reviews the passive cooling facility final design as to the appropriateness of the passive cooling design and analyzes the passive cooling components and performance of the passive cooling devices (ventilation, high mass and wind tower). Extensive computer simulations and modeling were employed.

In addition to the design review and analysis this report also provides the design specifications for the backup heating and air-conditioning system and the domestic solar hot water system.

Five previous design concepts that were evaluated in KFU Report 82-2 "Peliminary Design Concepts and Final Design" were simulated and load analysis performed utilizing the BLAST computer simulation program. BLAST is a program developed by the U.S. Army for building loads analysis and is a widely accepted program.

A. PROJECT GOALS

This project has been conceived with the very clear objective of demonstrating to the academic and professional community the potential for an integrated energy-conscious approach applicable to the contemporary middle class Saudi family in the Kingdom of Saudi Arabia and, in particular, the areas of the Eastern Region.

B. RESEARCH OBJECTIVES

The overall objective of the current project is to investigate the effectiveness of applicable passive cooling design techniques for utilization in domestic buildings in the hot-arid maritime desert climate of the coastal areas of the Eastern Province.

C. RESEARCH METHODOLOGY

The current research has been carried out by the faculty of the College of Architecture and Planning of the King Faisal University. In an architectural educational institution it is imperative that the development of a design process itself be given sufficient importance as one of the research objectives.

The process adopted may be categorized in the following manner:

1. Climatic data collection and analysis leading to the establishment of preliminary climatic design criteria.

2. Identification and refinement of the appropriate passive solar cooling strategies applicable in the selected climatic region.

3. Identification and definition of essential socio-cultural requirements (i.e. privacy) of a middle income contemporary Saudi family in detached urban dwellings.

4. Evolution of different preliminary design concepts based upon the similar climatic design criteria established earlier and incorporating selected passive solar cooling strategies.

5. Quantitative comparison of the preliminary design concepts through computer simulations of their thermal performance, followed by the selection of a design concept for further development.

6. Development and detailing of the selected design through preliminary construction drawings.

7. Review and refinement of various design details of passive cooling techniques in the proposed design.

8. Completion of final working drawings and construction documents.

9. Definition and development of a Data Acquisition System (DAS) to be incorporated in the house for complete monitoring of its thermal performance.

10. Selection of a definitive multi-zone, thermal performance simulation computer program for analysis of the building's performance.

11. Construction of the house, installation and checkout of data acquisition system.

12. A continuous program of monitoring, experimentation, and analysis. This feedback may be used to verify and develop the computer thermal performance simulation program as well as to further modify various elements in the house in order to improve the performance.

13. The constructed house will serve as a passive solar laboratory for the K.F.U. to conduct various other related studies and research outside the current funding arrangements.

Activities 1 to 6 have been previously accomplished in the three previous reports (82-1, 82-2, and 83-3). This report addresses activities 7 to 10.

D. PASSIVE COOLING SYSTEMS

In terms of overall cooling needs it was observed that different strategies such as cross ventilation, induced ventilation, evaporative cooling and refrigeration, would be needed during different times of the day. Because of the extreme humidity in the Dammam area, air-conditioning during some parts of the year is necessary to achieve desirable indoor comfort conditions.

Landscaping is also considered as a means of controlling dust, and creating a more congenial microclimate around the building. Trees may be utilized to shade wall surfaces; however, the building should be, and is designed to be, energy efficient without this shading.

Several techniques are utilized in the building to reduce the heat gain. First is orientation: the north-south orientation, and the windowless east and west walls, are essential elements to a passively cooled house. The structure is super insulated throughout with 10 cm foam insulation.

The preliminary research on the local climate indicated that ventilation could be used to achieve comfort during significant times of the year. As will be seen in later sections, when ventilation is coupled with high-mass construction a significant improvement results. Most of the rooms have been provided, where possible, with cross-ventilation possibilities through the use of large operable windows and flow through wall/door louvers. The south facing windows are provided with external shading devices to block the direct solar gain during the cooling periods. In addition, a wind tower orientated to the prevailing winds is incorporated into the overall ventilation scheme. Wind towers have been used effectively in traditional houses for a number of years in some areas of the Arabian Gulf. Provisions for filtration of the dust and evaporative cooling of the air have been incorporated into the wind tower design. To further reduce the impact of solar radiation on the vulnerable roof surface, most of the roof area of the house is shaded by a louver system which allows for the use of the roof as a living area, and provides protection from the sun. The inclination of the louver support system will allow the future installation of solar collectors (PV or thermal) for a possible active solar powered air-conditioning system.

E. THE PASSIVE SOLAR COOLING HOUSE

1. Plans

The house, as planned, is double story, with a total floor area of 265 square meters, including walls, but excluding the garage and terrace. The length to width ratio of the main building block, excluding the garage, is 1.45 : 1, with the longer sides orientated North and South. There are no openings on the East and West walls. The West wall is further protected by the garage.

The internal layout of the house is based upon considerations of the local climate, as well as Saudi cultural requirement of privacy. The entry to the house is centrally located on the south side. From the entrance hallway, direct access is obtained to the male visitor's living room ("Majlis") on the left side. A folding door links the formal living room with the dining room which, in turn, is linked to the kitchen. It is thus possible for the family to use the rest of the house by isolating the male visitor's area. The family and female visitor's living room is located towards the east, and is also conveniently close to the kitchen, because families often take their informal meals in the family living area. A toilet is provided at the ground floor in the neutral zone, so that it can be used by both visitors and the family. An outside family patio is provided to the north of the family living room with access to the kitchen.

The first floor comprises the sleeping area, which consists of three bedrooms. The master bedroom is provided with an attached bath, while the other two bedrooms share one bath, located in the hallway in front of the staircase. Laundry facilities are also located in the same area, with access to a balcony on the north of the children's bedroom. Vertical circulation is provided by a centrally located staircase.

2. Elevations and Cross Sections

The east and west elevations have no openings—the openings are concentrated on the north and south exposures. The end walls on the north project 60 cm, and 120 cm on the south. The south projections provide for some azimuthal shading, and the north projections, when coupled with other devices, can help augment the cross ventilation effects. The sloping roof of the staircase incorporates a Batch, or "Breadbox"-type passive solar water heater, sized to meet 87% of the annual demand for hot water. Section V provides details of this system. This water is supplied from an underground storage tank.

The east and west walls over the main house support a lightweight aluminium louver roof shading system. The slope of the roof was determined based upon the future possibility of incorporating active solar collectors for electricity (PV), or thermal, for air-conditioning. Architecturally the rising mass of the centrally placed wind tower is the dominant feature.

3. Construction

The objective has been to keep the house as conventional in construction as possible. The walls are load bearing cavity walls with inner and outer skins of 10 cm and 20 cm, respectively. The 10 cm cavity is filled with polystyrene insulation. The walls thus have an overall thickness of 40 cm. The insulation is continued through all walls and roof. All structural elements—foundations, floor slabs, beams and lintels—are fabricated of reinforced concrete. The upper part of the wind tower and roof shading louver system is metal frame.

4. Electricity

The house is liberally provided with lighting and power outlets. All the points and sockets and other electrical outlets are on a number of branch circuits. Each circuit has an individual watt-hour meter to enable monitoring of the power consumption of various components. All of the main equipment is located in the garage for easy access and control. The garage is planned to house most of the monitoring equipment which shall be used in the building.

5. Water

Water is supplied by gravity from the main water tower on the University campus to an underground water reservoir located at the NE corner of the house. From here the water is then distributed to the kitchen, bathrooms and other points where it is required. Hot water is supplied from the batch type solar water heater system located over the staircase.

6. Sewage

The University temporary campus does not have a sewage system. The house will, therefore, have to be provided with its own septic tank and sockage pit to be located on the leeward side of the house (SW corner of the plot).

7. Air-conditioning

The air-conditioning system is intended mainly as a backup system for those periods of the year when passive cooling systems do not fulfill the cooling requirement. It is separately monitored to enable an assessment of the energy needs of the system as it is used. Section VI details the design of the HVAC system.

II. ARCHITECTURAL REVIEW

A. INTRODUCTION

The plans for the most recent version of the revised final design by the King Faisal University research team were reviewed jointly by the KFU research team and the ERL staff in relationship to their appropriateness for studying passive cooling strategies in Saudi Arabia, and specifically in the Dammam area. Strategies that were reviewed included the use of cross ventilation, the wind tower and its placement, window locations and shading, and the roof pond. In addition, the basic plan of the building was reviewed for compatibility with testing the passive cooling strategies.

In terms of overall cooling needs, it was observed that different strategies for ventilation, evaporative cooling and refrigeration would be needed during different periods of the cooling season, and even during different times of the day. Because of the extreme humidity in Dammam, air conditioning was considered essential. Thus the main goal for the design of the house was to reduce the cooling load as much as possible, given budget constraints.

Placement of the building on the site was studied. The major factors are wind and solar orientation. Since ventilation would only be useful during a small percentage of the year, it was decided to weight the orientation decision slightly more toward cooling reduction needs. However, it was also pointed out that if there was a desire to capture the winds for ventilation, appropriate orientation would be essential. Landscaping was also discussed, primarily as a means of controlling dust, rather than reducing heat loads on the building.

Since the design of the building was fairly well established before the review started, few major changes were made in the floor plan. It was observed that only the rooms on the east side were particularly well-suited for cross-ventilation studies. On the west side, a bathroom and ventilation shaft reduced the possibilities for cross-ventilation on the ground floor. The ventilation shaft was removed and replaced by a mechanical ventilation system for the bathroom. On the first floor, increased ventilation was achieved by providing for air flow beneath the closets. This will be discussed further in the ventilation section.

Configuration of the windows was also discussed. Various recommendations are made in the ventilation section of this report, and in the building heating and cooling load evaluation. The use of removable and reconfigurable wall panels was discussed and recommended.

Placement of the wind tower near the center of the house was approved. However, it was suggested that the wind tower be enlarged. This caused minor modifications in the plan. Duct systems and ventilation strategies for air distribution from the wind tower will be discussed further in the wind tower section.

A roof pond was shown in the plans over the garage. Much research has already been done on roof ponds and much remains to be done for them to work properly. Because of the predominance of overcast skies, hazy conditions, and humidity in the KFU location, the roof pond would be ineffective for cooling during most of the year. Thus it was decided that this cooling strategy be dropped. (The garage will be used to house the data acquisiton system.) A major report on roof pond systems was recently completed by ETEC, Rockwell International, Canoga Park, California, with Walt Ingle as the principal investigator.

Further details resulting from the architectural review may be found in the specific report sections for other related tasks.

III. ANALYSIS OF FINAL DESIGN

A. INTRODUCTION

The final King Faisal Passive Cooling Experimental Facility design was evaluated by three different computer codes. Two of the codes utilize finite difference calculation techniques and the other utilizes conduction transfer function techniques. The three codes are:

1. The Building Loads Analysis and System Thermodynamics (BLAST) (1)

   U.S. Army Construction Engineering Research Laboratory
   Conduction Transfer Functions

2. MICROPAS

   Advanced Energy Group
   Finite Difference

3. ERL PASSCOOL

   Environmental Research Laboratory
   Finite Difference

All three simulations show good agreement for peak cooling and total cooling. All the simulations are based upon the building model developed for the BLAST simulations; however, the weather for the MICROPAS simulation was for El Centro, Ca., as the weather there closely approximates the weather in Dammam, Saudi Arabia.

The MICROPAS analysis was conducted for MRI SOLERAS by J. Mark Hannifan, Consultant to MRI, Advanced Energy Group.

B. COMPUTER SIMULATIONS/HEAT-COOL LOAD ANALYSIS USING BLAST

1. General Description of BLAST

   The Building Loads Analysis and System Thermodynamics (BLAST) (1) program is a comprehensive set of subprograms for predicting energy consumption and energy systems performance and cost in buildings. There are three major subprograms (see Fig. III.B.1):

   a. The Space Load Predicting Subprogram computes hourly space loads in a building or zone based on user input and weather data.

   b. The Air Distribution System Simulation Subprogram uses the computed space loads, weather data, and user inputs describing the building air-handling system to calculate hot water, steam, gas, chilled water, and electric demands.

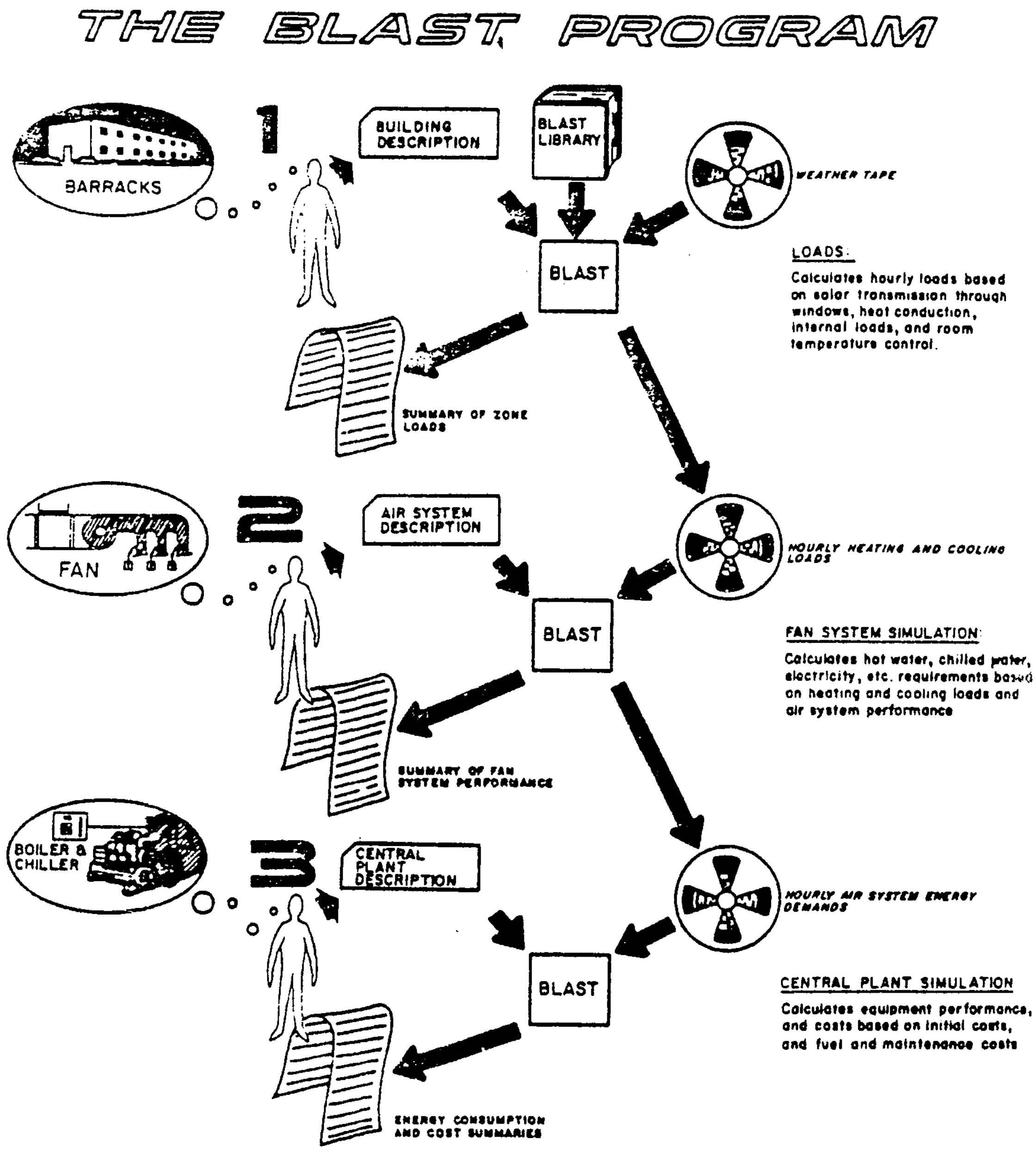


Figure III.B.1. The BLAST Program

c. The Central Plant Simulation Subprogram uses weather data, results of air distribution system simulation, and user input describing the central plant to simulate boilers, chillers, onsite power generating equipment and solar energy systems, and computes monthly and annual fuel and electrical power consumption.

The program was developed by the U. S. Army Construction Engineering Research Laboratory (CERL). The source code was written in FORTRAN and can be run on the University of Arizona Cyber 175 computer system. The current version is version 3.0 which was released in 1981.

Apart from its comprehensiveness, the BLAST program differs in four key respects from similar programs used in the past.

a. The BLAST program uses extremely rigorous and detailed algorithms to compute loads, simulate fan systems, and simulate boiler and chiller plants.

b. The program has its own user-oriented input language and is accompanied by a library which contains the properties of all materials, wall, roof, and floor sections listed in the ASHRAE "Handbook of Fundamentals".

c. The program execution time is brief enough to allow many alternatives to be studied economically.

d. The program is not proprietary and is, therefore, open to inspection by its users and those who rely on its results.

While BLAST provides valuable assistance in performing calculations required to design heating, ventilating and air-conditioning systems and select equipment, it is most useful as a tool to evaluate design alternatives. Through an iterative process of changing the design and evaluating the results, it is possible to optimize both the building design and the energy system design; however, the analysis procedure is not automatic and considerable judgement, intuition, and analysis by the designer are still required.

The next section considers the specific application of the BLAST program in the analysis of the proposed design for the Passive Solar Cooling Project at the King Faisal University in Dammam, Saudi Arabia. In this case the building design is essentially complete, but some options can be studied and the system design can be expedited through the use of BLAST.

2. Blast Input and Output

In order to perform a BLAST simulation, it is first necessary to prepare an input deck including;

a. The job control cards required for BLAST to run at a particular installation.

b. The lead input: This includes information to control the simulation and specify the output format.

c. The building description: A detailed geometrical description of the building along with information about temperature control, infiltration, and internal load.

d. Fan system description: (only required for system simulation).

e. Central plant description: (only required for central plant simulation, e.g., when the air system requires chilled water from an external source).

For building load analysis, only the first three are required, Specific instructions for setting up input decks are contained in the BLAST Version 2.0 User's Manual, as updated by the Version 3.0 User's Manual.

For any BLAST simulation, the output consists of:

a. A printout of the entire input deck

b. A series of several default reports

c. Any of several optional reports

For a building load run, the default reports include:

a. Control schedules - shows schematically the control schedule used for heating and cooling.

b. General schedules - shows the schedules used for internal load and infiltration in the format shown in Fig. III.B.2.

c. Description of Zone report - gives data on all surfaces bordering each zone, including U-values, areas, geometric information, and surface type (from BLAST library).

d. Zone Group Loads report - gives the total and peak heating and cooling loads for the period of the simulation.

The optional reports include:

a. Zone Loads report - gives hourly loads with separate listings for latent, electric and infiltration loads. This report was helpful in analyzing diurnal trends.

b. Zone report - gives a geometrical description of the zones described using Cartesian coordinates, along with a simplified plant view of the zones. This was very helpful in verifying the building descriptions.

c. Walls report - gives detailed information on the wall construction of each zone, including the conduction transfer

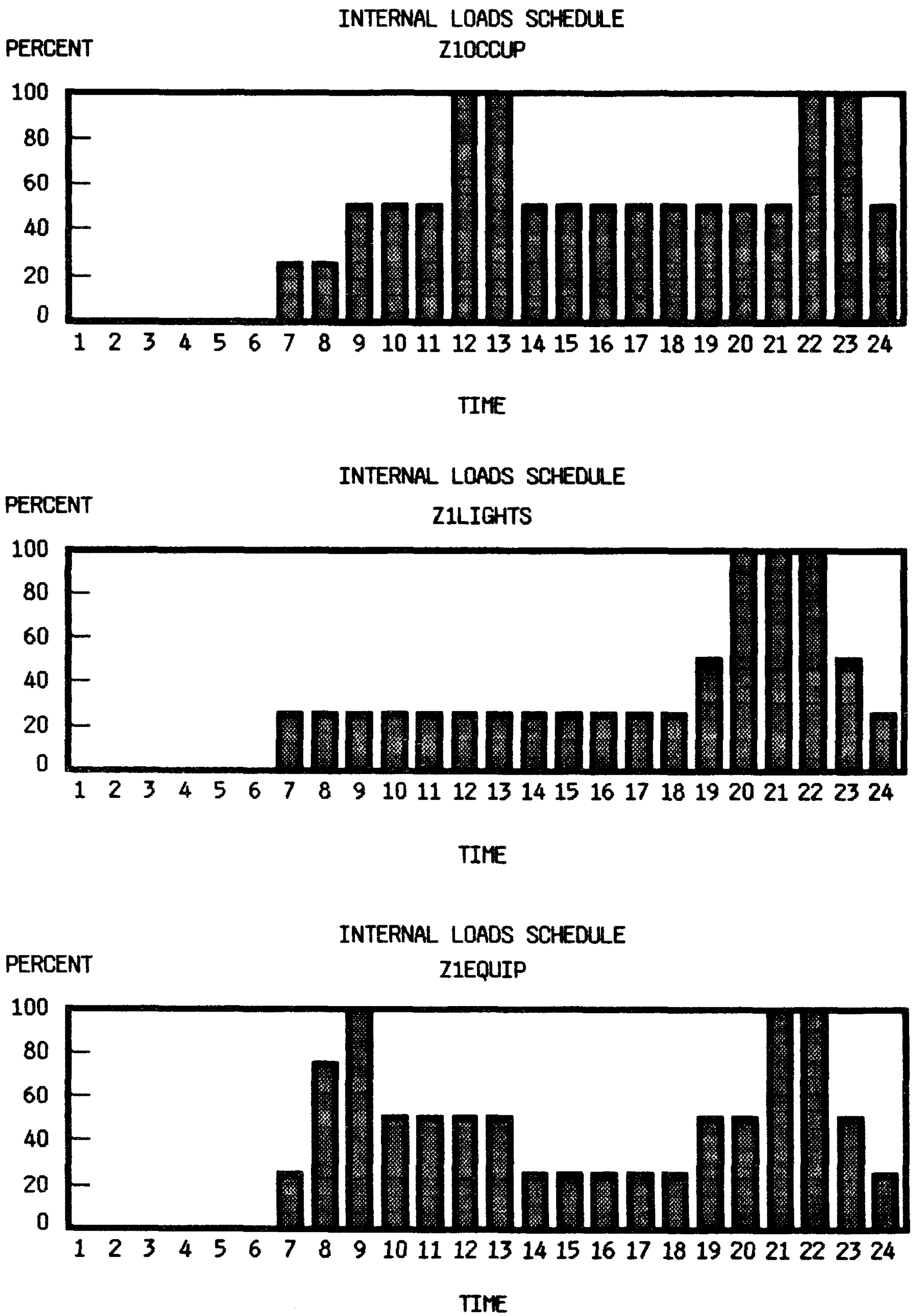


Figure III.B.2a. Internal Load Schedules

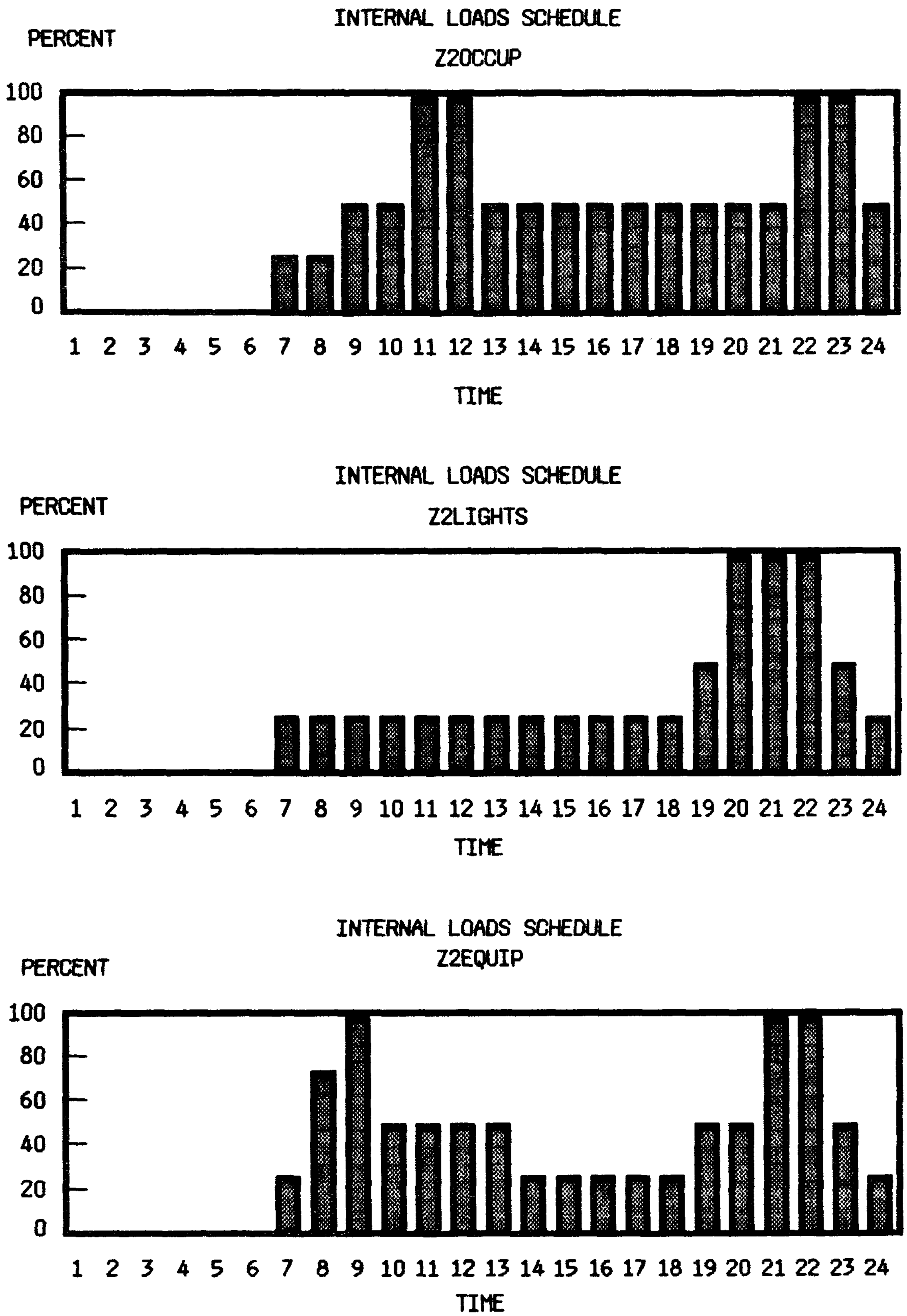
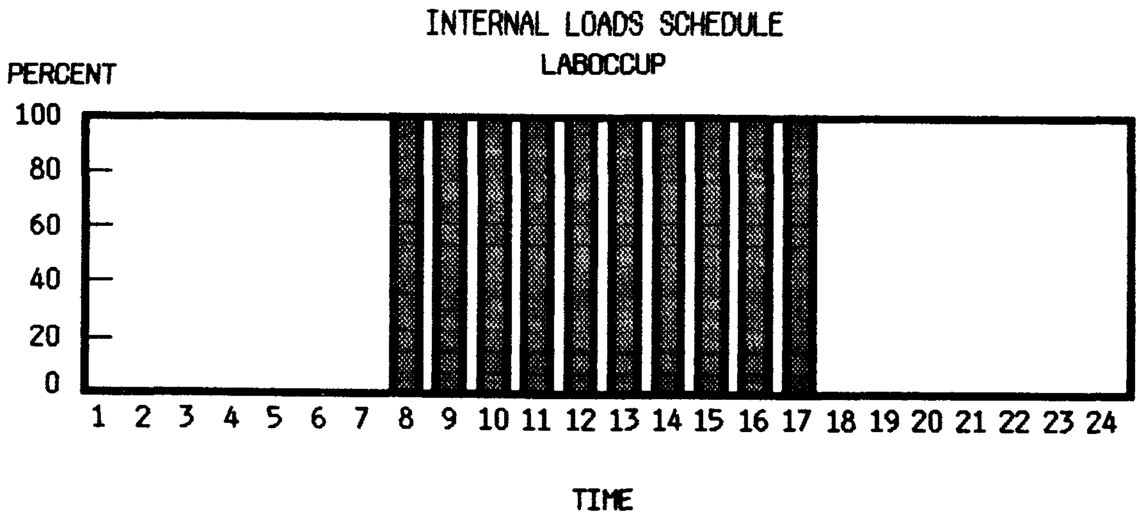


Figure III.B.2b. Internal Load Schedules



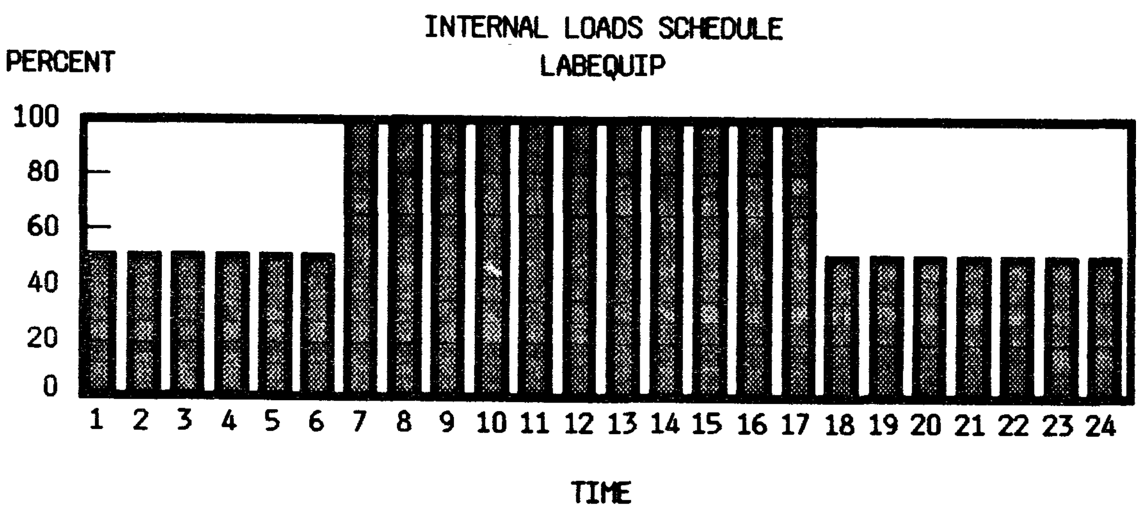


Figure III.B.2c. Internal Load Schedules functions used to define the time dependent thermal conductivity of the surfaces.

d. Shade report - gives information in which areas are shaded or sunlit. This was used to help verify the simplifications made to the building shading devices.

For a system simulation run, there are several other default and optional reports which are available. These include a System Energy Use Summary, a Loads Not Met Summary, a Component Loads Summary, and a System Description report. These can be seen in the attached one year simulation in Appendix III.

3. Simulation of Final Design Using BLAST

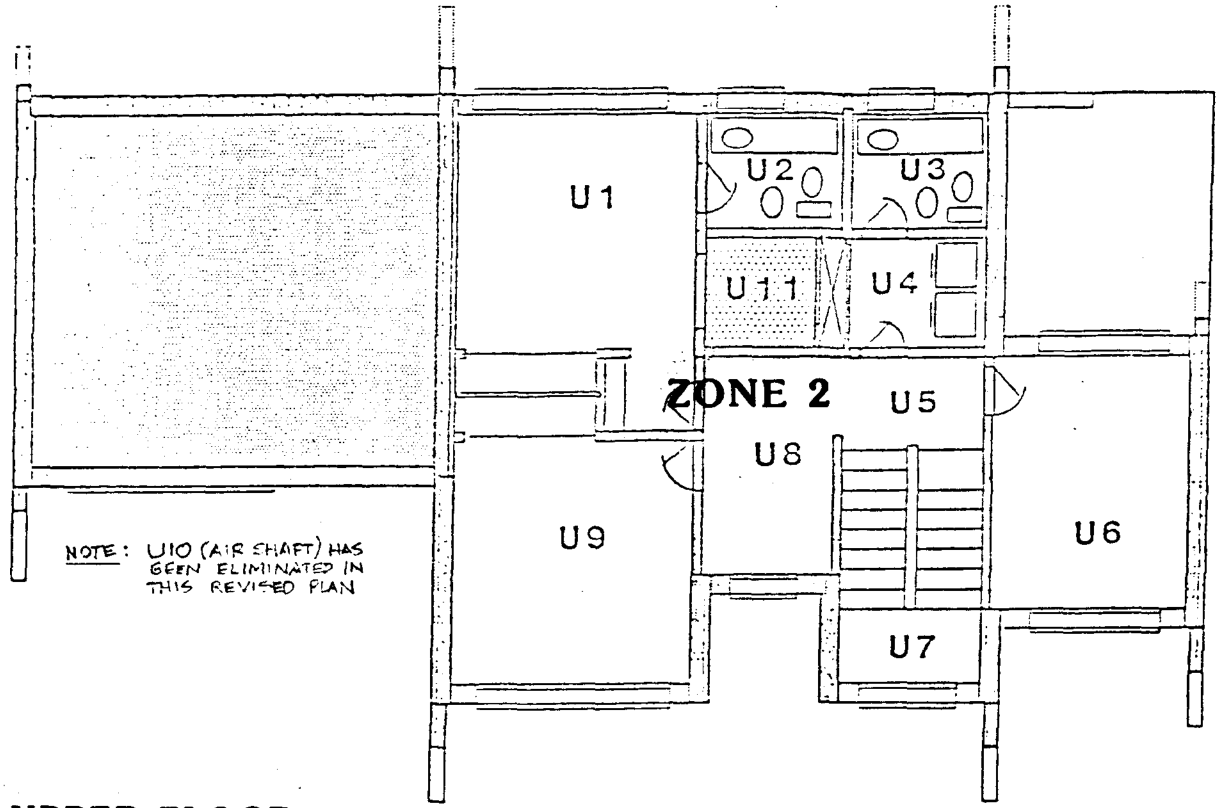
The building under study represents a compromise of several design features, influenced by factors such as local weather conditions, accepted religious and social customs, cost, aesthetics, and local building codes. This is reflected in the blueprints and reports received from King Faisal University which were used to generate the BLAST building description. The intention of the BLAST analysis is not to significantly alter the basic design as presented, but to investigate the relative effects of different wall construction, window construction, building orientation and shading effects on the building loads, and to aid in the design and selection of a heating and cooling system.

In simulating this building (designated Bldg. F, as explained later), there were some simplifications and assumptions required for the building description. The first step was to separate the building into zones, based on which areas would be controlled by a single thermostat. It was decided to simulate three zones:

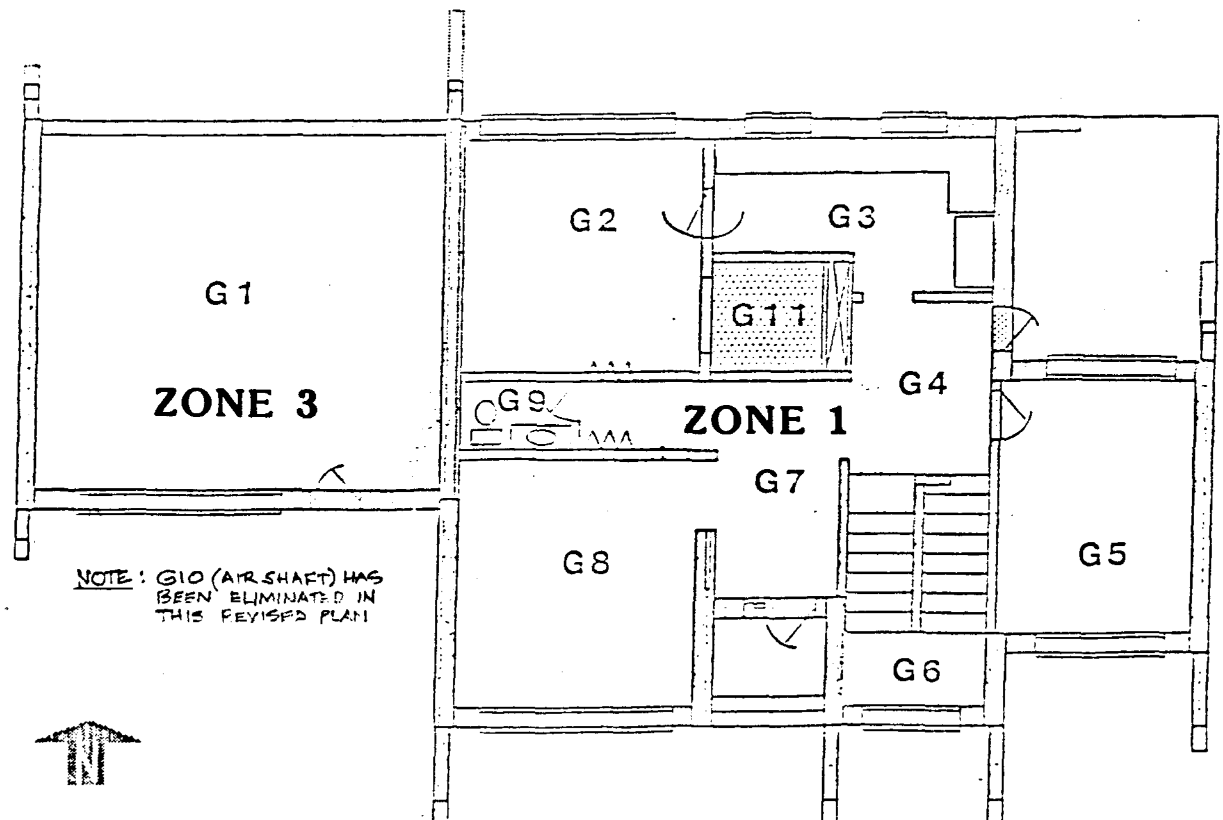
Zone 1 - Ground floor
Zone 2 - First floor
Zone 3 - Garage

(Note: A ten zone analysis was performed for the system analysis as discussed below). Each of the zones had to be described separately. The garage was simulated as a data room and was assumed to be air-conditioned. The zoning of the three zone building is shown on Figure III.B.3.

The most significant assumption involved the internal load due to people, lights, and equipment in the building. The building is intended to serve as a laboratory, but for the purpose of this analysis it was assumed to be a typical Saudi residence for a family of nine people. Based on conservative estimates, and on discussions regarding the living patterns of the typical Saudi family, the following maximum values were used:



UPPER FLOOR



GROUND FLOOR

FIG. III.B.3 : HVAC SIMULATION ZONES

MAXIMUM VALUES FOR INTERNAL LOAD

	ZONE 1	ZONE 2	ZONE 3
PEOPLE	9	9	3
LIGHTS (KW)	2.0	1.5	0.5
EQUIPMENT (KW)	4.0	0.2	1.0

The hourly load schedules which were assumed for the different zones are listed below, and the hourly profiles are shown in Figure III.B.2.

INTERNAL LOAD SCHEDULE NAME

	ZONE 1	ZONE 2	ZONE 3
PEOPLE	Z1OCCUP	Z2OCCUP	LABOCCUP
LIGHTS	Z1LIGHTS	Z2LIGHTS	LABOCCUP
EQUIPMENT	Z1EQUIP	Z2EQUIP	LABEQUIP

The internal load adds to the zone cooling load, and shifts the time at which the peak cooling occurs based on the particular zone load profile.

In describing the building envelope, several simplifications were required. The louvers on the windows could not be sloped, so they were treated as horizontal overhangs of dimensions which would give equivalent shading throughout the year. The sloping vertical wings of the house were treated as rectangular wings of nearly equivalent dimensions, using a different size for ground floor and first floor. The windows were simulated as double-pane windows with medium-weave drapes on the inside. Infiltration was determined by using the ASHRAE crack method, assuming a relatively tight window construction with relatively tight doors. The infiltration rate is assumed constant throughout the day, and this is represented by a schedule with the same format as an internal load schedule.

In order to describe the construction materials as accurately as posible, a new BLAST Library was created specifically for this project. Walls, windows, roofs, ceilings, floors, and doors are described in the library using ASHRAE data. Also included are data on location, weather, internal load schedules, and temperature control schemes. A printout of the library can be found in Appendix III.

The weather data contained in the library play an important role in the BLAST simulations, and considerable effort was made to try and characterize the Dammam weather as accurately as possible. Data from several sources were used including KFU report 82-1, the ASHRAE "Handbook of Fundamentals", a Dhahran weather station, and a NOAA weather tape from a U. S. Air Force base in Dhahran. These data were reduced into a design summer day, a design winter day, and an average day for each month of the year. It was also possible to run the simulation using the weather tape directly, as will be discussed below.

For the baseline building load analysis, a relatively simple deadband temperature control scheme was assumed, with heating below 21 deg. C, and cooling above 23 deg. C. Different control temperatures were studied to determine the relationship between load and setpoint, and this will be discussed below.

The wind tower operation was not considered in any of the BLAST simulations. The program does have the capability to include ventilation, but for the simulations performed for this report, the wind tower was assumed to be sealed and no building ventilation was accounted for.

The above discussion covers the description of the "base case" building which serves as the standard from which comparisons may be made for other design options. The next section gives results of some of the optimization studies, for the building envelope and the system design.

4. Simulation Results and Design Recommendations

Building Envelope and Construction

The following comparisons are based on the total cooling and peak cooling requirements on the summer design day. The summer design day is included in the BLAST library and is defined as:

DATE	- July 17
HIGH TEMP	- 43.9 deg C (ASHRAE 1% design value)
LOW TEMP	- 30.9 deg C (based on mean daily range)
WET BULB	- 28.9 deg C (coincident with HIGH TEMP)
WIND SPEED	- 5.4 m/sec.
WIND DIR	- 330 degrees
CLEARNESS NO.	- 0.9 (assumed using ASHRAE guidelines)

Heating is not considered in these comparisons since the internal load of the house generally precludes any heating requirements. Simulation runs were made with and without internal load, and the results were similar. Note that the results given below and on Tables III.B.1. - III.B.3. refer to the base case with no internal load, except as noted.

Walls: The base case assumed that the 200 mm concrete block was filled with sand, and that a 100 mm concrete block wall was included under the stucco surface layer. Two comparisons were made here. First, the base case was compared with unfilled concrete block. The results showed that it was not worth the added cost to fill the block. Both the peak cooling and total cooling increased only 0.5% on the summer design day with the unfilled 200 mm block. The second comparison involved removal of the 100 mm concrete block layer from the exterior walls. Here the results showed a slight decrease in thermal performance from removal of the 100 mm layer. The total cooling increased 0.6% and the peak cooling increased 2.0%. This consideration alone does not justify the 100 mm layer, but there may be other reasons for including it in the design.

	Wall U Value ($W/m^2 °C$)	Total Cooling (KWH/day)	Peak Cooling (KW)	Remarks
Base Case	0.304	164.0	7.74	
200 mm Block unfilled	0.307	165.0	7.78	Very slight increase in cooling load.
100 mm Block omitted	0.316	165.0	7.90	Peak cooling slightly higher.

Table III.B.1 Wall Optimization

	Wall U Value ($W/m^2\ ^oC$)	Total Cooling (KWH/day)	Peak Cooling (KW)	Remarks
Base Case	3.14	164.0	7.74	Clear glass, double pane, drapes inside
Klos Windows unfilled	3.04	166.0	7.86	Venitian blind between panes, no drapes, clear glass
Reflective film	3.14	148.0	6.77	10% reduction total cooling. 12% reduction peak cooling.
Heat absorbing glass	3.04	166.0	7.86	4% reduction total cooling. 5% reduction peak cooling.

Window Area Effects

	Window Area (m^2)	Total Cooling (KWH/day)	Peak Cooling (KW)	Remarks
Base Case	38.8	258.3	14.6	Window area is 14% of floor area.
Window area reduced ≈ 50%	19.1	234.7	13.4	9% reduction total cooling. 8% reduction peak cooling.

Table III.B.2 Window Optimization

Note: Window area effects was performed with internal loads and without the data room zone.

Building Orientation (deg)	Total Cooling (KWH/day)	Peak Cooling (KW)	Remarks
0° N	164.0	7.74	Building aligned with front door S.
15° NNE	168.0	7.84	
30° NE	177.5	8.72	
15 ° NNW	166.0	8.53	Optimum for ventilation: 10% increase peak cooling.
30 ° NW	173.3	9.50	6% increase total cooling. 23% increase peak cooling.

Table III.B.3 Optimum Orientation of Base Case Design

In both of these cases, the design change resulted in a higher U-value for the wall, but in a transient analysis of the building loads, there is still enough mass in the walls to minimize the effect of a slight increase in thermal conductance. The results of the wall studies are shown on Table III.B.1.

Windows: The base case window condition was assumed to be a double-pane clear sheet glass with louvers on the outside and drapes on the inside. This configuration effectively eliminates direct solar gain in the summer, and greatly reduces it in the winter. This also results in the lowest cost situation among all the window options. Three basic comparison studies were done for windows.

The first was a comparison of the base case condition with a Klos window design, consisting of a double-pane window with a 100 mm air gap and venetian blinds in between. The Klos windows showed a slightly higher cooling load (1-2%). The U-value was slightly lower for Klos, but the solar gain was apparently a little higher. The net result was similar thermal performance. The choice must be based on functional and cost considerations.

Next, various treatments were considered, including heat-absorbing glass and reflective glass. These designs had the same U-values, but different transmissivities from the base case. Window treatments were considered for the Klos design, also. The results showed that the optimum configuration had reflective treatments on the north and south windows. The results can be seen more clearly on Table III.B.2.

The third window study involved the relative window area of the building. The window area of the base case was determined to be 14% of the floor area of the house. For comparison, the window area was cut in half. The results showed a decrease of 8% in total cooling, and 9% in peak cooling on the summer design day. It can be deduced that a reduction in window area to 10% of the floor area would result in about a 5% reduction in cooling load. This benefit must be weighed against any possible detriment to ventilation, or daylighting in the house.

Building orientation: Due to the unique wind situation of the Dammam area (i.e., hot, dry winds from the northwest and sea breezes from the northeast), comparisons were made with different building orientations. The base case building was facing directly north, and comparisons were made at 15 and 30 degrees on either side of north to see the effects on thermal performance. The optimum wind orientation was assumed to be 15-20 degrees to the west of north. At this orientation the total cooling increased only slightly, but the peak cooling increased by 10% over the base case. This thermal trade-off must be weighed against any potential ventilation improvements at this orientation. The results of the building orientation comparisons are shown on Table III.B.3.

Shading: The various shading features of the house were also studied. The original design had a steep north-facing louvered roof above the roof terrace, which had virtually no effect on the building loads, although it might be useful as a windscreen if the terrace were occupied. The south-facing louvered roof is much more effective in shading the sun, but its net effect on building load is less than 1%. The triangular-shaped wings of the building have some small shading effect, although it is probably not their primary function. But the window louvers are one shading feature which is quite important. Since heating in the winter may only be a problem during a relatively brief period, these louvers should be adjusted to exclude direct sunlight during all but the coldest months of the year.

Appendix III contains samples of the printed output from two summer design day simulations. The first is the base case including the optional Walls, Zone, and Zone Loads reports. The Walls and Zone reports are shown only for example in this case. The second is a comparison run with all of the windows changed to reflective windows. The optional Zone Loads report along with the default Zone Group Loads report can be used for comparing the loads between the base case and reflective windows. This is an example of the method used in this design optimization study.

5. Heating and Cooling System Design

Prior to the system design, it is instructive to look at some general considerations relating to the thermal performance of buildings in general. In any heating and cooling system, the control temperature setpoint plays an important role in determining energy use. For the base case, an average room temperature of 22 deg C was assumed. For the base case, a 21 - 23 deg C deadband control scheme was simulated to provide cooling when the room is above 23 deg C, and heating when the room is below 21 deg C. As mentioned above, cooling is the most critical consideration, so the summer design day is used as a point of reference to design the cooling system. For peak cooling and total cooling there is an inverse relationship between load and control temperature setpoint. In the range of 20 - 25 deg C, the peak cooling was found to drop 0.7 KW for each 1 deg C rise in cooling setpoint. The total cooling dropped 16 KWH/day for each 1 deg C rise in setpoint. This information might be ueful in estimating the effects of different setpoints on the cooling load.

Another consideration is the "float" temperature, or the interior temperature of the house without any heating or cooling. Two BLAST simulations were performed for the summer design condition, one with internal load, and one without. The "float" temperatures were found to be 33 - 36 deg C without internal load, and 36 - 40 deg C with internal load. The diurnal variation of temperature inside the house was very small, on the order of 1 deg C for the case with no internal load. But the time of the peak is also important. Without internal load the peak temperature occurred at 17:00, but with internal load the peak occurred at 21:00 to 22:00.

This points out the effect of the internal load on the peak cooling load.

To provide maximum accuracy in sizing the system, the BLAST program was used to simulate the house with ten zones, instead of only three. The same building description data was used, but the internal loads were distributed appropriately throughout the individual zones. The most significant observation from the system simulation was that the total system load was 20 - 30 percent higher than the space load due to the latent component. Several types of systems can be simulated in BLAST, but most are used only in larger commercial buildings. Simulations of Bldg F were performed for both a fan-coil and a DX packaged unit with similar results. The attached one year simulation was run with a two-zone DX system (garage excluded) to give an approximation of the annual energy requirements of the house, if it were used as a residence. Details of the system design and selection have been discussed separately, and will not be covered here.

6. One Year Simulation with 1957 Weather Tape Data

The BLAST program can be run with weather input from a weather tape. Several common formats are acceptable including SOLMET, NOAS, and TMY. For this project, a NOAA TDF-1440 tape was obtained from a U. S. Air Force Weather Station in Dhahran. The tape contains hourly data from 1949 to 1962, but some of the data seems unreliable. The year 1957 was selected because the tape had a full 8760 hours of data. Monthly and daily reports of this data are contained in the Appendix, along with a sample hourly report for 1 January. Inspection of the weather data shows that much of the data looks good, but there are some very suspicious temperature readings, and the hourly wind data are not complete. Other years on the tape were inspected, but the results were the same. It is unfortunate that these incongruities exist, however, the weather tape is still useful.

The results of a one year simulation with the 1957 weather tape data were compared with the results of a run using 12 monthly average days, and the weather tape total cooling load was 8.4% higher. This agreement is reasonable in light of the very high temperatures periodically recorded on the tape. But for comparisons on a monthly or annual basis, the monthly average data are sufficient, and the peak loads will not be unrealistically extreme.

A one year simulation is included in Appendix III to give an example of the output format for a weather tape run, and to give an estimate of the annual energy requirements of the house if it were used as a residence. The building is simulated as a three zone building, but only two zones are cooled; the garage is not conditioned. Due to the problem with the weather data, the "peak" values should be disregarded, as well as the "DXUNIT CAP EXCEEDED" warning messages which are erroneously generated due to high ambient temperatures.

C. PASSCOOL: COMPUTER MODEL FOR THERMAL SIMULATION OF HIGH-MASS BUILDINGS

1. INTRODUCTION

PASSCOOL, an in-house computer model, was written in APL (1) for use on an IBM Personal Computer. APL was used because of the ease of matrix manipulation with this language, especially important in programs involving the solution of transient heat flow problems by finite difference methods which require the manipulation of large matrices.

The primary reference used in writing the program was the widely available 1977 ASHRAE Handbook (2). The units in the ASHRAE Handbook are based on the British system, which is also employed in the program.

The program is similar to one prepared for the Electric Power Research Institute (EPRI) (3) to study the effect of thermal mass in residences on peak power demand. That program was verified against experimental results, as illustrated in Figure III.C.1.

PASSCOOL is similar to the ERL/EPRI program in that the Crank-Nicolson method (4) is used to determine heat fluxes associated with massive walls; however, the present program also computes humidity, PMV (2) (Predicted Mean Vote—a method of indicating thermal comfort conditions), and the performance of composite walls and slabs. The program can also be used to determine the performance of low-mass structures with either refrigeration, evaporative cooling, or heating. The ASHRAE (2) method for computing solar heat gain is incorporated in the program. It is limited in that it does not compute shading effects on walls by building components or external objects; to allow for these effects the user must estimate appropriate values for the absorptivity of the various surfaces. It also does not allow for condensation of moisture on windows or walls if their temperatures should fall below the dew-point temperature. While most of the program is written in general terms, applicable to any building in any location, the portions of the program relating to wind tower performance and natural ventilation are specific to the KFU building design.

The method of computing heat storage and temperatures in the building used in the program is explained in the following sections.

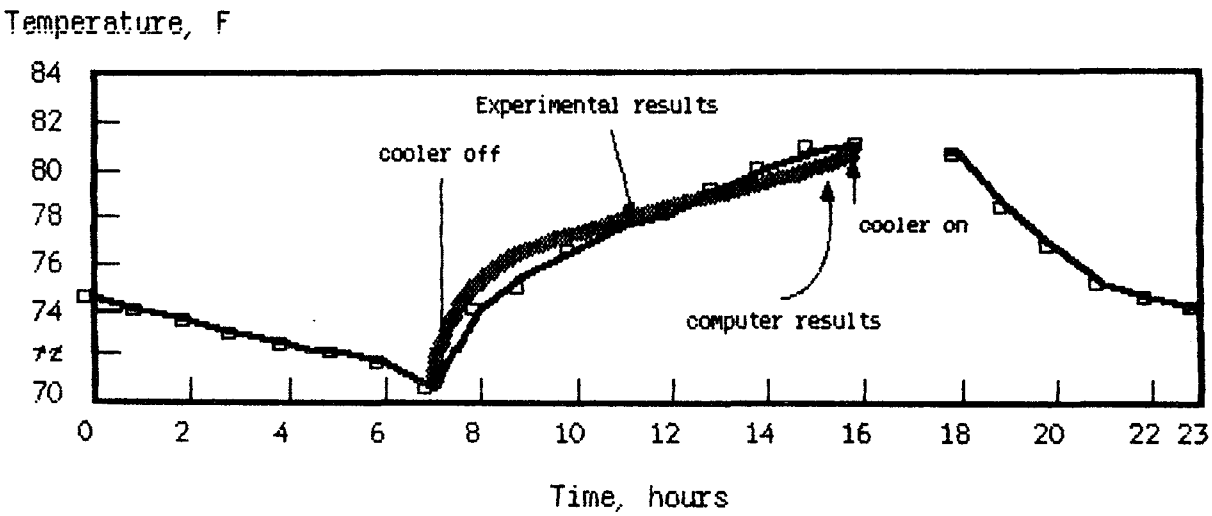


Figure III.C.1. Comparison of experimental data and computer simulation for daytime conditions in a nocturnally cooled house. Data from June 16, 1981, U.S. Home solar home

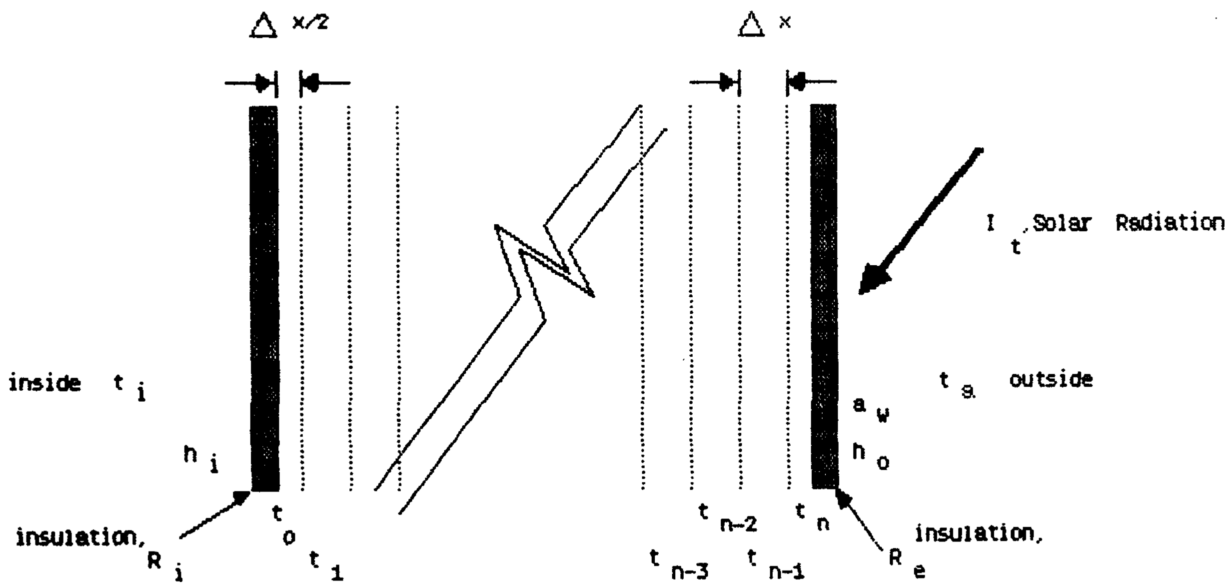


Figure III.C.2. Wall Section

2. ENERGY STORAGE IN MASSIVE WALLS

Determination of energy storage and temperature gradients within massive masonry walls generally follows the Crank-Nicolson finite difference method described by Myers (4), modified to allow for solar radiation and low-mass insulation on the wall surfaces. An exterior mass wall is used to describe the method of analysis which follows; however, the method can also be applied on interior walls or the floor slab with obvious modifications. Referring to Figure III.C.2, the wall is considered to be divided into interior sections of thickness "Δx", with two half-sections of thicknesses "$\Delta x/2$" at the inside and outside surfaces. At the interior and exterior wall surfaces are two layers of low-mass insulation, having resistances R_i and R_e, $(ft^2)(hr)(^oF)/Btu$, and surface heat transfer coefficients h_i and h_o, $Btu/(ft^2)(hr)(^oF)$, which combine both convective and long-wave radiative components (2). The exterior wall may also receive solar radiation, I_t, $Btu/(ft^2)(hr)$ of which the fraction absorbed is given by the wall absorptivity, α_w. Using the "sol-air temperature" method (2), heat transfer to the exterior wall surface can be simplified by replacing the outside temperature and solar radiation with an effective temperature, t_e, ^oF, as:

$$\alpha_w I_t + h_o(t_a - t_s) = h_o(t_e - t_s)$$

$$t_e = t_a + \alpha_w I_t/h_o \qquad \text{(IIIC-1)}$$

where t_s is the surface temperature of the insulation. Further simplification is possible by combining the surface heat transfer coefficients with the low-mass resistances as:

$$U_i = 1/[(1/h_i) + R_i] \qquad \text{(IIIC-2)}$$

$$U_e = 1/[(1/h_o) + R_e] \qquad \text{(IIIC-3)}$$

If either of the layers of insulation have appreciable heat capacity, then the wall must be treated as a composite high-mass wall.

A heat balance around the first half-section of the inside of the mass wall is:

$$U_i(t_i - t_o) = \rho C_p(\Delta x/2)dt_o/d\theta + (k/\Delta x)(t_o - t_i) \qquad \text{(IIIC-4)}$$

where ρ, C_p and k are the density, specific heat, and thermal conductivity of the wall material. θ is time.

A balance around the next section is:

$$(k/\Delta x)(t_o - t_1) = \rho C_p(\Delta x)dt_1/d\theta + (k/\Delta x)(t_1 - t_2) \qquad \text{(IIIC-5)}$$

Balances around succeeding sections are similar to Eq. IIIC-5 until the last section is reached:

$$\rho C_p(\Delta x/2)dt_n/d\theta + (k/\Delta x)(t_{n-1} - t_n) = U_e(t_n - t_e) \qquad \text{(IIIC-6)}$$

The balance around any interior slab "j", similar to slice "1", Eq. IIIC-5 can be rewritten as:

$$dt_j/d\theta = (k/\rho C_p\Delta x^2)[(t_{j-1} - t_j) - (t_j - t_{j+1})] \qquad \text{(IIIC-7)}$$

If $t_j^{\theta 1}$ is the temperature at time θ_1, and $t_i^{\theta 2}$ is the temperature of the slab at θ_2, where $\theta_2 - \theta_1 = \Delta\theta$, the change in temperature by the Crank-Nicolson method (3) is given by:

$$t_j^{\theta 2} = t_j^{\theta 1} + \frac{1}{2}\left[\left.\frac{dt_j}{d\theta}\right|^{\theta 1} + \left.\frac{dt_j}{d\theta}\right|^{\theta 2}\right]\Delta\theta \qquad \text{(IIIC-8)}$$

That is, the average value of the derivative is used to move ahead in time. If $p = (k/\rho C_p)(\Delta\theta/\Delta x^2)$, where the group $k/\rho C_p$ is the thermal diffusivity, Eqs. IIIC-7 and IIIC-8 can be rewritten as:

$$-(p/2)t_{j-1}^{\theta_2} + (1+p)t_j^{\theta_2} - (p/2)t_{j+1}^{\theta_2} = (p/2)t_{j-1}^{\theta_1} + (1-p)t_j^{\theta_1} + (p/2)t_{j+1}^{\theta_1} \qquad \text{(IIIC-9)}$$

Similarly, if $H_i = U_i\Delta x/k$, $H_e = U_e\Delta x/k$, $\bar{t}_i = \frac{1}{2}(t_i^{\theta_1} + t_i^{\theta_2})$, and $\bar{t}_e = \frac{1}{2}(t_e^{\theta_1} + t_e^{\theta_2})$, then Eq. IIIC-4 can be written:

$$[1 + p(1 + H_i)]t_o^{\theta_2} - pt_1^{\theta_2} = 2pH_i\bar{t}_i + [1 - p(1 + H_i)]t_o^{\theta_1} + pt_1^{\theta_1} \qquad \text{(IIIC-10)}$$

and Eq. IIIC-6 becomes:

$$-pt_{n-1}^{\theta_2} + [1 + p(1+H_e)]t_n^{\theta_2} = pt_{n-1}^{\theta_1} + [1 - p(1 + H_e)]t_n^{\theta_1} + 2pH_e\bar{t}_e \qquad \text{(IIIC-11)}$$

The system of equations can be written in matrix form as:

$$\begin{bmatrix} [1 + p(1 + H_i)] & -p & 0 & 0 & \cdots & 0 \\ -p/2 & 1+p & -p/2 & 0 & \cdots & 0 \\ 0 & -p/2 & 1+p & -p/2 & 0 & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & 0 & -p/2 & 1+p & -p/2 \\ 0 & \cdots & 0 & 0 & -p & [1 + p(1 + H_e)] \end{bmatrix} \begin{bmatrix} t_o \\ t_1 \\ t_2 \\ \cdots \\ t_{n-1} \\ t_n \end{bmatrix}^{\theta_2} =$$

(IIIC-12)

$$\begin{bmatrix} 2p\,H_i & [1 - p(1 + H_i)] & p & 0 & 0 & 0 & \cdots & 0 \\ 0 & p/2 & 1-p & p/2 & 0 & 0 & \cdots & 0 \\ 0 & 0 & p/2 & 1-p & p/2 & 0 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 0 & p/2 & 1-p & p/2 & 0 \\ 0 & 0 & \cdots & 0 & 0 & p & [1 - p(1 + H_e)] & 2pH_e \end{bmatrix} \begin{bmatrix} \bar{t}_i \\ t_o^{\theta_1} \\ t_1^{\theta_1} \\ t_2^{\theta_1} \\ \cdots \\ t_{n-1}^{\theta_1} \\ t_n^{\theta_1} \\ \bar{t}_e \end{bmatrix}$$

If $n = x_t/\Delta x$, where x_t is the total wall thickness, ft., the dimensions of the matrix on the LHS of Eq. IIIC-12 are $(n + 1)x(n + 1)$ while those of the RHS are $(n + 1)x(n + 3)$. The solution temperature vector at θ_2 contains n + 1 elements, while the input temperature vector at θ_1 contains n + 3 elements, i.e. the temperatures of the wall interior plus the average values of the inside temperature and the exterior sol-air temperature.

In the computer program, the product of the inverse of the LHS matrix and RHS matrix, which are conformable, is computed once and stored as a "constant" matrix for the wall, which is multiplied by succeeding temperature vectors to step through the total period of the run.

Composite walls are treated similar to the single slab model. For example, take the case of a composite wall consisting of inner and exterior slabs of different high mass materials, separated by low mass insulation having a resistance R_c. The inner slab variables are:

$$p_i = (k_i/\rho_i C_{pi})(\Delta\theta/\Delta x_i^2)$$

$$H_{ci} = \Delta x_i/R_c k_i \qquad \text{Note:} R_c \neq 0$$

while the outer slab variables become:

$$p_o = (k_o/\rho_o C_{po})(\Delta\theta/\Delta x_o^2)$$

$$H_{co} = \Delta x_o/R_c k_o$$

$\Delta\theta$ is the same for these expressions; however, Δx, k, ρ and C_p may differ. Then a balance around the last section of the inner slab gives:

$$- p_i t_{n-1}^{\theta_2} + [1 + p_i(1 + H_{ci})] t_n^{\theta_2} - p_i H_{ci} t_o^{\theta_2} =$$

$$p_i t_{n-1}^{\theta_1} + [1 - p_i(1 + H_{ci}) t_n^{\theta_1} + p_i H_{ci} t_o^{\theta_1} \qquad \text{(IIIC-13)}$$

Similarly, a balance around the first section of the outer slab is:

$$-p_o H_{co} t_n^{\theta_2} + [1 + p_o(1 + H_{co})] t_o^{\theta_2} - p_o t_1^{\theta_2} =$$

$$p_o H_{co} t_n^{\theta_1} + [1 - p_o(1 + H_{co}] t_o^{\theta_1} + p_o t_1^{\theta_1} \qquad \text{(IIIC-14)}$$

where t_{n-1} and t_n refer to the inner slab and t_o and t_1 refer to the outer slab. The matrices in (IIIC-12) are modified by inserting the constants from (IIIC-13) and (IIIC-14) and replacing p by the appropriate values of p_o and p_i. Any number of slabs may be connected to form a composite wall by this method.

Thermal properties for various slabs are stored within the computer program in a wall properties matrix, shown in table III.C.1. The thermal properties used in preparing this matrix are from the BLAST reference library. The programmer selects the wall type, or in the case of a composite wall the slab types and intermediate R values, and specifies the wall absorptivity, area, and orientation.

Table III.C.1

WALL PROPERTIES

Wall type	1	2	3	4	5
Thickness, X FT	0.0833	0.1250	0.1667	0.3333	0.4167
Therm.cond., k BTU/FT/HR/DEG F	0.7575	0.7575	0.7575	0.7575	0.7575
Therm.diff., SQ FT/HR	0.0271	0.0271	0.0271	0.0271	0.0271
ΔX FT	0.0417	0.0625	0.0833	0.1667	0.2083

Wall type	6	7	8	9	10	11
Thickness, X FT	0.5000	0.6667	0.3333	0.3333	0.6667	0.3333
Therm.cond., k BTU/FT/HR/DEG F	0.7575	0.7575	0.0200	0.4180	0.6310	0.0300
Therm.diff., SQ FT/HR	0.0271	0.0271	0.0383	0.0208	0.0380	0.0094
ΔX FT	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667

Note: Nos. 1-7 are concrete, No. 8 is styrofoam, Nos. 9&10 are hollow concrete block, and No. 11 is roof insulation.

3. ENERGY STORAGE IN FLOOR

If the floor slab is insulated underneath, or rests on low conductivity material, the treatment is similar to a massive wall with the exterior heat transfer coefficient equal to zero.

If heat transfer into the soil underneath the floor slab is significant, the slab-soil combination can be treated as a composite wall.

The effect of a carpet on the floor can be estimated by assigning a thermal resistance value to the carpet, similar to R_i. The effect of furniture on the floor requires further research, but may be estimated by either increasing the thermal resistance of the carpet or reducing the area of the floor below its true value in proportion to the area covered by the furniture.

4. HEAT TRANSFER THROUGH LOW-MASS WALLS AND CEILINGS

Low-mass walls, such as frame walls insulated with mineral or glass fiber, and ceilings, may be assigned a single total resistance term, R_t, (hr) (sq. ft.) (^{o}F)/Btu:

$$R_t = 1/h_o + \Sigma R + 1/h_i \qquad \text{(IIIC-15)}$$

where ΣR is the sum of the resistances of wall components, e.g. siding, wallboard, air spaces, etc. Resistances for different wall types have been computed and are available in a number of reference texts (2). In the computer program, the resistance term used is the total resistance, less the film or surface resistances, or ΣR in Eq. IIIC-15, so that single values of h_i and h_o are used for all surfaces to reduce data input. Where different values are desired for the surface coefficients, ΣR may be adjusted by $\Delta(1/h)$.

Typical R values for low-mass walls without surface coefficients are 4 for uninsulated frame walls, 11.4 for frame walls insulated with R-11 blanket, and 17 for well-insulated frame walls.

Heat transfer by convection and long-wave radiation through windows may be treated similarly, and it is particularly important that the input R factor to the computer be calculated properly from the usual overall heat transfer coefficient and not include surface resistances:

$$R_{window} = (1/U)_{window} - 1/h_o - 1/h_i \qquad \text{(IIIC-16)}$$

For a single-glazed window, R will be the thermal resistance of the glass pane alone ($\cong$ 0.03); while for a double-glazed window R $\cong$ 0.6.

Low-mass roofs are treated in a similar manner to low-mass walls, with R values ranging from 4 to 30. Since the roof and ceiling areas may differ, the R value for the computer program should be calculated based on the ceiling area; that is, heat transfer through the roof to the interior should be expressed as:

$$Q = U_c A_c (t_e - t_i) \qquad \text{(IIIC-17)}$$

where $U_c = 1/(\Sigma R + 1/h_i + A_c/A_r h_o)$ (IIIC-18)

To remove the surface coefficients from the tabulated values of roof resistance, subtract $1/h_i + A_c/A_r h_o$. In many tables of R values, the total resistances are based on the exterior roof area, so it may be necessary to first multiply by A_c/A_r, where A_c is the ceiling area, sq. ft., and A_r is the roof area.

Also, as recommended by the ASHRAE Handbook, (2), the sol-air temperature, Eq.IIIC-1, is reduced for the roof equation by the amount $\varepsilon \Delta r/h_o$, where ε is the emittance, and Δr is the difference between the long-wave radiation on the roof from the sky and surroundings, and the radiation emitted by a blackbody at outdoor air temperature, Btu/(ft^2) (hr). The value of this term is about -7^{o}F.

5. SHADING COEFFICIENTS

Solar radiation through the windows can be conveniently calculated using the shading coefficient (SC) and solar heat gain factor method as explained in the ASHRAE guide (2). The shading coefficient is defined as the ratio of the solar heat gain through a glazing system under a specific set of conditions to the solar gain through a single layer of double-strength sheet glass under the same conditions. Typical values for shading coefficients are 1.0 for a single-glazed unshaded window, 0.88 for double-glazed insulating windows, 0.55 for light-colored venetian blinds behind a single-glazed window and 0.45 for light drapes behind a double-glazed insulating glass window.

6. INFILTRATION

Infiltration may be estimated by various techniques described in the literature (2). One of the more common methods of describing this quantity is in terms of the "number of air changes per hour" (N_c), or an air flow exchange rate equal to the number of times per hour a volume of air contained in the house interior is exchanged with outside air. The computer program requires that this quantity be expressed in terms of pounds of air per hour exchanged, or $\dot{m}_a = N_c V_H \rho_a$, where V_H is the volume of the house, cu. ft., and ρ_a is the density of air, lb/cu. ft.

7. INTERIOR TEMPERATURE

The interior house temperature is assumed to be that of the air and interior furnishings; that is, the area of interior furnishings and the rate of heat exchange between them and the air is assumed to be very large. If $\Sigma mC_p = (mC_p)_h$, or the sum of the products of the mass and heat capacity of furnishings and air in the house, then the rate of change of the interior temperature (t_i) is:

$$(mC_p)_h dt_i/d\theta = [\Sigma UA(t_e - t_i)]_{lm} + [\Sigma U_iA(t_o - t_i)]_{ehm} + 2[\Sigma U_iA(t_o - t_i)]_{ihm} + [U_iA(t_o - t_i)]_{flr} + \dot{m}_aC_{pa}(t_a - t_i) + \Sigma Q \tag{IIIC-19}$$

The subscripts lm refer to low-mass walls, windows, and roofs; with U being the overall heat transfer coefficient, A the area, and t_e the effective or "sol-air" temperature for each surface. The subscripts ehm refer to exterior high-mass interior walls, with U_i as defined in Eq. IIIC-2 and t_o as shown in Figure IIIC.2. The subscripts ihm refer to high-mass interior walls; this group must be multiplied by two, to account for each surface of the wall exposed to interior air. The subscripts flr refer to the floor. The group $\dot{m}_aC_{pa}$ is the product of the infiltration air flow rate and the heat capacity of air; while ΣQ is the sum of the solar heat input through windows and the rate of internal heat generation by occupants, electrical appliances, etc. When air conditioning is employed, the sensible heat removed is included as a negative term in ΣQ. This expression assumes that solar radiation through the windows is absorbed by the interior mass, and not the floor, walls, or ceilings directly; also, direct, long-wave radiation exchange between walls, ceiling, and floor is not included; and the interior geometry of the house is not specified.

Eq. IIIC-17 may be used in an integrated form over a period $\Delta\theta$, where the temperatures and coefficients can be considered constant by using average values. If

$$[\Sigma UA(t - t_{i1})]_o = [\Sigma UA(t_e - t_{i1})]_{lm} + [\Sigma U_iA(t_o - t_{i1})]_{ehm} + 2[\Sigma U_iA(t_o - t_{i1})]_{ihm} + [U_iA(t_o - t_{i1})]_{flr} + \dot{m}_aC_{pa}(t_a - t_{i1}) \tag{IIIC-20}$$

and

$$[\Sigma UA]_o = [\Sigma UA]_{lm} + [\Sigma U_iA]_{ehm} + 2[\Sigma U_iA]_{ihm} + [U_iA]_{flr} + \dot{m}_aC_{pa} \tag{IIIC-21}$$

where t_{i1} is the interior air temperature at the beginning of the time interval $\Delta\theta$, then

$$\Delta t_i = t_{i2} - t_{i1} = \{[\Sigma UA(t - t_{i1})]_o + \Sigma Q\}$$

$$\{1 - EXP - [\Sigma UA]_o \Delta\theta/(mC_p)_h\} / [\Sigma UA]_o \quad \text{(IIIC-22)}$$

When air conditioning is used to maintain some upper set-point temperature, Eq. IIIC-22 can be solved for ΣQ with t_{i2} equal to the set-point to determine the air conditioning required.

In evaluating expressions IIIC-20 and IIIC-22, the exterior air temperatures and "sol-air" temperatures are usually known over the period $\Delta\theta$, while the interior mass-wall temperatures are not. As an approximation, the interior mass-wall temperatures from the preceding time interval may be used; for this reason $\Delta\theta$ should be kept small.

8. INTERIOR TEMPERATURE WITH EVAPORATIVE COOLING OR NATURAL VENTILATION

The house interior can be cooled by ventilation with air from the outside or an evaporative cooler at an entering temperate of t_v. A number of different models for this type of cooling have been studied, most of which specify the path of ventilation air through the structure. The model used in PASSCOOL is probably the most straightforward:

$$\dot{m}_v C_{pa}(t_{v2} - t_v) = [\Sigma UA(t_e - t_i)]_{1m} + [\Sigma U_i A(t_o - t_i)]_{ehm}$$

$$+ 2[\Sigma UA(t_o - t_i)]_{ihm} + [U_i A(t_o - t_i)]_{flr} + \Sigma Q - (mCp)_h dt_i/d\theta \quad \text{(IIIC-23)}$$

The program assumes that infiltration is negligible during the ventilation mode, and that no refrigeration or heating occurs. The integrated form of Eq. IIIC-23 is:

$$\Delta t_i = \{[\Sigma UA(t - t_{i1})]_o + \dot{m}_v C_{pa}(t_v - t_{i1}) + \Sigma Q\}$$

$$\{1 - EXP - [\dot{m}_v C_{pa} + (\Sigma UA)_o][\Delta\theta/(mC_p)_h]\}/[\dot{m}_v C_{pa} + (\Sigma UA)_o] \quad \text{(IIIC-24)}$$

Evaporative coolers are rated according to their saturation efficiency η (5):

$$\eta = (t_a - t_v)/(t_a - t_w) = (W_v - W_a)/(W_w - W_a)$$

$$= (1 - EXP - N_{tu}) \quad \text{(IIIC-25)}$$

where t_a is the outside air dry bulb temperature, t_w is the outside air wet bulb temperature, W_v is the water vapor content of ventilation air leaving the evaporative cooler, W_a is the vapor content of outside air, and W_w is the vapor content of air saturated at the wet bulb temperature, lb water/lb dry air. N_{tu} is the number of transfer units provided by the evaporative cooling media; this can often be provided by the manufacturer of the cooler as a function of air and water flow rates.

9. HUMIDITY RELATIONSHIPS

Some knowledge of the humidity in the house interior is necessary to evaluate comfort conditions. PASSCOOL evaluates the changes in humidity due to occupants or interior latent heat load, Q_l, infiltration, ventilation or evaporative cooling, and refrigeration. It does not calculate moisture changes due to condensation or evaporation from windows, walls, etc., and does not consider sorption of moisture by fabrics or furnishings.

If $m_{ah} = \rho_a V_H$ = mass of air enclosed in the house, then the moisture addition due to the latent heat load is:

$$dW_i/d\theta = Q_l/\lambda m_{ah} \qquad \text{(IIIC-26)}$$

where λ is the heat of vaporization of water, Btu/lb,

while the change due to infiltration is:

$$dW_i/d\theta = (\dot{m}_a/m_{ah})(W_a - W_i) \qquad \text{(IIIC-27)}$$

Moisture change due to refrigerative air-conditioning uses the sensible heat ratio method (6), in which the sensible heat ratio (S_{hr}) is calculated based on the refrigerating coil surface temperature (t_c), and enthalpy (i_c), as:

$$S_{hr} = C_{pa}\ (t_i - t_c)/(i_i - i_c) \qquad \text{(IIIC-28)}$$

where i_i is enthalpy of interior air, Btu/lb dry air. Once the sensible heat removed (Q_s) by the air conditioner has been determined, as previously explained, the moisture change due to the air conditioner is determined as:

$$dW_i/d\theta = (1 - S_{hr})Q_s/\lambda\, S_{hr} \qquad \text{(IIIC-29)}$$

For the closed house, the integrated expression combining latent heat gain, infiltration, and air conditioning is:

$$\Delta W_i = \{(W_a - W_{il}) + [Q_l - (1 - S_{hr})Q_s/S_{hr}]/m_{ah}\lambda\}(1\text{-EXP-}\dot{m}_a\Delta\theta/m_{ah}) \qquad \text{(IIIC-30)}$$

This expression is also used for the ventilation or evaporative cooling case, with $Q_s = 0$, $W_v = W_a$ and $\dot{m}_v = \dot{m}_a$.

10. BUILDING SIMULATION USING REFRIGERATIVE AIR CONDITIONING: JULY-OCT

During the months July through October the use of natural ventilation or evaporative cooling to provide comfortable interior conditions is marginal at best. Hence the building must be closed and cooled by refrigerative air conditioning. Table IIIC-2 shows the requirements for a 23°C interior set-point using a 6-ton air conditioner, and a 25°C set-point with an undersized (4-ton) air conditioner.

There is no advantage in using PASSCOOL for calculating the performance of the 23°C, 6-ton unit case; since the air conditioner can maintain the 23°C set-point, the interior air temperature does not fluctuate, and a computer program based on steady-state heat transfer could compute the results in a shorter time. PASSCOOL does predict the beneficial effect of the building's mass when a slightly undersized air conditioning unit is used in the 25°C 4-ton case. The combination of the 4-ton air conditioner/high-mass building is able to maintain comfortable conditions with reduced power requirements. For 1-2 hours in the evening the 25°C set-point is slightly exceeded as indicated in Table III.C.2.

Table III.C.2

Air Conditioning Requirements
King Faisal University Solar Laboratory

	MONTH					
	JUNE	JULY	AUG	SEPT	OCT	BASE CASE
6-ton A.C. unit, 23°C:						
Kwh/day refrigeration req'd.	266	312	302	284	223	366
Percent latent load	13	17	20	25	27	27
Extreme PMV value	-0.4	-0.38	-0.38	-0.37	-0.37	-0.34
4-ton A.C. unit, 25°C:						
Kwh/day refrigeration req'd.	240	285	275	256	193	334
Percent latent load	14	18	21	26	28	29
Extreme PMV value	0.18	0.23	0.24	0.28	0.33	0.43
Maximum interior temperature	25.1	25.3	25.3	25.2	25	26

Note: For building case F, unfilled block. Temperature and wind velocities based on 1981 Dhahran monthly averages (Kingdom of Saudi Arabia, Ministry of Defense & Aviation, General Directorate of Meteorology). Solar radiation evaluated based on the ASHRAE method, clearness number = 1, for the 21st of each month. The base case is the 1% ASHRAE summer design temperature with solar radiation values for June 21.

D. COMPUTER SIMULATION/HEAT-COOL LOAD ANALYSIS USING MICROPAS (1)

1. Description

Building F is the building as described by ERL in the BLAST computer simulation. The building input file consisted of R18 walls, R18 roof deck, double-glazed windows with exterior fixed shading and internal drapery shading, internal massive walls and floors, internal gains via hourly profiles, thermostat setting at 69.8 F/73.4 F, 0.1 average air changes per hour, ventilation via an economizer, an air-to-air heat exchanger, and a heat pump with 2.5 COP heating and a 12.0 EER cooling rating. Duct gains in the cooling mode were assumed to be 5%, latent loads were 30% of the sensible loads, and El Centro, California historical hourly weather was used in lieu of Dammam data.

A second simulation was conducted with the same building file with the exception that the thermostat deadband has been changed to 69.8/78.0 F. Table III.D.1 gives the results of these runs.

Run #	Description		KWH-LOAD (KBTU) HTG.	KWH-LOAD (KBTU) CLG.		PEAK LOAD (KBTUH) HTG.	PEAK LOAD (KBTUH) CLG.
1	Building F	ZONE 1 "UP"	——	7135	(85615)	9.2	41.4
	"Base"	ZONE 2 "DWN"	——	5667	(68126)	0.4	30.8
	w/73F STAT	ZONE 2 "GARAGE"	——	4433	(53200)	2.5	20.1
		TOTAL		17245	(206941)		
2	Building F	ZONE 1 "UP"	——	5030	(60363)	7.7	38.8
	"Base"	ZONE 2 "DWN"	——	3276	(39312)	——	27.1
	w/78F STAT	ZONE 2 "GARAGE"	——	3651	(43807)	1.3	19.4
		TOTAL		12957	(143482)		

Table III.D.1 KFU Building Loads (MICROPAS)

2. Results

a. Heating is of little concern due to the predominance for cooling requirements year round. Any design emphasis on passive solar heating should be minimal.

b. Cooling from direct natural ventilation will not be possible during most of the non-winter months. Ventilation does provide cooling benefits during "shoulder" months, with a mechanical cooling reduction potential of nearly 10% during those months. Ventilation coupled with evaporative effects will likely extend the natural cooling potential of the building.

c. A thermostat setting of 78F saves significant cooling energy relative to a 73F setting.

d. Heat exchangers, even with 80% recovery efficiencies, aggravate the cooling requirement of the building but are necessary to ensure indoor air quality (approximately 0.4 ach).

e. Internal heat generation is significant due to the high occupancy profile assumed.

f. Tonnage requirements of cooling equipment is approximately 6.0 tons for the building with a 73.4F thermostat setting, excluding the garage space. The tonnage requirements for the building with a 78F thermostat setting is 5.5 tons, excluding the garage. These tonnage requirements are expected to be slightly overestimated relative to BLAST simulations because of the differing weather data bases. El Centro's peak summer design temperature is 121F, compared to a design temperature for Dammam of 111F. For comparison with BLAST runs using Dammam weather, the above tonnages should be reduced by approximately 9-10%, thus yielding tonnage requirements of 5.5 tons and 5.0 tons for the building with 73.4F and 78F thermostat settings, respectively.

g. Given the dynamic weather differences indicated below, the energy requirements (gross operational loads) of the BLAST runs should actually be higher than those generated by MICROPAS using El Centro weather. It would appear that by comparing the monthly average temperatures of the two data bases that the Micropas calculations will underestimate summer cooling energy requirements by approximately 5-10% relative to BLAST runs using Dammam weather. The following table III.D.2 summarizes these differences.

	El Centro (MICROPAS)	Dammam (BLAST)
Jan	53	62
Feb	58	64
Mar	64	69
Apr	71	79
May	78	88
Jun	85	95
Jul	92	96
Aug	92	96
Sep	86	92
Oct	75	84
Nov	63	74
Dec	56	64
Avg.	73	80
Peak HTG	29	45
Peak CLG	121	111

Table III.D.2 Monthly Average Temperatures (F)

3. Initial Recommendations for Thermal Improvement

a. Window areas are substantial (nearly 14% glass to floor ratio). Consideration should be given to downsizing window area or eliminating non-essential window area in the building. Glass removal from the south will have no detrimental heating effect yet provide a cooling benefit.

b. The thermal integrity of the windows that are installed should be much higher than those assumed in the initial computer simulations (R values of 1.8). Window products currently available yield R values in the 4.0 range (using reflective films - note this is one of the experiments to be conducted, multiple layers, etc.) and they should be considered.

III.B. REFERENCES

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III.C. REFERENCES

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2. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. ASHRAE Handbook Product Directory, 1977 Fundamentals. New York, New York: ASHRAE, 1978, pp. 8.24, 25.4, 22.12-22.25, 26.9-26.27, and 21.1-21.11.

3. Peck, J. F., Thompson, T. L., and Kessler, H. J. 1983. Off-Peak Power Use in Solar Homes: Performance, Monitoring, and Analysis of Periodic Heating and Cooling in High-Mass Homes. Final Report, EPRI Research Project 1191-7, Prepared by the Environmental Research Laboratory, University of Arizona, Tucson, for the Electric Power Research Institute, Palo Alto, California.

4. Glen E. Meyers. Analytical Methods in Conduction Heat Transfer. New York: McGraw-Hill Book Company, 1971, pp. 274-293.

5. Hollands, K. G. T., "Analysis and Design of Evaporative Cooler Pads." Mech. and Chem. Eng. Trans. pp. 55-72. Nov. 1970.

6. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. ASHRAE Handbook and Product Director, 1979 Equipment. New York, N.Y.: ASHRAE, 1979, pp. 6.1-6.20.

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1. Correspondence, J. Mark Hannifan, Advanced Energy Group, Kansas City, MO, June 1984.

IV. VENTILATION/WIND TOWER ANALYSIS AND STRATEGIES

A. OVERALL CONSIDERATIONS

From a review of the ventilation aspects of the most recent version of the revised final design, a series of proposed design changes have been developed. These changes are reflected in the drawings and specifications for the building. In formulating these changes, major modifications to the plan-form of the revised final design have been avoided. Two minor but necessary design modifications have been made:

1. Changing the rectangular wind tower (G11/U11) from its initial rectangular shape to a square on plan, which in turn required shifting the north wall of the building 50 cm toward the north; and

2. Enlarging the garage/data system/display room (G1), a change based on a change in the building's space requirements, which calls for adding office functions and a public-relations/display area. One change did not, however, require any change in the building's external perimeter: replacement of the ventilation air shaft (G10/U10) for the ground floor bathroom (G9) by mechanical ventilation, allowing G9 to shift westward, in turn improving cross-ventilation possibilities through G2 and G8.

A major consideration embodied in the proposed design relates to developing the correct orientation for wind, both for inlet windows on the upwind side of the building, and for inlet openings at the top of the wind tower. The direction of the local wind was first analyzed with respect to thermal comfort strategies throughout the year (Table IV.A.1). During those periods of the year when the Fanger Comfort Equations indicate that ventilation (air movement) is sufficient to provide thermal comfort during at least some hours of the day or night, the locally-prevailing wind direction varies from WNW (292.5^{o}) to NNE (22.5^{o}), lying within a 90^{o} quadrant or "wind wedge", centered on NNW (337.5^{o}). This suggests that an optimum facade orientation to capture the wind, i.e., optimum from the ventilation standpoint only, would be 337.5^{o}. This result was then compared with that obtained from the computerized (BLAST) load analysis, which indicates that an upwind facade orientation of N. (360^{o}) is the preferred orientation from the overall heat-load standpoint. It seems that a north-facing (360^{o}) inlet facade orientation, at least as regards ventilation, is nearly as good as the optimum orientation of 337.5^{o}. The orientation shown in the drawings, with the "inlet facade" facing north, i.e., with the major axis of the building aligned east-west, is probably the most favorable, when both load and ventilation factors are considered.

Ventilation requirements form an important consideration in the design of landscaping for the project site. Any landscape feature, including screen walls and plant materials, should be located sufficiently far from the perimeter of the buildings, and its height sufficiently controlled, to ensure that it does not constitute an obstruction to the free access of wind to the building.

Table IV.A.1 Wind/comfort analysis for "ventilation-critical" months in Dammam (Based on 1981 Dhahran Airport Data). Data in last column indicates velocities required for comfort based on outdoor shade conditions, i.e., without building envelope effect.

Month	Hour	Average Wind Direction	Average wind speed at 7.5 meters height from wind directions up to 90° either side of "average wind direction"		Average wind speed (in m/sec.) At center-line of ground floor windows	At center-line of upper floor windows	Air movement velocity required to maintain thermal comfort (listed only when ventilation alone is effective; based on Fanger Comfort Equations)
			Knots	M/Sec	M/Sec	M/Sec	M/Sec
March	0300	318°= NW	7.7	4.0	2.8	3.4	-
	0900	313°= NW	10.1	5.2	3.6	4.4	0.1
	1500	353°= N	11.5	5.9	4.2	5.0	0.5
	2100	005°= N	6.5	3.3	2.3	2.8	0.1
April	0300	336°= NNW	8.9	4.6	3.2	3.9	0.1
	0900	352°= N	13.8	7.1	5.0	6.1	-
	1500	038°= NNE	12.8	6.6	4.6	5.6	-
	2100	028°= NNE	8.1	4.2	2.9	3.6	0.3 or 0.5
May	0300	330°= NNW	8.1	4.2	2.9	3.6	0.5
	0900	342°= NNW	11.8	6.1	4.3	5.2	-
	1500	009°= N	13.2	6.8	4.8	5.8	-
	2100	358°= N	7.3	3.8	2.6	3.2	-
October	0300	327°= NNW	5.2	2.7	1.9	2.3	0.1, 0.3, or 0.5
	0900	342°= NNW	7.4	3.8	2.7	3.2	-
	1500	058°= NE	9.7	5.0	3.5	4.3	-
	2100	032°= NNE	5.0	2.6	1.8	2.2	-
November	0300	301°= NW	7.7	4.0	2.8	3.4	0.1
	0900	285°= WNW	10.4	5.3	3.8	4.6	-
	1500	358°= N	13.4	6.9	4.8	5.9	-
	2100	326°= NW-N	8.0	4.1	2.9	3.5	0.1 or 0.3
December	0300	288°= W	7.0	3.6	2.5	3.1	-
	0900	293°= WNW	8.4	4.3	3.0	3.7	-
	1500	352°= N	9.3	4.8	3.4	4.1	0.1, 0.3 or 0.5
	2100	342°= NNW	5.9	3.0	2.1	2.6	-

<u>Note:</u> To obtain "Average wind direction" (six-hourly-by-month) shown above, a "prevailing" wind direction for each month was first derived by inspection from monthly tables of "Number of Hours of Occurrence of Concurent Surface Wind Speed and Direction" (Dhahran Table 3), using "total" values from those tables summarizing wind direction data for each month. Then, using that "prevailing" direction as a "centerpoint", surface wind direction data for each six-hourly interval for each day from monthly tables of "Daily & Monthly Climatological Surface Data" (Dhahran Table 2) was scanned, recorded and totalled for all wind directions up to 90° on either side of the "prevailing" direction. The mean or average direction calculated from this total (dividing the total by the number of observations involved) is shown above as "Average wind direction" for each of the six "ventilation-critical" months. To derive "Average wind speed" shown above; the wind speed corresponding to each wind direction entering into the above calculation of "Average wind direction" was also recorded, totalled, averaged, and shown above as "Average wind speed" in both knots and meters/second.

In regards to the design of the building itself, perhaps the most fundamental ventilation consideration taken into account has been to ensure the provision of both inlet (positive pressure) and outlet (negative pressure) openings for each naturally-ventilated space in the building. Another major factor in formulating the proposed design has been the importance of selecting airflow inlets (including operating portions of windows and supply openings from the wind tower) to maximize air velocities throughout the habitable zones of the building.

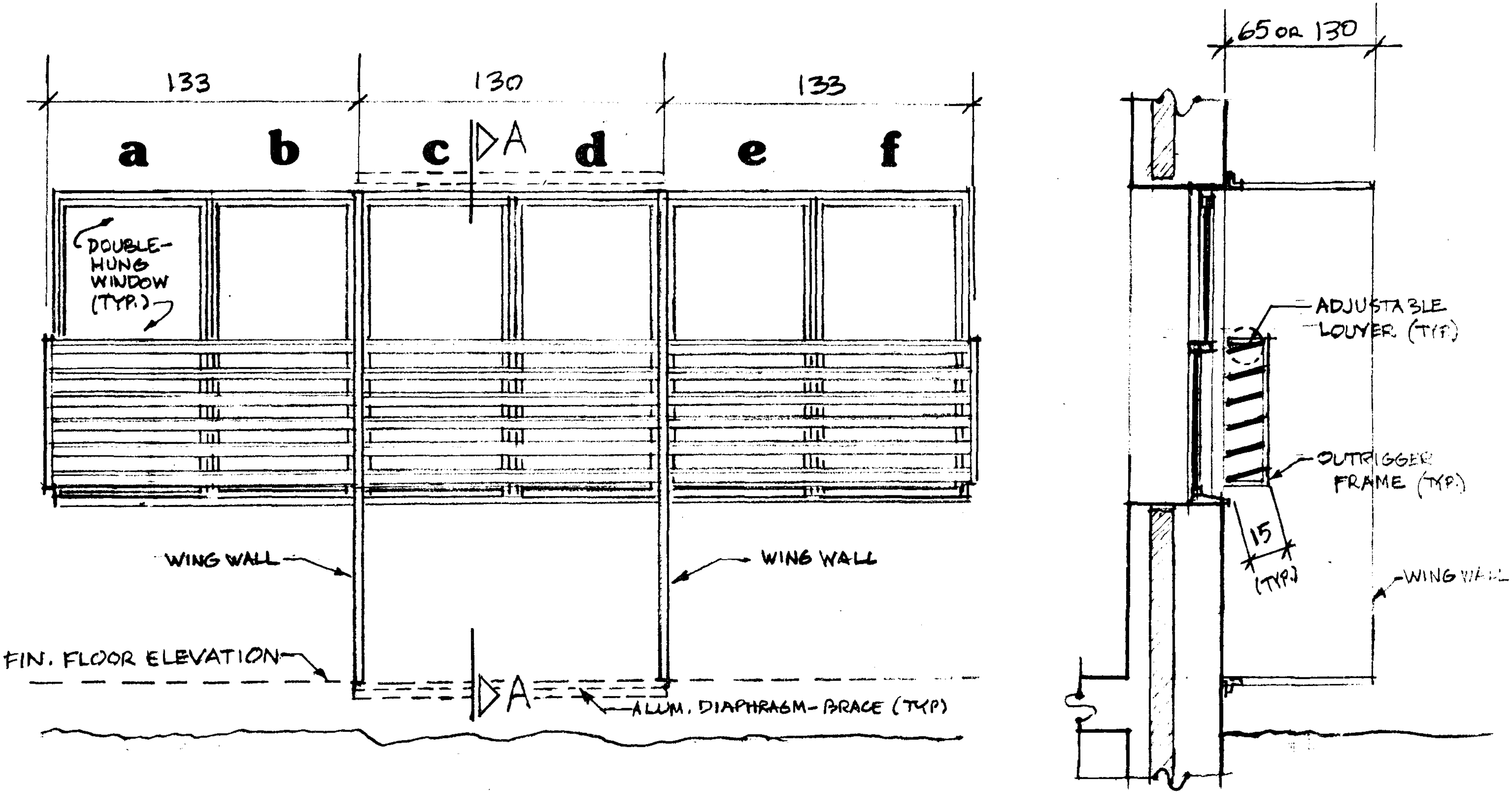
Two broad approaches have been taken to achieve this result. First, whenever possible, inlets have been selected to maximize the proportion of room areas which are covered on plan by the main jet of airflow entering the room. This desirable result is most readily obtained through the use of horizontally-shaped inlet openings, proportioned to provide an aspect ratio (height: width) of approximately 1:5 [Refs. 1 and 2]. Second, wherever possible, inlets have been selected to maximize the amount of air reaching the "occupied zone" of rooms in section. The "occupied zone" typically extends from 45 cm to 180 cm above finished floor level to accommodate most standing, seated and reclining postures. Maximizing air movement in the "occupied zone" is most readily obtained using two general approaches:

1. Locating the horizontal center line of inlet openings whenever possible at the horizontal center line of the "occupied zone", i.e., about 130 cm above finished floor level;

2. Adding deflector vanes to inlet openings, adjustable to direct air upwards or downwards into the "occupied zone", especially critical for those inlets which cannot be located at the center of the "occupied zone" [Ref. 3].

Five of the major spaces in the revised final design constitute single orientation rooms, that is, rooms with only one outside wall, thus lacking conventional cross-ventilation. Two of these rooms face toward the prevailing wind; three face away from the wind. In proposing solutions to the difficult problem of ventilating these single orientation spaces, three approaches have been taken:

1. For rooms with windward exposure, the use of "wing walls", consisting of perpendicular projections located at one vertical edge of each of two openings (See Figs. IV.A.1, IV.A.2 and IV.A.3) a system which under even slightly oblique wind directions creates positive pressure over one window, negative pressure over the other, thus achieving effective cross-ventilation of the room over a range of up to 140° in wind direction [Ref. 4].



EXT. ELEVATION

SECTION A-A

FIG. IV.A.1 : PROPOSED WINDOW DESIGN AT G2 & U1

SCALE - 1:25

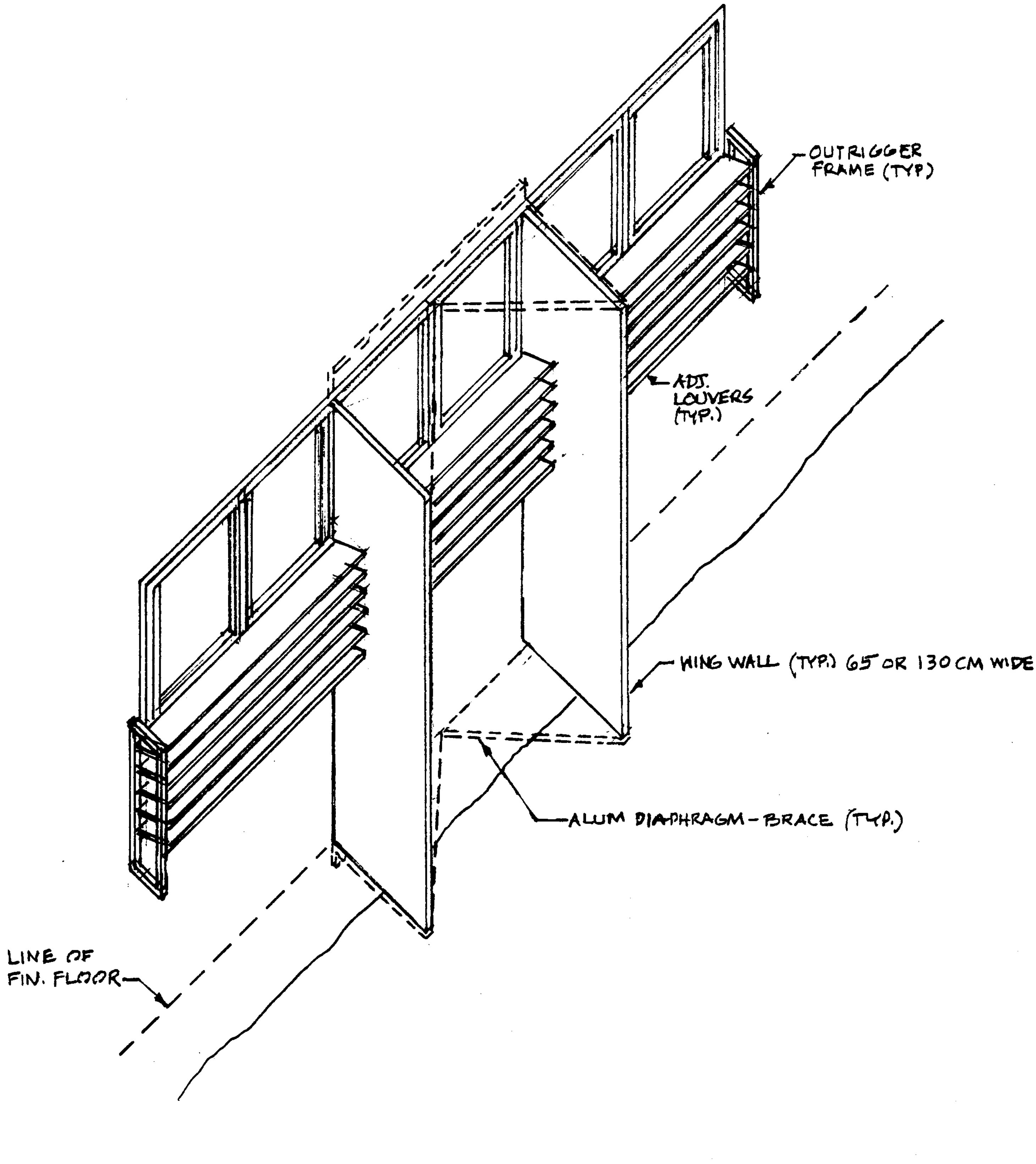


FIG. IV.A.2 : AXONOMETRIC OF WINDOWS AT G2 & U1

SCALE - 1:25

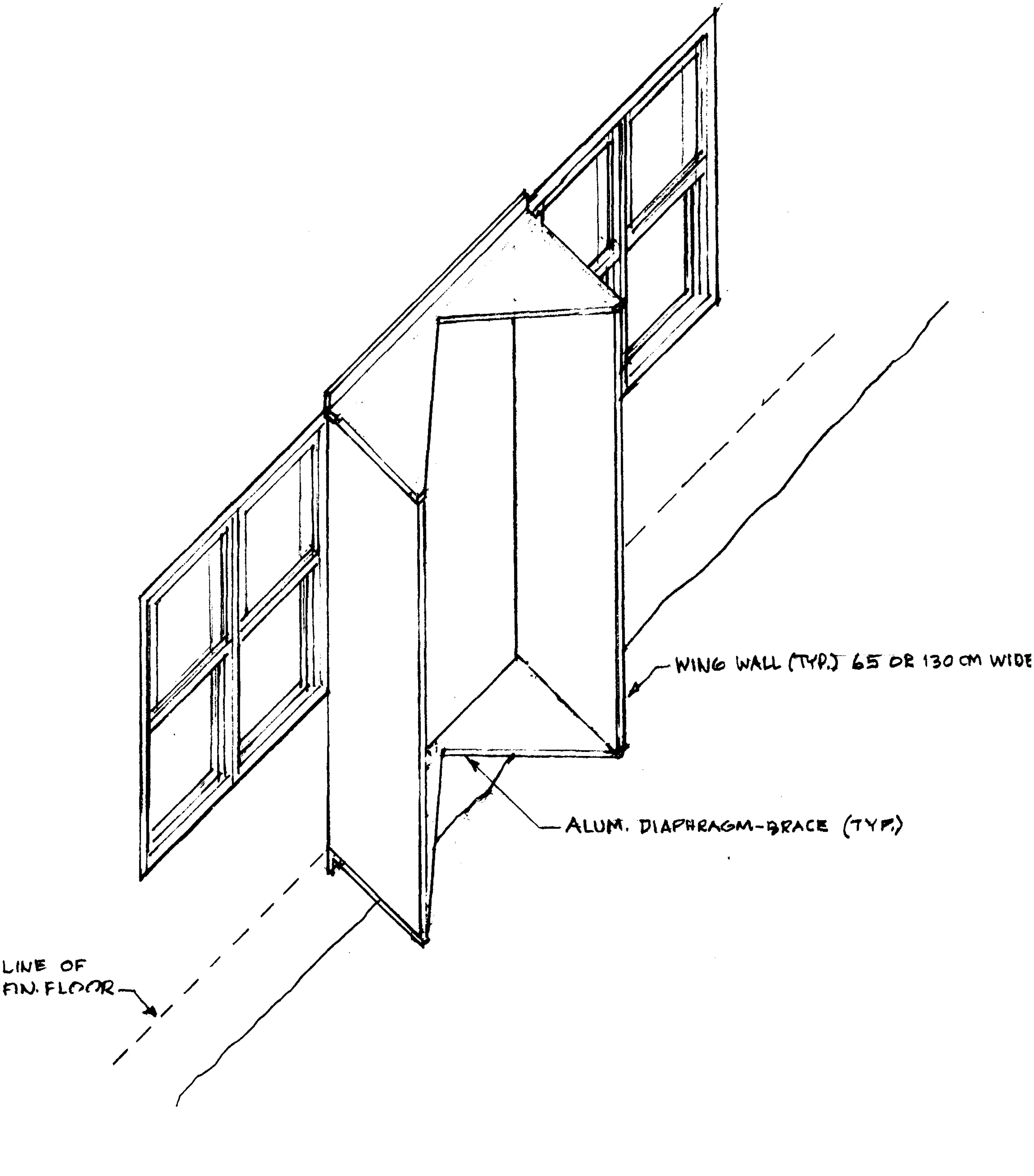


FIG. IV.A.3 : AXONOMETRIC OF WINDOWS AT G3

SCALE - 1:25

2. The use (as both inlets and outlets) of louvered transoms, louvered doors (Fig. IV.A.4) and banks of acoustic louvers (Fig. IV.A.5) as interior partitioning devices to facilitate conventional cross-ventilation through the building.

3. The use of the wind tower in its wind-driven mode to provide an air supply for rooms facing away from the wind.

Another problem which required consideration as part of the ventilation design is the presence, in Dammam, of intermittent dust storms, a particular feature of the Eastern Kingdom's climate. Among the approaches proposed for dealing with this problem are:

1. Adequate seals and gaskets for all doors and operable window sections.

2. Adequately sealed fixed glazing sections.

3. Use of the wind tower in the wind-driven evaporative cooling mode, which should precipitate out most dust particles from the incoming air by means of fog/spray action.

Still another design influence we have taken into account is the need to minimize smoke and odors, especially in spaces where they may be a problem (kitchen, bathrooms). The approach to this problem includes:

1. Use of standard mechanical extract ventilation.

2. Specification of barometric dampers, to prevent backflow from smoke- and odor-generating spaces back into the wind tower and then into the rest of the building (dampers may be either the cloth or the aluminum type; cloth dampers [See Appendix IV] are quieter, more economical, and offer substantially less resistance to air flow).

B. OPERATIONAL MODES

The proposed design is based on the use of five distinct ventilation strategies. The recommended uses of these strategies vary depending on the specific needs of the various ventilation zones within the building. These five strategies are as follows:

1. Cross-ventilation, both conventional and innovative (Figs. IV.B.1 and IV.B.2).

2. Wind tower/"wind-driven" mode (given sufficient wind speeds) (Fig. IV.B.3 and IV.B.4).

3. Wind tower/"density-driven" mode, (under calm or no wind conditions), powered by density differences between evaporatively cooled (heavier) air in the upper part of the tower, and warmer (lighter) ambient air in the lower part of the tower (Fig. IV.B.3).

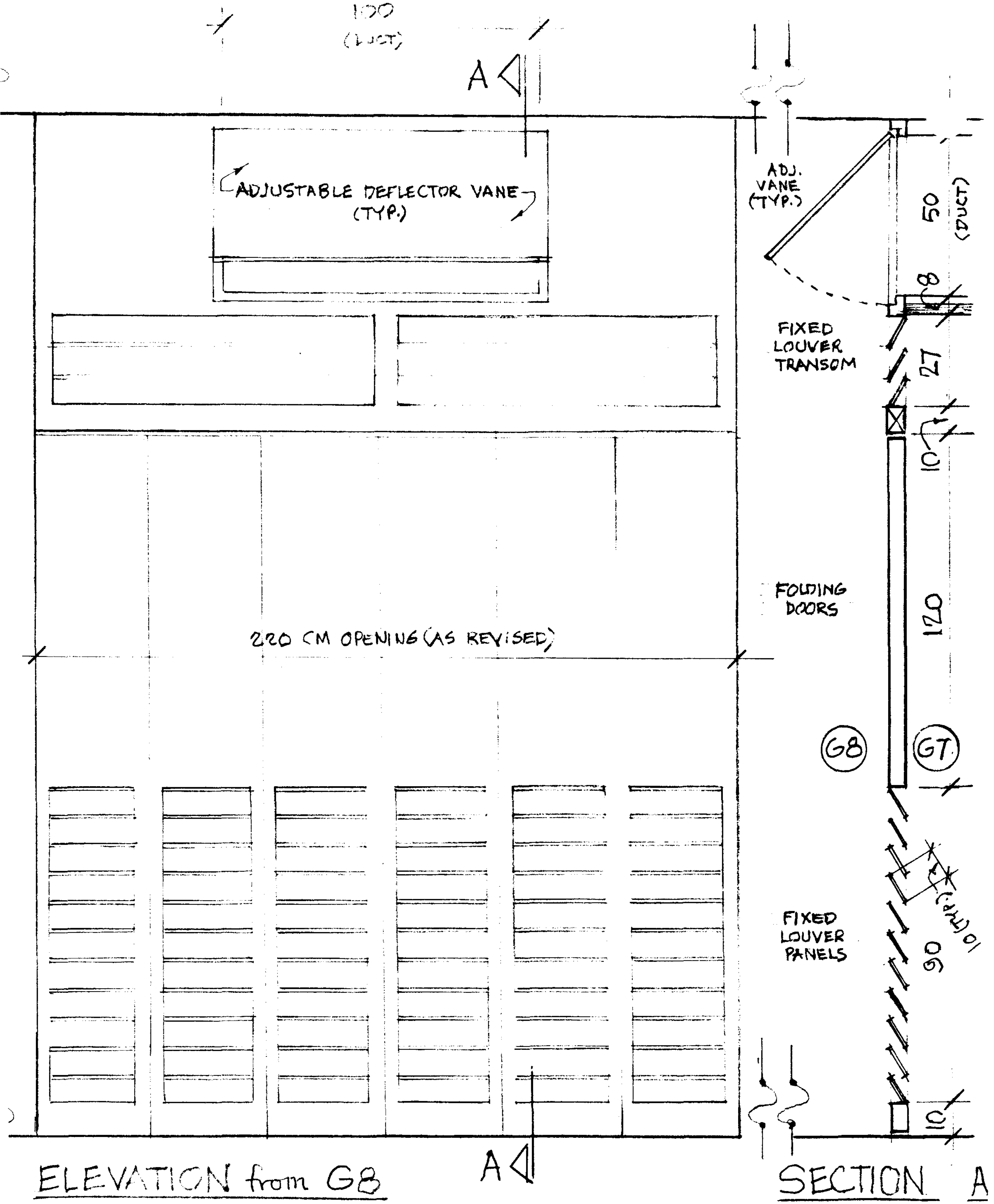


FIG. IV.A.4 : FOLDING DOOR WALL (BETWEEN G7 & G8)

SCALE - 1:15

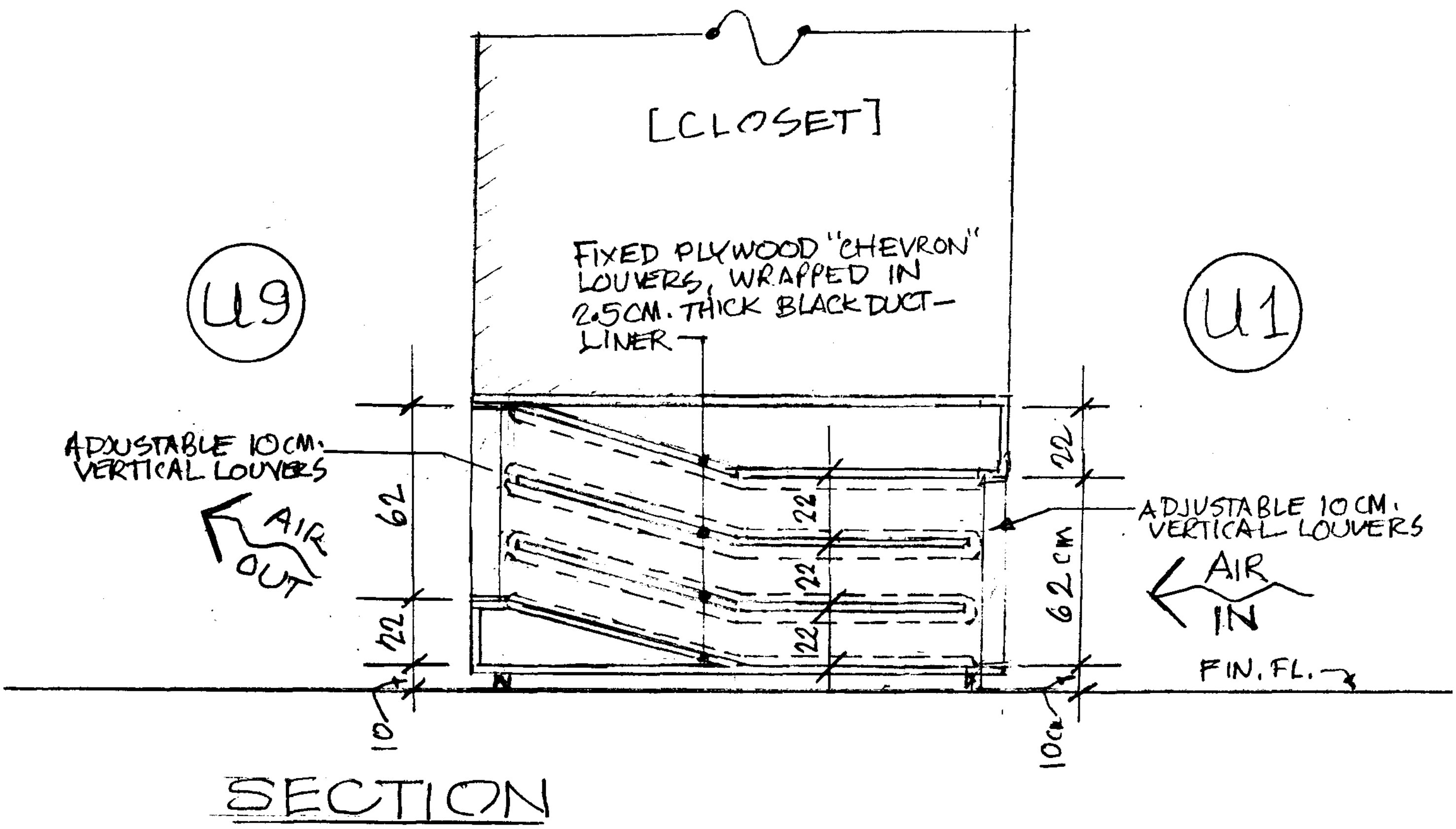
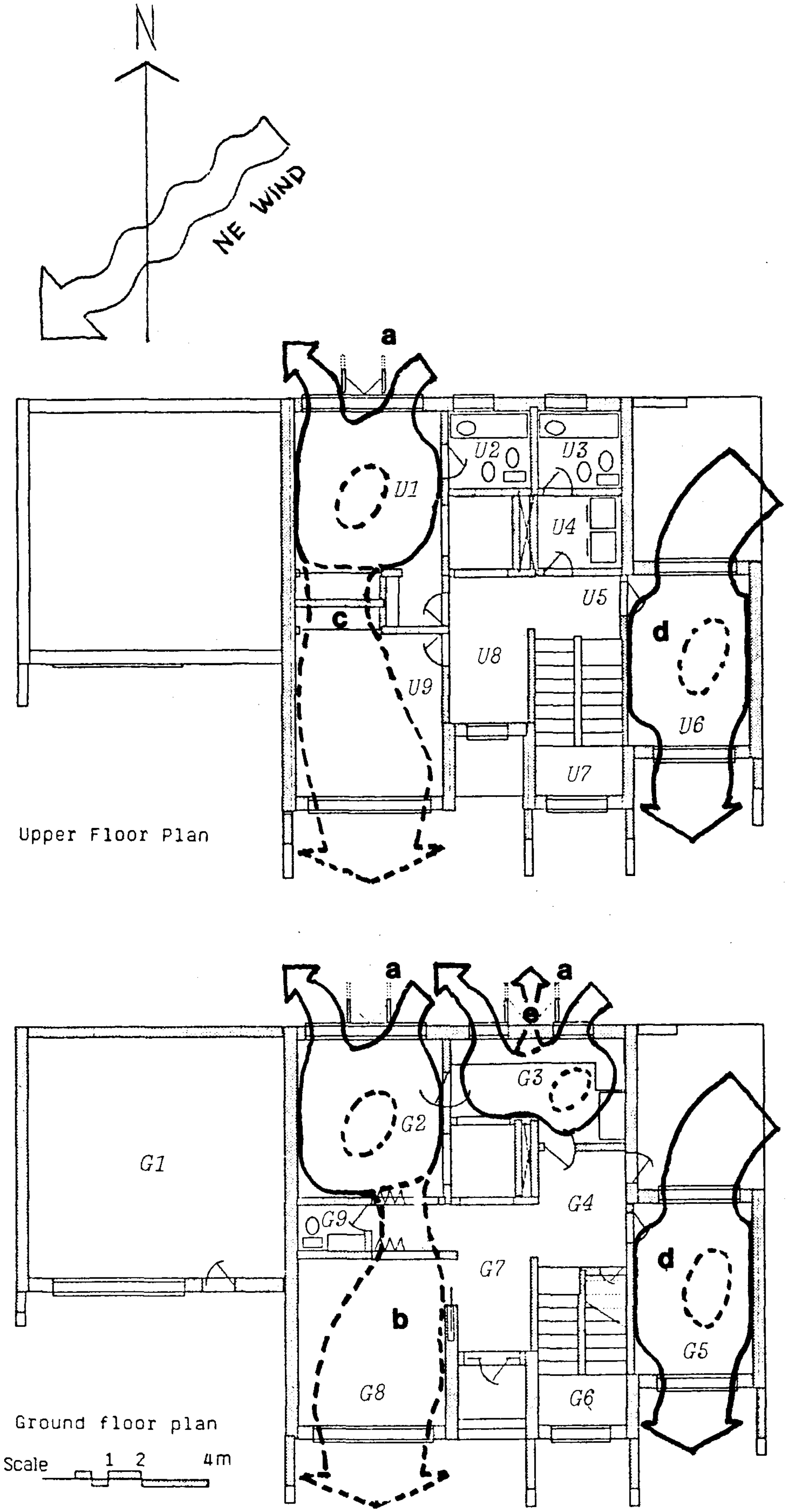


FIG. IV.A.5 : ACOUSTICAL LOUVERS BETWEEN U1 & U9

SCALE - 1:25



a "Wing-walls" promote ventilation in rooms with windows on one exterior wall only, e.g., G2 (with folding doors closed), G3 and U1.

b Cross-ventilation possible when folding doors are open; much reduced when closed.

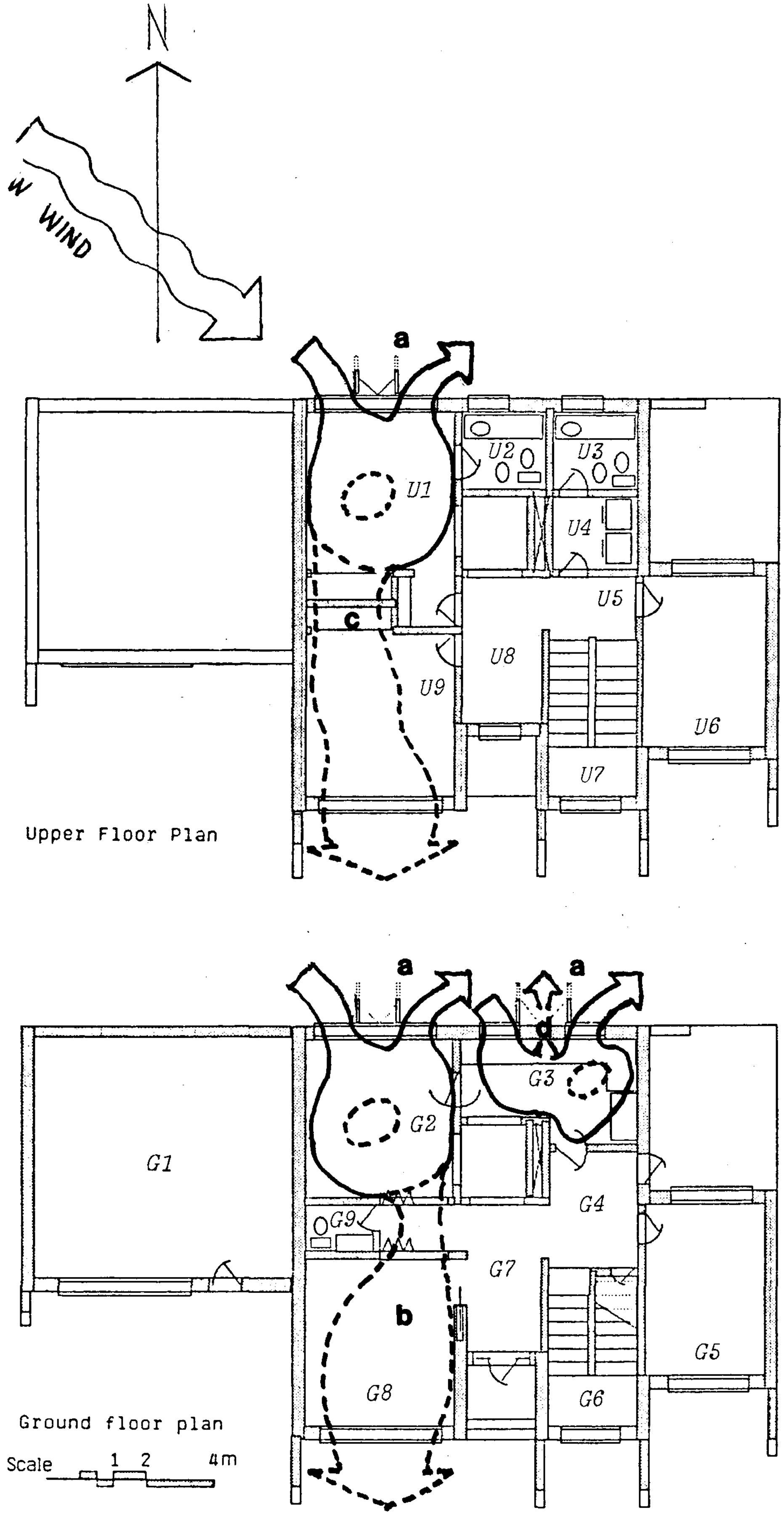
c "Chevron" louvers under closet create cross-ventilation path in bedrooms U1 and U9.

d Good cross-ventilation in G5 and U6 under N or NE wind condition.

e Exhaust fan removes smoke and odors and provides alternative outlet for cross-ventilation in kitchen, G3.

● Little cross-ventilation is projected for G4, G6 or G7; U2, U3, U5, U7 or U8.

FIG. IV.B.1 : CROSS-VENTILATION MODE / N.E. WIND



a "Wing-walls" promote ventilation in rooms with windows on one exterior wall only, e.g., G2 (with folding doors closed), G3 and U1.

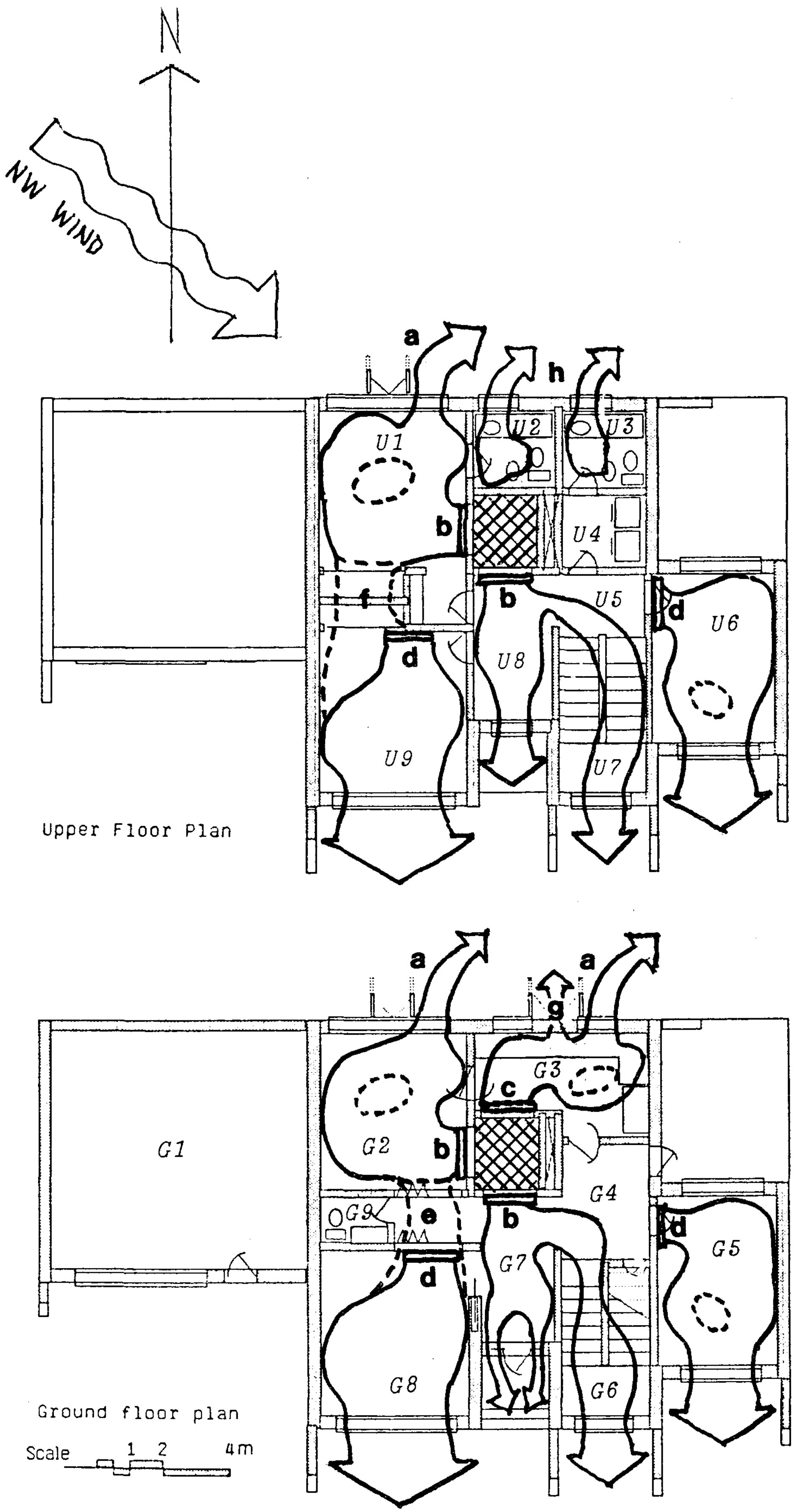
b Cross ventilation possible when folding doors are open, much reduced when closed.

c "Chevron" louvers under closet create cross-ventilation path in bedrooms U1 and U9.

d Exhaust fan removes smoke and odors and provides alternative outlet for cross-ventilation in kitchen, G3.

● Little cross-ventilation is projected for G4, G5, G6 or G7; U2, U3, U4, U5, U6, U7 or U8.

FIG. IV.B.2 : CROSS-VENTILATION MODE / N.W. WIND



a "Wing-walls" provide an alternative outlet for tower air in G2, G3 and U1 in either NW or NE wind conditions.

b Low-wall inlets supply tower air to living or occupied levels of G2, G7, U1 and U8.

c Mid-wall inlets supply tower air between base and upper cabinets in kitchen, G3.

d High-wall inlets with "deflector vanes", supply tower air to G5, G8, U6 and U9.

e Louvered doors provide alternative cross-ventilation path through G2 and G8.

f "Chevron" louvers provide alternative outlet for tower air in U1.

g Exhaust fan removes smoke and odors and provides alternative outlet for tower air in G3.

h Ceiling diffuser inlets supply tower air to U2 and U3.

● Only modest levels of tower air are projected for G6, G7, U4, U5 and U7.

FIG. IV.B.3 : WIND TOWER/WIND DRIVEN MODE/N.W. WIND (DENSITY-DRIVEN & EVAPORATIVE COOLING MODES SIMILAR)

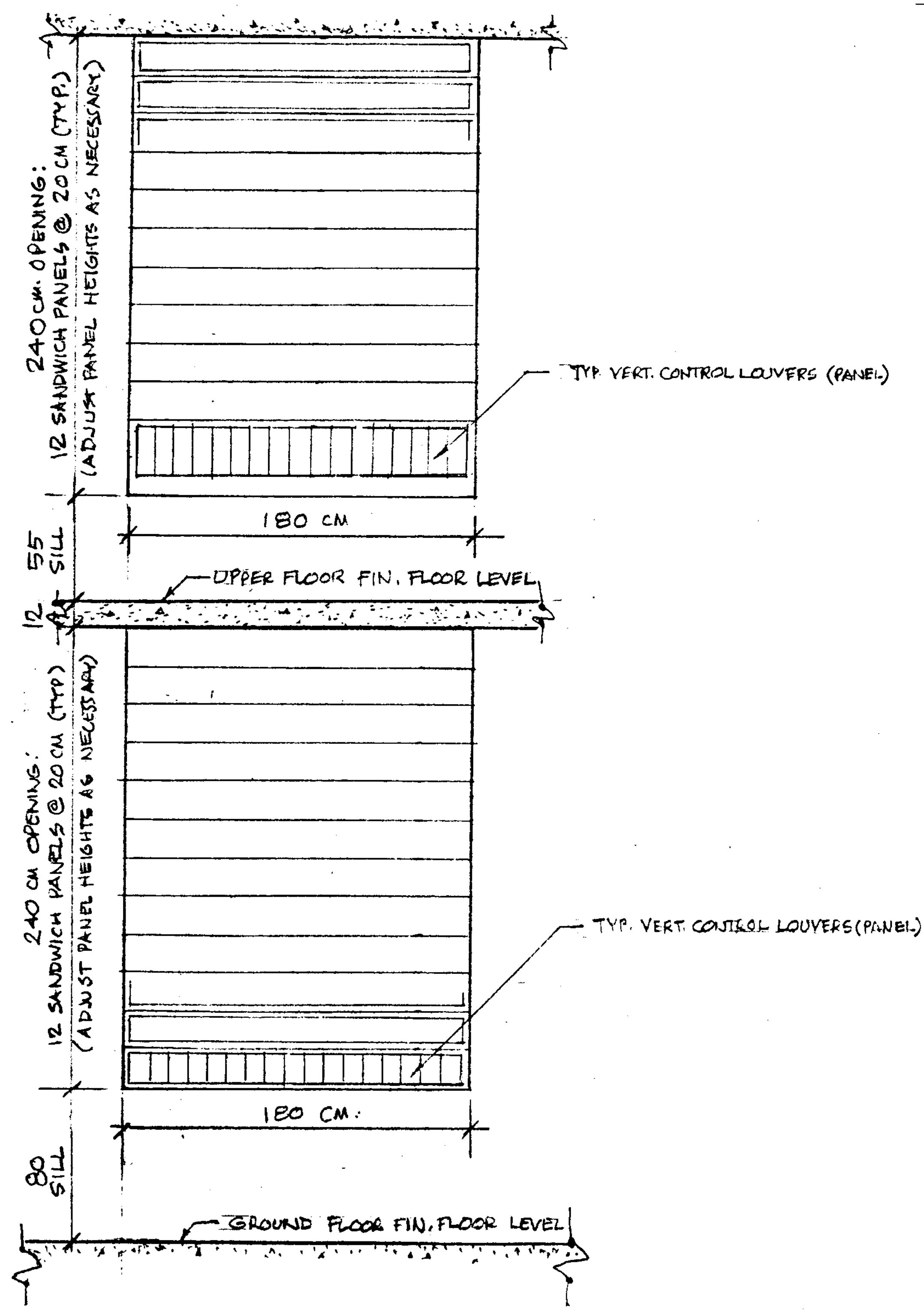


FIG. IV.B.4 : SECTION SHOWING TYPICAL TOWER AIR INLETS
SCALE - 1:25

4. "Mixed mode", employing a combination of cross-ventilation air for "upwind" rooms and wind tower air for "downwind" rooms (Fig. IV.B.5).

5. Ceiling fans, to achieve air movement when windows are closed against either afternoon heat or dust storms, and to achieve heating season destratification (Fig. IV.B.7).

In addition to these five modes of reducing effective temperatures in the building with air movement, two operational modes capable of reducing dry bulb temperatures have also been introduced:

1. Wind tower/evaporative cooling mode, utilizing a water fog or spray plus the prevailing wind as the driving force (Figs. IV.B.3, IV.B.5 and IV.B.6).

2. Multi-zone heat pump, to provide complete air conditioning to each space of the building.

C. VENTILATION ZONING PROGRAM

The following section is intended to outline an operational program for the application of the various ventilation strategies described in the preceding section of this report.

For ventilation purposes, each floor of the building has been divided into six distinct operational zones (see Figs. IV.C.1 and IV.C.2) as follows:

Zone (1): An upwind, single-orientation zone (G2, G3, & U1);

Zone (2): A downwind, single-orientation zone (G8 & U9);

Zone (3): A cross-ventilated, double-orientation zone (G5 & U6);

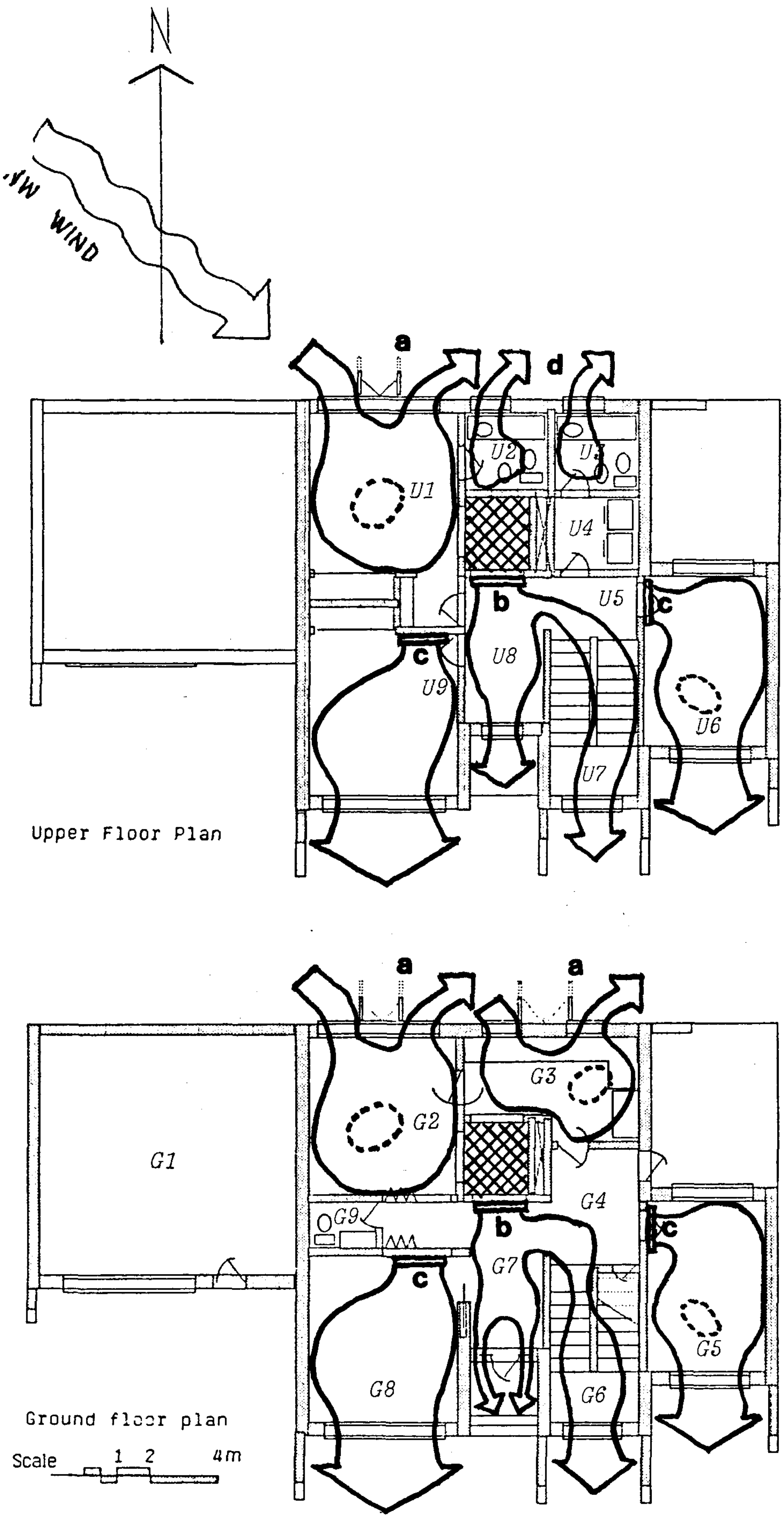
Zone (4): A tower air zone (G4, G6, G7, U4, U5, U7 & U8);

Zone (5): A mechanically-ventilated zone (G9, U2, U3 & U4); and

Zone (6): A permanently air-conditioned zone (G1).

Zone (1)

Although it faces the prevailing "wedge" of wind directions, Zone (1) is essentially composed of single-orientation spaces (G2, G3, & U1), i.e., spaces with windows on one side only. Therefore, the use of "wing walls" is proposed (see preceding section) as the primary ventilation mechanism in Zone (1). The correct mode of operation of windows equipped with such "wing walls" is to open operable windows (a) on the side toward the prevailing (oblique) wind, plus (b) those on the side away from the wind, keeping (c) any windows between the wing walls closed. The resulting pressure-difference between upwind and downwind windows effectively creates cross-ventilation of the room.



a "Wing-walls" create cross-ventilation in rooms with windows on one exterior wall only, e.g., G2 (folding doors closed), G3 and U1.

b Low-wall inlets supply tower air to living or occupied levels of G7 and U8.

c High-wall inlets with "deflector vanes", supply tower air to G5, G8, U6 and U9.

d Ceiling diffuser inlets supply tower air to U2 and U3.

FIG. IV.B.5 : MIXED MODE/N.W. WIND (N.E. SIMILAR)

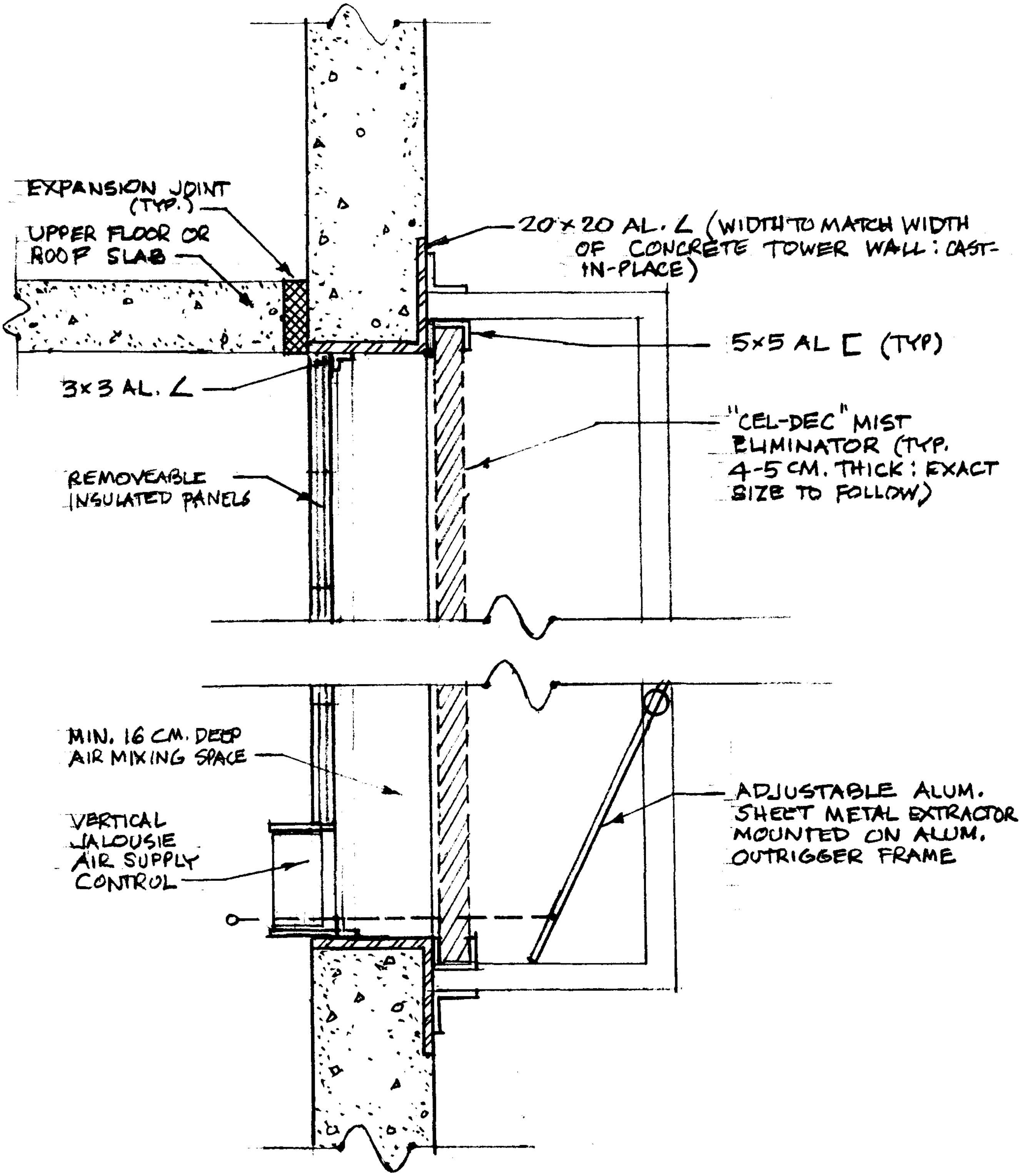


FIG. IV.B.6 : SECTION THROUGH TYPICAL TOWER AIR INLET

SCALE - 1:10

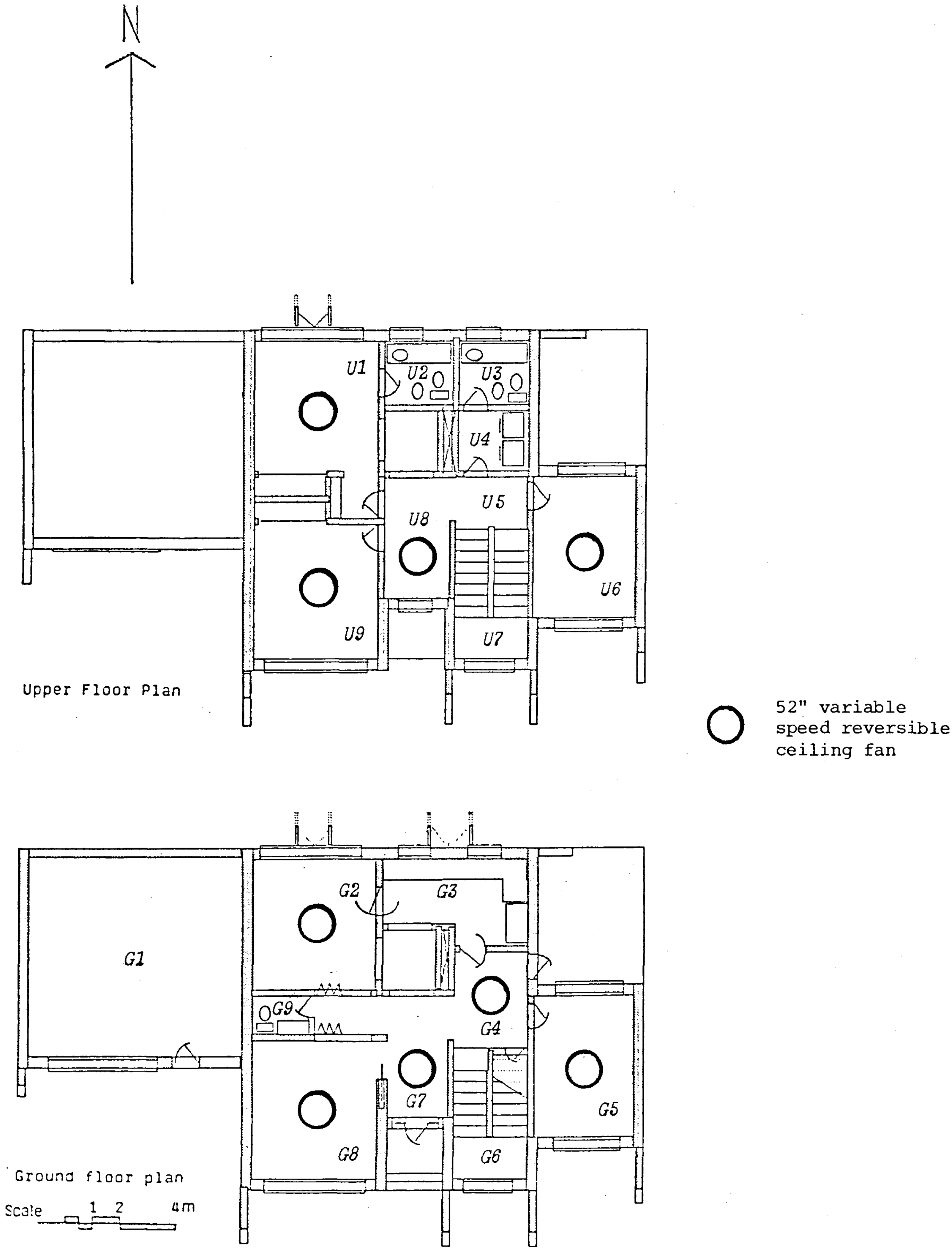


FIG. IV.B.7 : CEILING FAN LOCATIONS

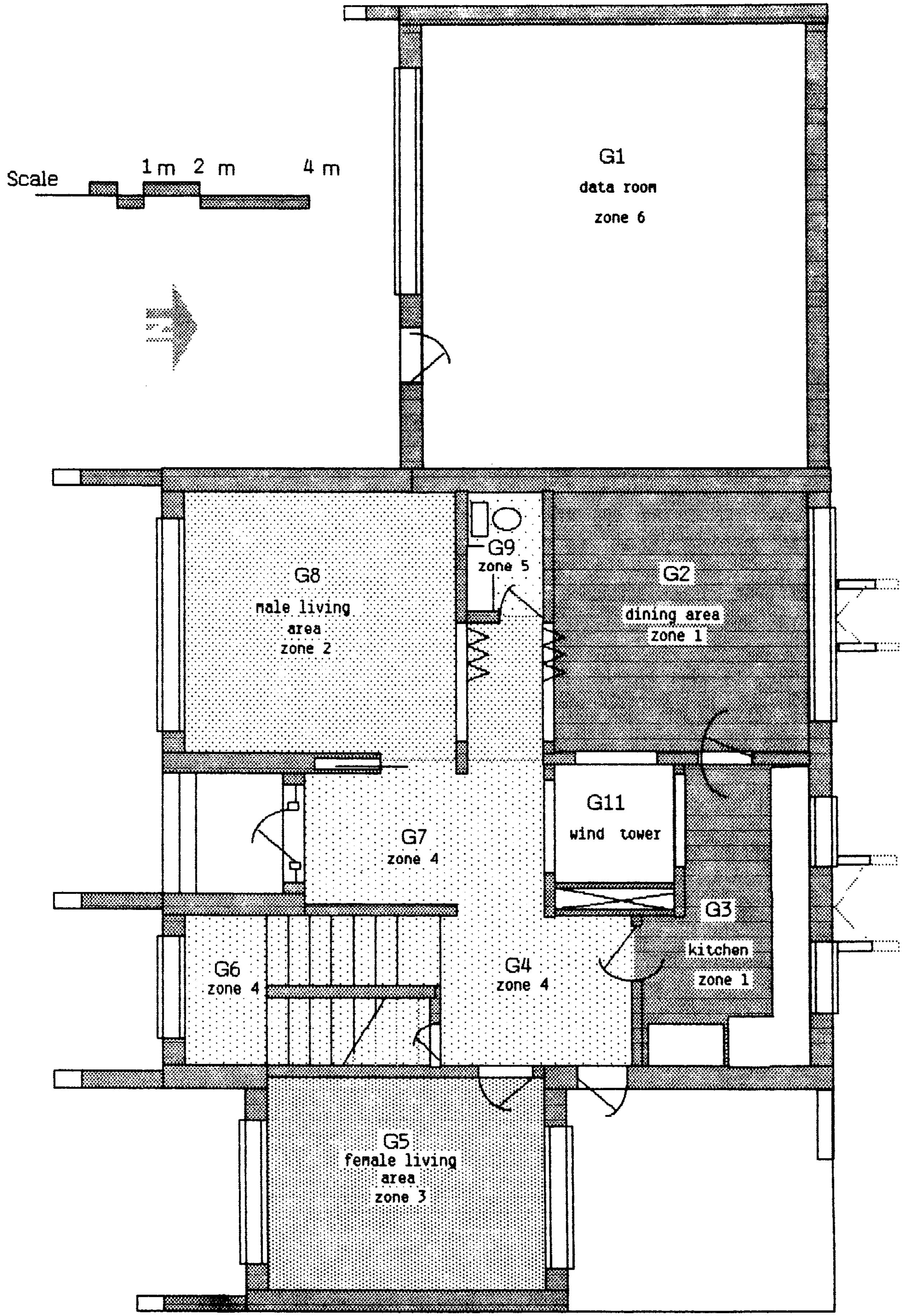


FIG. IV.C.1 : VENTILATION ZONES / GROUND FLOOR

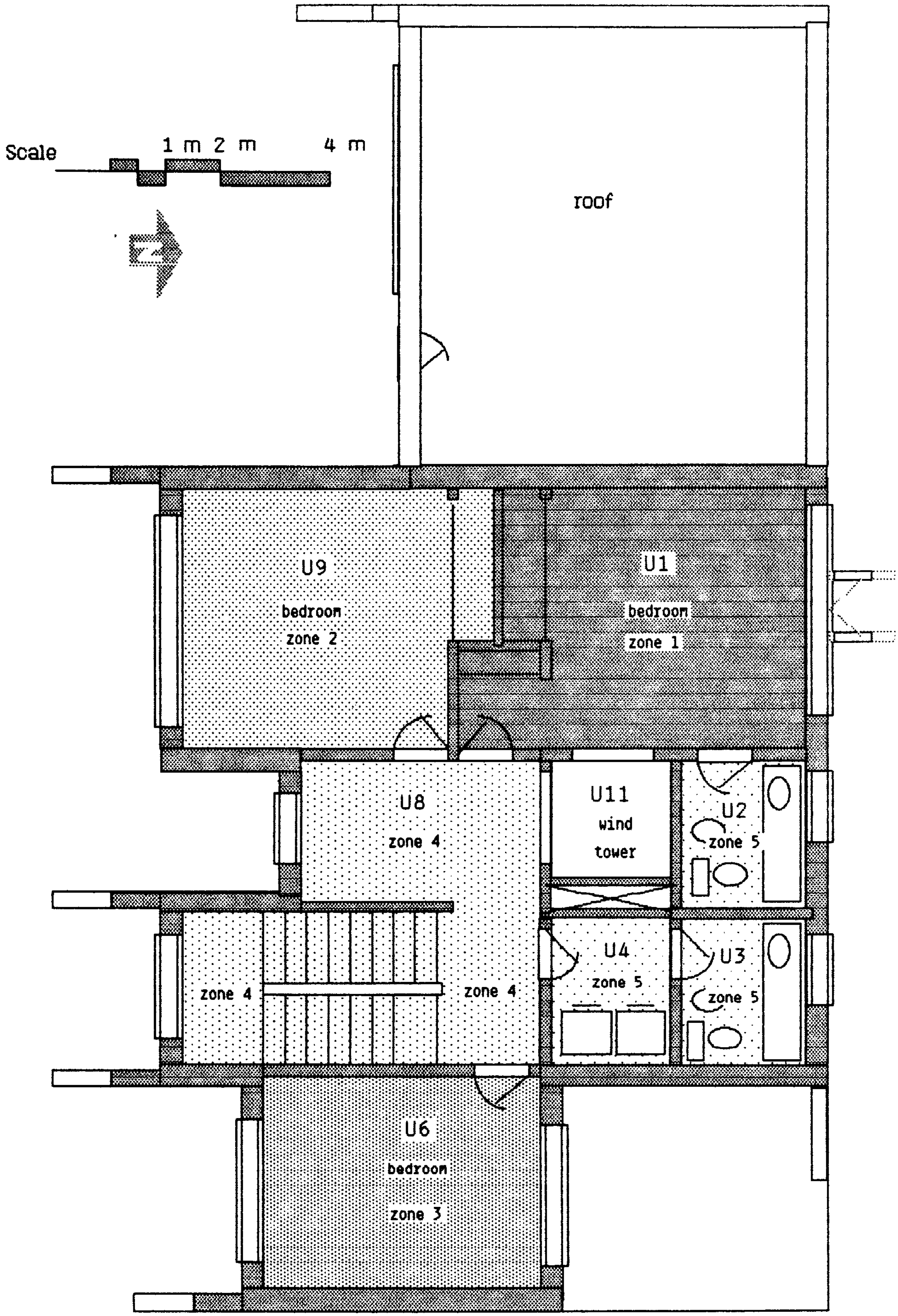


FIG. IV.C.2 : VENTILATION ZONES / UPPER FLOOR

It is possible to also create conventional cross-ventilation in G2 and U1. In G2, this can be done whenever the folding doors between G2 and G8 are open or shut, since it is proposed to equip both layers of downwind folding doors with louvered transoms plus louvered door-panels (Fig. IV.A.4). In U1, cross-ventilation is created by opening the vertical control louvers located on either side of the fixed chevron louver-bank between U1 and U9 (see Fig. IV.A.5). The success of these strategies relies, of course, on keeping open all operable upwind openings in G2 and U1, and all downwind openings in G8 and U9. Should downwind windows in G8 or U9 remain closed, ventilation in G2 and U1 must rely solely on the "wing wall" mechanism. Projected air movement velocities (IV.C.1.) indicate that either the "wing wall" or cross-ventilation strategies are sufficient, during these portions of the year ("ventilation-critical" periods) when ventilation (air movement) alone is effective to ensure thermal comfort.

Zone (2)

This zone, containing two rooms, G8 and U9, is characterized by a downwind location in the building. This "downwind" position of Zone (2) is in turn responsible for the fact that it lacks any direct access to the prevailing wind. Air movement in such downwind zones can (at least potentially) be created through the use of two alternative modes of operation: "borrowed" cross-ventilation, or tower air. In the case of G8, the first of these alternative modes, "borrowed" cross-ventilation, must rely on air which first passes through G2, then through the west end of G7, then into G8, either through two large louver-transomed doorways, or through two layers of folding doors hung in those doorways, equipped with louvered panels. Analysis of projected air movement velocities (IV.C.1.) shows that sufficient air movement will be available in G8, at least during "ventilation-critical" periods of the year, only when both sets of folding louvered doors between G2 and G8, all operable upwind openings in G2, and all downwind openings in G9 are open. This in turn indicates that with folding doors closed, as they will be whenever male guests are present, the louvered openings between G2 and G8 are responsible for enough airflow resistance to prevent adequate cross-ventilation conditions to prevail within G8, though all windows in G2 and G9 remain open. Under these conditions, adequate ventilation in G8 must rely on tower air alone.

In U9, cross-ventilation must also rely on "borrowed" air, which first passes through U1, then through a bank of fixed acoustical louvers (Fig. IV.A.5), then out into U9. Assuming all operable upwind openings in U1, all control louvers on either side of the acoustical louver bank between U1 and U9, and all downwind openings in U9 are kept open, projected air movement velocities (IV.C.1.) show that this cross-ventilation strategy will be unable to provide sufficient airflow during "ventilation-critical" periods of the year. Adequate ventilation in U9 therefore must rely on tower air. Considering both G8 and U9, it seems clear that for most of the time adequate ventilation in Zone (2) is forced to depend on air from the wind tower, operating in either its wind-driven or density-driven modes.

Zone (3)

This zone contains two rooms, G5 and U6, both characterized by a conventional cross-ventilated plan, i.e., with windows located in opposite walls of each room. Under normal circumstances, i.e., with good access for wind to the upwind facade, air movement in such doubly-oriented spaces would be readily created by means of conventional cross-ventilation. In the case of Zone (3), however, during approximately 60% of the "ventilation-critical" period of the year, the wind is from the NW or NNW (Table IV.A.1). Under those conditions, G3/U3 will throw a "wind shadow" on G5/U6. Only during approximately 40% of the "ventilation-critical" period of the year is the wind from the N or NNE. Thus only for a relatively modest proportion of the "ventilation-critical" time will G5/U6 enjoy unobstructed access for wind.

Based on this analysis, it is recommended that G5/U6 be relocated as far north as possible in order to minimize the effect of G3/U3 in casting a "wind shadow" on G5/U6, under prevailing NW or NNW wind directions (Table IV.A.1). Since Zone (3) is the only part of the building which will have nearly ideal air movement conditions (cross-ventilation plus good wind access) for even a portion of the year, this zone is particularly suitable for the purpose of ventilation experiments. For this reason, the north and south walls of G5 and U6 have been designated as "reconfigurable," which will make it possible to alternate several different types of operable sections (both inlets and outlets) in these rooms (See Experiments 1 and 2).

Without an extensive program of wind tunnel testing, no data exist for predicting the airflow behavior of G5/U6 under NW wind direction conditions, that is, when in the "wind shadow" of G3/U3. The air movement projections for G5/U6 (Table IV.C.1) are therefore confined to N and NE wind conditions only. Assuming that all operable inlets and outlets in G5 and U6 are kept open, these projections show that conventional cross-ventilation in this space will be sufficient to provide comfort conditions throughout the "ventilation-critical" periods of the year.

Zone (4)

This zone consists of seven rooms, three on the ground floor and four on the upper floor. None of these spaces can be conventionally cross-ventilated. The reason for this is two-fold: (a) the zone is characterized by a purely downwind location in the building, thus lacking any direct access to the prevailing wind, and (b) the zone is located downwind of spaces such as the kitchen or upstairs bathrooms through which ventilation air cannot as a practical matter be "borrowed". Adequate air movement in Zone (4) must, therefore, either (a) rely on tower air directly (as in G7 or U8), (b) rely on tower air indirectly (as in G4, G6, U4, U5 & U7, which depend on "spill-over" tower air from adjacent rooms) or (c) rely on the use of ceiling fans installed in the recommended locations (See Fig. IV.B.5). The group of rooms which rely on "spill-over" tower air fortunately consists of rooms normally utilized in a short-term basis only, and therefore somewhat more modest levels of ventilation air are not critical.

Table IV.C.1 Predicted Maximum Average Air Movement Velocity (in M/Sec) Available in Principal Rooms at 114 cm. above finished floor elevation (on plan). Underlined numbers indicate configurations or strategies which produce outright discomfort or borderline comfort conditions.

		Zone 1						Zone 2			Zone 3			
		G2 & G3			U1			G8		U9	G5		U6	
		Doors Closed	Doors Closed	Doors Closed	Closet Louvers Closed	Closet Louvers Closed	Closet Louvers Closed	Doors Closed	Doors Open	Closet Louvers and Operable Windows Open	All Operable Windows Open		All Operable Windows Open	
		No Wing Walls	With Wing Walls	No Wing Walls	No Wing Walls	With Wing Walls	No Wing Walls							
		WD: NE or NW	WD: NE or NW	WD: NE or NW	WD: NE or NW	WD: NE or NW	WD: NE or NW	WD: NE or NW	WD: NE or NW	WD: NE or NW	WD: N	WD: NE	WD: N	WD: NE
		Velocity Coefficients (% of unobstructed outdoor wind speed available on plan inside												
Month	Hour	34.6	35.8	44.6	15.7	35.8	34.0	8.6	27.4	6.4	32.0	43.24	32.0	43.4
March	0300	–	–	–	–	–	–	–	–	–	–	–	–	–
	0900	1.2	1.3	1.6	0.7	1.6	1.5	0.3	1.0	0.3	1.2	1.6	1.4	1.9
	1500	1.5	1.5	1.9	0.8	1.8	1.7	0.4	1.2	0.3	1.3	1.8	1.6	2.2
	2100	0.8	0.8	1.0	0.4	1.0	2.0	0.2	0.6	0.2	0.7	1.0	0.9	1.2
April	0300	1.1	1.1	1.4	0.6	1.4	1.3	0.3	0.9	0.2	1.0	1.4	1.2	1.7
	0900	–	–	–	–	–	–	–	–	–	–	–	–	–
	1500	–	–	–	–	–	–	–	–	–	–	–	–	–
	2100	1.0	1.0	1.3	0.6	1.3	1.2	0.2	0.8	0.2	0.9	1.3	1.2	1.6
May	0300	1.0	1.0	1.3	0.6	1.3	1.2	0.2	0.8	0.2	0.9	1.3	1.2	1.6
	0900	–	–	–	–	–	–	–	–	–	–	–	–	–
	1500	–	–	–	–	–	–	–	–	–	–	–	–	–
	2100	–	–	–	–	–	–	–	–	–	–	–	–	–
October	0300	0.7	0.7	0.8	0.4	0.8	0.8	0.2	0.5	0.1	0.6	0.8	0.7	1.0
	0900	–	–	–	–	–	–	–	–	–	–	–	–	–
	1500	–	–	–	–	–	–	–	–	–	–	–	–	–
	2100	–	–	–	–	–	–	–	–	–	–	–	–	–
November	0300	1.0	1.0	1.2	0.5	1.2	1.2	0.2	0.8	0.2	0.9	1.2	1.4	1.5
	0900	–	–	–	–	–	–	–	–	–	–	–	–	–
	1500	–	–	–	–	–	–	–	–	–	–	–	–	–
	2100	1.0	1.0	1.3	0.5	1.3	1.2	0.2	0.8	0.2	0.9	1.3	1.1	1.5
December	0300	–	–	–	–	–	–	–	–	–	–	–	–	–
	0900	–	–	–	–	–	–	–	–	–	–	–	–	–
	1500	1.2	1.2	1.5	0.6	1.5	1.4	0.3	0.9	0.3	1.8	1.6	1.3	1.8
	2100	–	–	–	–	–	–	–	–	–	–	–	–	–

Barometric "backdraft" dampers are specified between tower supply ducts or inlets and three spaces (G3, U2 & U3), in order to avoid unwanted redistribution of smoke or odors into outlet spaces of the building.

Zone (5)

This zone consists of four spaces (G9, U2, U3 and U4) which together make up the building's mechanically-ventilated zone. Three of these spaces are toilet rooms and the last is a laundry room, all of which require reliable extract ventilation to remove moisture and odors. These rooms are therefore all to be mechanically-ventilated by means of ducted exhaust fans.

Zone (6)

This zone consists of one room (G1), the garage/data systems/display room, which constitutes the building's only exclusively air-conditioned zone. Air-conditioning is a necessity here for the proper functioning of the room's computer installations, and can be deemed useful as well with respect to its display room/public relations functions.

D. WIND TOWER DESIGN

1. Tower and inlet sizing

The wind tower was analyzed utilizing a computer simulation program developed at ERL for this purpose. The design case was chosen based upon calm wind conditions and a wet bulb depression of 11C. The day selected from the weather data is April 26, 1981. The driving force therefore was only the evaporative downdraft effect. The tower was modeled with a cross-sectional area of 220cm x 220cm (48400cm^2) and a height of 17.22m. The gross outlet area to each floor was varied from .1 to .8 times the cross-sectional area of the tower and .5 was selected as optimal. Thus the outlet areas to each floor level are 24200cm^2. The following air flows were calculated for this case:

Tower Outlet Air Flows (CFM)	Time				
	3	9	15	21	Mean
Total	5083	9565	11427	9172	8579
Upper Fevel	1942	3654	4366	3504	3278
Lower Level	3141	5910	7061	5688	5301

Table IV.D.1 Wind Tower Outlet Air Flows

Tables IV.D.2 and IV.D.3 give the sizes required for the supply air duct/registers from the wind tower to each air-conditioning/ventilation zone. Figure IV.D.1 details the ducts necessary to supply air from the wind tower to rooms U9, U6, U2, U3, G8 and G5. These rooms cannot be directly supplied from the tower.

2. Tower Construction

The wind tower should be constructed of solid poured reinforced concrete to the roof level, with extension segments of the tower fabricated from welded steel tubing (see details on blueprint). Details for tower outlets, sizes and shapes can be found in the ventilation section. The upper reconfigurable tower segments should be easily removable for experments. The top section will be used to capture the wind (different geometries and operable configurations will be evaluated in experiments), and the extension section will house the evaporative cooling equipment (when installed for experiments) and an operable shut-off damper (see Fig. IV.D.2). The top section will have fixed (non-barometric) operable dampers on the north face and operable barometric dampers on the east and west face. All openings should have 2cm x 2cm hardware cloth screens on them to keep birds out, the Celdek demisters and/or evaporative pads may be adequate to filter out dust and insects. Figure IV.D.2 details the construction of these two removable segments.

Room Code	Load fraction	Tower CFM	Rect. Dimensions(cm)	Supply Grill(cm²)	Elevation above Finished Floor
From G11	1	5910		24200cm²	
G11>G2	.13	769	18 x 180	3146cm²	80cm
G11>G3	.35	2048	47 x 180	8470cm²	80cm
G11>G11'	.37	2187	50 x 180	8954cm²	270cm
G11'>G8	.20	1182	50 x 99	4840cm²	270cm
G11'>G5	.17	1005	50 x 82	4114cm²	270cm
G11>G7,4,6	.15	898	20 x 180	3630cm²	80cm

NOTE: 1. Total tower CFM based upon no wind (calm) condition and an evaporative cooling tower.
2. Total tower CFM to this floor: 5910 CFM @ 09:00 on Apr 26,1981
3. For calculation procedure see text on wind tower design.
4. Elevation above Finished Floor refers to required vertical dimensions between finnished floor and the bottom (sill) of supply/inlet grill.

Table IV.D.2 Wind Tower Supply Air Duct/Inlet Schedule - Ground Floor

Room Code	Load fraction	Tower CFM	Rect. Dimensions(cm)	Supply Grill(cm^2)	Elevation above Finished Floor
From U11	1	3654		24200cm^2	
U11>U1	.18	913	24 x 180	4356cm^2	80cm
U11>U11'	.42	1498	56 x 180	10164cm^2	239cm
U11'>U9	.18	658	56 x 78	4356cm^2	239cm
U11'>U6	.23	840	56 x 99	5566cm^2	239cm
U11>U2'	.14	1242	26 x 130	3388cm^2	269cm
U2'>U2	.7	1242	41 x 41	1694cm^2	269cm
U2'>U3	.7	1242	41 x 41	1694cm^2	269cm
U11>U4&8	.24	1242	46 x 180	8228cm^2	80cm

NOTE: 1. Total tower CFM based upon no wind (calm) condition and an evaporative cooling tower.
2. Total tower CFM to this floor: 3654 CFM @ 09:00 on Apr 26,1981
3. For calculation procedure see text on wind tower design.
4. Elevation above Finished Floor refers to required vertical dimensions between finnished floor and the bottom (sill) of supply/inlet grill.

Table IV.D.3 Wind Tower Supply Air Duct/Inlet Schedule - First Floor

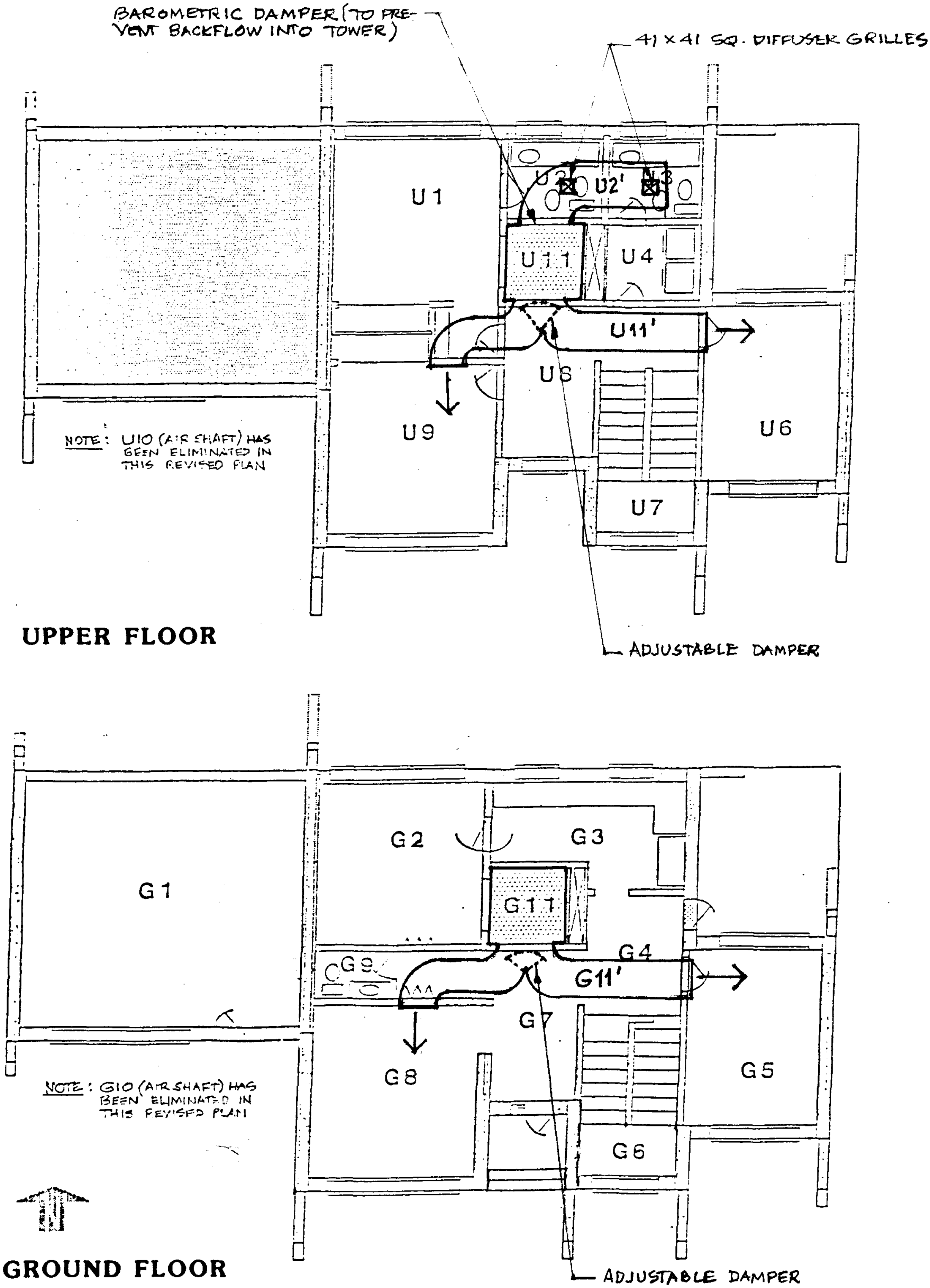
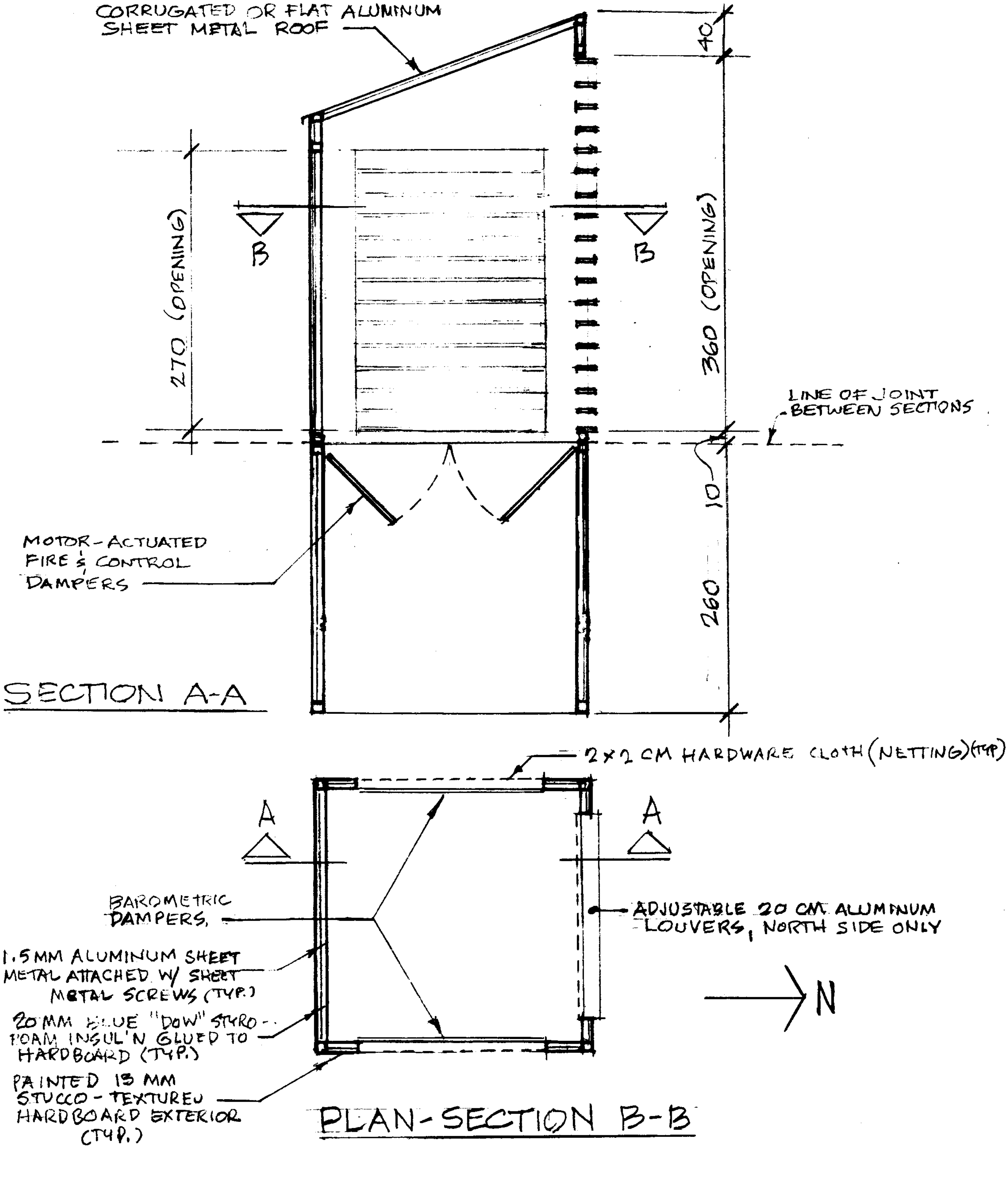


FIG. IV.D.1 : TOWER AIR DUCT PLANS



'IG. IV.D.2: WIND TOWER (STEEL-FRAMED SECTION) ALT. # 1

IV.A. REFERENCES

1. Sobin, H. J., Nov. 1981, "Window Design for Passive Ventilative Cooling—An Experimental Model-Scale Study," Proc. Intl. Passive and Hybrid Cooling Conf., Miami Beach, 1981, AS/ISES, pp. 191-195.

2. Sobin, H. J., 1983, Analysis of Wind Tunnel Data on Naturally Ventilated Models, Appendix A: Test Data Catalog, Harris Sobin & Associates, 6550 N. Skyway Drive, Tucson, AZ 85718.

3. Ibid.

4. Givoni, B., 1969, Man, Climate and Architecture, Elsevier Publishing Co., pp. 266-268.

E. VENTILATION AND WIND TOWER PERFORMANCE

Cross-ventilation due to the wind at velocity V_w, ft/sec, through the open north windows (ΣA_{wn}, sq.ft.), assuming negligible resistance to flow through the house interior, and out the open south windows (ΣA_{ws}) is given by (1):

$$q = V_w \sqrt{(C_{wpn}-C_{wps})/[(\Sigma C_d A_{wn})^{-2} + (\Sigma C_d A_{ws})^{-2}]} \quad \text{(IVE-1)}$$

where q is the ventilation rate, ft^3/sec, and $\Sigma C_d A_w$ is the summation of the products of discharge coefficients for the north (n) and south (s) windows. The discharge coefficient is tabulated in reference (1) for various cases, and is approximately 0.63 when the window area is small relative to the wall area. An expression for C_d obtained by fitting the data in reference (1), is: $C_d = [2.5-1.5(A_w/A_{wall})^2]^{-1/2}$. C_{wp} (dimensionless) is the wind pressure coefficient:

$$C_{wp} = P/(\rho_a V_w^2/2g_c) \quad \text{(IVE-2)}$$

where P is the static pressure on the surface, lb/ft^2, ρ_a is the density of air, lb/ft^3, and g_c is the Newton's law conversion factor, 32.2 lb_m-ft/lb_f sec^2. C_{wp} is generally positive on windward surfaces and negative on leeward surfaces. Tabulations of C_{wp} are available in the literature for a wide variety of cases (2), (3). In this analysis the wind is assumed to come from the north. C_{wpn} and C_{wps} are the pressure coefficients for the north and south walls of the building, respectively.

Calculation of the performance of the wind tower is more complicated because the driving force for ventilation combines wind pressure and a reverse stack effect when the evaporative cooler is operating, and there are outlets from the tower at two levels. For ventilation only, two equations are required; for ventilation with evaporative cooling a third equation is required describing the performance of the evaporative cooler under varying air flows. Variation of wind velocity and wind pressure coefficients with elevation will not be considered here; however, methods are described in the literature for treating this effect (1), (2), (3). Below the evaporative cooler, the tower operation is assumed to be isothermal.

The general form of the equation describing flow through the tower and building is:

$$\Delta C_{wp}(\rho_a V_w^2/2g_c) + (g/g_c) Z \Delta\rho = (\rho_t V_t^2/2g_c)\Sigma K \quad \text{(IVE-3)}$$

where ΔC_{wp} is the difference between the wind pressure coefficients at the tower inlet and window outlets; g is acceleration due to gravity, ft/sec^2; Z is the height from the bottom of the evaporative cooler to the outlet, ft; $\Delta\rho$ is the difference in air density between the inside of the tower and outside air, lb/ft^3; ρ_t is the density of air in the tower; V_t is the velocity of air in the tower between the evaporative cooler and first outlet, ft/sec; and ΣK is the sum of the pressure loss coefficients between the tower inlet and building window outlets.

For the upper section of the tower and building, ΣK consists of coefficients for the following: inlet (4) (contraction, louvers, screen, turning) the evaporative cooler (5), friction (4), branching flow (6), the mist eliminator (5), the tower outlet to the house, and the windows (1). Resistance to flow inside the house is taken as zero.

Two types of evaporative coolers were considered, the pad type and the spray type. Celdek$_{TM}$ (5), a rigid corrugated cellulose material, which is manufactured in rectangular blocks and is self-supporting, was selected as the pad-type cooler. It would be mounted at an angle in the tower, or in a vee arrangement, to increase its face area and reduce pressure drop. The mist eliminator, to remove water droplets from air entering the house, was assumed to be Celdek$_{TM}$, or a similar material, and pressure drop data for Celdek$_{TM}$ was used to estimate the mist eliminator loss. For the spray type cooler, the air side pressure drop was taken as zero. There are a large variety of spray nozzles available; those producing fine droplets provide very high saturation efficiencies, however, the fine droplets are often difficult for the mist eliminators to remove. In computer runs, the model employing a Celdek type evaporative cooler was tested first; if it was unable to produce comfortable conditions in the house, the program was changed to simulate a spray and the effectiveness required to provide comfortable conditions determined, without specifying the type of spray.

The equation for flow between the tower and first outlet is:

$$\Delta C_{wp}(\rho_a V_w^2/2g_c) + (g/g_c) Z_u \Delta\rho = (\rho_t V_t^2/2g_c)$$

$$\Big\{ \underset{\text{(inlet)}}{3.12} + \underset{\text{(friction)}}{(4f_u Z_u/D_h)} + \underset{\text{(cooler)}}{(5.87x_p/r_p^2)} + \underset{\text{(branch)}}{(5/4)\,\{1.8[(1-F)/r_u]^2 - 0.368F\}}$$

$$+ [(1-F)/r_u]^2 \{ \underset{\text{(mist eliminator)}}{5.87x_m(r_u/r_{mu}n_u)^2} + \underset{\text{(outlet)}}{[2.5 - 1.5(r_u/n_u)^2]} \}$$

$$+ \underset{\text{(windows)}}{[(1-F)/C_d r_{wu}]^2} \Big\} \qquad \text{(IVE-4)}$$

where Z_u is the distance from the tower inlet to upper outlet, ft; f_u is the Fanning friction factor for the upper section; D_h is the hydraulic diameter of the tower (4 x Area ÷ perimeter), ft; x_p is the packing thickness in the evaporative cooler (normally 0.5 ft); x_m is the mist eliminator (normally 1/3 ft); and n_u is the number of outlet ports at the take-off point (normally 3). r refers to the ratio of area to the tower cross-section; r_u the ratio of the total upper outlet area to the tower cross-sectional area; r_p, of the packing face area in the cooler; r_{mu}, of the mist eliminator area; and r_{wu}, of the second story windows. F is the fraction of total airflow into the bottom outlet.

For flow through the lower outlet, ΣK consists of coefficients for the inlet, evaporative cooler, upper section friction and branch, lower section friction, turning, mist eliminator, outlet, and windows. The equation is:

$$\Delta C_{wp}(\rho_a V_w/2g_c)^2 + (g/g_c) Z_l \Delta\rho = (\rho_t V_t^2/2g_c)$$

$$\Big\{ \underset{\text{(inlet)}}{3.12} + \underset{\text{(friction)}}{(4f_u Z_u/D_h) + [4 f_l (Z_l - Z_u) F^2/D_h]} + \underset{\text{(cooler)}}{(5.87 x_p/r_p^2)}$$

$$+ \underset{\text{(branch)}}{(5/4)(1.36 F^2 - 0.72F - 0.64)} + \underset{\text{(turn)}}{(5/4)[1.8(F/r_l)^2 - 0.368F^2/r_l]}$$

$$+ (F/r_l)^2 \{ \underset{\text{(mist eliminator)}}{5.87 x_m (r_l/r_{ml} n_l)^2} + \underset{\text{(outlet)}}{[2.5 - 1.5(r_l/n_l)^2]} \}$$

$$+ \underset{\text{(windows)}}{(F/C_d\, r_{wl})^2} \Big\} \qquad \text{(IVE-5)}$$

where Z_l is the distance from the tower inlet to lower outlet, ft; f_l is the friction factor for the lower section; n_l is the number of lower outlet ports (usually 3); r_l is the ratio of total lower outlet area to the tower cross-section; and r_{wl} is the ratio of first floor window area to the tower cross-section. The window area used is that on the leeward side of the house.

To evaluate the $\Delta\rho$ terms in these equations, the saturation effectiveness for wetted $Celdek_{TM}$ is:

$$\eta = 1 - EXP(-18.3 x_p^{0.872}/V_p^{0.346}) \qquad \text{(IVE-6)}$$

where V_p is the velocity of air through the packing face, ft/sec. With equation IVE-6 and the equation relating to temperatures and humidities from Section IIIC, the density difference ($\Delta\rho$) can be evaluated by either the perfect gas equation or those from ASHRAE.

Equations IVE-4, IVE-5, and IVE-6 are solved by iteration, and the total ventilation rate is $q = V_t A_t$, where A_t is the tower cross-sectional area.

This analysis holds for a closed stairwell; computation of flow between the two floors through the stairwell would require a fourth equation.

BUILDING SIMULATION USING VENTILATION ONLY: NOV-APRIL

Simulation of building performance was carried out using PASSCOOL coupled with programs for ventilation/wind tower performance on an IBM Personal Computer, using monthly average Dhahran weather data for 1981. Data were available for four hours daily: 03, 09, 15, and 21; the monthly average data were interpolated to a 24-hour basis by fitting with smooth curves having the same beginning (0 hrs) and end-point (24 hrs). Wind velocity data were restricted to those winds from the E-N-W (90-360-270 deg) general direction. Solar radiation values were computed using ASHRAE techniques for clear days, 26.4 degrees north latitude.

Both ventilation and evaporative cooling employed the wind tower with air exhausting through the south windows. Heat rejection from the building is required throughout the year, including the winter months. During the months Nov-April the heat rejection rate is controlled by varying the period and amount the south windows are open. The air flow path chosen, i.e., through the tower—into the house—out the windows, could also allow dust filters to be installed over the tower-house vents; while a dust filter design has not been selected at the present time, both the evaporative cooler and mist eliminator air flow resistances were present during the ventilation computer runs, which could be considered an allowance for a filter resistance.

During periods when the building was closed or unventilated, ceiling fans were considered to be present capable of providing room air circulation velocities of from 0 to 0.2 mps.

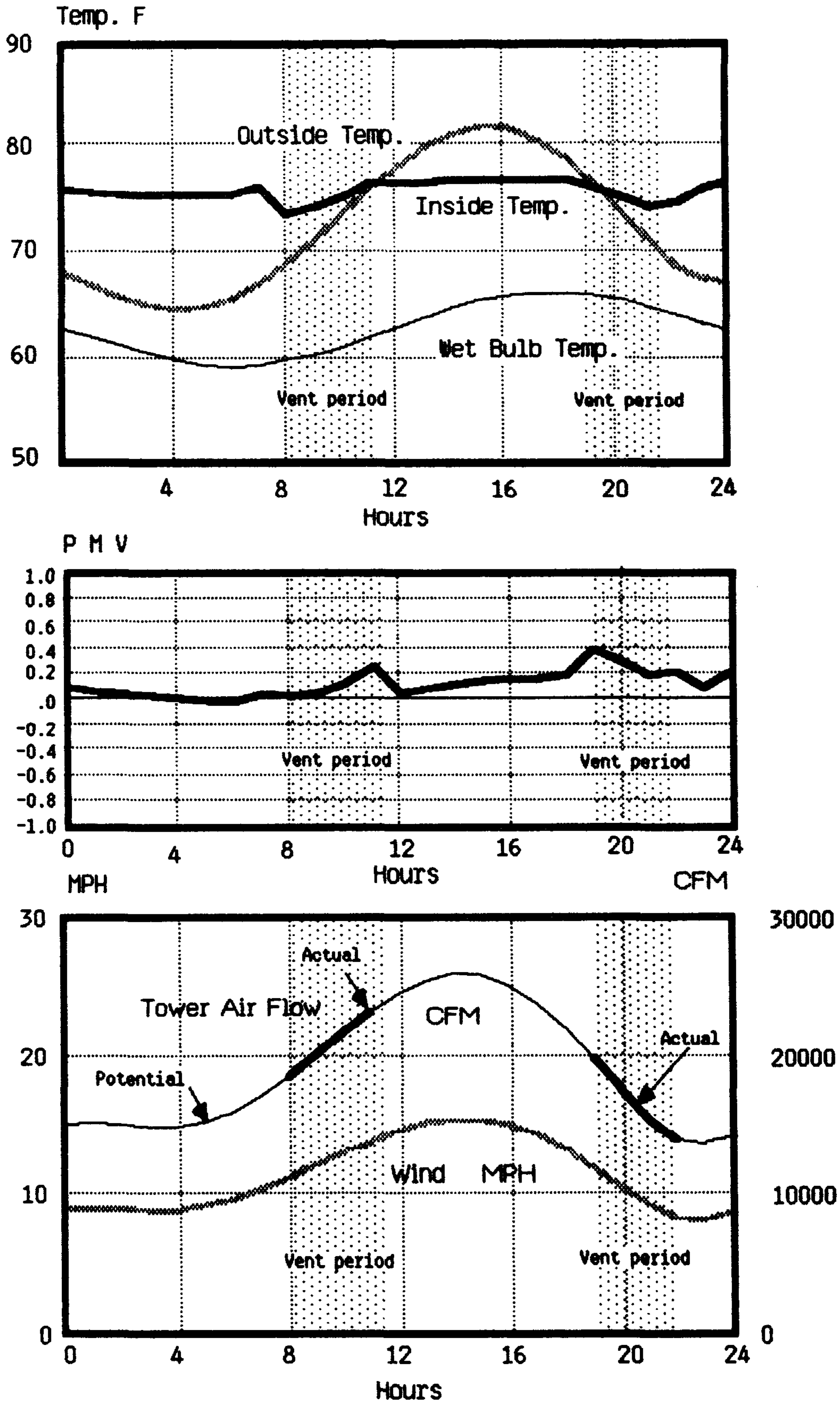
Ventilation rates and periods for providing comfortable interior conditions during Nov-April were determined by trial using the computer model; other operational modes than those presented may also provide comfort.

Operation for the months Dec., Jan., and Feb. is somewhat similar; it is only necessary to reject heat for several hours in the afternoon by ventilation with a small (5%) window opening. The mass of the building and internal heat generation allow the building to "float" through the remaining period under comfortable conditions. A PMV between +0.5 and -0.5 is considered comfortable.

November and March operation are also similar. Outdoor temperatures are somewhat low at night, and somewhat high during the day, for ventilation, so the building is ventilated during the morning and evening (40% window opening) and allowed to float during the remaining periods.

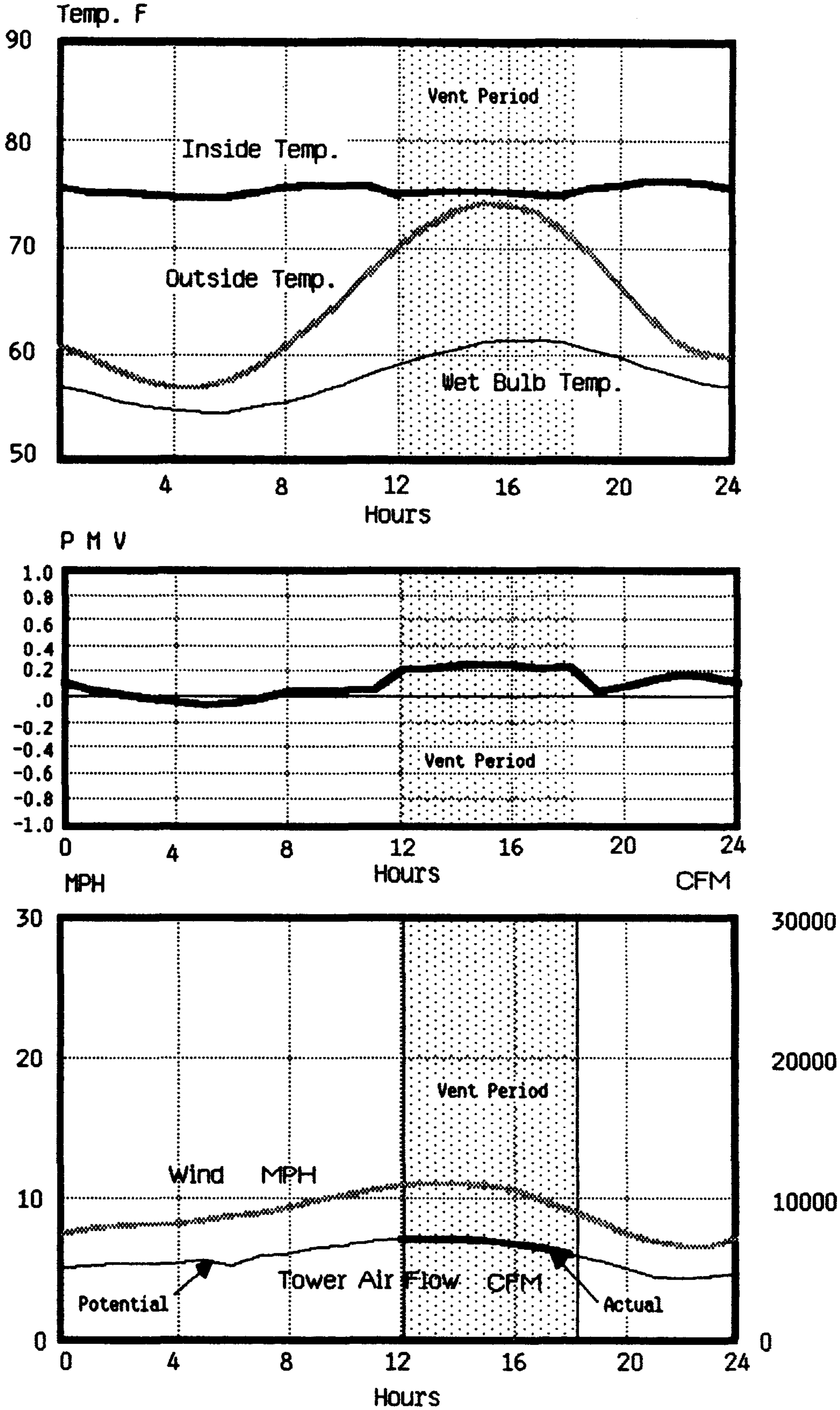
During April, it is necessary to ventilate throughout the night (40% window opening) and allow the closed house to float during the day and early evening.

On the graphs (Figures IV.E.1 through IV.E.6) showing tower air flow, the available air flow to the house is shown for the entire 24-hour period; in evaluation of the building performance, only the indicated (actual) portions were used.



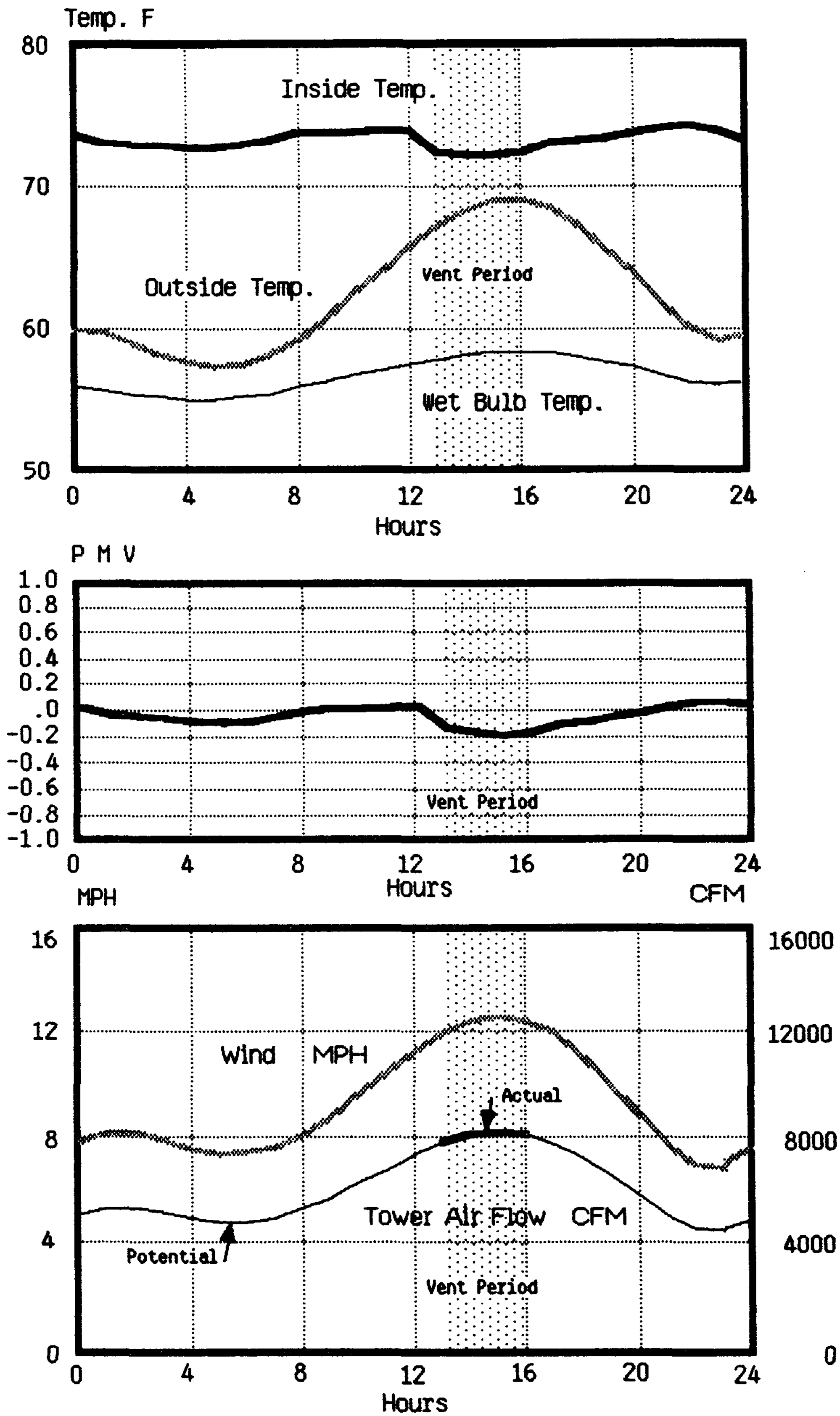
Note: 40% of south window area open during ventilation.
Room Air Velocity = 0.2 mps, during unventilated period

Fig. IV. E. 1 Building / Tower Performance
Nov.



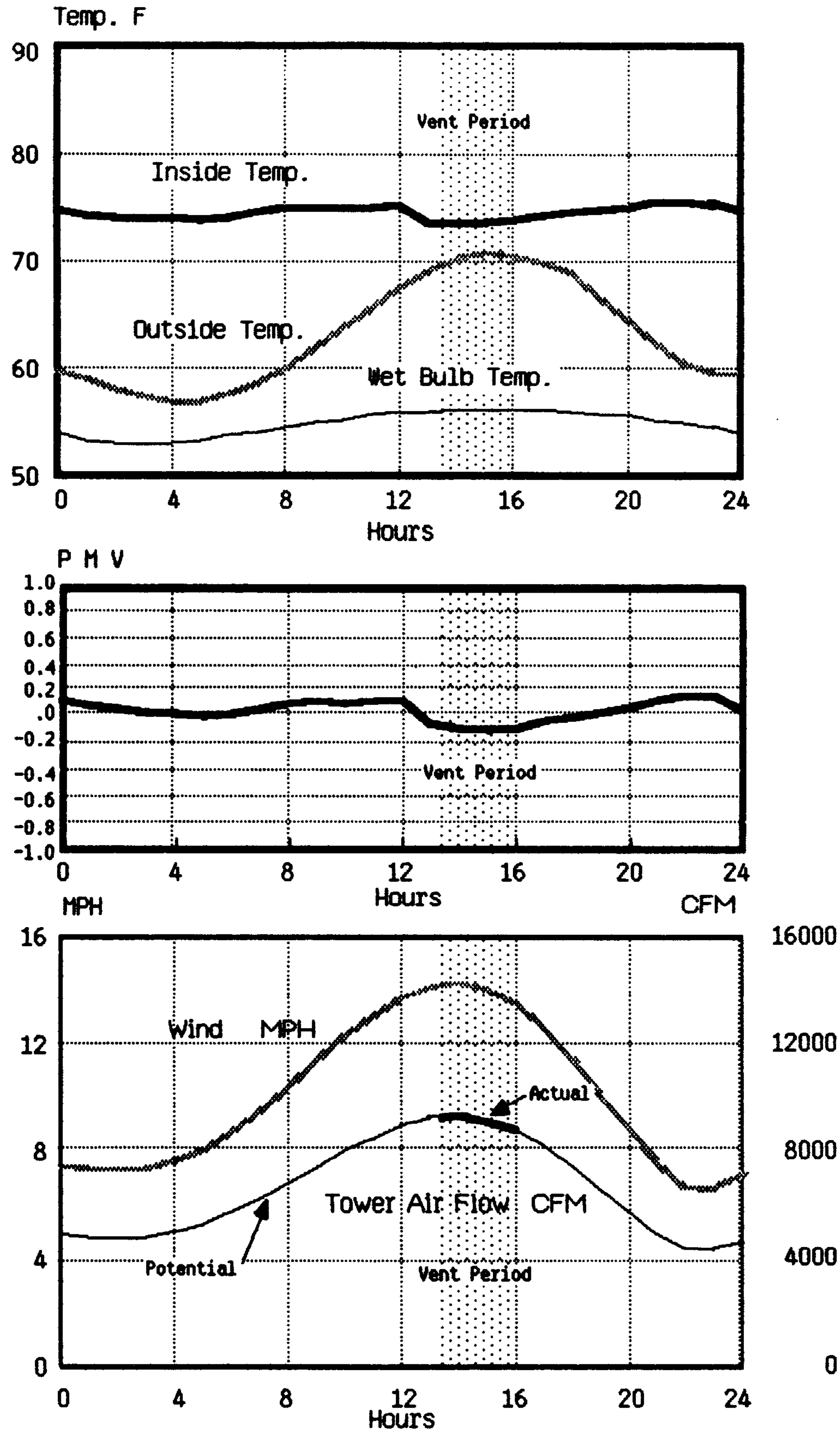
Note: 5% of south window area open during ventilation.
Room Air Velocity = 0.2 mps, during unventilated period

Fig. IV. E. 2 Building / Tower Performance
Dec.



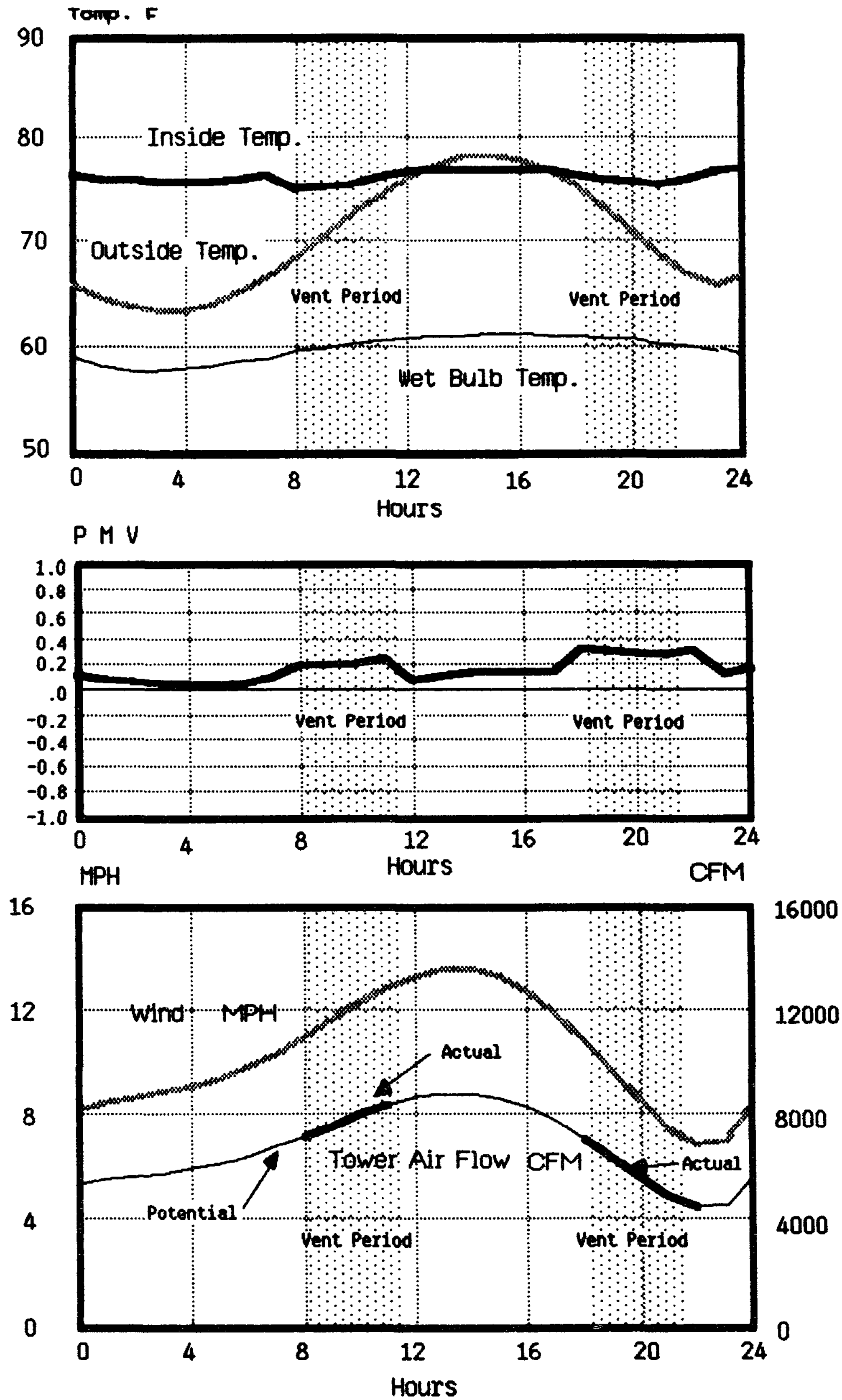
Note: 5% of south window area open during ventilation.
Room Air Velocity = 0, during unventilated period

Fig. IV. E. 3 Building / Tower Performance
Jan.



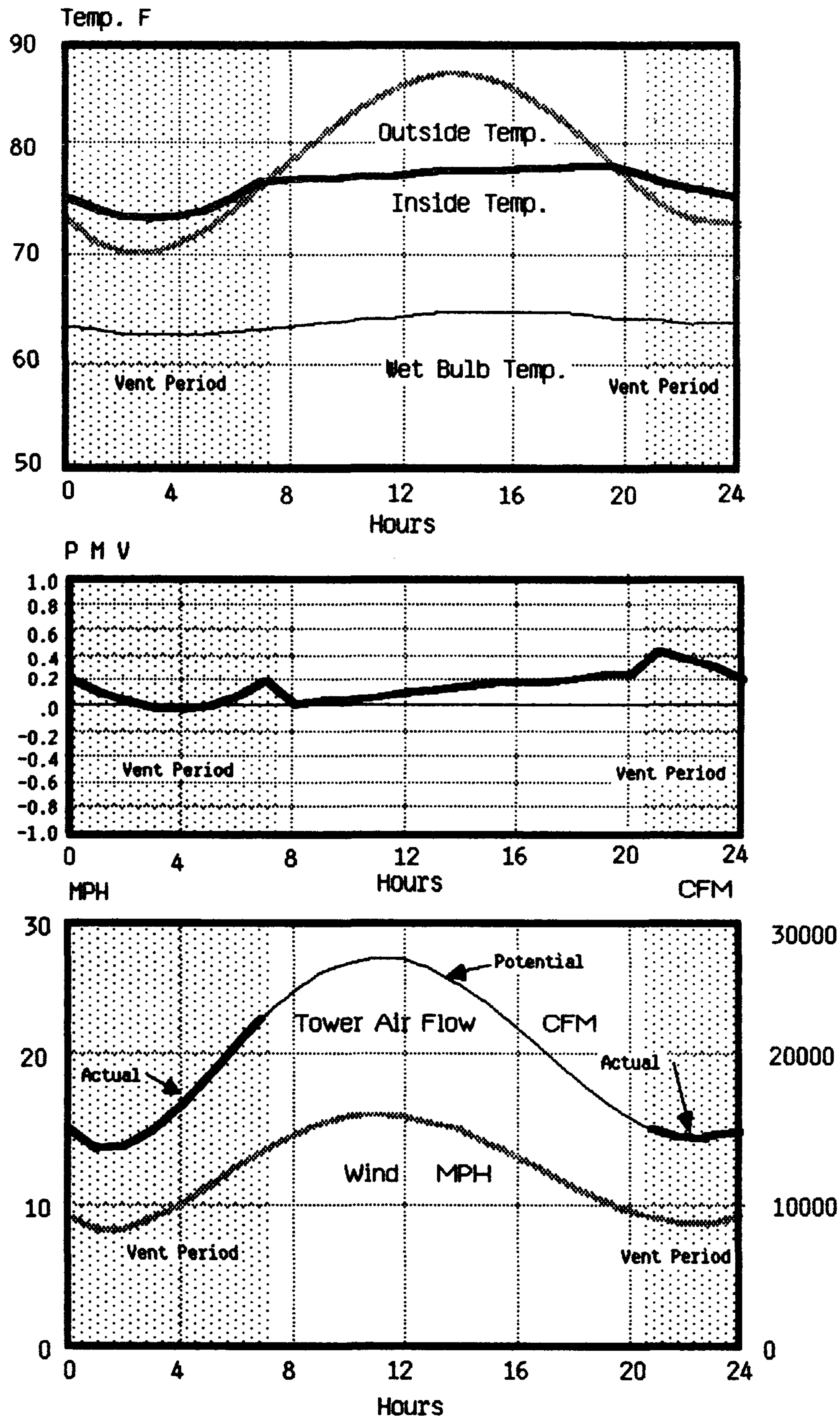
Note: 5% of south window area open during ventilation.
Room Air Velocity = 0, during unventilated period

Fig. IV. E. 4 Building / Tower Performance
Feb.



Note: 5% of south window area open during ventilation.
Room Air Velocity = 0.2 mps, during unventilated period

Fig. IV. E. 5 Building / Tower Performance
Mar.



Note: 40% of south window area open during ventilation.
Room Air Velocity = 0.2 mps, during unventilated period

Fig. IV. E. 6 Building / Tower Performance
April

BUILDING SIMULATION USING EVAPORATIVE COOLING: MAY-OCT

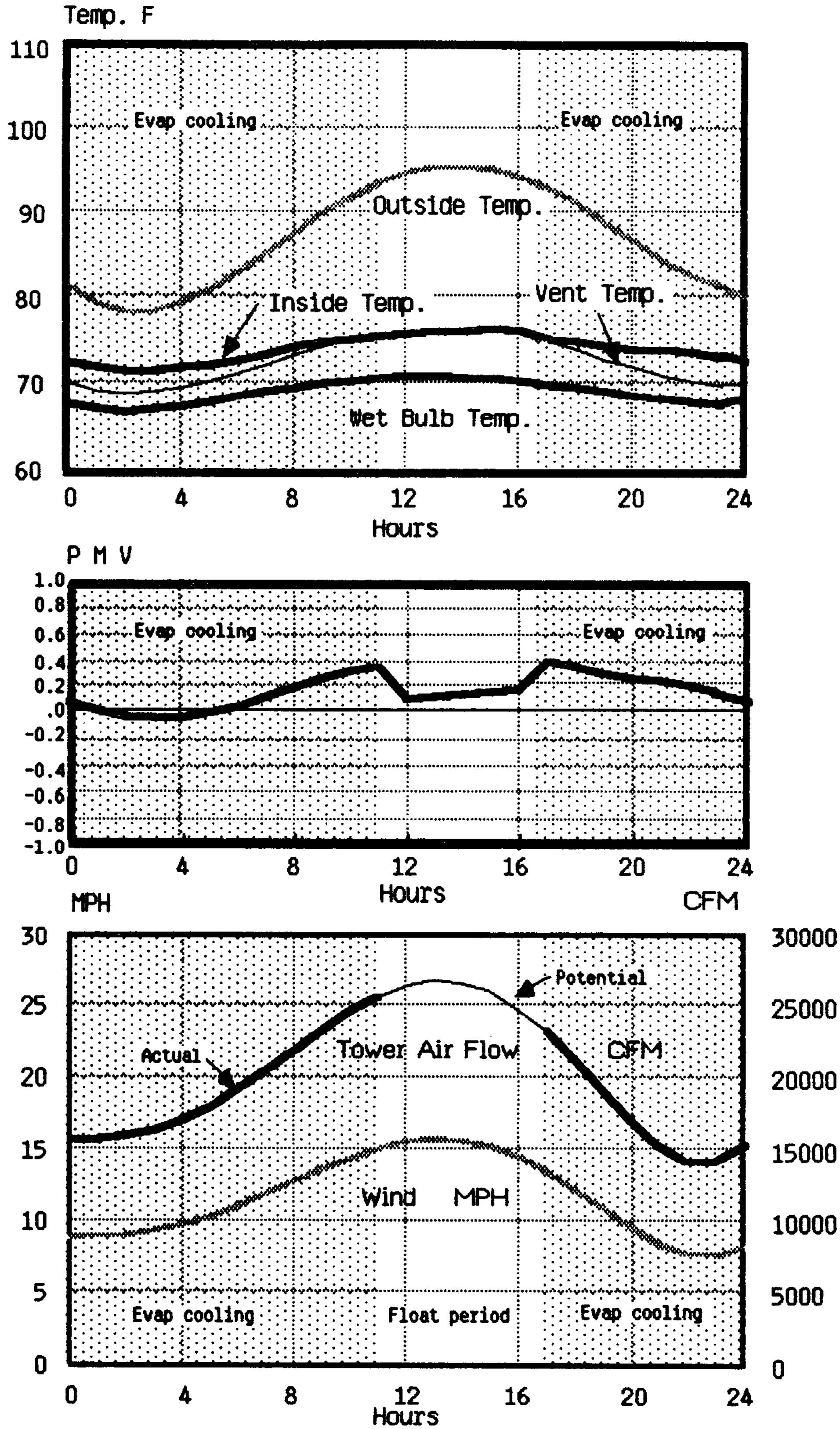
During May and June (Figures IV.E.7 and IV.E.8) comfortable conditions can be maintained by evaporative cooling using Celdek, although performance of Celdek becomes marginal in June. During May evaporative cooling is operated for the major part of the day; however, the cooler can be turned off from 11 a.m. to 5 p.m. and the building allowed to "float" during that period. In June the evaporative cooler is operated for the entire 24-hour period; comfort conditions are marginal from 4 p.m. to 10 p.m., with a PMV of approximately, + 0.5.

Comfort conditions in June are improved if the Celdek evaporative cooler is replaced by a spray-type unit having an 85% efficiency, as shown in Figure IV.E.9. The efficiency of the spray is considered constant during the day, while that of the Celdek cooler is a function of air velocity, as explained earlier. The higher efficiency of the spray unit provides a slightly lower air temperature and greater comfort.

It is very difficult to provide comfortable conditions in July, August and September (Figures IV.E.10, 11, 12) with evaporative cooling. Celdek is inadequate and spray efficiencies of from 90 to 98% are required, as well as supplemental air circulation. In all other cases involving evaporative cooling or ventilation, air movement inside the building has been provided by the wind tower, except when the building was closed during "float" periods. During July-Sept. conditions are so extreme that internal fans would need to be operated during evaporative cooling, producing room air velocities of 0.5 mps. The combination of high spray efficiencies and supplemental air circulation produces PMV's within the $\pm$ 0.5 comfort range; however, humidities inside the house sometimes approach saturation, so the occupants would probably experience a damp sensation at times, even though the predicted PMV's, as calculated, appear acceptable. Two-stage evaporative coolers are capable of providing air at the outdoor wet-bulb temperature (100% apparent efficiency), but at a lower absolute moisture level, and should be much more satisfactory than the very efficient single-stage evaporative cooler model used here. Research at the KFU laboratory should include the design of a two-stage evaporative cooler/wind tower.

Simulated October performance for the building and wind tower are shown in Figures IV.E.13 and 14, for Celdek and spray evaporative cooling. October performance is similar to June; Celdek is inadequate and a 90% efficient spray, higher than in June, is required. In the latter case supplemental air circulation from ceiling fans is also required (0.2 mps).

Figure IV.E.15 is included to illustrate the operational flexibility allowed by the mass of the building, and the effects of reducing the thermal mass on comfort. In Figure IV.E.15, the building is evaporatively cooled with Celdek from 8 p.m. to 7 a.m. and allowed to float during the day. Case one is the KFU laboratory building (F) with all of the thermal mass present; the highest PMV was 0.35 occurring near the end of the float period. Case two is the KFU design with the mass of the interior walls and floor slabs omitted, but the high-mass exterior walls included; the highest PMV was 0.72, outside the comfort range with a maximum temperature of 81.5^{o}. In case three the internal walls and floor slabs are present, but the exterior block walls have been replaced by a low-mass wall having the same R value; the highest PMV was 0.5 with an internal temperature of 79.6^{o}. Case four is a hypothetical zero thermal mass KFU building with the inter furnishings and air constituting the only thermal mass present; the building wou be quite uncomfortable in the afternoon, with a PMV of 4.1 and a maximum temperature of 104.4^{o}F.



Note: 40% of south window area open during evap. cooling.
Room Air Velocity = 0.2 mps, during float period

Fig. IX. E. 7 Building / Tower Performance
May

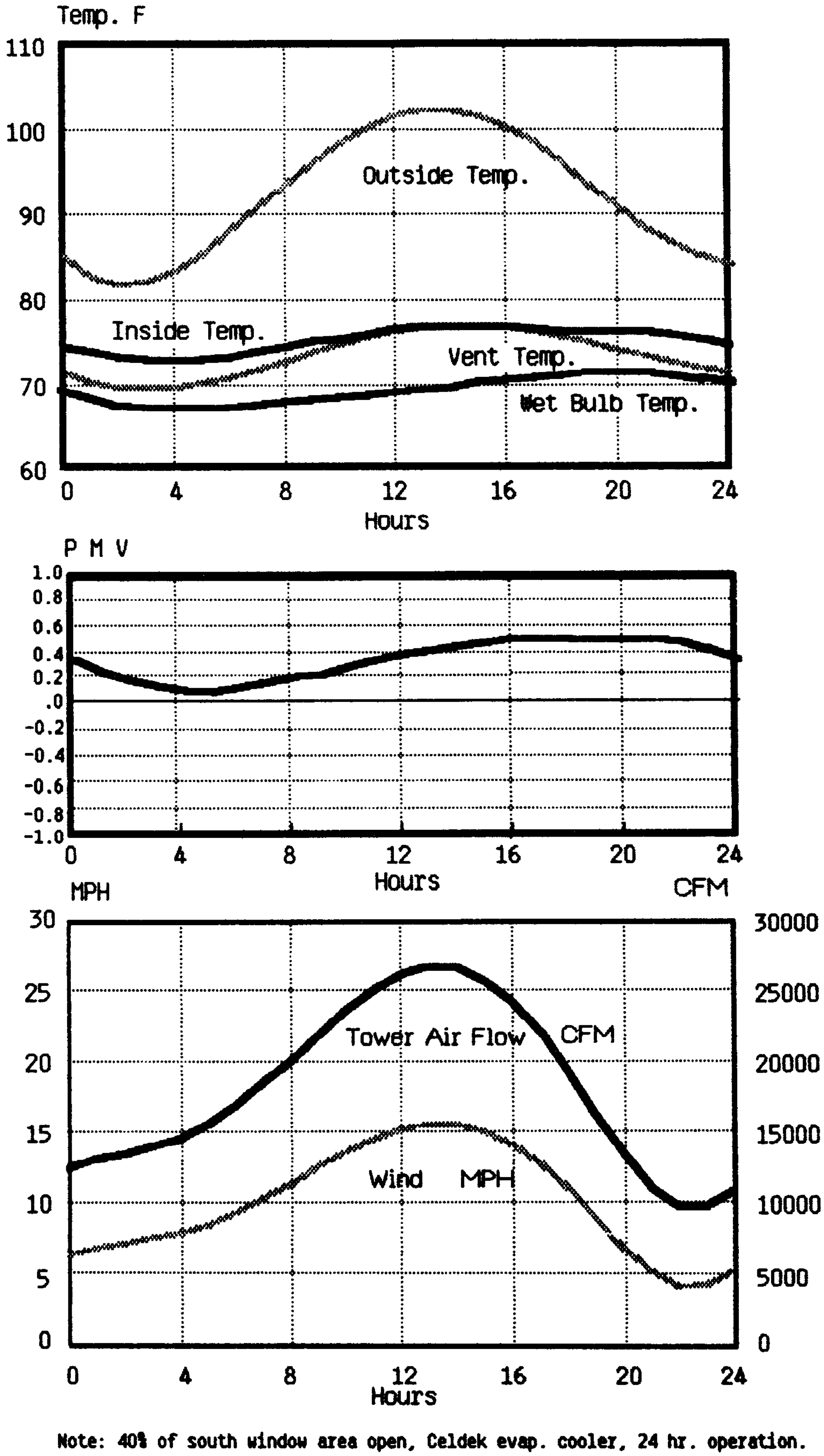
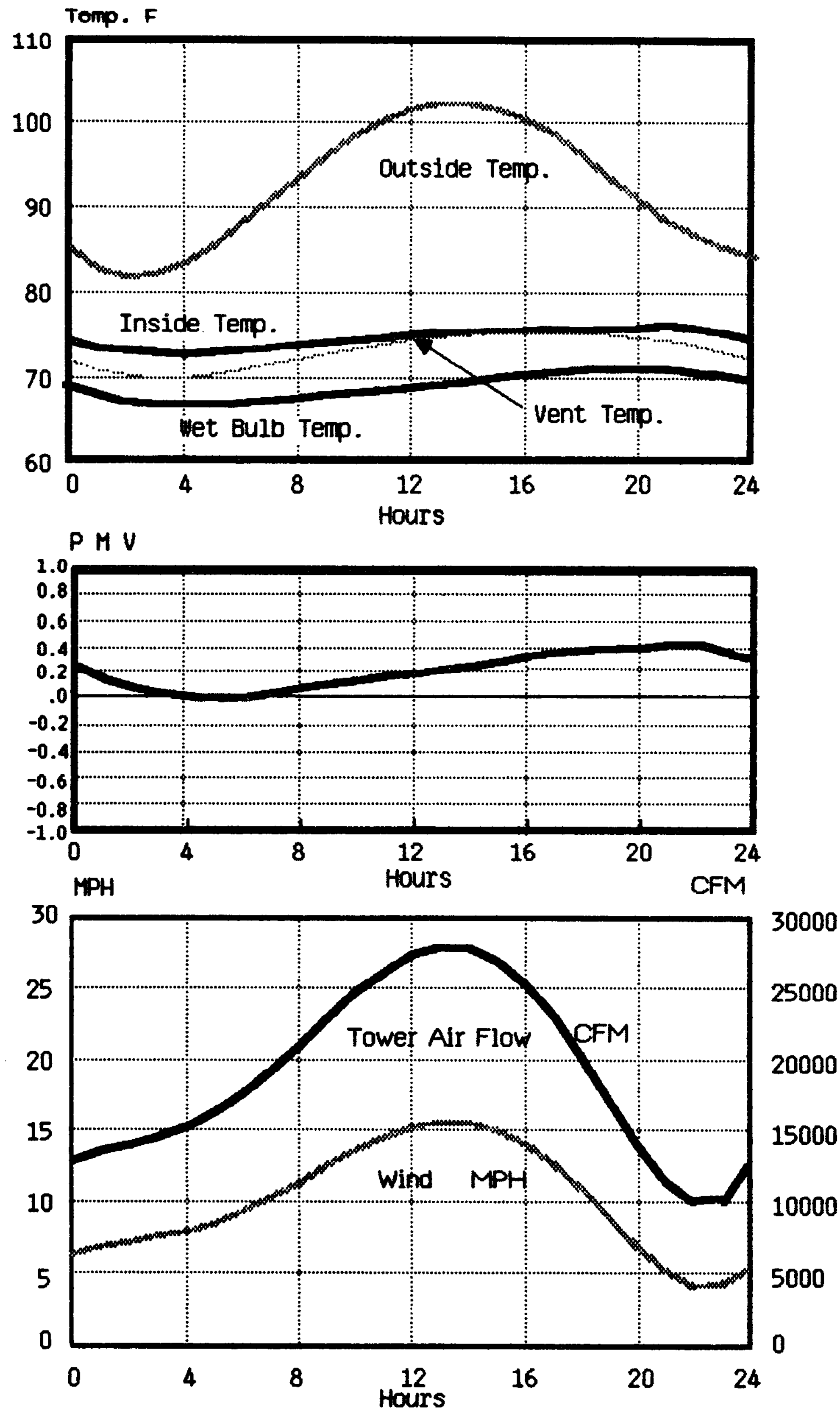


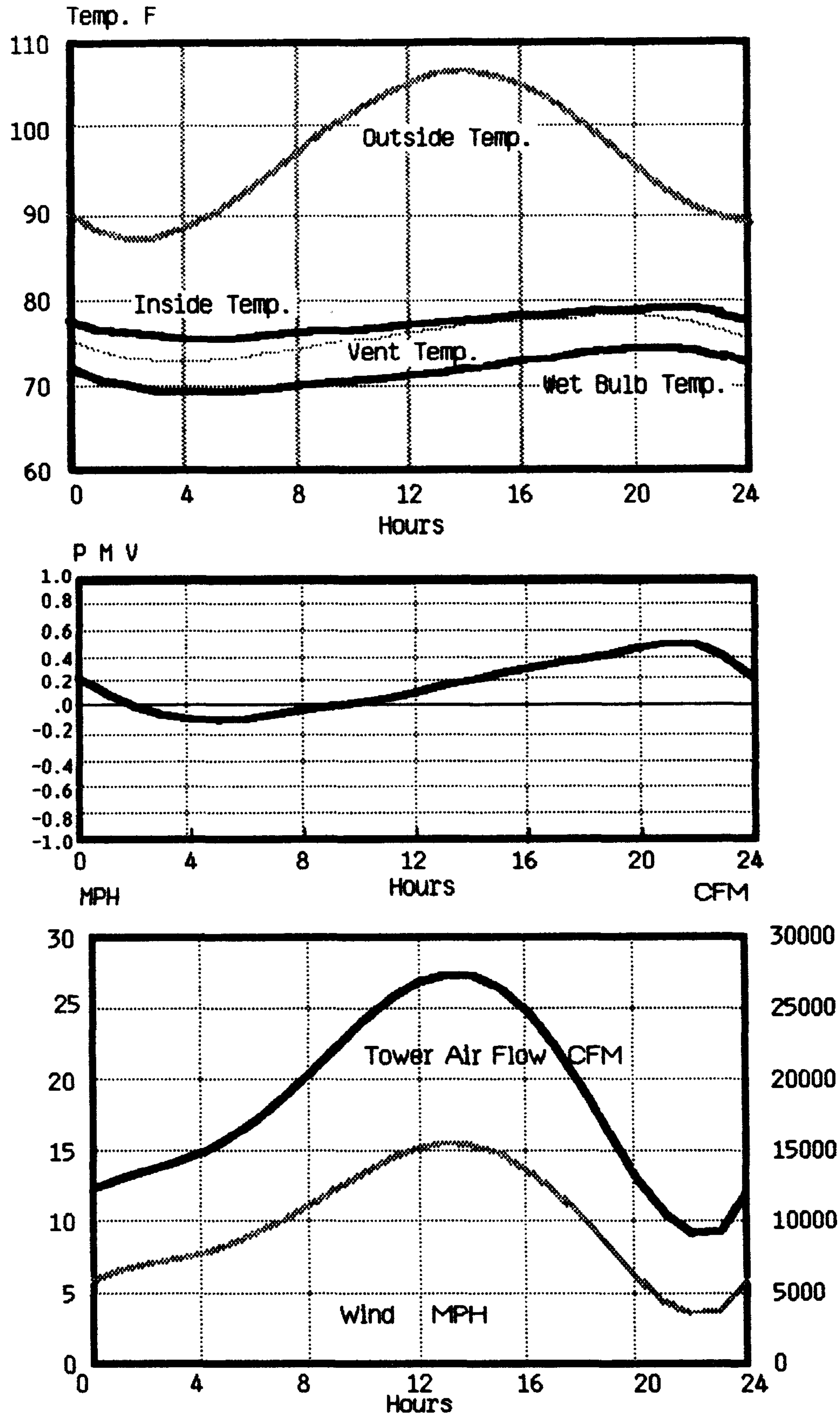
Fig. IV. E. 8 Building / Tower Performance
June - Celdek



Note: 40% of south window area open, 85% eff. spray, 24 hrs. evap cooling.

Fig. IV. E. 9 Building / Tower Performance

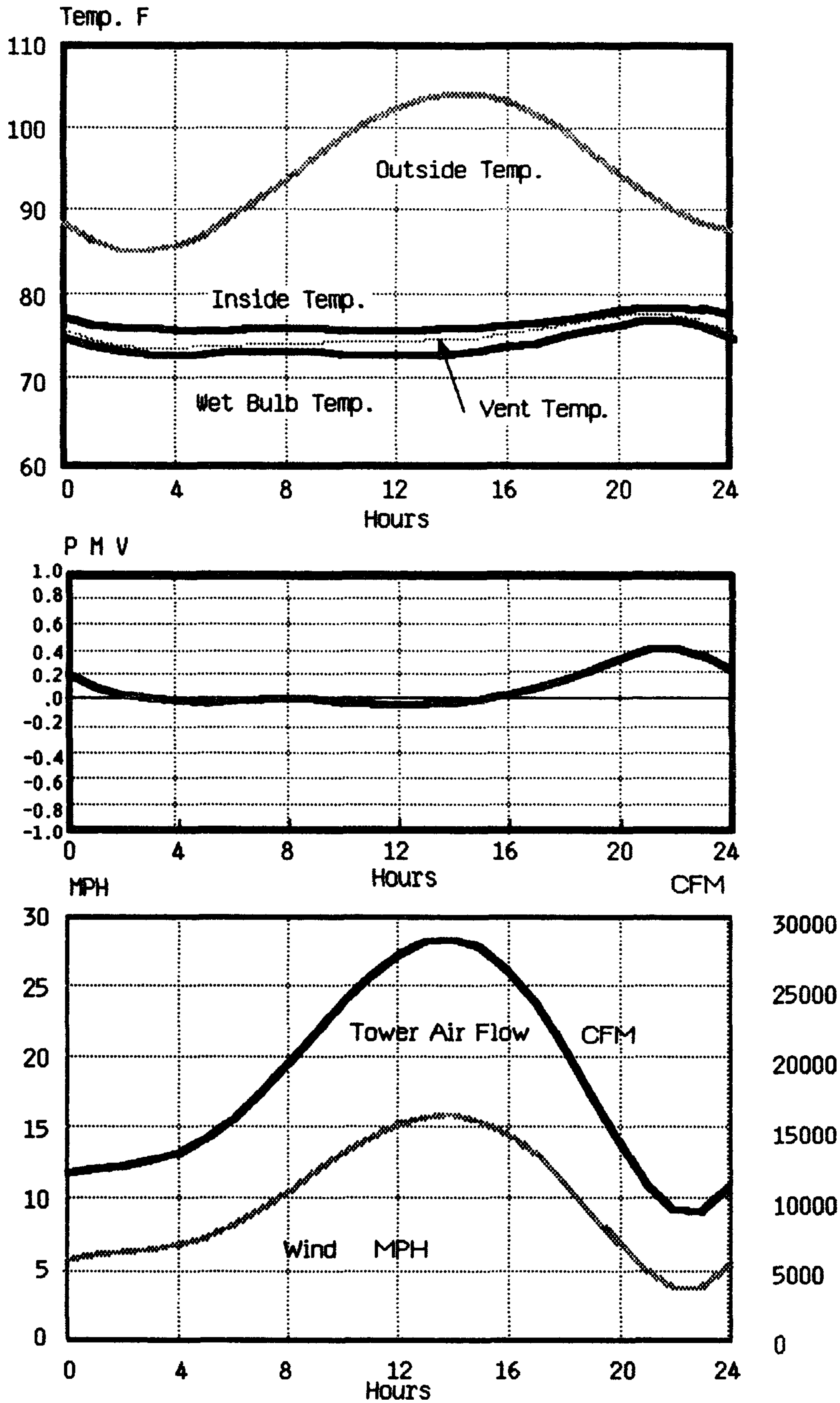
June - Spray



Note: 40% of south window area open, 90% eff. spray, 24 hrs. evap. cooling.
Room Air Velocity = 0.5 mps.

Fig. IV. E. 10 Building / Tower Performance

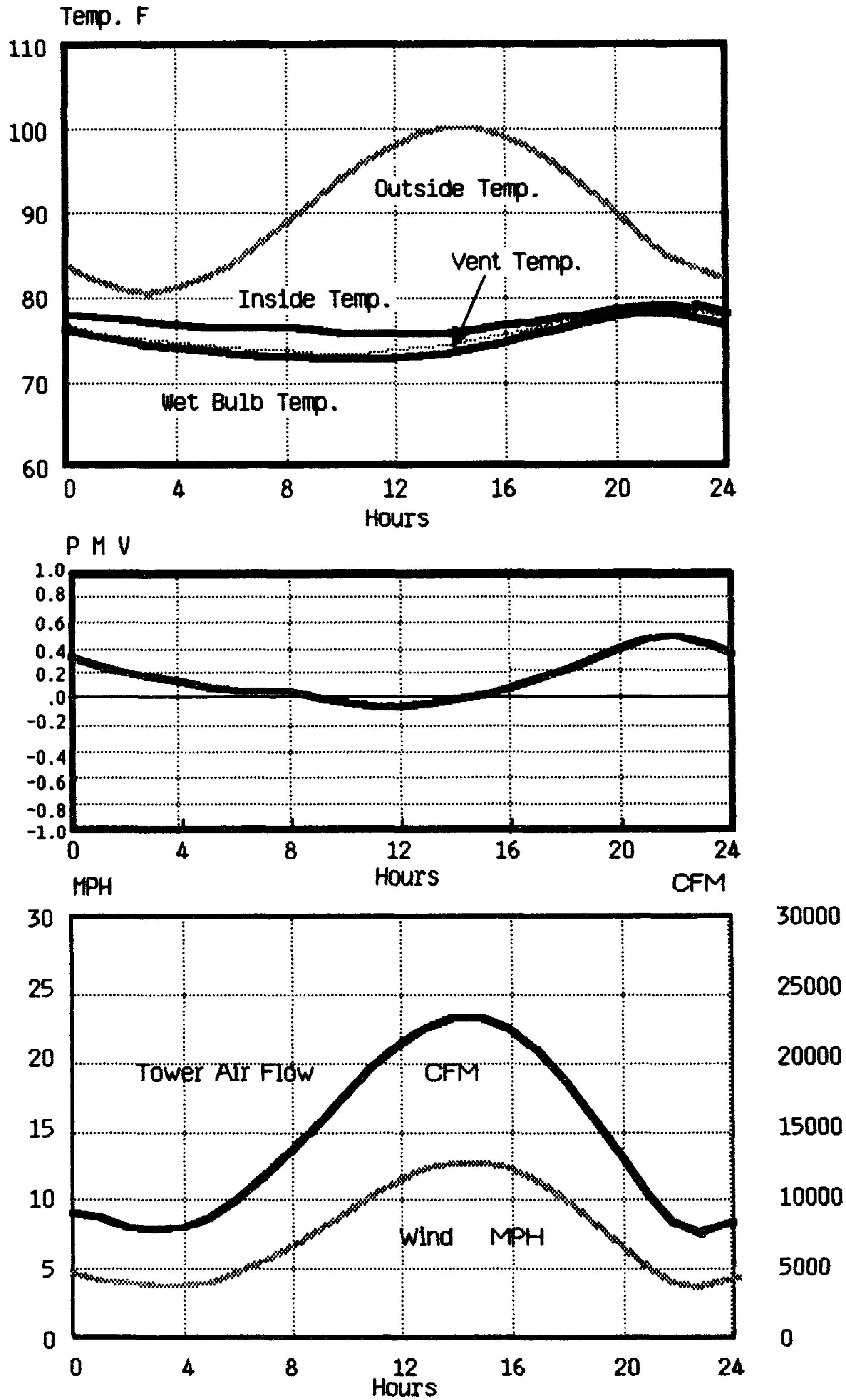
July



Note: 40% of south window area open, 95% eff. spray, 24 hrs. evap. cooling.
Room Air Velocity = 0.5 mps.

Fig. IV. E. 11 Building / Tower Performance

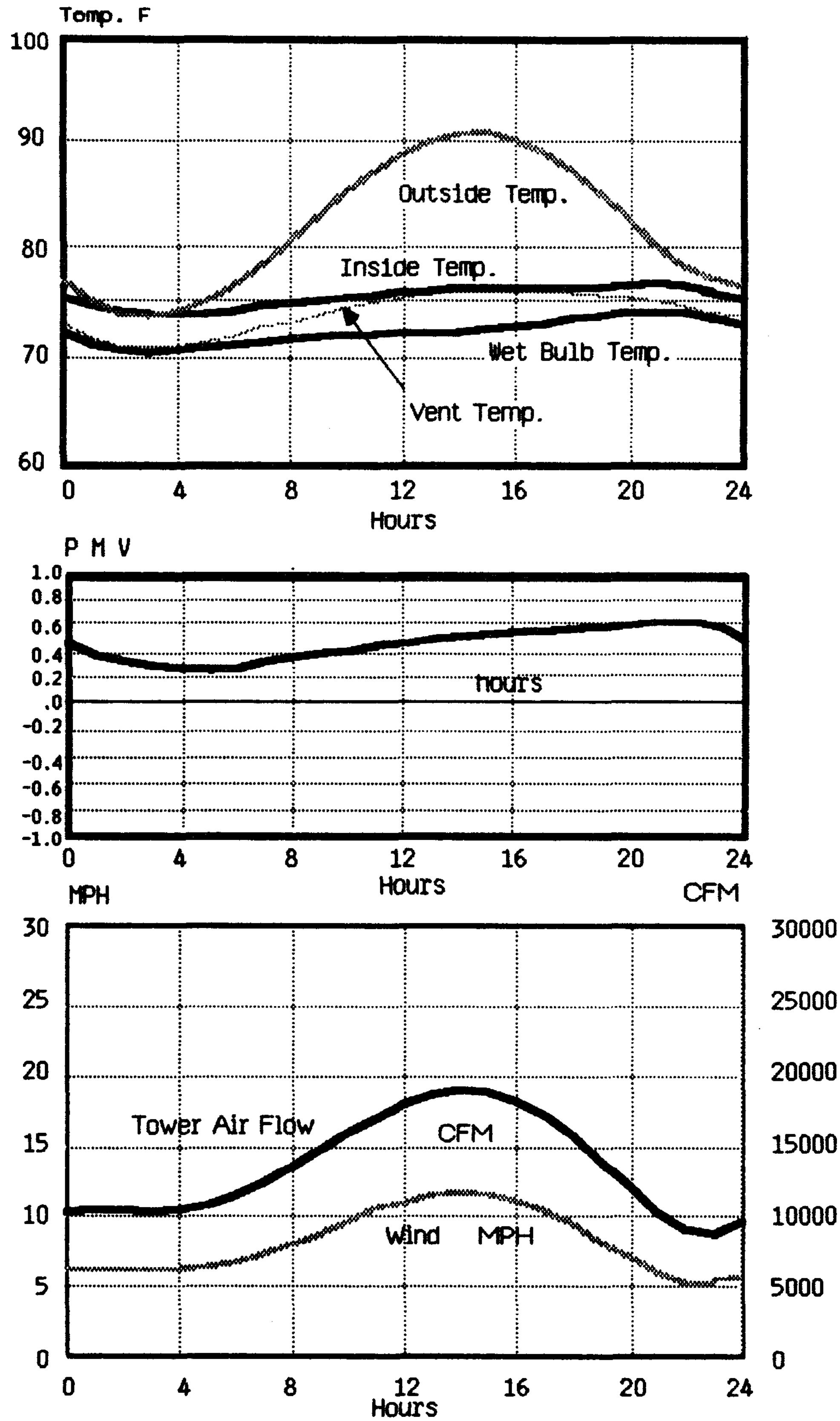
Aug.



Note: 40% of south window area open, 98% eff. spray, 24 hrs. evap. cooling.
Room Air Velocity = 0.5 mps.

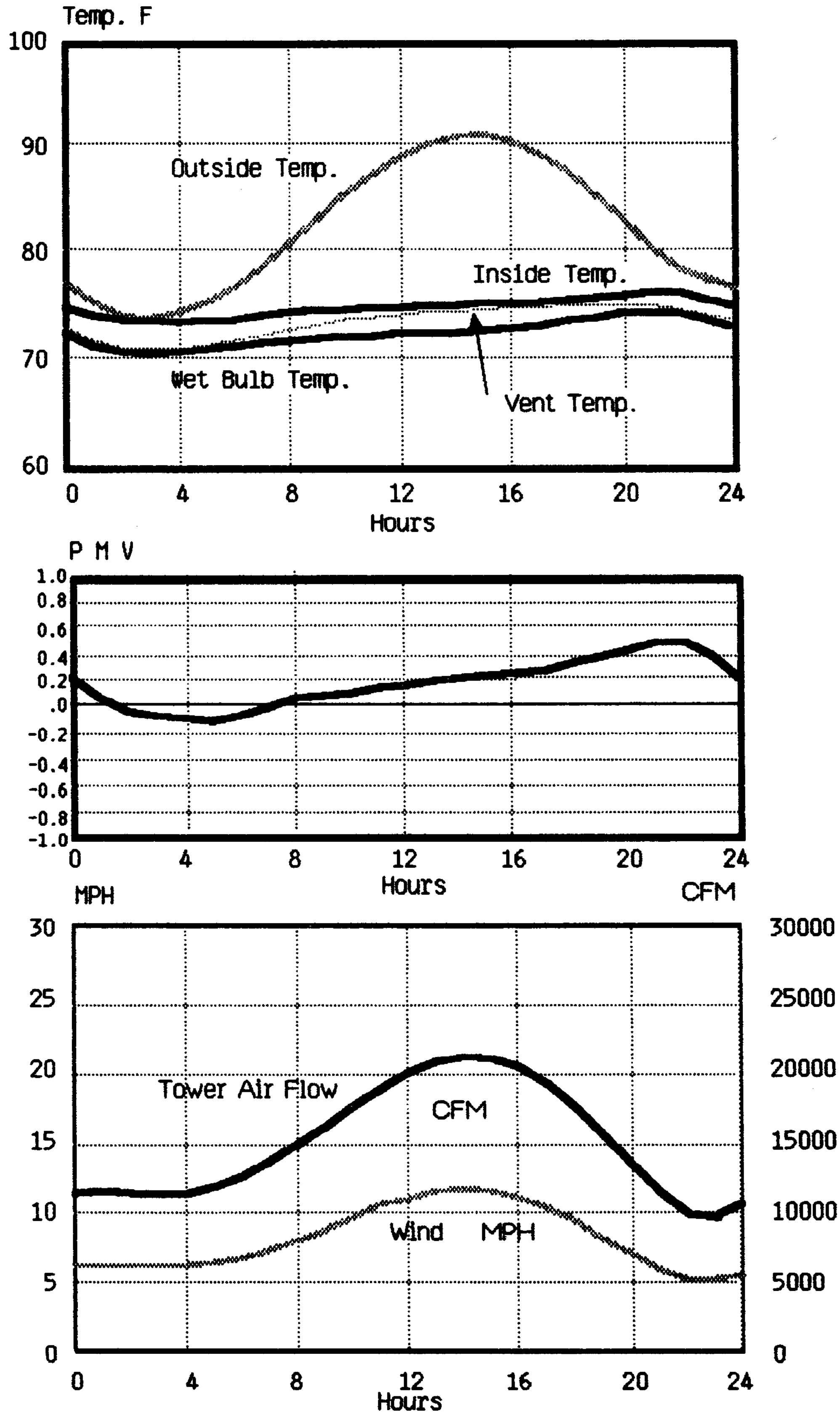
Fig. IV. E. 12 Building / Tower Performance

Sept



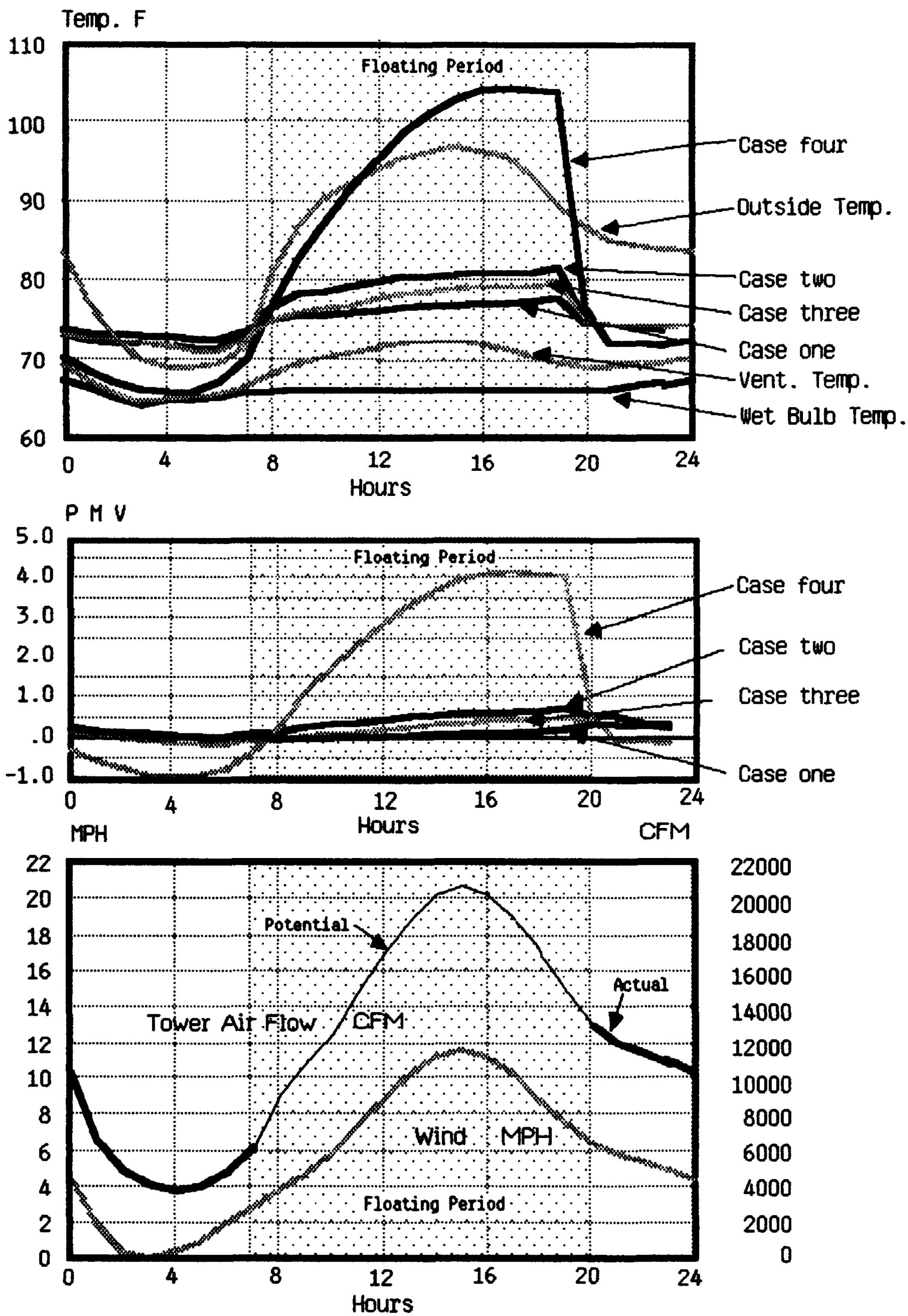
Note: 40% of south window area open. 24 hrs. evap. cooling - Celdek.

Fig. IX. E. 13 Building / Tower Performance
Oct.- Celdek



Note: 40% of south window area open, 24 hrs. evap. cooling - Spray, 90% Eff.
Room Air Velocity = 0.2 mps.

Fig. IV. E. 14 Building / Tower Performance
Oct.- Spray



Note: 40% of south window area open during evap. cooling with Celdek.
Room Air Velocity = 0.2 mps during float period.

Fig. IV. E. 15 Building / Tower Performance

04/26 Mass Effects

IV.E. REFERENCES

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3. K. Handa. Wind Induced Natural Ventilation. Stockholm, Sweden: Swedish Council for Building Research, 1979.

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5. The Munter Corporation, P.O. Box 6428, Ft. Myers, Florida 33901.

6. A. Vaszonyi. "Pressure Losses in Elbows and Duct Branches", Trans. ASME, vol. 66, pp. 177-183, 1944.

V. DOMESTIC SOLAR WATER SYSTEM

A. SYSTEM DESCRIPTION

Water is supplied to the system from a 4000-liter storage tank which is filled daily by a local delivery service. The water is pressurized by a pump, and the pressure is stored in a 310-liter hydro-pneumatic tank. A pressure switch on the tank turns the pump on when the pressure falls below 20 psi (1.4 kg/cm^2). This switch turns the pump off when the pressure reaches 40 psi (2.8 kg/cm^2). The storage tank is equipped with a low-water safety switch that turns off the pump when the tank is almost empty providing protection for the pump. This system will supply 120 liters to the house before the pump will turn on. The design was based on a maximum flow rate of 76 liters per minute (20 gallons per minute).

B. COMPUTER MODELS

Two basic types of domestic solar hot water heating systems were considered for this project. Computer simulations were used to analyze the performance of each type. A typical active flat-plate type collector was simulated with Version 4 of a commercially available program called F-CHART. The program found this type of system would perform satisfactorily, however, the initial and operating costs would be higher.

The second type of system considered was the passive Batch or Breadbox type system. Since a commercial program is not available for this type of system, a computer simulation model was developed by ERL to analyze the performance. The source code for this program is enclosed in Appendix V. The mathematical model uses an hourly energy balance on the system to determine the collector (tank) temperature. Dammam weather data are used to calculate the energy losses. A daily hot water usage of 630 liters was used which would be sufficient for nine people. Variable inputs to the program include: collector specifications, insolation (I), usage load profile (Flow), supply temperature, and hot water setpoint. Outputs from the program include: useful energy gained or lost, auxillary energy (Quax) needed to raise water temperature to the setpoint, fraction of the domestic hot water supplied by solar (FDHW), and the output temperature of each collector in the system (tank).

An hour-by-hour simulation was run for one day per month for a year to find the annual performance of the system. An annual simulation was run for three sizes of systems: four, five and six collectors. The fraction of hot water supplied by solar for these three system sizes are: .79, .87 and .92, respectively. For more details see the computer output tables titled "Thermal Performance" Tables V.B.1 through V.B.3. Appendix V contains the hour-by-hour calculations. Five collectors are being recommended because they would provide over 90% of the hot water demand during seven months of the year, and would supply 58% of the hot water during December, which is the lowest solar fraction of the year.

The Batch type heaters are recommended due to their high reliability, low maintenance and long life.

C. SYSTEM SPECIFICATIONS

Five Batch type solar collectors plumbed in series will provide 87% of the annual domestic hot water for nine people. A 310 liter gas or electric fired hot water heater provides a backup source of heated water in cloudy weather. The three-way diverting valve can remove this water heater from the system during the summer months when backup is not necessary. This saves energy since it can then be turned off. A tempering valve is required to prevent scalding, since the solar hot water can be 95°C at certain times of the day. A pressure relief valve is connected to the feed line of the lowest collector. Although it would work almost anywhere in the system, it is located at the low point in the system so it can be used as a drain valve. Performance efficiency tests on this system may require draining the collectors. In this event, the relief valve can be replaced with a hose bib to accommodate draining the system. CAUTION: DAMAGE TO THE COLLECTORS MAY RESULT FROM OVERHEATING OF AN UNCOVERED, EMPTY COLLECTOR. ALWAYS COVER COLLECTORS WHEN THEY ARE DRAINED DURING DAYLIGHT HOURS. Eliminating a drain valve in the system's plumbing is a safety precaution to prevent the system from being accidently drained. This is recommended by the manufacturer.

A circulation pump is not required or recommended for a system of this type. Circulating hot water around the house will cool the water and reduce the performance of the system. If it is desirable to circulate heated water around the house either to conserve water or have hot water more rapidly, it should be installed as per Figure V.B.1. The pump is to be located between the hot water supply (after the tempering valve), and a tee between the fourth and fifth collector. This will allow only the hottest water to be circulated through the house, and will prevent the hottest water from being moved to tanks one through four, where it would in inaccessible. This is very important for proper system performance.

A BTU meter is located between the fifth tank and the three-way diverting valve. It is connected by wire to a temperature sensor on the cold supply line into the collectors. The BTU meter has a turbine flow meter and two temperature sensors, which will electronically calculate the BTU's. It will be very useful in the experiments involving this system's performance and efficiency.

Table V.B.4 and Figure V.B.1 detail the system specifications and layout. See Appendix V for details of the system.

The advantage of this system is that it is completely passive and requires no motorized components, and no electronic differential controllers. Maintenance will be very low or non-existent. The tempering valve is the only device in the system that may require cleaning, if the water is high in minerals or salts. (For this reason it must be accessible.) This system requires no freeze protection even if night temperatures fall below 0°C.

ERL Solar Hot Water Heater Analysis Program * Date: 07-02-1984
Location: Dammam, Saudi Arabia * Lattitude: 26.3° * Longitude 50°
No. of collectors: 4 (89.6 ft²) * Collector Type: Breadbox * Slope: 20°
Hot Water Setpoint: 120.00 F

THERMAL PERFORMANCE

Mo	Itot (BTU)	Tavg (F)	Tsuply (F)	HWload (BTU)	Qtot (BTU)	Qloss (BTU)	Qaux (BTU)	FDHW
Jan	4.23E+06	65.60	65.60	2.18E+06	2.11E+06	6.53E+05	1.10E+06	0.49
Feb	4.36E+06	65.97	65.97	2.02E+06	2.61E+06	8.05E+05	6.93E+05	0.66
Mar	4.78E+06	76.55	76.55	1.74E+06	2.39E+06	7.37E+05	5.37E+05	0.69
Apr	4.47E+06	82.92	82.92	1.43E+06	2.68E+06	8.28E+05	2.45E+05	0.83
May	4.45E+06	92.22	92.22	1.11E+06	2.67E+06	8.24E+05	1.14E+05	0.90
Jun	4.19E+06	95.07	95.07	9.65E+05	3.35E+06	1.03E+06	2.56E+04	0.97
Jul	4.38E+06	94.77	94.77	1.01E+06	3.50E+06	1.08E+06	3.13E+04	0.97
Aug	4.50E+06	91.32	91.32	1.15E+06	3.60E+06	1.11E+06	6.36E+04	0.94
Sep	4.45E+06	88.40	88.40	1.22E+06	3.56E+06	1.10E+06	8.03E+04	0.93
Oct	4.50E+06	82.25	82.25	1.51E+06	3.15E+06	9.73E+05	2.17E+05	0.86
Nov	4.04E+06	70.85	70.85	1.90E+06	2.83E+06	8.70E+05	5.13E+05	0.73
Dec	4.01E+06	56.52	56.52	2.54E+06	2.40E+06	7.39E+05	1.31E+06	0.48
YR	5.23E+07	80.21	80.21	1.88E+07	3.49E+07	1.08E+07	4.93E+06	0.79

Table V.B.1

ERL Solar Hot Water Heater Analysis Program * Date: 07-02-1984
Location: Dammam, Saudi Arabia * Lattitude: 26.3° * Longitude 50°
No. of collectors: 6 (134.4 ft²) * Collector Type: Breadbox * Slope: 20°
Hot Water Setpoint: 120.00 F

THERMAL PERFORMANCE

Mo	Itot (BTU)	Tavg (F)	Tsuply (F)	HWload (BTU)	Qtot (BTU)	Qloss (BTU)	Qaux (BTU)	FDHW
Jan	6.34E+06	65.60	65.60	2.18E+06	3.17E+06	1.33E+06	6.62E+05	0.70
Feb	6.53E+06	65.97	65.97	2.02E+06	3.92E+06	1.64E+06	2.51E+05	0.88
Mar	7.17E+06	76.55	76.55	1.74E+06	3.58E+06	1.50E+06	1.70E+05	0.90
Apr	6.70E+06	82.92	82.92	1.43E+06	4.02E+06	1.68E+06	2.49E+04	0.98
May	6.67E+06	92.22	92.22	1.11E+06	4.00E+06	1.68E+06	0.00E+00	1.00
Jun	6.29E+06	95.07	95.07	9.65E+05	5.03E+06	2.10E+06	0.00E+00	1.00
Jul	6.57E+06	94.77	94.77	1.01E+06	5.25E+06	2.20E+06	0.00E+00	1.00
Aug	6.76E+06	91.32	91.32	1.15E+06	5.41E+06	2.26E+06	0.00E+00	1.00
Sep	6.68E+06	88.40	88.40	1.22E+06	5.34E+06	2.23E+06	0.00E+00	1.00
Oct	6.75E+06	82.25	82.25	1.51E+06	4.72E+06	1.98E+06	8.84E+03	0.99
Nov	6.05E+06	70.85	70.85	1.90E+06	4.24E+06	1.77E+06	1.42E+05	0.93
Dec	6.01E+06	56.52	56.52	2.54E+06	3.60E+06	1.50E+06	8.12E+05	0.68
YR	7.85E+07	80.21	80.21	1.88E+07	5.23E+07	2.19E+07	2.07E+06	0.92

Table V.B.2

ERL Solar Hot Water Heater Analysis Program * Date: 07-02-1984
Location: Dammam, Saudi Arabia * Lattitude: 26.3° * Longitude 50°
No. of collectors: 5 (112 ft²) * Collector Type: Breadbox * Slope: 20°
Hot Water Setpoint: 120.00 F

THERMAL PERFORMANCE

Mo	Itot (BTU)	Tavg (F)	Tsuply (F)	HWload (BTU)	Qtot (BTU)	Qloss (BTU)	Qaux (BTU)	FDHW
Jan	5.29E+06	65.60	65.60	2.18E+06	2.64E+06	9.62E+05	8.76E+05	0.60
Feb	5.45E+06	65.97	65.97	2.02E+06	3.27E+06	1.19E+06	4.47E+05	0.78
Mar	5.97E+06	76.55	76.55	1.74E+06	2.99E+06	1.09E+06	3.33E+05	0.81
Apr	5.59E+06	82.92	82.92	1.43E+06	3.35E+06	1.22E+06	1.09E+05	0.92
May	5.56E+06	92.22	92.22	1.11E+06	3.34E+06	1.22E+06	3.27E+04	0.97
Jun	5.24E+06	95.07	95.07	9.65E+05	4.19E+06	1.52E+06	0.00E+00	1.00
Jul	5.47E+06	94.77	94.77	1.01E+06	4.38E+06	1.59E+06	0.00E+00	1.00
Aug	5.63E+06	91.32	91.32	1.15E+06	4.50E+06	1.64E+06	0.00E+00	1.00
Sep	5.57E+06	88.40	88.40	1.22E+06	4.45E+06	1.62E+06	0.00E+00	1.00
Oct	5.62E+06	82.25	82.25	1.51E+06	3.94E+06	1.43E+06	9.18E+04	0.94
Nov	5.05E+06	70.85	70.85	1.90E+06	3.53E+06	1.28E+06	3.02E+05	0.84
Dec	5.01E+06	56.52	56.52	2.54E+06	3.00E+06	1.09E+06	1.06E+06	0.58
YR	6.54E+07	80.21	80.21	1.88E+07	4.36E+07	1.59E+07	3.25E+06	0.87

Table V.B.3

Table V.B.4. DOMESTIC SOLAR WATER SYSTEM SPECIFICATIONS

BATCH TYPE SOLAR COLLECTOR: CORNELL 480, or equivalent.

<u>Capacity:</u> 158 liters
<u>Area:</u> 2.0m net
<u>Dimensions:</u> Length-189cm, Width-118cm, Height-50cm
<u>Tank:</u> Glass lined steel
<u>Selective Coating:</u> α=.97, ϵ=.10
<u>Double Glazed:</u> Low iron tempered glass
<u>Insulation:</u> Polyisocyanate, 5-10cm
<u>Test Pressure:</u> 150psi (10.55 kg/cm^2)

PUMP: PACO, Model 1070 type 1 impeller no. 204 or equivalent.

<u>Performance:</u> 4.3m^3/hr @ 27 meter head
<u>Power:</u> 2hp
<u>Suction:</u> 1 inch (2.54 cm)
<u>Discharge:</u> 1¼ inches (3 cm)
<u>Construction:</u> All bronze
<u>RPM:</u> 3500

HYDRO-PNEUMATIC TANK: A. O. SMITH V-260 or equivalent.

<u>Total Volume:</u> 321 liters
<u>System Connection:</u> 1¼ inch (3 cm)
<u>Drawdown @ 20-40 psi (1.4 - 2.8 kg/cm^2):</u> 118 liters
<u>Maximum Pressure:</u> 100 psi (7 kg/cm^2)

STORAGE TANK:

<u>Capacity: 4000 liters</u>
<u>Construction:</u> Steel
<u>Fill:</u> Lockable
<u>Connections:</u> 1¼ inch (3 cm), one at bottom and one at top
<u>Manhole:</u> access

TEMPERING VALVE: Watts #3L-3/4 or equivalent

<u>Connections:</u> 3/4 inch (1.9 cm)

DIVERTING VALVE: AMERICAN BRAND or equivalent

<u>Construction:</u> Brass
<u>Type:</u> 3 - way

PRESSURE RELIEF VALVE:

<u>Setpoint:</u> 75 psi (5.3 kg/cm^2)
<u>Connection:</u> 3/4 inch (1.9 cm)

ACKUP HOT WATER HEATER:

Fuel: Gas or Electric
Capacity: 310 liters
Insulation: .0833 BTUH/ft^2F (R12)

CHECK VALVE:

Type: spring
Connections: 1¼ inches (3 cm)

PRESSURE SWITCH:

On @ 20 psi (1.4 kg/cm^2)
Off @ 40 psi (2.8 kg/cm^2)

PIPE SPECIFICATIOns:

Overflow and vent: 1 inch (2.5 cm) or larger galvanized, sch 40
Storage Tank to pump: 1 inch (2.5 cm) or larger galvanized, sch 40
Unions on both sides of pump
Pump to pressurized tank: 1¼ in (3 cm) galvanized, sch 40
Pressurized tank to house: 1¼ in (3 cm) galvanized, sch 40
Cold Water System in House: 3/4 in (1.9 cm) or larger type L copper
Hot Water System in House: 3/4 in (1.9 cm) or larger type L copper (insulated with at leat ½ in (1.3 cm) closed-cell type)
Connections to/from and between collectors: 3/4 in (1.9 cm) type L copper, high temperature solder 95/5 (tin/antimony). No valves or connections (tees or unions) permitted between collectors. Insulated with 3/4 in (1.9 cm) thick closed-cell foam type.

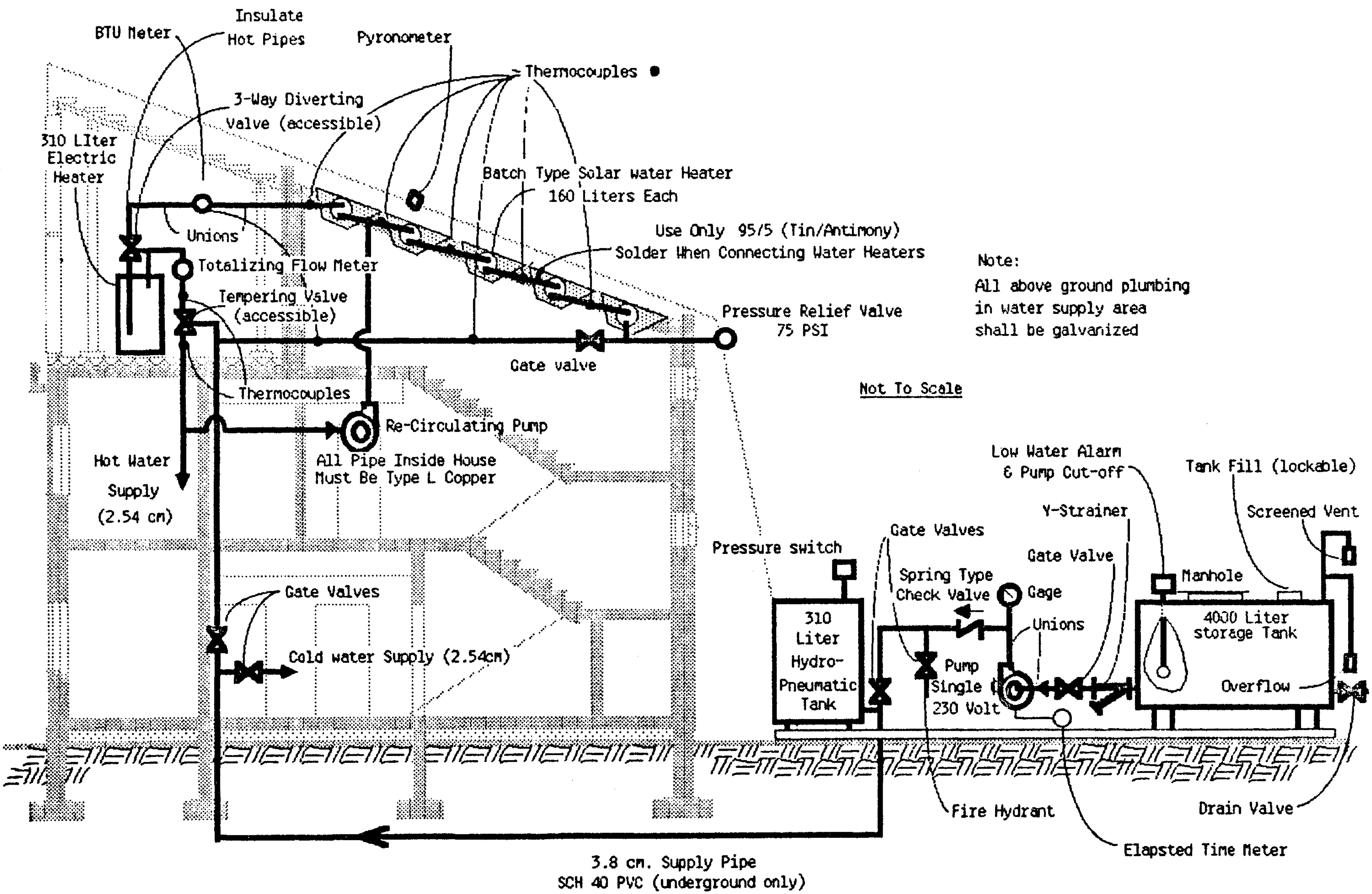


Fig. V.B.1 PASSIVE SOLAR DOMESTIC WATER SYSTEM

VI. RECOMMENDED BACK-UP AIR CONDITIONING EQUIPMENT

INTRODUCTION

Three types of air conditioning systems were considered for this project: chilled water, central ducted air, and the multi-zone heat pump system. The zone loads as calculated by BLAST can be found in Table VI.A.1 and the building HVAC zone layout can be seen in Figures VI.A.1 & VI.A.2.

A. CHILLED WATER SYSTEM

The chilled water system would have the following disadvantages:

1. The compressor/condenser unit would be less efficient due to the use of heat exchangers, and frequent on/off cycling when operating at reduced loads.

2. The smallest unit we could locate was a 10-ton (120,000 BTUH) unit and it did not match the design requirements of 5 to 6 tons.

3. The system requires a circulation pump which is therefore more complex and expensive both to operate, and on a first-cost basis.

B. DUCTED CENTRAL AIR

A ducted central air system is another possibility but has the disadvantage of requiring the installation of air ducts. The ducts would require several drop ceilings and could interfere with the operation of the wind tower. Air ducts add expense to the system and could hinder the performance of the downdraft cooling tower air distribution system. For optimum performance the system should also have return air ducts which are bulky and add to the cost and complexity. Routing of both the supply and return ducts would be difficult given the need for ducts to distribute the tower air.

Included in this report is a duct design and routing which specifies duct sizes and air flow rates to each zone. The air could be returned from each zone through registers mounted in the door to that zone. Another method for return air is to shorten the doors by 5cm, and let the air pass under the door. The air could then return to the roof-mounted fan by either the wind tower shaft or a return duct installed in the duct chase. Figures VI.B.1 and VI.B.2 show the duct routing and Tables VI.B.1-VI.B.3 give the duct and grill sizes.

C. MULTI-ZONE HEAT PUMP

A multi-zone heat pump was selected for the backup system for the following reasons:

1. No duct work is required.

2. Excellent zone controllability. Each zone has its own thermostat.

Zone #	Room Code	Peak Load (Kw)	Peak Load (BTUH)	Supply Air CFM
1	G8	2.28	7787	312
2	G5	2.03	6941	278
3	G3	4.03	13754	551
4	G2	1.51	5163	207
5	U2,3	1.07	3654	141
6	G4,6,7	3.68	12548	483
7	U1	1.44	4932	190
8	U9	1.46	4975	192
9	U6	1.88	6428	248
10	G1	3.92	13385	545
TOT		23.31	79565	3147

Table VI.A.1 Zone Loads

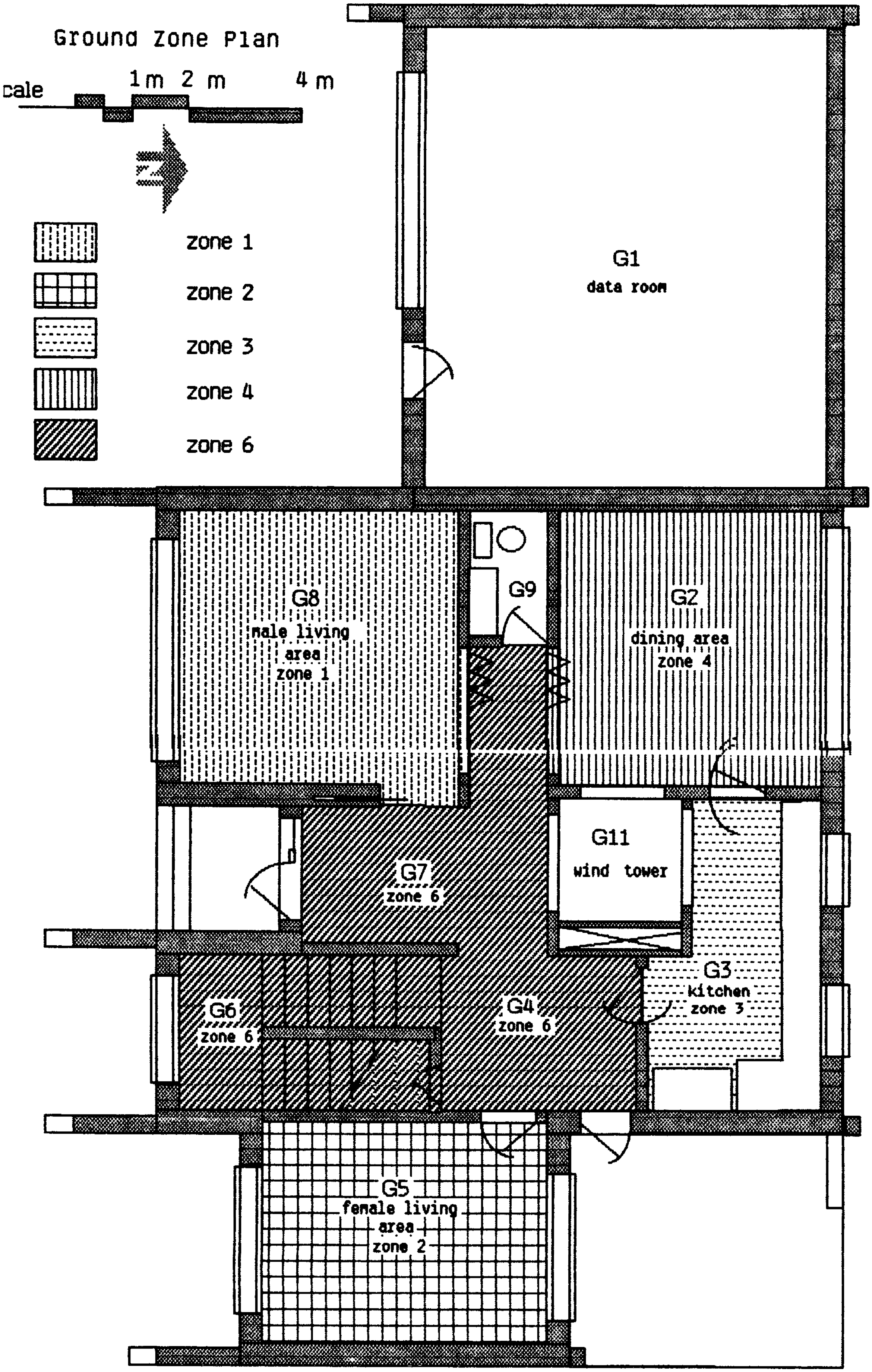
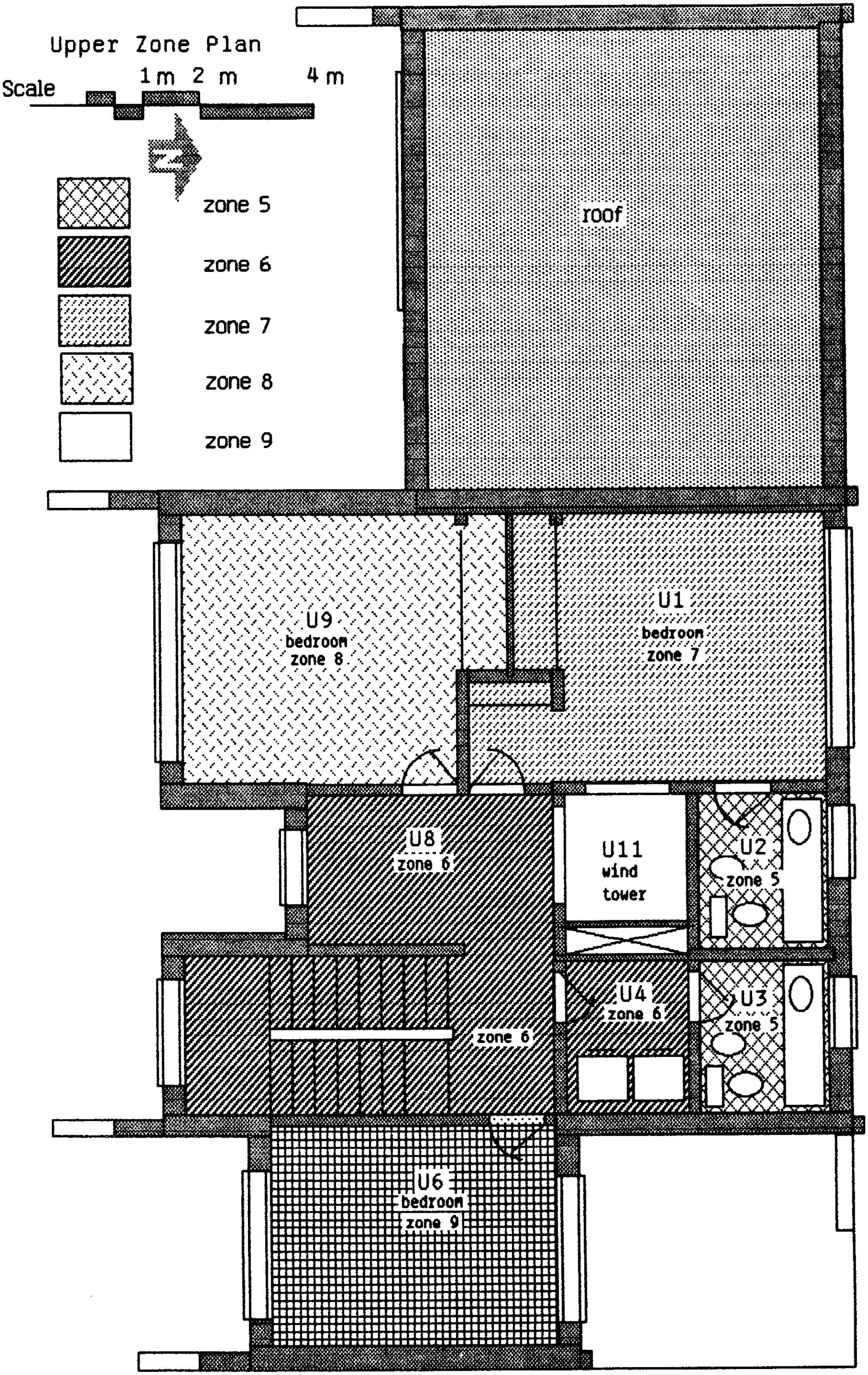


Figure VI.A.1 HVAC Zone Layout

ground zone plan



upper zone pl

Figure VI.B.2 HVAC Zone Layout

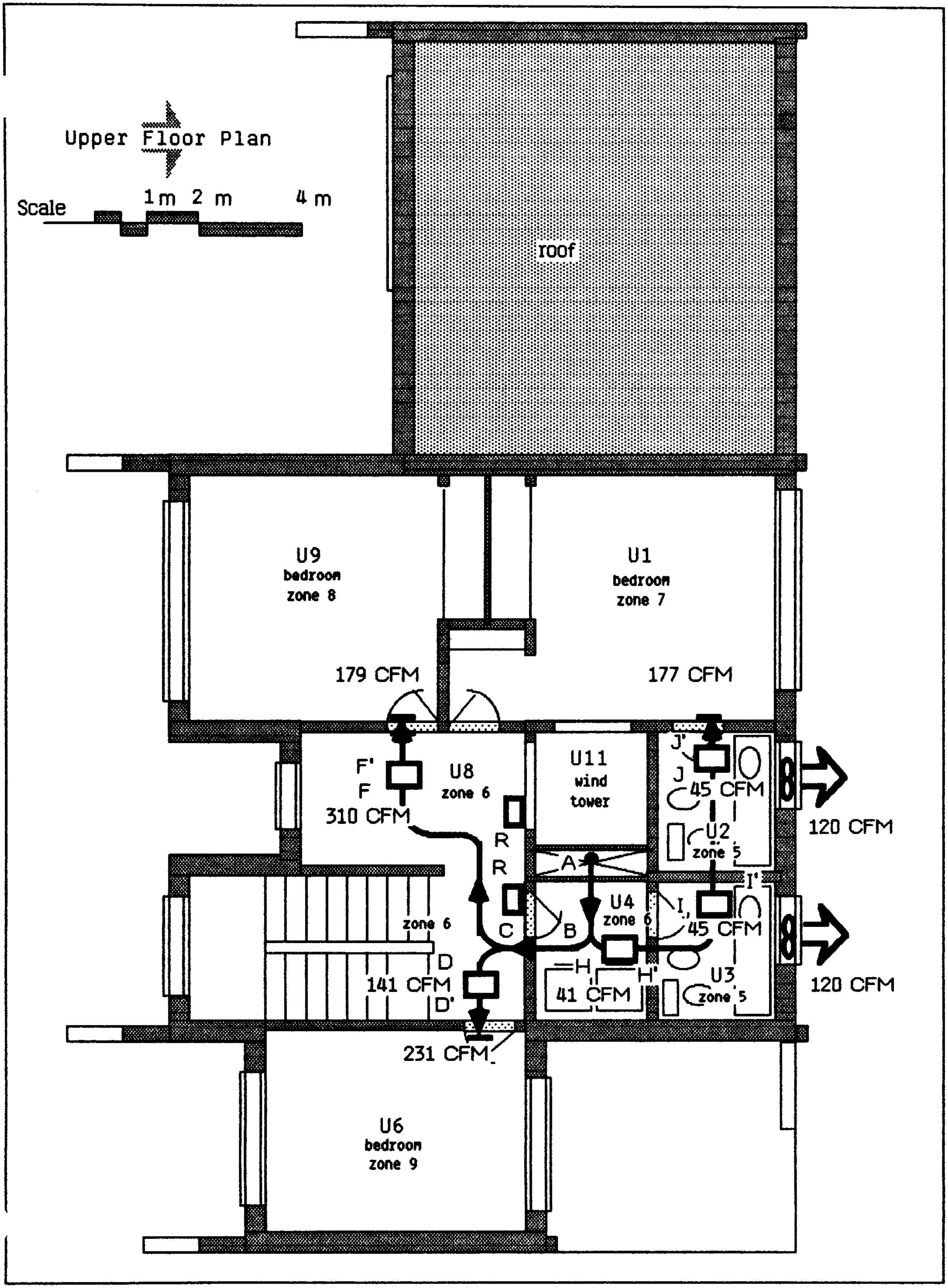


Fig. VI.B.1. HVAC Duct Routing

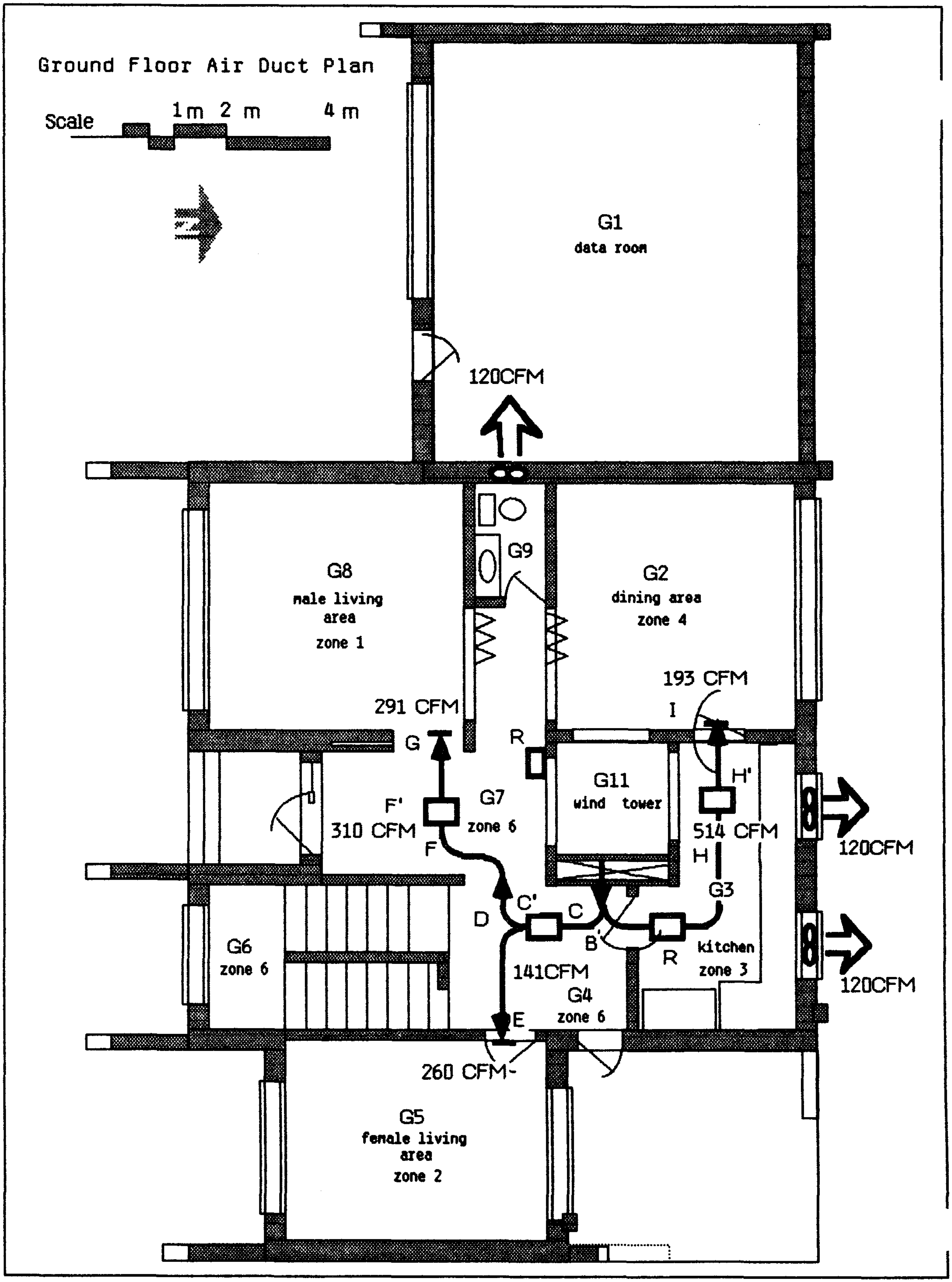


Fig. VI.B.2. HVAC Duct Routing

Line	CFM	Rect. dimensions(in)	Outlet Grill(in)
A>B	1709	13 x 17	
B>C	1002	13 x 13	
C>C'	141	5.5 x 5.5	5.5 x 7
C'>D	861	11 x 11	
D>F	601	10 x 10	
F>F'	260	5.5 x 10	5.5 x 16
F'>G	310	8 x 9	8 x 12.5
D>E	291	6 x 10	6 x 16
B>H	707	13 x 9	5.5 x 7
H>H'	514	9 x 9	9 x 17
H'>I	193	6 x 7	6 x 10.5

NOTE: 1. Two return openings each of 8.5" x 8.5".
2. Use dampers to balance the system.
3. Use doors with louvers for return air.

Table VI.B.1 HVAC Duct Schedule - Ground Floor

Line	CFM	Rect. dimensions(in)	Outlet Grill(in)
from fan	2878	18 x 19	
A>B	1169	9 x 19	
B>H	308	9 x 8	
H>H'	41	4 x 3.5	4 x 3.5
H'>I	267	7 x 8	
I>I'	45	4 x 3.5	4 x 3.5
I'>J	222	6 x 7	
J>J'	45	4 x 3.5	4 x 3.5
J'>K	177	6 x 7	6 x 11
B>C	861	9 x 14	
C>D	372	9 x 8	
D>D'	141	5.5 x 5.5	5.5 x 7
D'>E	231	7 x 7	7 x 10.5
C>F	487	9 x 9	
F>F'	310	8 x 9	8 x 12.5
F'>G	179	6 x 7	6 x 11

NOTE: 1. Two return openings each of 7" x 7".
2. Use dampers to balance the system.
3. Use doors with louvers for return air.

Table VI.B.2 HVAC Duct Schedule - First Floor

HVAC Zone	Room Zones	Peak Coil Load (Kw)	Coil Energy Use (KwH)	DX Condensing Unit		Fan Power (Kw)	Fan HP
				Peak Elec Demand (Kw)	Elec Energy Use (KwH)		
1	1,2,3 4,6	12.4	210.5	3.25	60.7	0.66	2/3
2	5,6,7 8,9	8.9	182.0	2.70	50.5	0.44	1/2

SYSTEM SPECIFICATIONS:

HVAC Zone 1:
Derated Equipment:
Heat Pump: 13.75Kw (46928BTUH, ≈4tons)
Fan: 2/3HP @1590 CFM

HVAC Zone 2:
Derated Equipment:
Heat Pump: 10.0Kw (34130BTUH, ≈3tons)
Fan: 1/2HP @1060 CFM

HVAC Zone 3:
Derated Equipment:
Heat Pump: 4.35Kw (14872BTUH, ≈1.25tons)
Fan: 1/4HP

Table VI.B.3 Two Zone Heat Pump System

3. The same equipment is used for heating, which eliminates the need for a separate heating system.

4. Higher overall system efficiencies are achieved due to the variable capacity of the system, and there are no losses due to air ducts or water type heat exchangers.

5. The system lends itself to computer control which has unlimited possibilities for automatic setback, thermostat hysteresis experiments, and independent zone control.

6. More reliability due to having four independent systems rather than one.

Other considerations for multi-zone heat pump systems are:

* Insulated small diameter tubing must be installed in or on the walls. The maximum length run to an air handler is 14 meters and a maximum vertical lift of 6.1 meters.

* This is a new type of system which is not yet widely used.

Figures VI.C.1 and VI.C.2 show the placement of the equipment in the building.

Using zone 1 as the ground floor and zone 2 as the first floor the sensible and latent breakdown of the system loads is as follows in Table VI.C.1.

The total peak coil loads (Table VI.C.3) are obtained by applying the SHF to the values in Table VI.A.1.

Zone #	Peak Sensible System Load (Kw)	Peak Latent System Load (Kw)	Total System Peak Load (Kw)	SHF
1	9.4	3.0	12.4	.76
2	6.3	2.6	8.9	.71

Note: This table does not include the garage (G1)

Table VI.C.1 Sensible Heat Factor

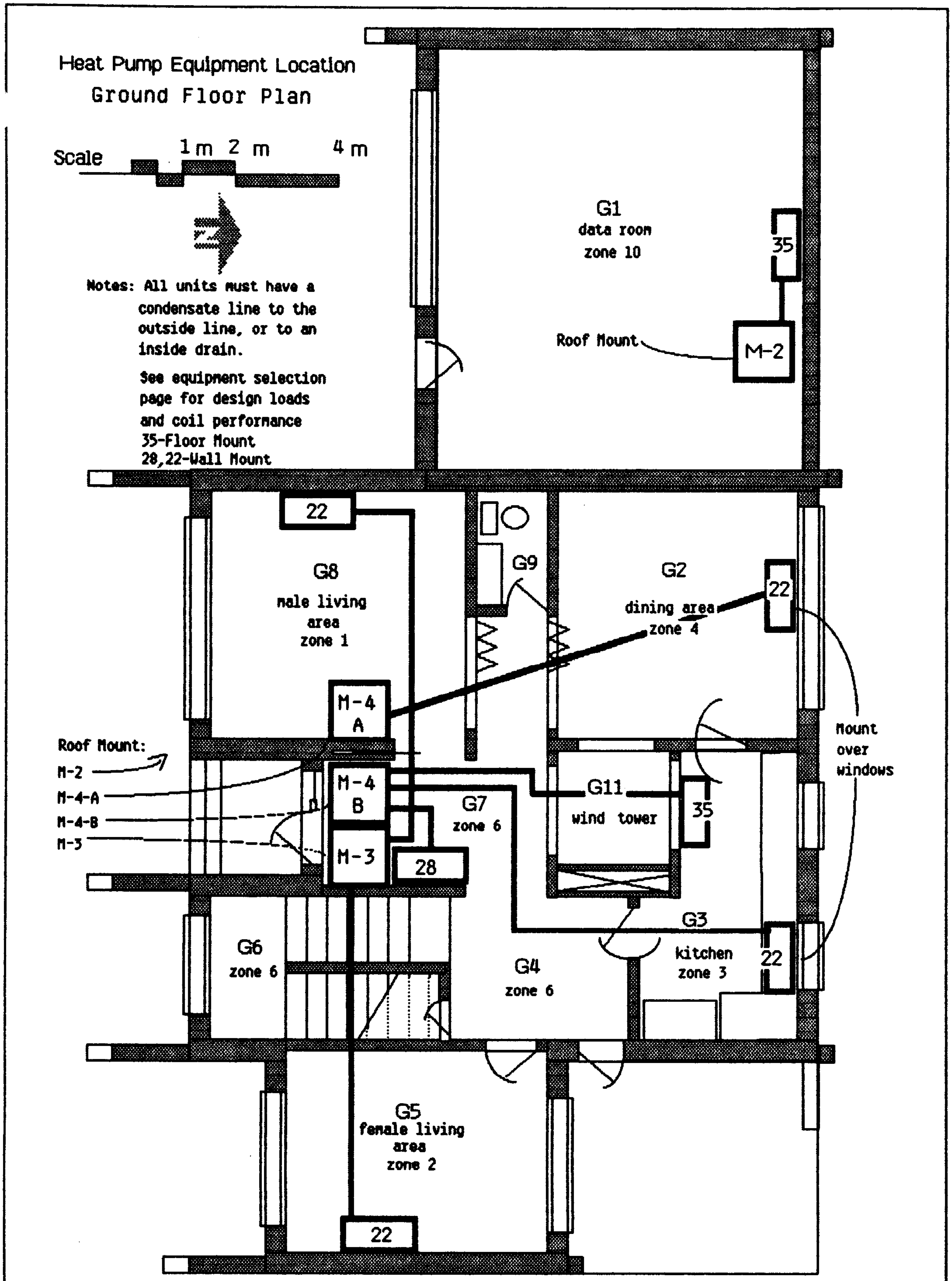


Fig. VI.C.1. Heat Pump Equipment Location

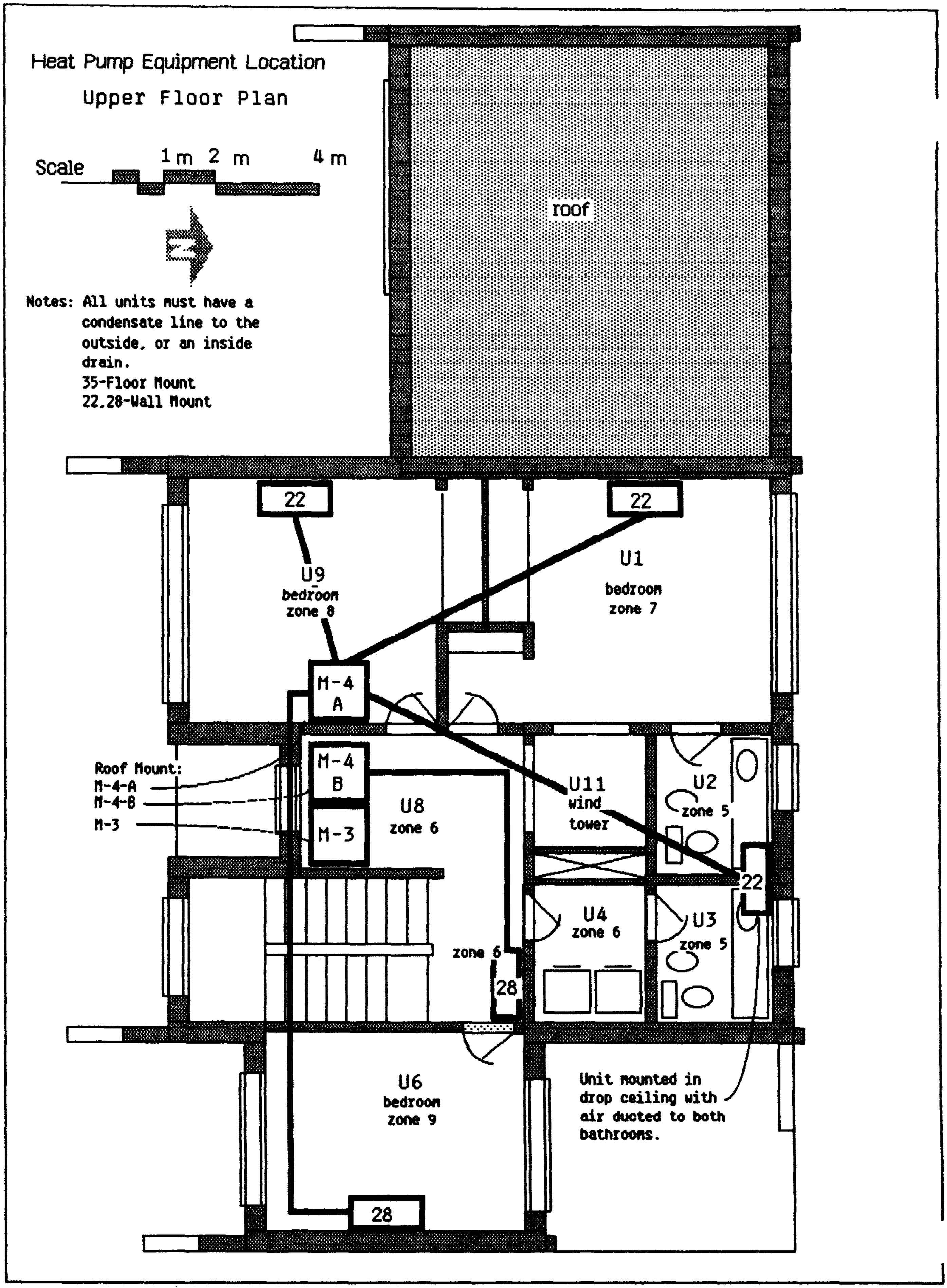


Fig. VI.C.2. Heat Pump Equipment Location

Zone #	Room Code	Peak Coil Load (Kw)	Peak Coil Load (BTUH)	Derated Equip Size (BTUH) *	DX Unit No (Daiken)
1	G8	2.28	7787	8652	22
2	G5	2.03	6941	7712	22
3	G3	4.03	13754	15282	35,22
4	G2	1.51	5163	5737	22
5	U2,3	1.07	3654	4061	22
6	G4,6,7	3.68	12548	13942	28,28
7	U1	1.44	4932	5479	22
8	U9	1.46	4975	5528	22
9	U6	1.88	6428	7143	28
10	G1	3.92	13385	14872	35
TOT		23.31	79565	88407	

Note: This equipment was sized by derating the units by 90% corresponding to an ambient of 41.6C (107F). See page 15 of the service manual. Heating values are on pages 2 &3 of the service manual and should be derated by 15%. (The manuals can be found in Appendix VI)

* Derated equipment size (BTUH) was obtained by increasing the peak coil load by 11%. Hence equipment can be selected directly from the tables on pages 2&3 of the service manual. Derated equipment total without zone #10 (73535BTUH, ≈6.1tons).

Table VI.C.3 DX Split Coil Multi-Zone Heat Pump Equipment Schedule

Outdoor Unit	Indoor Unit	Zone #	Room Code	Cooling Output Capacity (BTUH)	Heating Output Capacity (BTUH)
M4	22	4	G2	5550	5400
	22	5	U2,3	5550	5400
	22	7	U1	5550	5400
	22	8	U9	5550	5400
	28	9	U6	7100	6800
M4	22,35	3	G3	15300	14500
	28,28	6	U4,5,7 G4,6,7	13900	14000
M3	22	1	G8	9155	8040
	22	2	G5	9155	8040
M2	35	10	G1	17080	16080

Table VI.C.4 Derated Equipment Schedule

VII. BASELINE COMPARISON OF FINAL DESIGN WITH FIVE OTHER PROPOSED DESIGNS

A. METHODOLOGY

The final design (Bldg F) was compared with five other designs including the original concepts A, B, C and D, and the original "final design" (Bldg E). The purpose was to compare the thermal performance of the different designs using the same construction materials, with no consideration of ventilation or heating and cooling systems. Internal load and infiltration were considered, but the same values were used for each building.

The building total cooling and peak cooling load were used as the parameters for comparison, and the total cooling per square meter and per cubic meter were also compared. Monthly average weather data were used to calculate the loads on an average day of the month, and monthly totals were calculated from the daily results. Tables VII.A.1 through VII.A.4 and Figures VII.A.1 through VII.A.4 show these results.

The six buildings were simulated with the BLAST program following the procedure developed previously in the design optimization study of Bldg F. Each building was modeled basically as a two-zone house plus a garage in some cases. The loads for the garage were not figured into the final results since some designs had attached garages and others did not. The building descriptions for each of the other five buildings were developed from the drawings and information furnished by KFU, including Report Number 82-2 "Preliminary Design Concepts and Final Design" and some additional blueprints, pictures and other information.

The development of the input decks closely followed that of Bldg F, and the same values were used for internal load and infiltration. In some cases assumptions or simplifications were required, but an effort was made to maintain uniformity by making similar assumptions for all of the buildings under study. The base case walls, windows, roofs, ceilings, floors and doors were specified for all of the buildings. Each building was assumed to be north facing except for Concept A which was simulated facing as shown on the drawings. Shading in each case was treated similarly. The wind towers were assumed inoperative and were assumed to have no effect on the building load, except for possible shading effects. The printed output from these comparison runs is in Appendix VII.

B. RESULTS OF ANALYSIS

The results of Tables VII.A.4-VII.A.7 and Figures VII.A.1-VII.A.4 can be compared to the previous results of KFU Report Number 82-2. There are some differences but the general trends are the same. The original study did not consider building floor area or building volume when comparing heating and cooling loads. In addition, it seemed to give the impression that Concept D performed significantly better than Concepts A, B, and C. In the BLAST comparison, however, when the

	Design Concepts					
Mo	A	B	C	D	E	F
Jan	4.05	3.99	4.12	3.83	6.78	4.10
Feb	4.67	4.31	4.64	4.29	6.62	4.21
Mar	5.75	5.76	5.91	5.74	6.77	5.60
Apr	8.02	8.50	8.06	7.93	6.94	8.02
May	10.35	11.46	10.30	10.23	9.40	10.57
Jun	12.29	13.38	12.10	11.69	11.02	12.14
Jul	12.54	13.57	12.30	11.89	11.24	12.41
Aug	12.35	13.29	12.14	12.18	11.13	12.68
Sep	11.20	12.42	11.11	11.13	10.22	11.47
Oct	9.3	10.14	9.27	9.22	11.00	9.45
Nov	6.80	7.50	6.96	6.72	9.95	7.09
Dec	4.50	4.87	4.69	4.24	7.64	4.62
Max Peak	12.54	13.57	12.30	12.18	11.24	12.68

Table VII.A.1 King Faisal University Design Comparison
Peak Cooling (Kw)

	Design Concepts (Kwh/month)					
Mo	A	B	C	D	E	F
Jan	1011	1516	1175	945	1837	1264
Feb	1137	1274	1240	1131	1765	1088
Mar	2118	2089	2146	2070	2464	1928
Apr	3726	3960	3651	3558	3645	3635
May	5480	6129	5367	5267	5382	5549
Jun	6745	7611	6519	6502	6687	6860
Jul	7124	8007	6868	6867	7084	292
Aug	6934	7762	6701	6730	7037	7107
Sep	5887	6588	5724	5739	6351	5970
Oct	4644	5189	4565	4547	5509	4668
Nov	2864	3585	2904	2739	3822	3125
Dec	1408	2056	1495	1253	2245	1687
Max Peak	49078	55766	48355	47288	53828	50173

Table VII.A.2 King Faisal University Design Comparison
Total Cooling (Kwh/month)

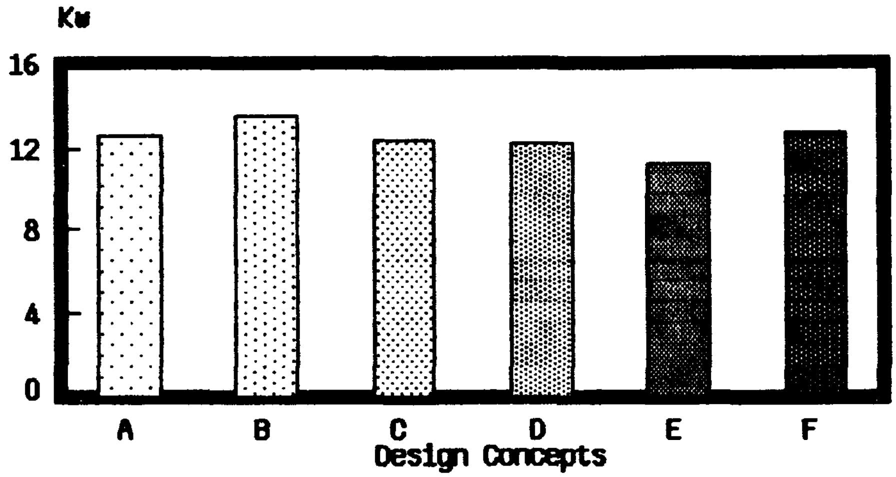


Figure VII.A.1. King Faisal University Design Comparison
Peak Cooling (Kw)

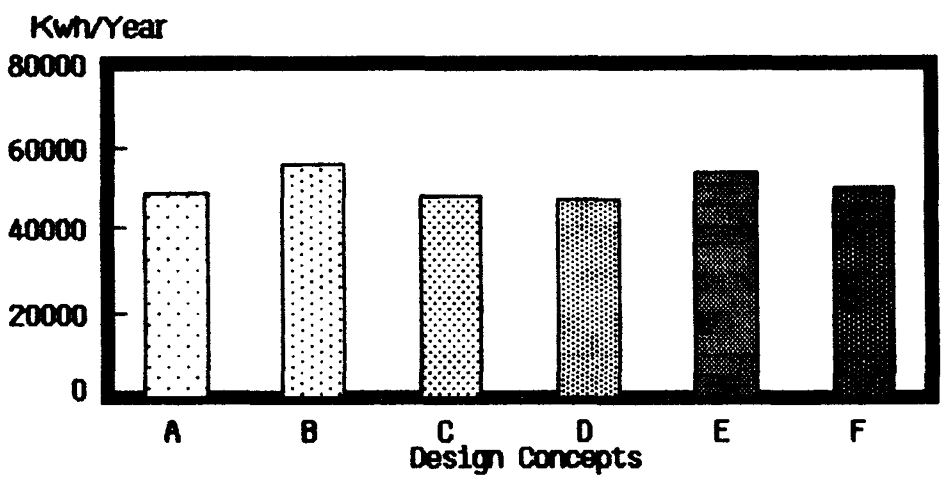


Figure VII.A.2. King Faisal University Design Comparison
Total Cooling (Kwh/Year)

	Design Concepts (Kwh/m²)					
Mo	A	B	C	D	E	F
Jan	4.93	6.40	4.42	4.57	7.29	4.55
Feb	5.54	5.38	4.66	5.46	7.00	3.92
Mar	10.33	8.83	8.07	10.00	9.77	6.95
Apr	18.18	16.73	13.73	17.78	14.46	13.10
May	26.73	25.90	20.18	25.44	21.36	20.00
Jun	32.90	32.15	24.51	31.41	26.54	24.73
Jul	34.75	33.83	25.82	33.17	28.11	26.29
Aug	33.82	32.79	25.19	32.50	27.92	25.62
Sep	28.70	27.83	21.52	27.73	25.20	21.52
Oct	22.65	21.92	17.17	21.97	21.86	16.83
Nov	13.97	15.15	10.92	13.23	15.17	11.26
Dec	6.87	8.69	5.62	6.05	8.90	6.08
Flr Area (m^2)	205.00	236.70	266.00	206.70	251.84	277.40
Year Tot /m^2	239.40	235.60	181.80	228.70	213.60	180.90

Table VII.A.3 King Faisal University Design Comparison
Cooling Load/Floor Area (Kwh/m^2)

	Design Concepts (Kwh/m3)					
Mo	A	B	C	D	E	F
Jan	1.73	1.94	1.47	1.69	2.39	1.47
Feb	1.94	1.63	1.55	2.03	2.30	1.27
Mar	3.62	2.67	2.69	3.71	3.21	2.24
Apr	6.37	5.07	4.57	6.37	4.75	4.23
May	9.38	7.85	6.73	9.44	7.01	6.45
Jun	11.54	9.75	8.17	11.65	8.71	7.97
Jul	12.19	10.25	8.60	12.30	9.23	8.48
Aug	11.87	9.94	8.40	12.06	9.16	8.26
Sep	10.07	8.44	7.17	10.28	8.27	6.94
Oct	7.95	6.64	5.72	8.15	7.17	5.43
Nov	4.90	4.59	3.64	4.91	4.98	3.63
Dec	2.41	2.63	1.87	2.25	2.92	1.96
Vol-ume (m3)	584.30	781.00	798.00	558.12	767.60	859.90
Year Tot /m3	83.97	71.40	60.58	84.84	70.10	58.33

Table VII.A.4 King Faisal University Design Comparison
Cooling Load/Internal Volume (Kwh/m3)

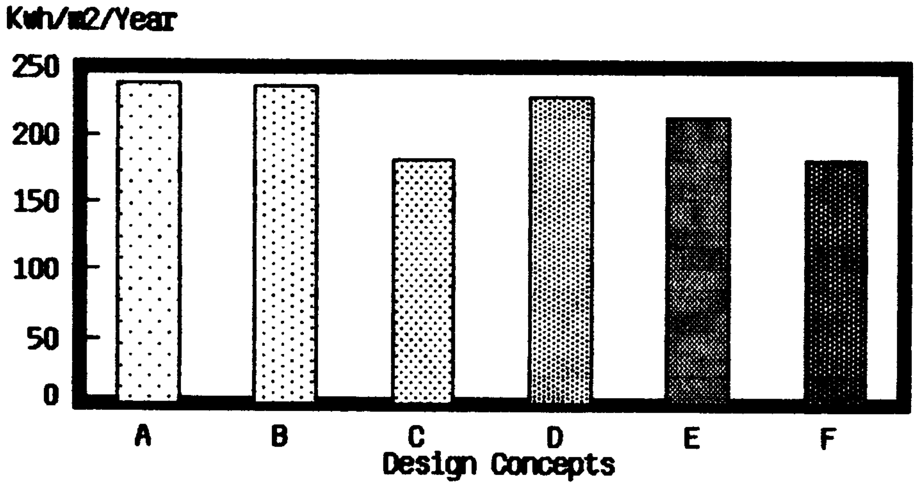


Figure VII.A.3. King Faisal University Design Comparison
Cooling Load/Floor Area (Kwh/m2/Year)

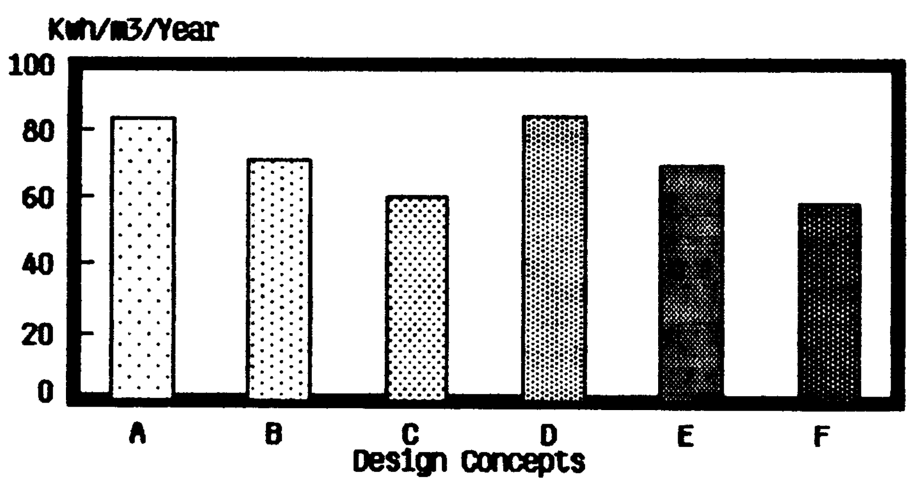


Figure VII.A.4. King Faisal University Design Comparison
Cooling Load/Internal Volume (Kwh/m3/Year)

buildings are compared only on the basis of total cooling and peak cooling, no one building shows dramatically better performance than all of the others. Also, by considering the building floor area and volume, differences in building size can be accounted for. And with this consideration, the final design (Bldg F) performs better than the other designs, with Concept C a close second.

From the results of the comparison, several general observations can be made.

1. The buildings with less relative window area performed better.

2. Buildings with a lower surface-to-volume ratio (i.e., buildings which were more cubical in shape) seemed to perform better.

3. A larger building will have a higher cooling load than a smaller building.

Other conclusions may be drawn from the data in Tables VII.A.4-VIIA.7. For a more detailed discussion of the method used in simulating the six buildings, refer back to the previous section on the three-zone house which was modeled for design optimization.

III. LANDSCAPING

A. ANALYSIS AND STRATEGIES

Landscaping and microclimate effects on human comfort and building performance have been discussed by Deering, Parker, and others. The application of these techniques in Saudia Arabia is possible, but the design strategies must be suited to the rigors of the environment. The arid condition, prevailing winds, nature of the water supply, and lack of organics and presence of salt in the soil, place testing the microclimatic effects of landscaping on a level of importance equal to the need for expanding the information on plant materials suitable for the Arabian desert condition. These considerations are recognized in the conclusion remarks on landscaping in the passive cooling project proposal (82-1). p. 67.

Water is the most critical element. The testing of microclimate effects on architecture and human comfort is dependent on water. Water quality, soil characteristics, and exposure, limit plant species variability and thus limit the strategies available for microclimate manipulation. With the goal of improving the energy efficiency of the structure, environmentally appropriate landscape strategies must be tested. We must quantitatively determine the effectiveness of landscape design strategies for improving energy efficiency and for providing human comfort, but not at the expense of costly support systems for the developing landscape, therefore plant screening goes hand in hand with landscape strategy assessment. The passive cooling project and site provides a unique opportunity to experiment with the environmental appropriateness of both plant materials and landscape techniques, in order to provide both quantitative and qualitative measures of the effectiveness of landscaping and the capability of various plant materials to accommodate this need.

A two-fold research approach is recommended:

1. A horticultural screening program for landscape plants to test growth rate, salt and wind tolerance, water and maintenance needs, and disease resistence of both natives and newly introduced plant materials, particularly halophytic species.

2. A plan for testing the influences of landscape on architecture, both elements and exposure and human comfort including:

   - Leaf shading and air enclosure effects on mass

   - Shade densities of various tree species

   - Human comfort measurements of small-scale exterior landscaped spaces

   - Leaf surface reflectance of various species and plant types

   - Small-scale wind flow control experiments

Specific designs of horticultural screening program and landscape strategy assignment follows.

A landscape analysis and experimental plan could be developed for The King Faisal Passive Cooling Facility, which would prove to be invaluable in developing and fostering the use of low water use and salt-tolerant environmental plants for the Dammam area. A similar plan was developed in collaberation with ERL horticulturists and scientists for Al Batin in Saudi Arabia. This plan could form the basis for sound scientific research in this area. Appendix VIII contains a preliminary draft of the Al Batin Plan.

B. LANDSCAPING DESIGN

An attempt has been made to shade west walls, and as much paving as possible. Grass, shrubs and groundcovers have been used adjacent to the house to keep the heat from bare ground surfaces from radiating toward the house as well as to produce more livable outdoor temperatures. They have also been used to increase the evaporative cooling during dry conditions - though not to interfere with the breezes during humid weather.

Enclosure of the garden areas by walls is most important, not only as protection against wind and dust, but to contain the newly developed microclimate and the cool body of air produced by the trees, grass, ground cover and vines.

The front walls were designed with screens in them to permit air flow between the garden areas and the outside.

The front yard has been divided into two gardens - the entrance garden and the more private family garden of the walkway.

A terrace located on the north-east corner of the house will be usable in the summer afternoons, although it could be usable all day if it were covered.

The large grass area to the rear (N. side) would be suitale for children's play, but also serves to produce a cool body of air close to the house. The area is sufficiently large for the development of a swimming pool if desired in the future.

Space is available on the north-west side for a vegetable garden, and a few fruit trees are included in the landscape plan. The front entrance drive is of perforated concrete material, similar to the product "grass-crete", which allows grass to grow through. It would support the weight of any family car. The use of this material should materially reduce the amount of heat absorption and resulting radiation. The part of the driveway intended to provide turning space for the car when it backs out of the garage is covered with a light structure. This area can thus double up as a temporary parking space either for a visitor's car or for the resident's car during the day. It will also serve as parking during monitoring activity while garage is not available. A side entrance on the west of the property has been included to provide a suitable entrance for service.

All plants selected for the project have been found growing in the vicinity of the project. They have been found growing successfully where saline soil conditions are high and many of them require only moderate amounts of water.

Certain species have been selected because of their tolerance to the strong prevailing north-west winds. Landscaping details, and a complete description of the plant material used in the landscaping scheme are given in the construction drawings, however, a cumulative list is given below for general reference:

Trees:

Scientific Name	Common Name
Albizzia Lebec	Siris
Azadirachta Indica	Neem
Citrus - Lemon	Lemon
Citrus - Tangerine	Tangerine
Delonix Regia	Poinciana
Eucalyptus Camaldulensis	Red Gum
Ficus Carica	Edible Fig
Ficus Microcarpa Nitida	Indian Laurel Fig
Ficus Religiosa	Bo-Tree
Olea Europae	Common Olive
Parkinsonia Aculeata	Jerusalem Thorn
Phoenix Dactylifera	Date Palm
Pistacia Chinensis	Chinese Pistache
Pithecolobium Dulce	Madras Thorn
Plumeria Obtusa	Plumeria
Prosopis Juliflora	Mesquite
Terminalia Catappa	Indain Almond, Loz
Zizyphus Spina-Cristi	Sidr Tree

Shrubs:

Atriplex Halimus	Salt Buh
Caesalpina Pulcherima (Red)	Dwarf Ponciana
Caesalpina Pulcherima (Yellow)	" "
Callistemon Viminalis	Weeping Bottle Brush
Carissa Grandiflora Prostrata	Prostrate Natal Plum
Catharanthus Roseus (White)	Madagascar Periwinkle
Catharanthus Roseus (Pink)	" "
Clerodendron Indica	Clerodendron
Dodonea Viscosa	Hopseed Bush
Hisbiscus Rosa-Sinensis (Pink)	Hibiscus
Hisbiscus Rosa-Sinensis (Red)	"
Hisbiscus Rose-Sinensis (Yellow)	"
Lantana Camara (Orange)	Lantana
Lantana Camera (Pink)	"
Lawsonia Inermis	Henna

Leucophylllum Frutescens	Texas Ranger
Malvaviscus Arboreus	Turk's Cap
Nerium Olender (Single Pink)	Oleander
Nerium Olender (Single White)	"
Nerium Olender Dwarf	"
Punica Granatum	Pomegrantae
Tecoma Stans	Yellow Trumpet Flower
Tecomaria Capensis	Cape Honeysuckle
Thevetia Nerifolia	Yellow Oleander
Vitex Agnus-Castus	Chaste Tree
Xylosma Congestum Compacta	Xylosma

<u>Vines</u>

Antiginon Leptopus	Coral Vine
Bougainville Glabra (White)	Bougainville
Bougainville Glabra (Orange)	"
Bougainville Glabra (Pink)	"
Ficus Pumila	Creeping Fig
Ipomea Horsfallei	Clematis Red Morning Glory
Jasminum Species	Jasmine
Vitis Vinifera (Seedless)	Grape

<u>Ground Cover</u>

Asparagus Sprengeri (40 cm O.C.)	Asparagus Fern
Ipomea Pes-Caprea (50 cm O.C.)	Soilbind Morning Glory
Paspalum Paspaloides (20.5 cm O.C.)	Qatif Grass

CONCLUSION

The current phase of this project deals with a detailed fine-tuning of the architectural design in relation to its appropriateness for testing the chosen passive techniques. The cooling strategies in turn were also reviewed with the objective of further refinement in their application. These have subsequently been incorporated in the construction drawings and documents for the actual construction of this experimental house at K.F.U. Campus.

The next phase, if approved by the SOLERAS, will comprise the construction activity, data acquisition system, fabrication, testing and installation, and monitoring the thermal response of the house under the current Joint United States - Saudi Arabian Program for Cooperation in the field of Solar Energy, scheduled to last up to 31 December 1985.

It would, however, be essential to continue monitoring and analysis of the acquired data if any meaningful conclusions are to be derived from this experiment. It was therefore, hoped that the King Faisal University would be able to continue the monitoring activity through a Saudi graduate assistant and another member of K.F.U. faculty who were required to work closely with the ERL, University of Arizona, during the designing, fabrication and installation of Data Acquisition System. The K.F.U. research team strongly recommends that K.F.U. retain the Environmental Research Laboratory as overall consultants for the specialized research activity beyond the current SOLERAS program.

Apart from providing detailed information regarding the effectiveness of chosen passive cooling techniques, the project has been conceived with the objectives of encouraging and initiating further research in various aspects of solar cooling and energy saving technologies by providing a full-scale test facility. Furthermore, by having a real family live in the house at a later date, the interaction of the occupants with the house can be another area of study.

IX. DATA ACQUISITION PLAN

A. INTRODUCTION

The data acquisition plan developed provides for a sensor field capable of measuring all parameters required for the understanding of the operation of systems to be tested at the facility. On the basis of this plan components of the data system were specified, storage system and data analysis/correction methods specified. The computer-based data Acquisition System (DAS) specified is capable of controlling the experiments to be performed.

The data system will consist of three computers and a Data Acquisition System (DAS). Sensors will be directly connected to the DAS. A complete plan and specifications are developed in later sections. Provisions are provided for routing instrumentation wires from room to room. Due to the nature of the laboratory many of the sensors will be portable, thus necessitating surface wiring. All wires required for sensor installation will be supplied and installed by KFU and its subcontractors and is not the responsibility of the building contractor. The wiring is all low-voltage (millivolt range) and therefore pose no risks. At scheduled times, instrumentated construction elements will need to be put in place by the building contractor. These elements will be detailed and instructions given as to the installation procedure in a later section. The following sections detail where and how these sensors will be installed.

B. DATA CATEGORIES AND INSTRUMENTS

1. Ambient Weather and Conditions

   a. Measure the ambient dry bulb and wet bulb temperatures, the sky radiation, the total insolation on a horizontal surface, and the diffuse radiation on a horizontal surface. The wind velocity and direction at various points and the earth temperatures in an open area will be measured.

   b. Instruments

      i. Dry bulb temperature, wet bulb temperature.

      One dry and one wet type T thermocouple inside two, aspirated concentric white radiation shields will measure these temperatures.

      Air will be drawn across the thermocouple at 600 feet per minute. The wet bulb thermocouple will be kept wet by capillary action in a wick in a constant level water reservoir. This equipment will be made at ERL using our standard design for aspirated, radiation shielded temperature sensing stations.

This apparatus will be enclosed in a standard white, wooden louvered NOAA approved enclosure.

ii. Effective sky temperature

An Eppley PIR pyrgeometer will be used to measure the long wavelength (4-50 um) radiation emitted to the sky. The effective sky temperature will be calculated from this measurement.

iii. Insolation on a horizontal surface.

An Eppley PSP pyranometer will be used to measure the total insolation, while an Eppley 8-48 pyranometer in an Eppley SBS shadow band will measure the diffuse radiation.

iv. Wind velocity

Three R.M. Young Gill propellor/vane integral wind velocity and direction sensors will be mounted on a 10 m tower located approximately 44 m north of the structure to avoid wind shadowing. The propellor/vane sensors will be located at three different heights corresponding to the center lines of each floor level and tower opening. These instruments sense a wind at .2 -4 m/s. The 540^{o} wind direction sensors will be used to improve the readability of the data.

v. Earth temperature and moisture

Soil Test Inc. MC 373 soil moisture cells will be used. Earth temperatures will be measured with type T thermocouples placed according to the plan.

2. Comfort Conditions

a. Measurements

The dry and wet bulb temperatures, the globe thermometer temperature and the air velocity will be measured at 2-5 locations in each structure. The mean radiant temperature will be calculated from the globe thermometer temperature, and from the air velocity. The dry bulb temperature will be measured from floor to ceiling in 60 cm increments where stratification is a factor.

b. Instruments

i. Dry and wet bulb temperature

The equipment described in Section B.1.b.i will be used, without the NOAA enclosure. It will be built at ERL and will be shielded from radiation and aspirated.

ii. Globe thermometer temperature

A type T thermocouple at the center of a 15.24 cm copper sphere coated with "Nextel" brand paint (emissivity=.98) will be used.

iii. Air velocity

In fan driven options, the air velocities will be measured for standard operating conditions, which will be entered into the data acquisition system. An Environmental Instruments Incorporated omni-directional "thick film" air flow meter will be used (+2% full-scale accuracy, 0-1, 0-10. and 0-50 m/s ranges).

For natural draft options, the air velocity will be continuously monitored with the same type instrument, which will record velocities of 0-5 meters per second (0-1000 feet/minute) at +.1 m/s or +20.0 fpm accuracy.

3. Heat Flow Measurements

a. Measurements

The heat entering and leaving typical wall sections will be measured with heat flow plates (heat flux meters). The temperature gradients in the walls will be measured with thermocouples at 5-8 points in typical wall sections. The thermal capacity and conductivity of typical wall materials can be calculated from such data. The insolation entering each typical window will be measured.

The soil temperature gradients around the structure and under the structure will be measured.

The insolation entering typical windows will be measured in a vertical plane.

b. Instruments

i. Heat flux meters —— Hy-Cal #BI-7 or BI-6

ii. Temperature sensors —— type T thermocouples will be used

iii. Window insolation —— Li-Cor #LI 200B pyranometers will be used

iv. Earth temperatures, soil moisture levels —— these will be measured as in B.1.b.v.

4. Cooling Effectiveness Measurements

a. Measurements

The input and output dry bulb temperatures (and wet bulb where evaporation or condensation occurs) of sources of coolth will be measured. The airflow rates will be measured where required.

b. Instruments

i. Aspirated, radiation shielded, dry and wet bulb temperature instruments as described in Section B.1.b.i will be used.

ii. Environmental Instruments Inc. air flow meters will be used as described in Section 2.b.iii. Typical velocities will be measured in fan-driven systems, while natural draft systems will be constantly monitored.

5. Power Usage

a. Measurements

The power used to drive fan-driven systems will be recorded independently of the power used which adds to the heat load of the building.

b. Instrument

Westinghouse watt-hour meters (or equal) will be used. R/S Electronic Watt transducers will be connected to the DAS to monitor power in real time. (See Appendix IX for details).

6. Water Usage

a. Measurements

The water usage of all cooling devices using evaporation will be measured and manually entered into the data acquisition system.

b. Instrument

"Recorall" Badger #15 water meters, sensitive to low-flow conditions down to 1/8 gallon per minute will be used. The data will be entered manually into the data acquisition system.

C. DATA ACQUISITION EQUIPMENT

1. General Description

A HP #3497A programmable scanner will measure the output voltages of the sensors and direct the information to the appropriate data location in the IBM PC/XT data acquisition computer, which is initially used to record the data.

An IBM PC/XT will be used to process the data and produce graphs. These two computers will be connected via a Local Area Network (LAN) to a third display IBM PC computer. (See Appendix IX for details on the LAN). The overall system design can be seen in Figure IX.C.1.

2. The HP 3497A Programmable Scanner

This equipment will have a battery-powered back-up clock to allow useful data to be collected after a short power failure. It will have 688 channels. 30 channels will be able to switch 24 volts at 1 ampere if control functions are desired.

3. The IBM PC/XT Acquisition Computer

This unit will have 256 bytes of RAM, and will convert sensor output data to the desired units. It will also allow the verification of data as it is produced. It has a CRT and a dot matrix printer. (See Appendix IX for details).

4. The IBM PC/XT Data Analysis Computer

This unit will process the data by calculating comfort parameters infiltration, daily and weekly averages, and mixima/minima for rapid scanning of the data. It will have a printer with graphics capability, a terminal for data transmission, and be networked.

Data will be stored online on an integral 10 M Byte Winchester hard disk.

A Tallgrass streaming magnetic tape system will be used for long-term, backup and archival storage. (See Appendix IX). A second tape system will be installed at ERL to provide for media transfer of data.

5. The IBM PC Display Computer

In order to provide for visitor interaction and information dissemination, an IBM PC with Color Graphics monitor will be linked via IBM's Local Area Network (LAN) with the other two IBM computers. Visitors will be able to call up data from the data base by simple menu-driven commands.

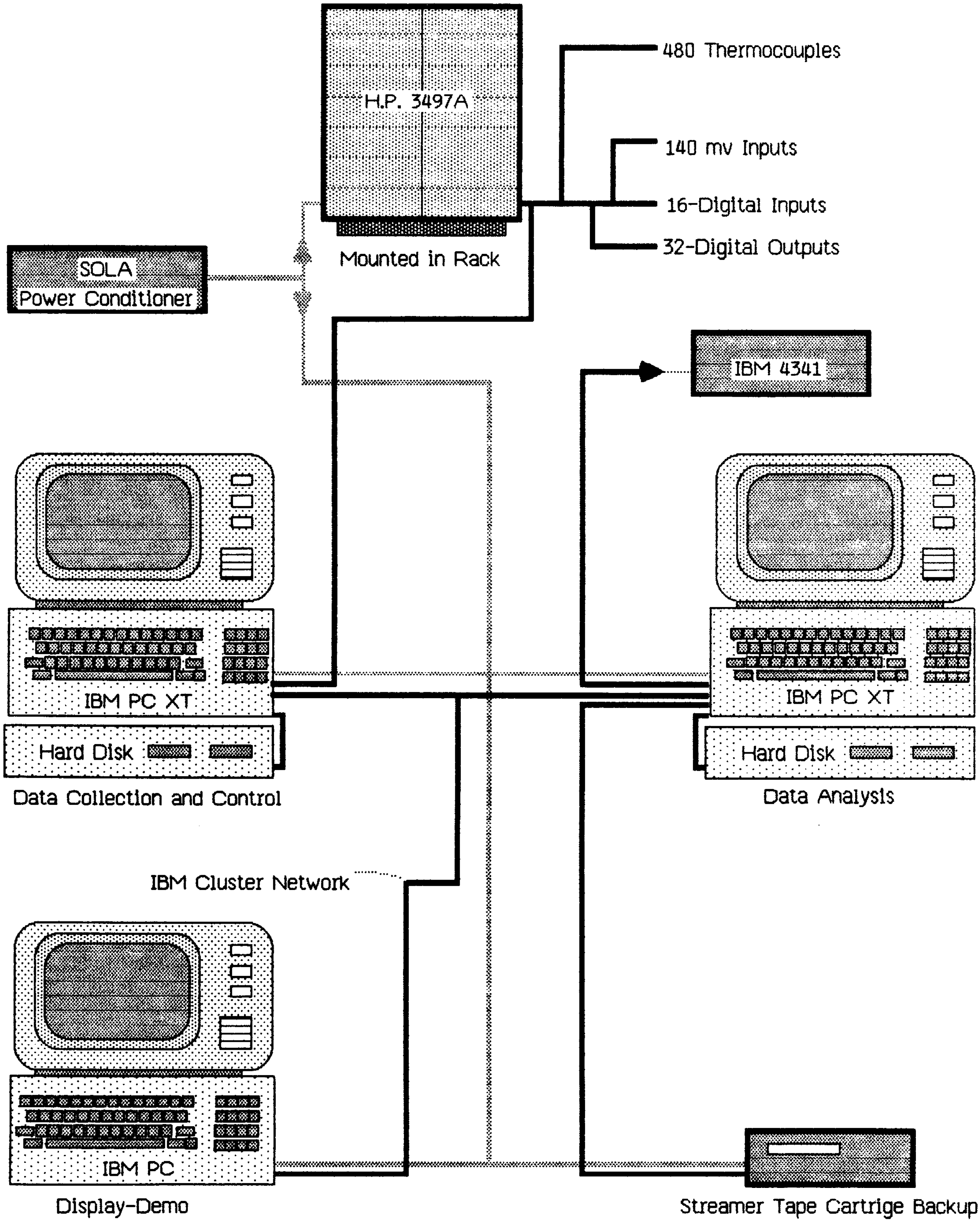


Fig. IX. C. 1 DATA ACQUISITION SYSTEM

6. SOLA Power Conditioner

SOLA Power Conditioner will supply regulated and faltered power to all the elcetronics hardware in order to prevent system failures, due to line power fluctuations (see Appendix IX for details).

7. OPTIMA Equipment Rack

All of the electronics hardware and thermocouple/millivolt interface patch panels will be mounted in 19-inch metal cabinets. Figure IX.C.2 shows the layout of these cabinets.

8. Software

Software will be developed suitable for data acquisition analysis, graphics and control. The programs will be written in a high-level language such as C, Fortran, Basic or Pascal.

D. INSTRUMENTATION SELECTION

1. INTRODUCTION

The purpose of the Passive Cooling Experimental Facility is to acquire data and perform experiments regarding different passive cooling techniques and strategies. In order to adequately explain the cooling techniques employed, sufficient instrumentation and data logging equipment needs to be installed.

Sensors are selected based on their accuracy, cost effectiveness, and ability to calibrate consistently and with ease. This section decribes the sensors and instrumentation and the basis for their selection, installation, verification and calibration.

Installation and calibration details are provided for certain selected critical sensors, i.e. heat flux meters, pyrgeometers, etc.

The following list summarizes the critical sensors and instruments selected.

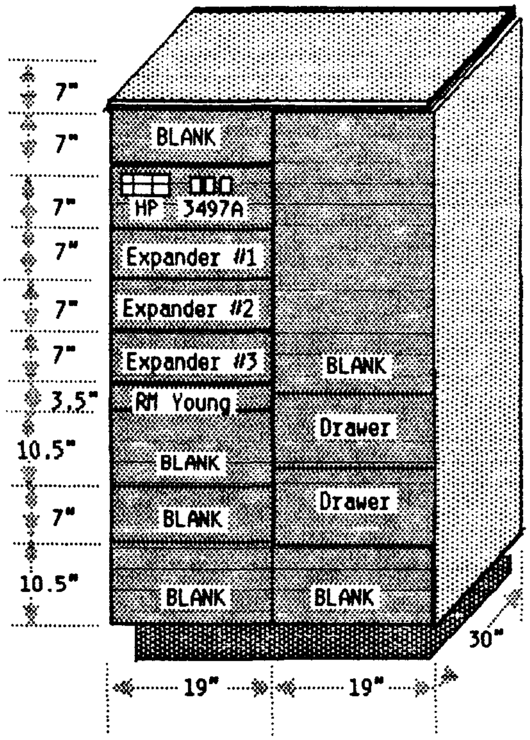
Heat Flux: Hy-Cal Engineering BI-7 thermoelectric sensors.

Temperature (wet and dry bulb): Copper-constantan thermocouples, Hewlett Packard reference junction.

Pyranometers: Eppley PSP, LICOR photovoltaic pyranometers and Eppley Shadow Band 8-48 pyranometer.

Infrared Radiometer: Eppley PIR pyrgeometer.

Ambient Wind Velocity: Gill Propeller Vane Anemometer by R. M. ' g



Optima-Accent
Vertical Cabinet

AR-2-701930
Black Frame, light
Gray Side Panels
(Charcoal)

RACK-Rear View

480 Thermocouple Inputs
150 MV Inputs
32 Digital Inputs
16 Digital Outputs

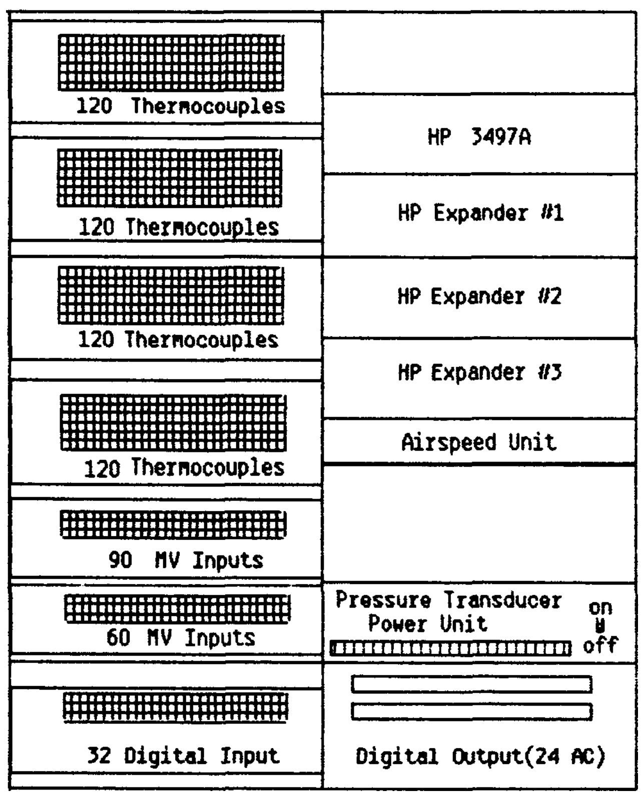


Fig. IX. C. 2 **Data Acquisition Rack**

Air Flow: EII Air Flow Meters

Infiltration: SF_6 gas chromatography

2. Sensor and Instrument Selection

a. Dry Bulb Temperature

i. Utilization

Temperature sensors are utilized to measure the thermal performance of the structure. They are distributed throughout the structure. Temperature measurements are used in the heat balance calculations and to measure the relative effectiveness of the passive systems. Temperature sensor locations can be seen in Figures IX.E.3-IX.E.9.

ii. Accuracy Requirements

The primary purpose of the temperature sensors is to determine how effective the passive features are and to help verify performance models. The accuracy required would only need to be $\pm$ 1 to 2°F. The order of magnitude of the heat flux due to temperature differences is about 10 BTU/hr. sq. ft. and thus a 1 or 2°F error would only yield an absolute error of less than 10%.

iii. Selected Sensors

Electric thermometers are adapted to automatic recording. Basically there are two main types of electrical transducers, self-generating and non-self-generating. The self-generating transducers produce an electric current as a function of temperature. The non-self-generating transducers require the application of an external signal in order to detect a change in property. Thermocouples are examples of the former, while resistance elements, thermistors and RTD's are examples of the latter.

Three types of sensors fall within this accuracy range: Thermistors, Resistance Temperature Devices (RTD) and Thermocouples. Since there are about 500 (including backups) temperature sensor locations, cost was the driving element in this decision.

Thermistors are semiconductors of ceramic materials made from sintering mixtures of oxides of manganese, nickle, cobalt, copper, iron, and uranium. Thermistors have very large negative temperature coefficients; each temperature increase of 1°C will increase the resistance 5%. Thermistor resistance change with temperature is much larger than for resistance thermometers, however the change is quite nonlinear. Thermistors can be calibrated to measure temperature to within ± 0.1°F, and can, with suitable bridge networks, yield outputs of 0-5 volts, thus eliminating the need for instrumentation with microvolt resolution. The self-heating errors in a thermistor can be quite large because of the large temperature coefficient. Thus they require frequent calibration. Thermistors are relatively expensive in comparison to thermocouples.

RTD's are resistance temperature devices which change resistance with temperature. The electrical resistance of most materials varies with temperature. This characteristic is utilized to measure temperatures with resistance thermometers made from a variety of materials. Given a known resistance-temperature relationship and appropriate recording equipment, temperatures can be determined to a high degree of precision. These devices exhibit good long-term stability and linear output; however, they are expensive and fragile.

Thermocouples have won a permanent role as temperature sensors for numerous industrial applications. Their favorable characteristics include acceptable accuracy, suitabilty over a wide range of temperatures, adequate thermal response, ruggedness, high reliabilty, low cost, ease of installation and compatibilty with most measuring and recording systems.

Based upon cost and desired accuracy thermocouples were chosen for the temperature transducers for this project. The required accuracy of ± 1 to 2°F falls well within the error of type T copper constantan thermocouples. In order to avoid detailed and time consuming calibration of each sensor, enough wire should be acquired from the same lot number to assure consistency of the calibration.

b. Wet Bulb Temperature

i. Utilization

In order to measure the humidity, and in turn to calculate the Fanger PMV comfort index, the wet bulb temperatures need to be measured. The temperature transducers to be utilized are the same as for dry bulb temperature measurements.

The temperature transducer (thermocouple) is enclosed in a capillary sock and then placed in an aspirated and shielded device of ERL design.

Calculations are then made to determine the humidity and other psychrometric properties.

ii. Accuracy Requirements

The accuracy required for this sensor is the same as for the dry bulb temperature sensors.

iii. Selected Sensors

Considerations for selection of sensors is the same as for the dry bulb temperature sensors.

c. Radiant Temperature

i. Utilization

In order to calculate the Fanger PMV comfort index, the Mean Radiant Temperature needs to be measured. The temperature transducers to be utilized are the same as for the measurement of dry bulb temperatures. The Mean Radiant Temperature is derived from the Globe Temperature (the device utilized to measure the radiant temperature).

The temperature transducer (thermocouple) is enclosed in a six inch copper sphere that is painted flat black (Dupont Nextel flat black paint) with absorptivity and emissivity of about .95, nearly a black body receiver.

ii. Accuracy Requirements

The accuracy required of this sensor is the same as for the dry bulb temperature sensors.

iii. Selected Sensors

Consideration for selection of sensors is the same as for the dry bulb sensors.

d. Heat Flux Meters

i. Utilization

The heat flux meters are utilized to measure the heat flow in and out of the structure. They are used in conjunction with the temperature and insolation sensors to arrive at a general heat balance for the structure.

ii. Accuracy Requirements

The accuracy required from this instrument is similar to the accuracy required of the pyrgeometer and pyranometers. The accuracy should be about 1 to 2% full scale, with a range of 0 to 10 BTU/hr. sq. ft.

iii. Selected Sensor

All heat flux meters utilize a thermopile type arrangement. The differences arise in the accuracy, consistency of calibration, size and cost. Two manufacturer's devices were considered: HY-CAL Engineering BI series, and International Thermal Instrument Company.

HY-CAL BI series Heat Flux Meters have a ± 2% accuracy, and exhibit fairly consistent calibration. They are factory calibrated prior to delivery. The BI series is a very sensitive instrument and is suitable for low temperatures (-50 to 200°F). In addition, the devices measure heat flow uniformly in both directions. They cost about $260.

International Thermal Instrument Company (ITI) devices are not as accurate (± 3%) and cost about $180.

Based upon the cost, desired accuracy and consistency of calibration, the HY-CAL BI series heat flux meter was chosen.

e. Pyranometer

i. Utilization

The pyranometers will be utilized to measure solar insolation incident upon horizontal and vertical surfaces. These measurements will aid in determining the heat gains due to fenestration for each structure. Several instruments are required in order to fully assess the solar heat gains to the structures.

ii. Accuracy Requirements

The primary purpose of the project is to determine how well certain passive features work. When dealing with solar insolation, the flux is on the order of 300 BTU/hr. sq. ft. maximum, and thus an error of 1% is about 3 BTU/hr. sq. ft. The order of magnitude of heat flux due to passive design features is about 10 BTU/hr. sq. ft., thus an instrument with only 1% accuracy is marginally acceptable, and in practice, unachievable. The most that can be expected is about 3%. This would yield an error of about 9 BTU/hr. sq. ft. Thus, better than 50% of the heat gain/loss could be due to instrument error.

iii. Selected Sensors

Two different types of pyranometers were considered, thermopile and photovoltaic.

The Eppley Precision Spectral Pyranometer is of the thermopile type and utilizes a multijunction copper-constantan plated thermopile. The thermal transducer is blackened with optical black lacquer and is shielded from the weather with two removable concentric hemispheres. The instrument has a sensitivity of 9 micro volts/watt.

This instrument is a very accurate and stable commercially-available sensor. The calibration of this instrument can be maintained at about 1%. Cost is $1400.

Another Eppley thermopile pyranometer considered was the Eppley Black and White pyranometer Model 8-48. This pyranometer is a development of the well-known Eppley 10 and 50 junction 180° pyreheliometer. The detector is a differential thermopile with the hot-junction receivers blackened and the cold junction receivers whitened. The linearity, cosine response, response time and spectral response are not quite as good as that of the Eppley PSP, but they are adequate for the measurements required. The cost of the Eppley Black and White is about $850.

The LICOR Photovoltaic pyranometer is not nearly as accurate as the Eppley PSP pyranometer; however, it is considerably less expensive. This type of sensor utilizes a photodiode. The response of the silicon photodiode does not cause serious errors provided it is used only for solar radiation and not under conditions of altered spectral distribution. The relative spectral response of the silicon photodiode does not extend uniformly over the full solar radiation range. The changes in the spectral distribution of the incident light, coupled with the non-uniform spectral response, can cause errors in the photodiode output.

The LICOR LI-200SB pyranometer has been calibrated against an Eppley Precision Pyranometer. Under full sun conditions at solar noon, the uncertainty of the calibration was 5%. When the error of the PSP is taken into account, the absolute error of the LICOR sensor is about 6%. While this is an extremely high error in relation to the desired accuracy, it is acceptable for the measurements required. The cost of these sensors is about $165, considerably less than the Eppley PSP.

Based upon cost and accuracy, the Eppley PSP was chosen to measure the site horizontal insolation and the LICOR's were chosen to measure the insolation of specific surfaces (i.e. windows) of the structure. In addition to these instruments, the Eppley Model 8-48 Black and White Pyranometer was chosen for use with the Eppley Shadow Band Stand Model SBS to measure diffuse insolation.

f. Infrared Radiometer

i. Utilization

This sensor is utilized for continuous measurement of net radiative heat exchange between the sky and surface. In particular, the radiation exchange between the roof and the night sky are measured in order to determine the heat exchange ability of the roof.

ii. Accuracy Requirements

The net radiation errors should be small in comparison to typical nocturnal radiative heat fluxes and other heat transfer rates. This goal is exceedingly difficult to attain because typical radiative heat transfer rates are of the order of 100 BTU/hr. sq. ft. from a roof surface. An error of 1% in the irradience would give a 1 BTU/hr. sq. ft. error and would result in a 10% error in the net radiation rate.

Most sensors surveyed had a greater than 1% error. Even those with 1% error could only achieve this accuracy under ideal conditions and at radiation rates in excess of 10 BTU/hr. sq. ft.

iii. Selected Sensor

There were two basic types of instruments to select from:

Funk type radiometers utilize thermopiles which contain about 250 thermal junctions bonded with two blackened plates. Hemispherically formed windshields made from polyethylene are used on both sides to reduce the thermal convection term. This type of sensor, when operated with both windows, yields a net radiation. When operated with only one window, it gives the sky irradience. This type of instrument is very accurate, but requires careful maintenance. In addition, the polyethylene windows degrade with ultraviolet light and thus the calibration is not very stable. Cost is about $1300.

The Eppley pyrgeometer also utilizes a thermopile. The thermopile is protected by a silicon dome with an interference filter and a temperature compensation circuit. The output voltage is proportional to the irradiance incident from the sky, not the net radiation. These instruments in practice are generally accurate to within 2% of the received irradience, however they are not accurate in daylight due to heating of the silicon dome. Cost is about $1300.

Based on cost, accuracy, calibration and ease of maintenance, the Eppley PIR was selected.

g. Wind Velocity

i. Utilization

The wind velocity is required in order to determine convective heat transfer losses and gains to the structure and also to determine infiltration rates.

ii. Accuracy Requirements

A sensitivity analysis indicates that a wind speed accuracy of 1 m/s is required in order to verify any heat transfer algorithms. In addition, the Fanger PMV comfort index requires the air velocity. Several comfort stations are to be monitored. The PMV correlation falls apart at air velocities greater than 5 m/s.

iii. Selected Sensors

Two types of wind sensors were considered, hot wire/film and tachometer type. The following sensors were evaluated:

Tachometer type drives are rugged and reliable units that require little maintenance and are easily calibrated. The Gill Propeller Vane anemometer by R. M. Young has an azimuth range of 0-540^{o} and a threshold sensitivity of 0.1 to 0.2 m/s, well within the accuracy required. The output signal from the generator is analog. The signal is linearized by the power supply translator. Cost including translator is about $2500.

The hot film type anemometers are more sensitive than the tachometer drive units and have lower ranges. The Environmental Instruments, Inc. (EII) 300 series hot film anemometer was evaluated. This sensor utilizes a temperature compensated hot film probe. The accuracy is about 2% full scale. These sensors are only wind speed sensors and do not yield the velocity direction vector.

The 0-5 m/s scale is accurate to within $\pm$ 0.1 m/s. The cost of the EII sensors including power supplies and electronics is about $750.

It was decided to place three wind speed and direction stations at three heights (2.5 m, 5 m, and 10 m) at the north side of the site. Gill Propeller Vane anemometers are to be used.

Additionally, where lower air flow measurements and greater accuracy are required, the EII meters were chosen. These sensors are to be placed at selected comfort stations to measure the air velocity for use in the Fanger PMV calculations and ventilation studies.

h. Infiltration Method

i. Utilization

Air infiltration measurements are necessary in order to arrive at a thermal balance for the structures and also to assess the effectivenes of different building techniques.

Due to the continuing experiments in progress the method of measurement should have as little impact as possible. It is hoped that the infiltration measurements will be as accurate as the other measurements; however, allowing for the variance in weather conditions, it would not be practical to assume the measurements will be.

There are two general means of determining infiltration, pressure differential and tracer gas. It is decided to utilize the SF_6 tracer gas technique to determine the quasi-static infiltration rate for the structure, and to use the Sherman and Grimsrud Method in conjunction with the computerized data acquisition system.

ii. Tracer Gas Method

The tracer gas technique has reasonably well-defined limits of error. This method was chosen due to the availability of a gas chromatograph here at the Environmental Research Lab. See Appendix IX.

iii. Pressure Differential Method

This method, as implemented, would utilize the Sherman and Grimsrud methodology. The data required for this is collected on an hourly basis by the data system. See Appendix IX.

E. DETAILED SENSOR PLAN

The data system layout and wire chases should follow the plan layout on Figures IX.E.1 - IX.E.9. The wire chases, both vertical and horizontal provide penetrations from room to room and from the inside to out.

1. Miscellaneous Outside Locations

a. Wind

Three R.M. Young Propellor Vane units mounted on a 10 meter Rohn tilting tower connected with three Belden 8449 cables. Units to be mounted on extenesion arms at 2.5m, 5m and 10m heights (see Figure IX.E.2 & IX.E.10)

b. Ambient Dry and Wet Bulb Temperatures

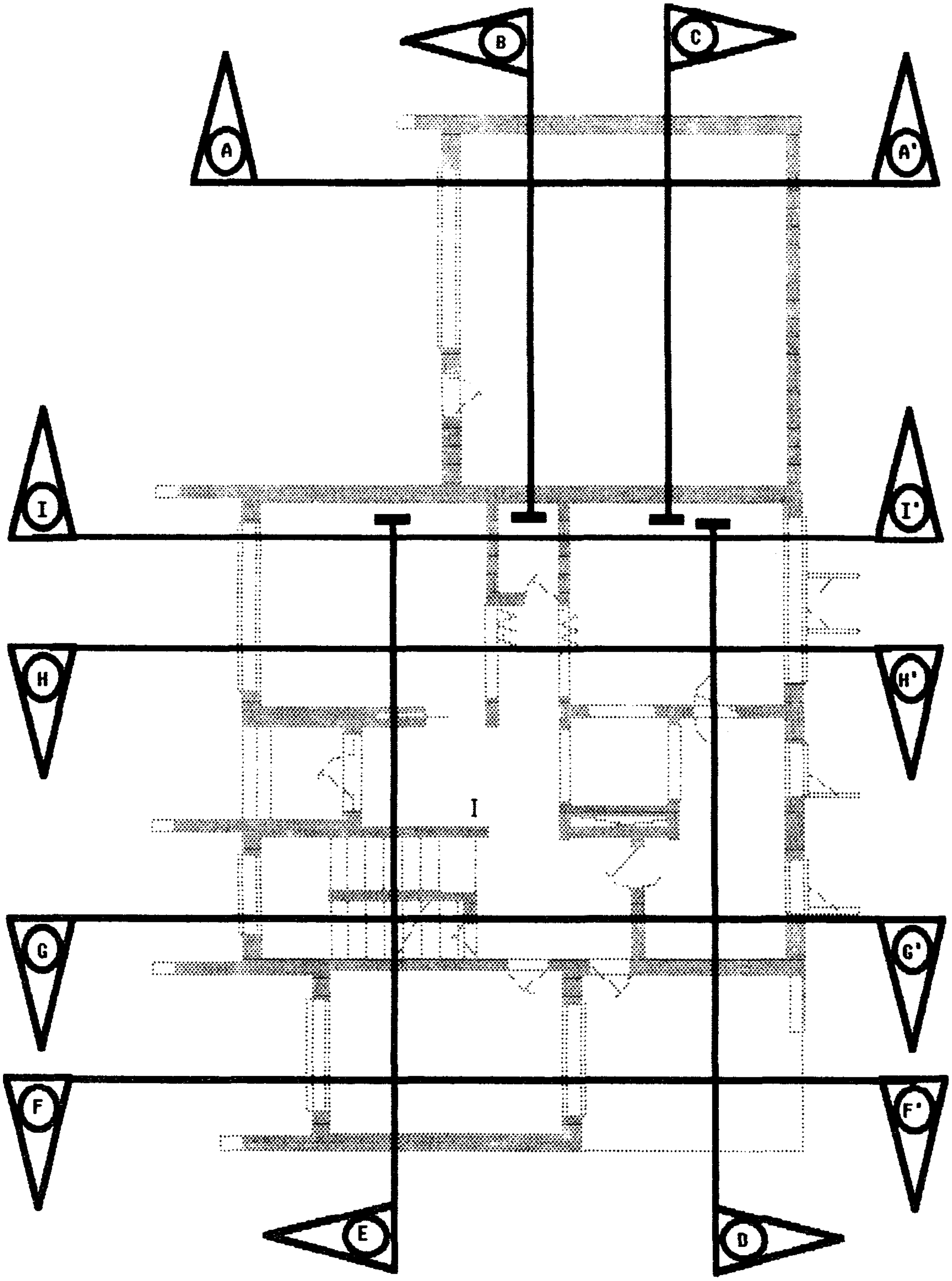


Fig. IX. E. 1 Sections Plan Scale 1 2 4 m

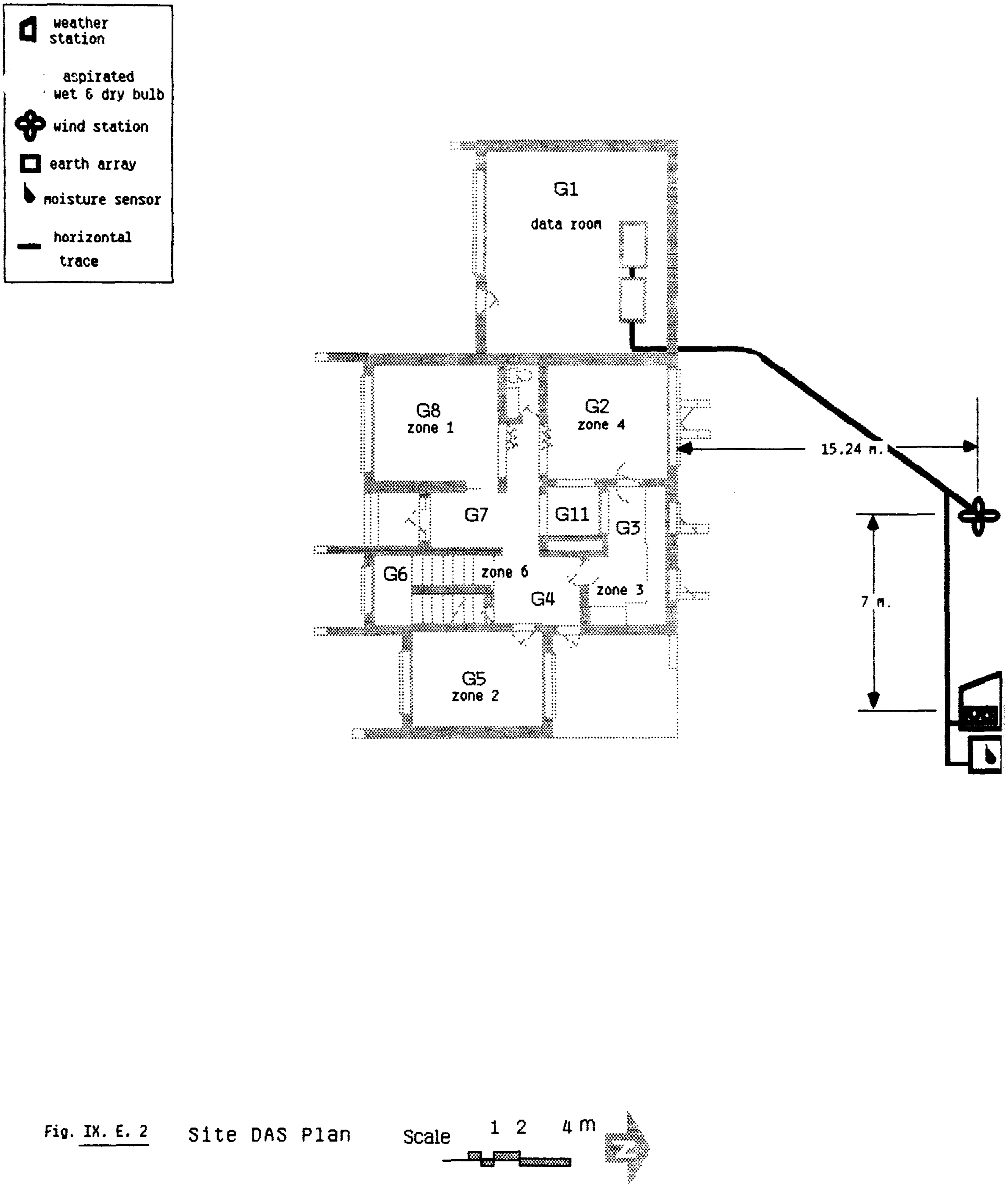


Fig. IX. E. 2 Site DAS Plan

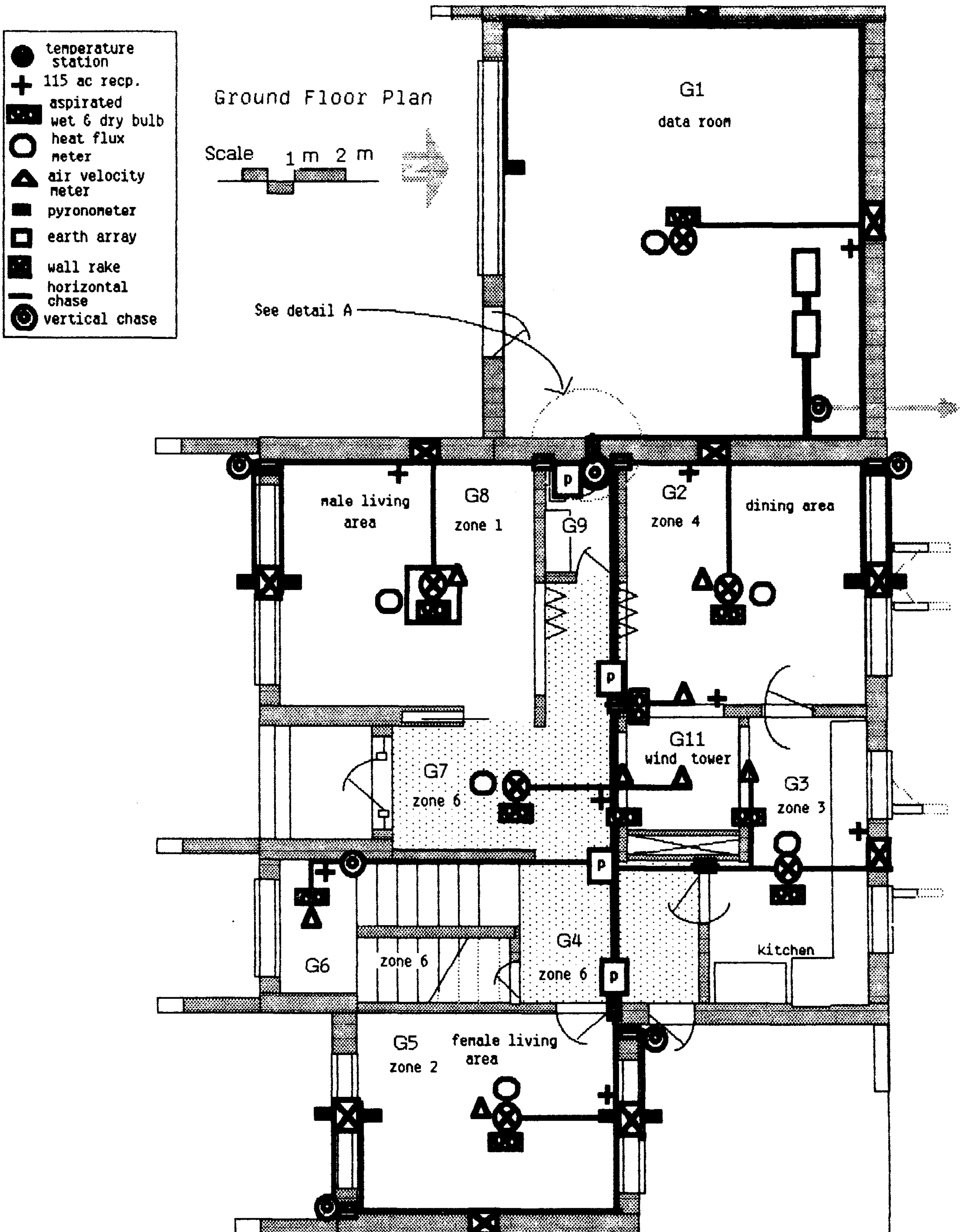

temperature station
115 ac recp.
aspirated wet & dry bulb
heat flux meter
air velocity meter
pyronometer
earth array
wall rake
horizontal chase
vertical chase
Ground Floor Plan
Scale 1 m 2 m
See detail A
G1
data room
male living area
G8
zone 1
G9
G2
zone 4
dining area
G11
wind tower
G7
zone 6
G3
zone 3
kitchen
G6
zone 6
G4
zone 6
G5
zone 2
female living area

Fig. IX. E. 3

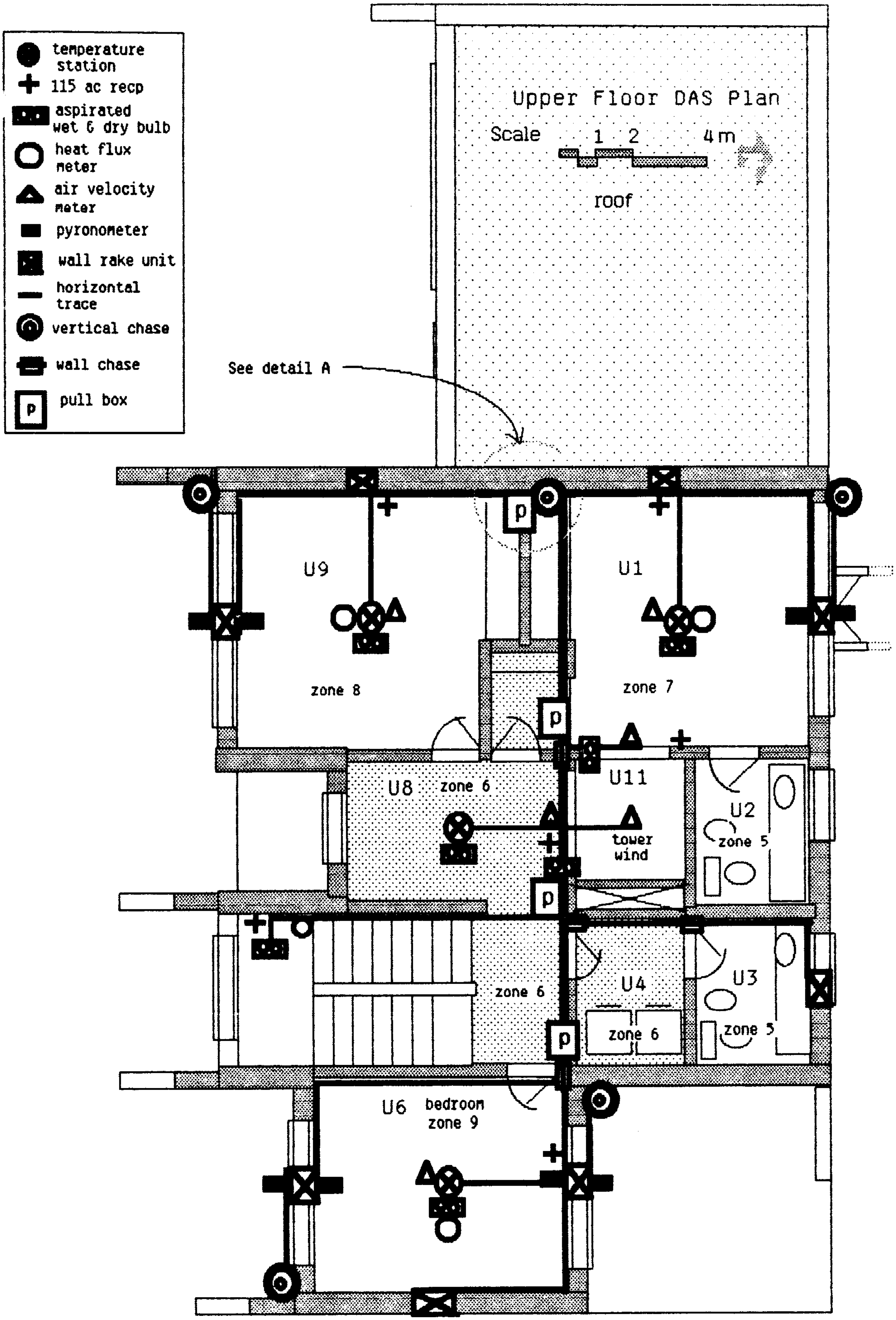

temperature station
115 ac recp
aspirated wet & dry bulb
heat flux meter
air velocity meter
pyronometer
wall rake unit
horizontal trace
vertical chase
wall chase
pull box
Upper Floor DAS Plan
Scale 1 2 4 m
roof
See detail A
U9
zone 8
U1
zone 7
U8 zone 6
U11
tower wind
U2
zone 5
zone 6
U4
zone 6
U3
zone 5
U6 bedroom
zone 9

Fig. IX. E. 4

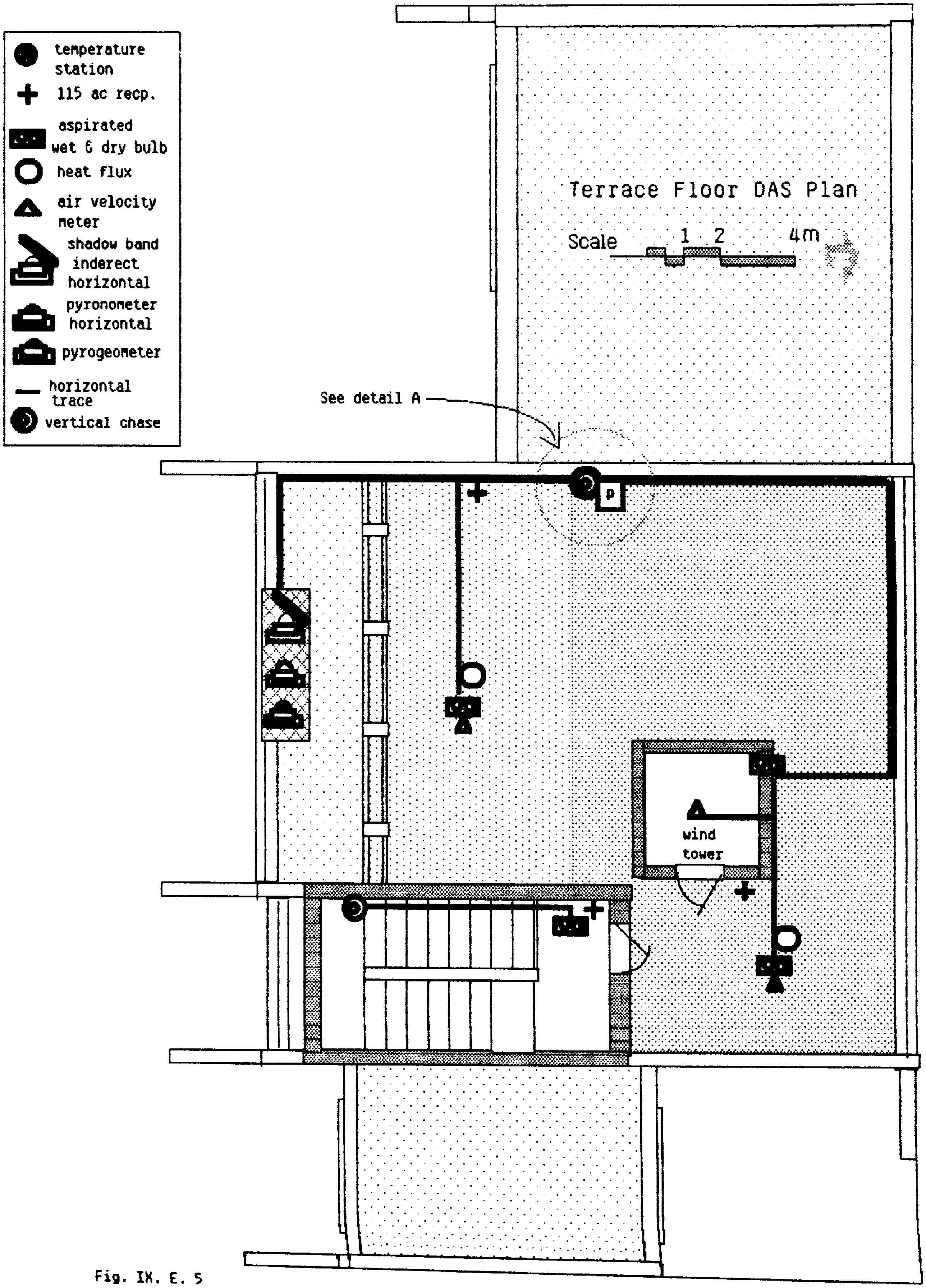


Fig. IX. E. 5

terrace DAS

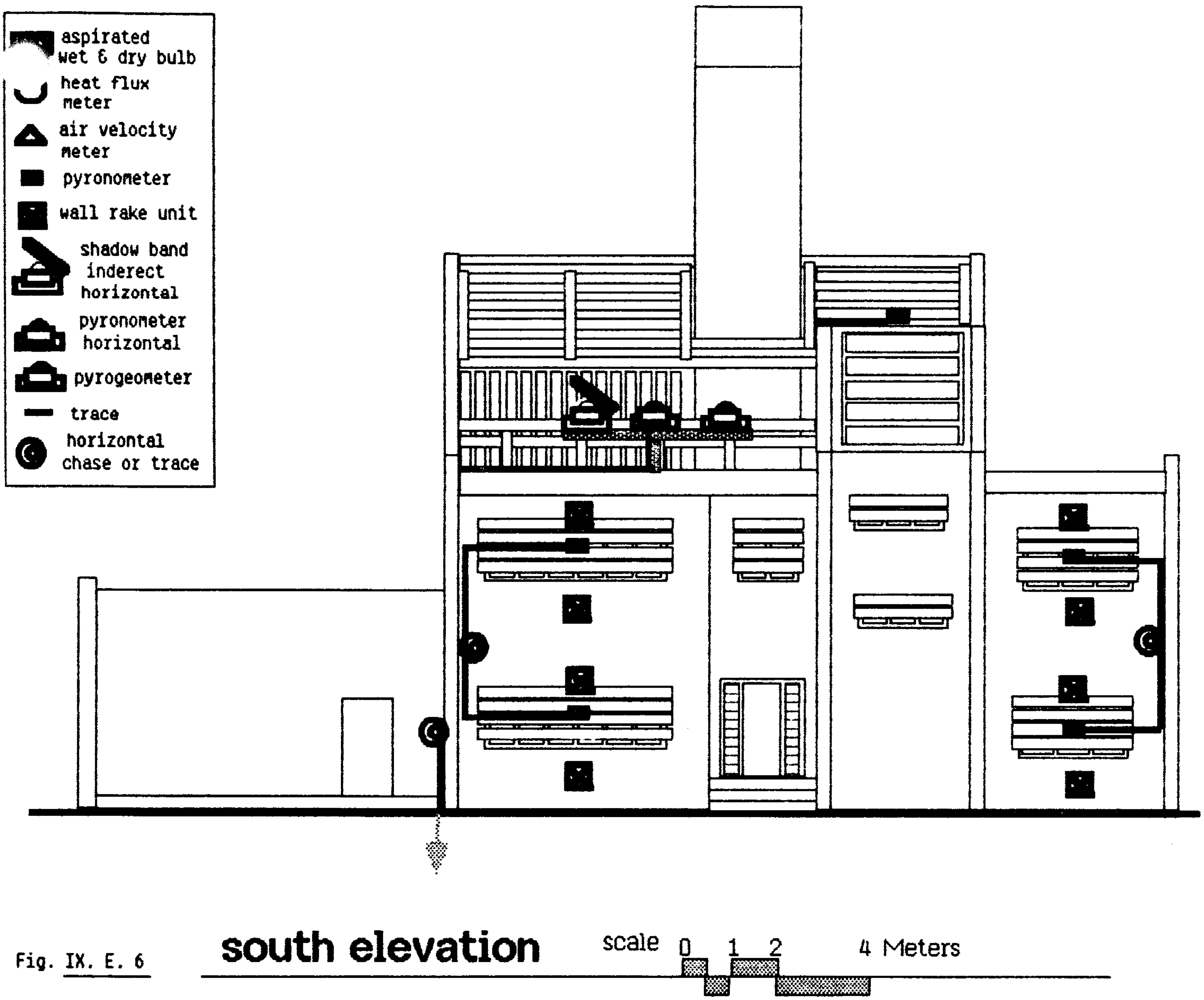


Fig. IX. E. 6 **south elevation**

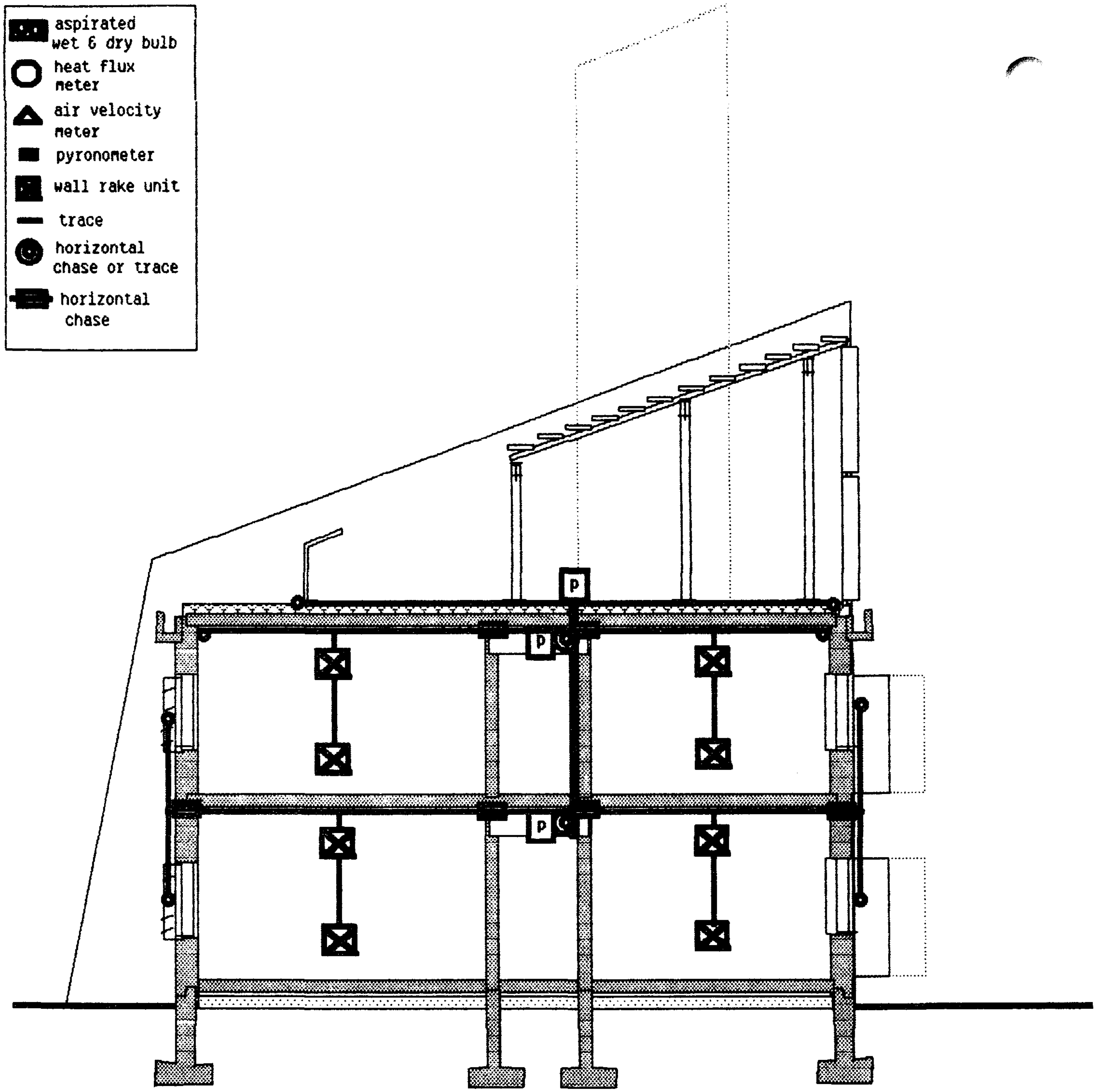


Fig. IX. E. 7 Section I-I' scale 0 1 2 4 Meters

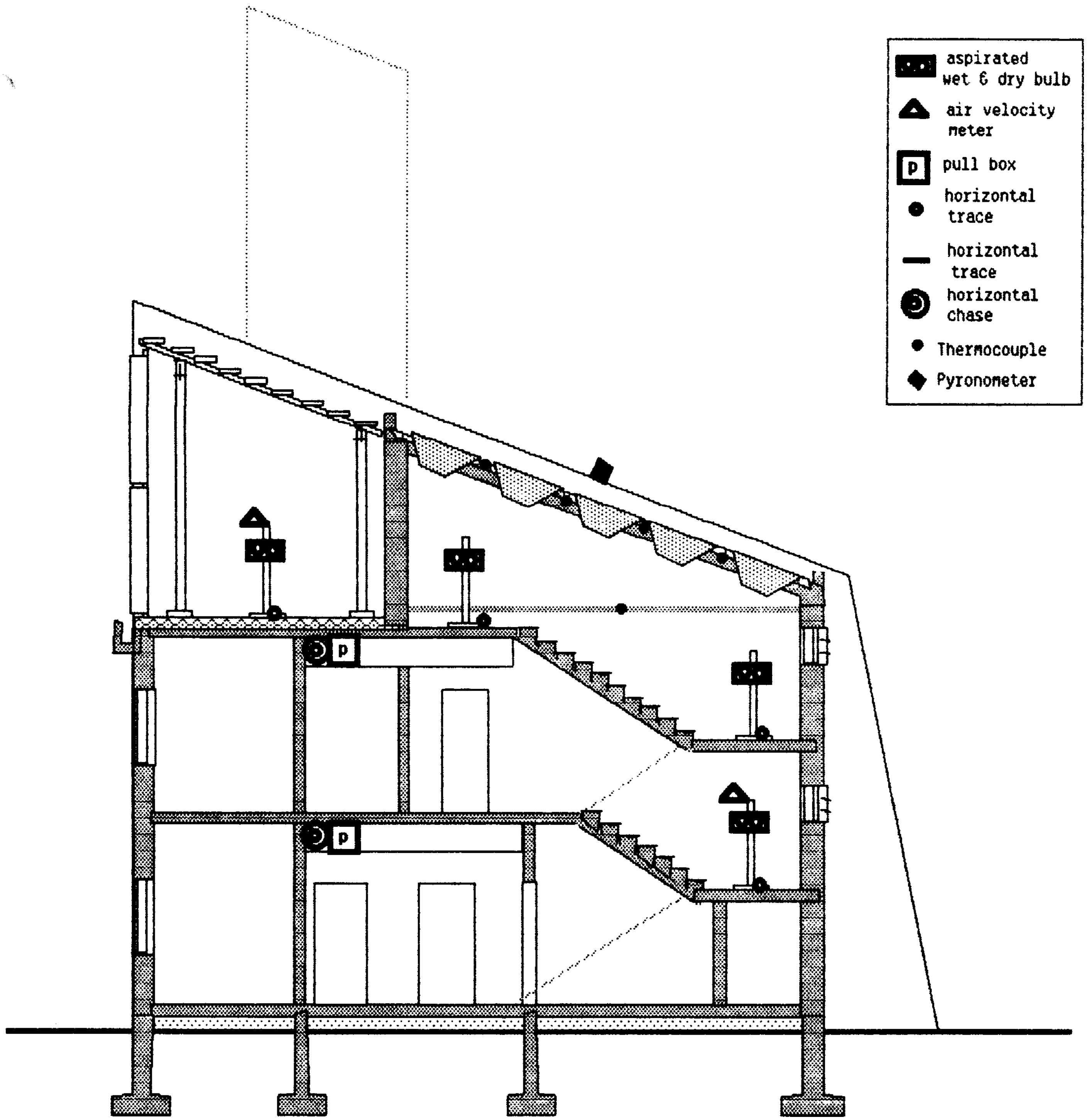
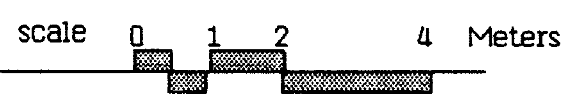


Fig. IX. E. 8 Section G-G'



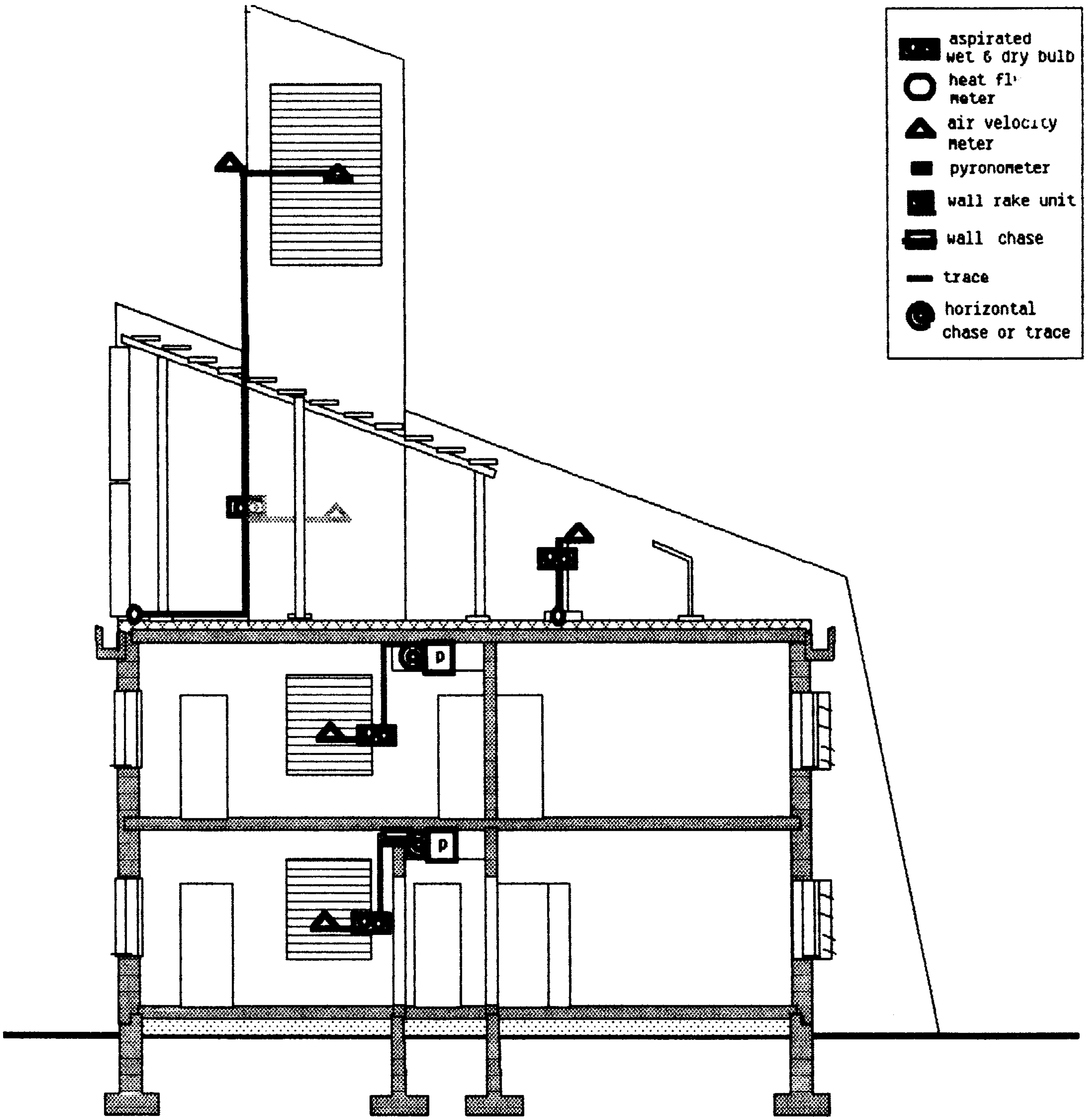
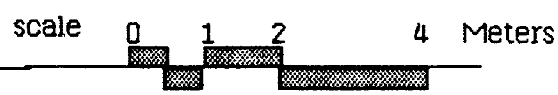


Fig. IX. E. 9 Section H-H'



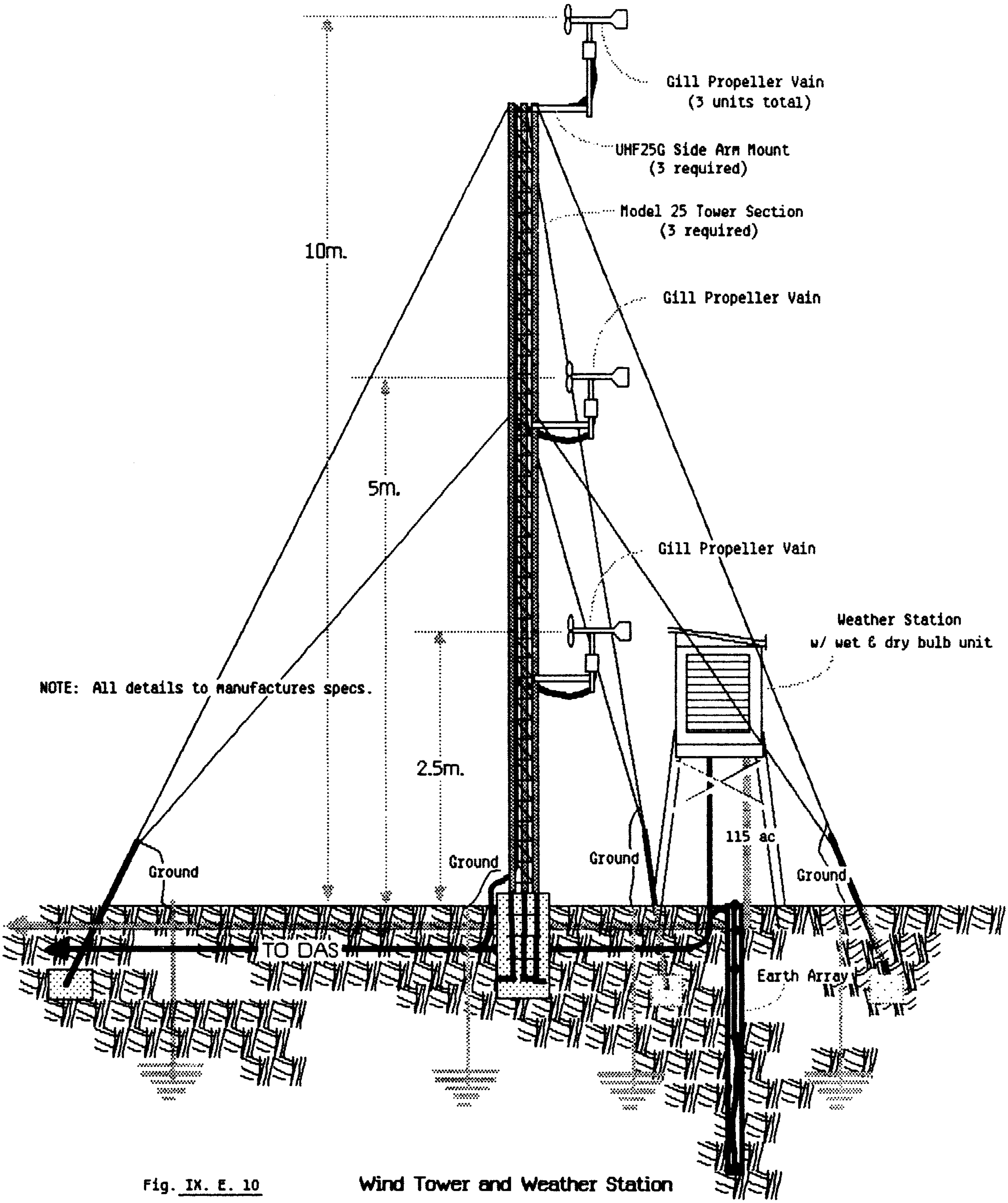


Fig. IX. E. 10 **Wind Tower and Weather Station**

One standard ERL Dry bulb and Wet bulb Temperature radiation shielded, aspirated instrument (see Figure IX.E.11) and one WEATHERTronics Relative Humidity Probe Model 5120 (see Appendix IX) and one WEATHERTronics Solid-State Analog Output Barometer (see Appendix IX) in a NOAA approved enclosure is required and is connected to the Data Room with two thermocouple wires, 2 Belden shielded cables and one AC powerline. This station is located with the wind sensing tower (see Figure IX.E.10).

c. Open Area Earth Temperatures

Seven thermocouples (20 gauge type T) at approximately 1.0 cm below the surface, and at intervals of 10 cm, 20 cm, 30 cm, 60 cm, 1 meter and approximately 2 meters per Figure IX.E.3 will be installed at the wind sensing tower location (see Figure IX.E.2 & IX.E.12).

d. Open Area Soil Moisture

Seven soil moisture sensors (Soil Test Inc. MC 373) to be installed at the same location as the Open Area Earth Temperatures (see Figure IX.E.2 & IX.E.12).

e. Roof Mounted Solar and Thermal Radiation Instruments

i. One Eppley PSP Pyranometer, one shilded 2 conductor 20 gauge conductor required to be mounted on roof according to the plan on Figure IX.E.5 & IX.E.6

ii. One Eppley Shadow Band and one Eppley 8-48 Pyranometer, one shilded 2 conductor 20 gauge conductor required to be mounted on roof according to the plan on Figure IX.E.5 & IX.E.6

iii. One Eppley PIR Pyrgeometer (sky radiation), one shielded 2 conductor 20 gauge conductor required to be mounted on roof according to the plan on Figure IX.E.5 & IX.E.6

iv. One Li-Cor pyranometer will be installed in the plane of the of the solar collectors.

2. Comfort Measurement

a. Six floor to ceiling comfort measurement stations with continuous air velocity measurement (EII Air Velocity Sensors Model 300) will be placed per the sensor plan on Figures IX.E.3 - IX.E.5. (see Figure IX.E.13 for details of this station).

Each of these stations will measure:

6 Dry Bulb Temperature (0.61 m increments)

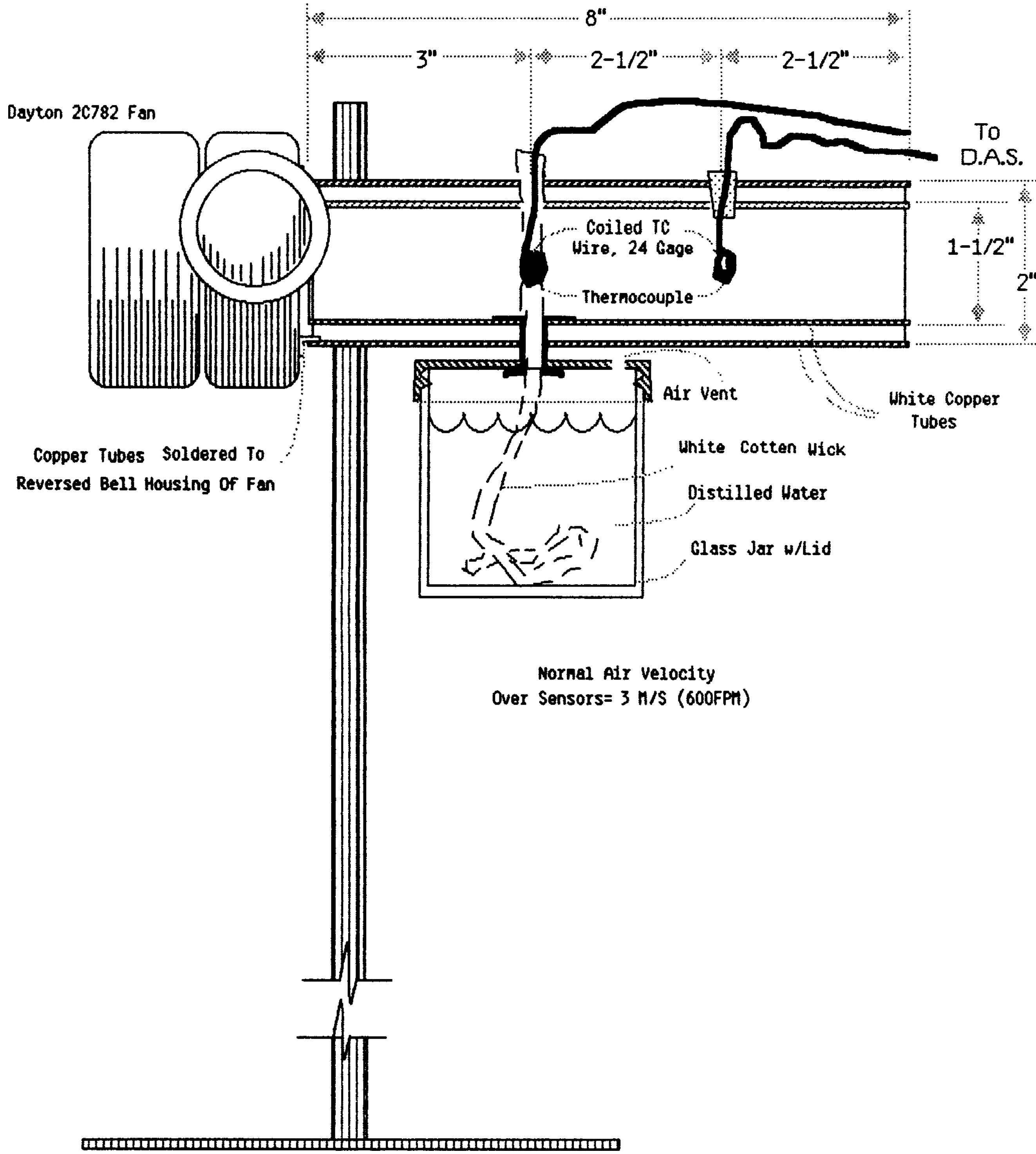


Fig. IX. E. 11 Single Point Wet & Dry Bulb Temperature Station

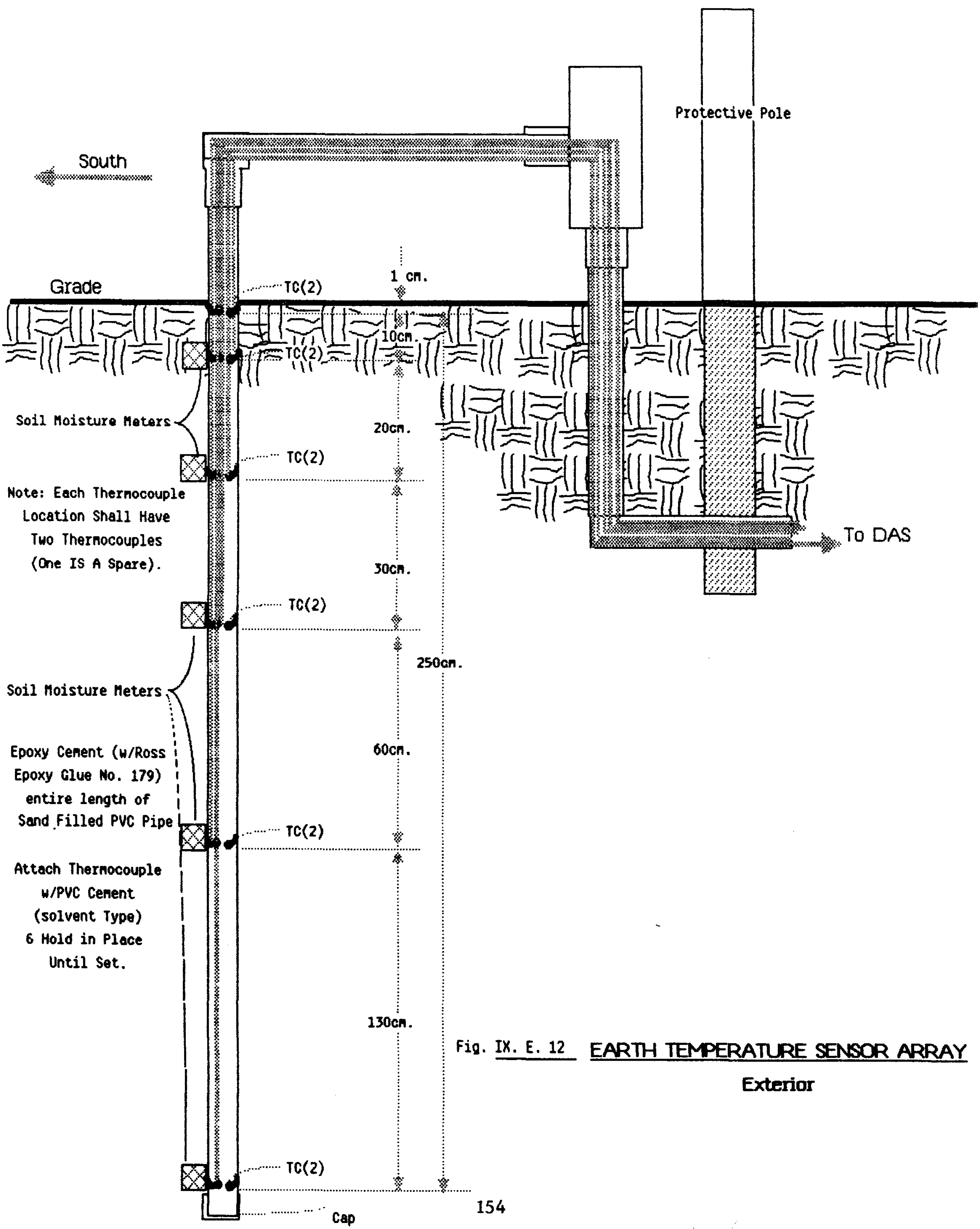


Fig. IX. E. 12 **EARTH TEMPERATURE SENSOR ARRAY**

Exterior

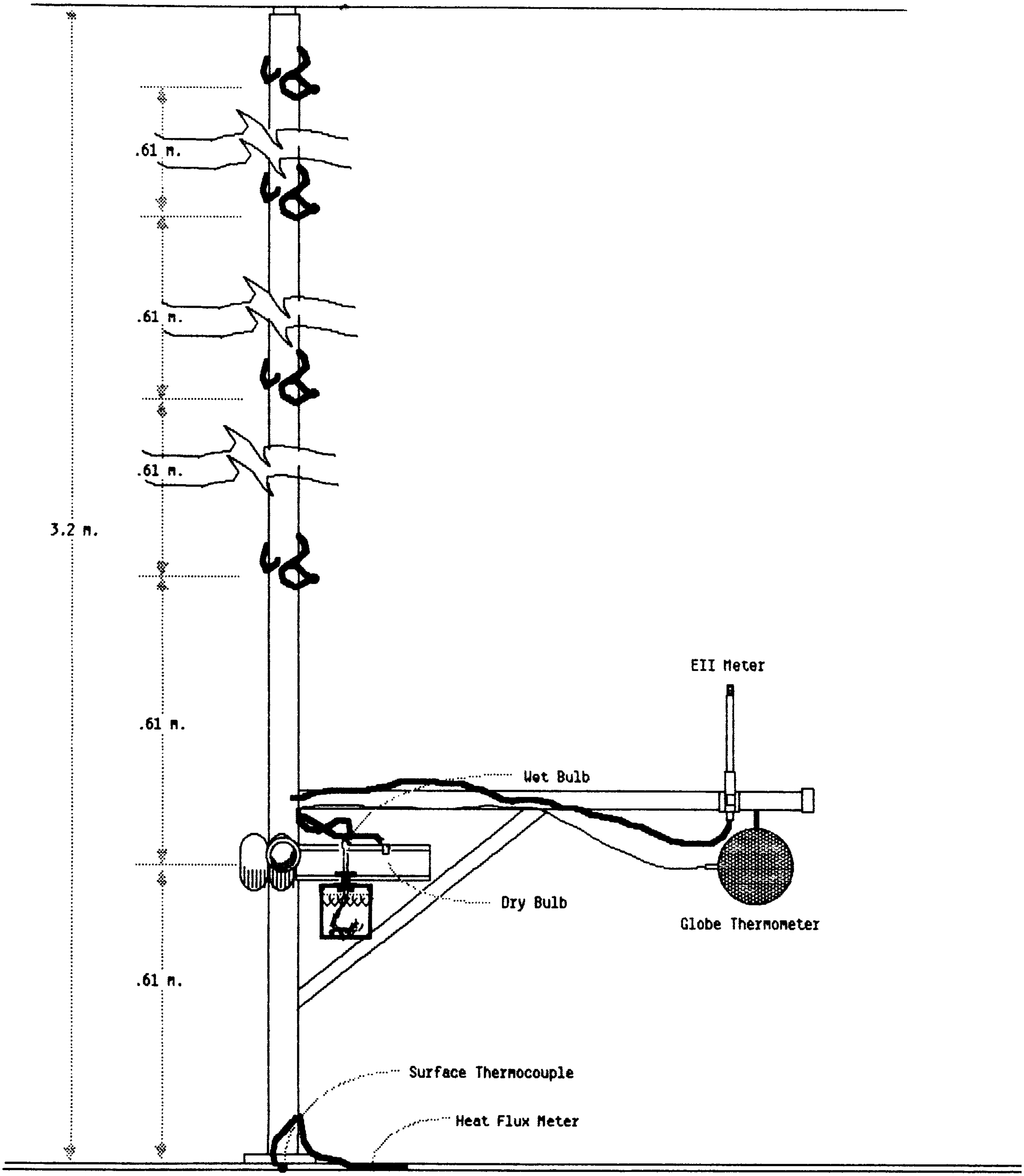


Fig. IX. E. 13 Comfort Sensing Station with EII Meter

1 Wet Bulb Temperature (0.61 m above finished floor)

1 Globe Thermometer (0.61 m above finished floor)

1 Air Velocity Sensor (0.61 m above finished floor)

b. Four floor to ceiling comfort stations without air velocity measurement will be located per the plan. See Figure IX.E.14 for details of the Comfort Sensing Stations (CSS).

Each of these stations will measure:

5 Dry Bulb Temperature (0.61 m increments)

1 Wet Bulb Temperature (0.61 m above finished floor)

1 Globe Thermometer (0.61 m above finished floor)

c. Two single point CSS stations with air velocity measurements will be located on the roof terrace as per the plan (see Figure IX.E.15 for details).

Each of these stations will measure:

1 Dry Bulb Temperature (0.61 m above finished floor)

1 Wet Bulb Temperature (0.61 m above finished floor)

d. Three ERL aspirated wet/dry bulb stations will be installed at three locations in the stairwell. At one location on the stairwell air velocity will be measured.

e. The Globe thermometer and the naturally aspirated dry bulb temperature sensing stations details can be found on Figure IX.E.16.

3. Building Shell Heat Flow and Thermocouple Sensors

At 34 different locations throughout the building instrumentated concrete blocks would need to be installed, these block sets (1- 100 mm and 1- 200 mm) will be pre-wired by KFU and ERL and supplied to the contractor at the time it is required. Approximately one hour additional time would be required per block for installation. Each instrumentated wall element will consist of an exterior surface thermocouple, thermocouples every 2 inches through the wall, interior surface thermocouple, naturally aspirated thermocouple and a heat flux meter.

a. Mass wall heat flow plates and thermocouple rakes

i. Eighteen instrumentated wall segments containing 9 thermocouples and one heat flux sensor will be installed in the walls as indicated in Figures IX.E.3 - IX.E.5. These elements will be installed in the lower part of the

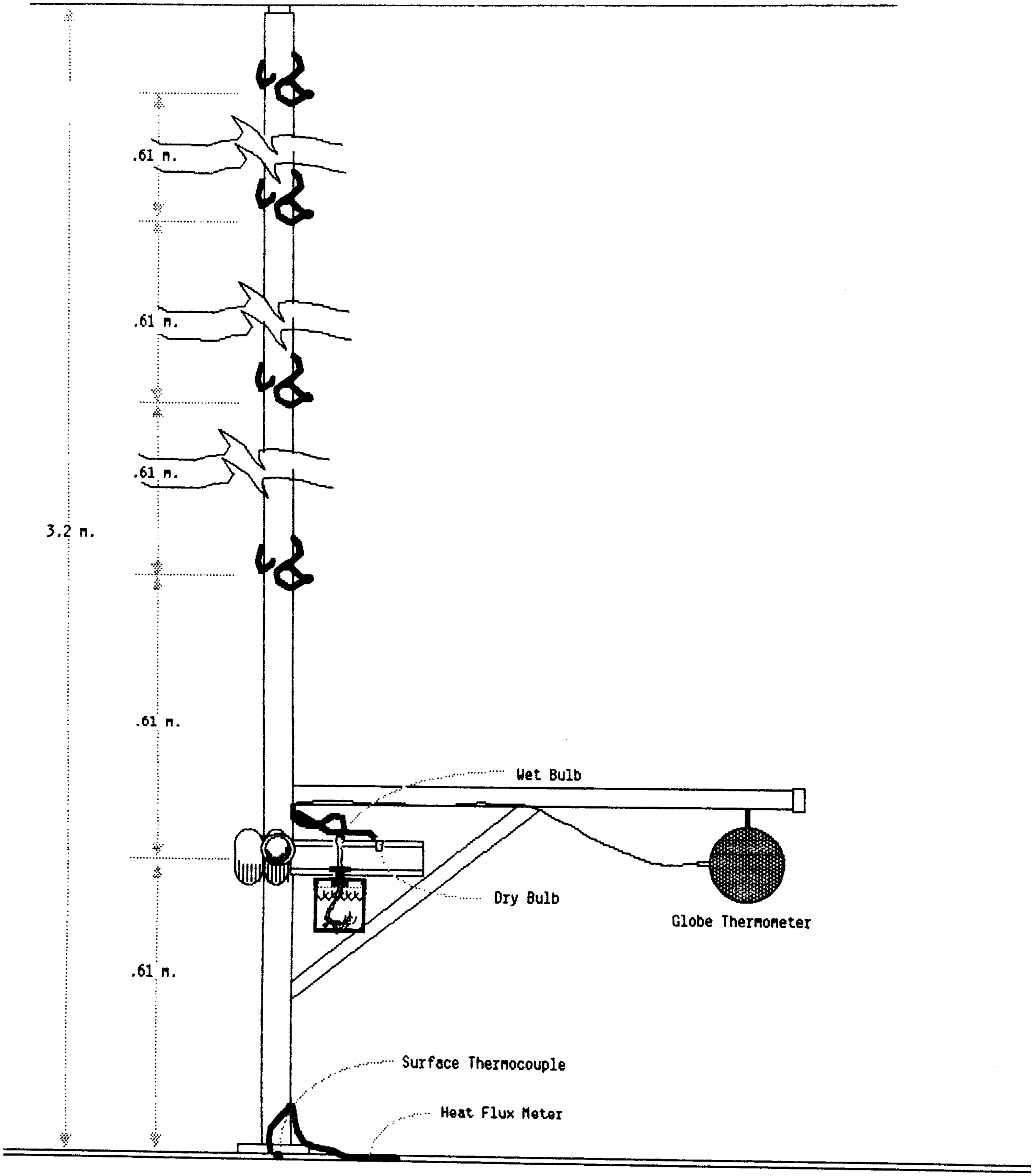


Fig. IX. E. 14 Comfort Sensing Station without EII Meter

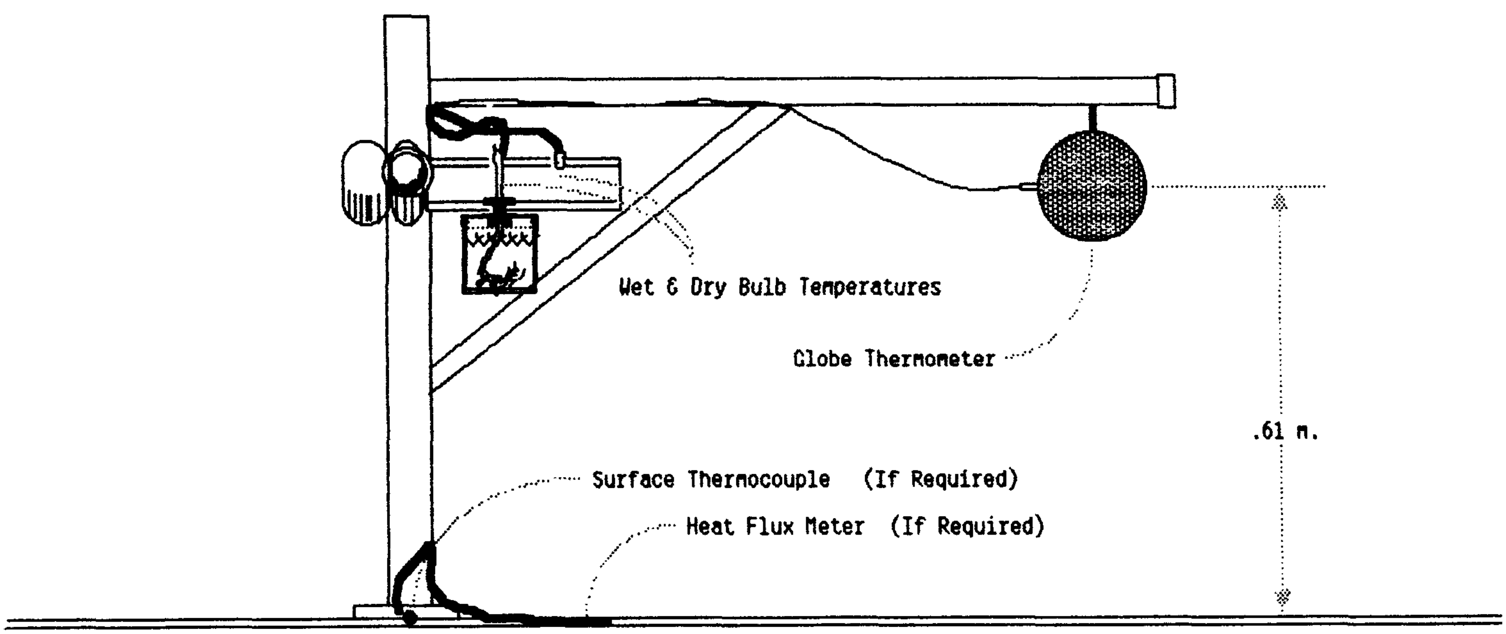
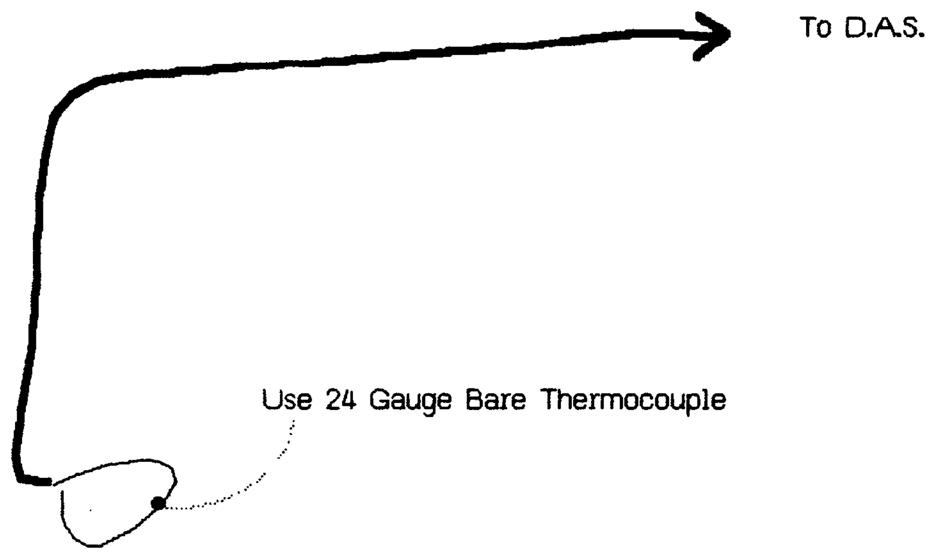


Fig. IX. E. 15 Single Point Comfort Sensing Station



Dry Bulb Temperature Station, Naturally Aspirated

Use on floor to ceiling comfort stations, and adjacent to all heat flux meters.

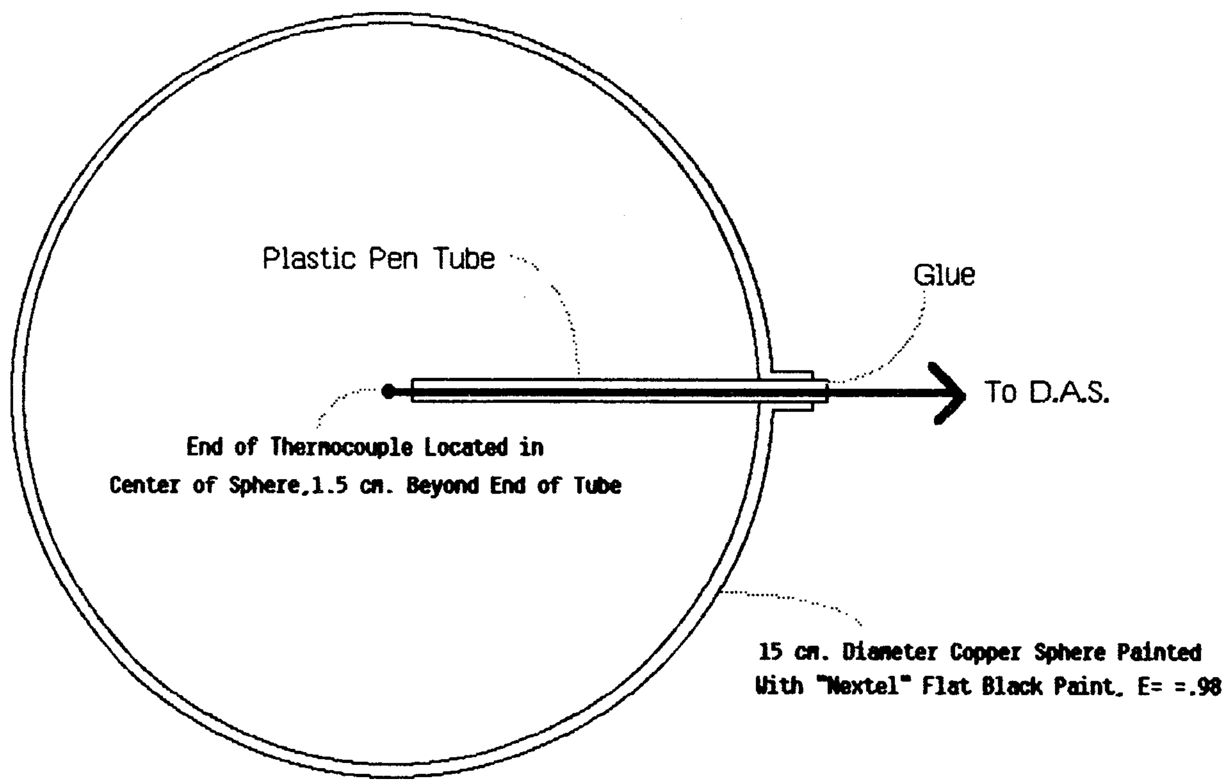


Fig. IX. E. 16 GlobeThermometer

wall at approximately 0.61 m above finished floor (see Figure IX.E.17 for details of the wall elements). The thermocouples will be installed in the webs of the block.

ii. Sixteen instrumentated wall segments containing 7 thermocouples will be installed in the walls as indicated in Figures IX.E.3 - IX.E.5. These elements will be installed in the upper part of the wall at approximately 2 m above finished floor (see Figure IX.E.18 for details of the wall elements). The thermocouples will be installed in the hollow cores of the block.

Figure IX.E.19 illustrates the typical heat flux installation and Figure IX.E.20 illustrates the typical surface thermocouple installation.

b. Floor and ceiling surface temperature sensors with heat flux meters and adjacent temperature sensors.

At twelve CSS loctions as indicted in figures IX.E.3 - IX.E.5 heat flux meters will be installed on the floor surface (see Figure IX.E.10 for details) in addition surface mounted thermocouples will be installed on both floor and ceiling at these locations (see Figure IX.E.20 for installation details).

4. Earth Temperature Thermocouples

Two vertical earth arrays as shown on Figure IX.E.3 below the Comfort Sensing Stations on the ground floor (see Figure IX.E.21 for details).

At 2 locations in the building (ground level) earth probes will be installed. The probes will require a hole to be drilled to a depth of 244cm and a pre-fabricated thermocouple probe installed and then backfilled. The wires should be brought to the surface and extend through the concrete slab.

These sensors will be installed by KFU and ERL staff and will not require any time from the contractor. The sensors will be placed prior to pouring concrete and just after the forms are set.

5. Window Insolation

Sixteen Li-Cor pyranometers will be installed in the center of the windows as indicated on Figures IX.E.3 thru IX.E.4. One Li-Cor will be installed in the plane of the window outside the window, facing outside, and the other will be installed inside. The mounting hardware will be configured so as to cast a minimal shadow (see Figure IX.E.22 for mounting details).

6. Coolth Output

a. Evaporative cooling, ventilation

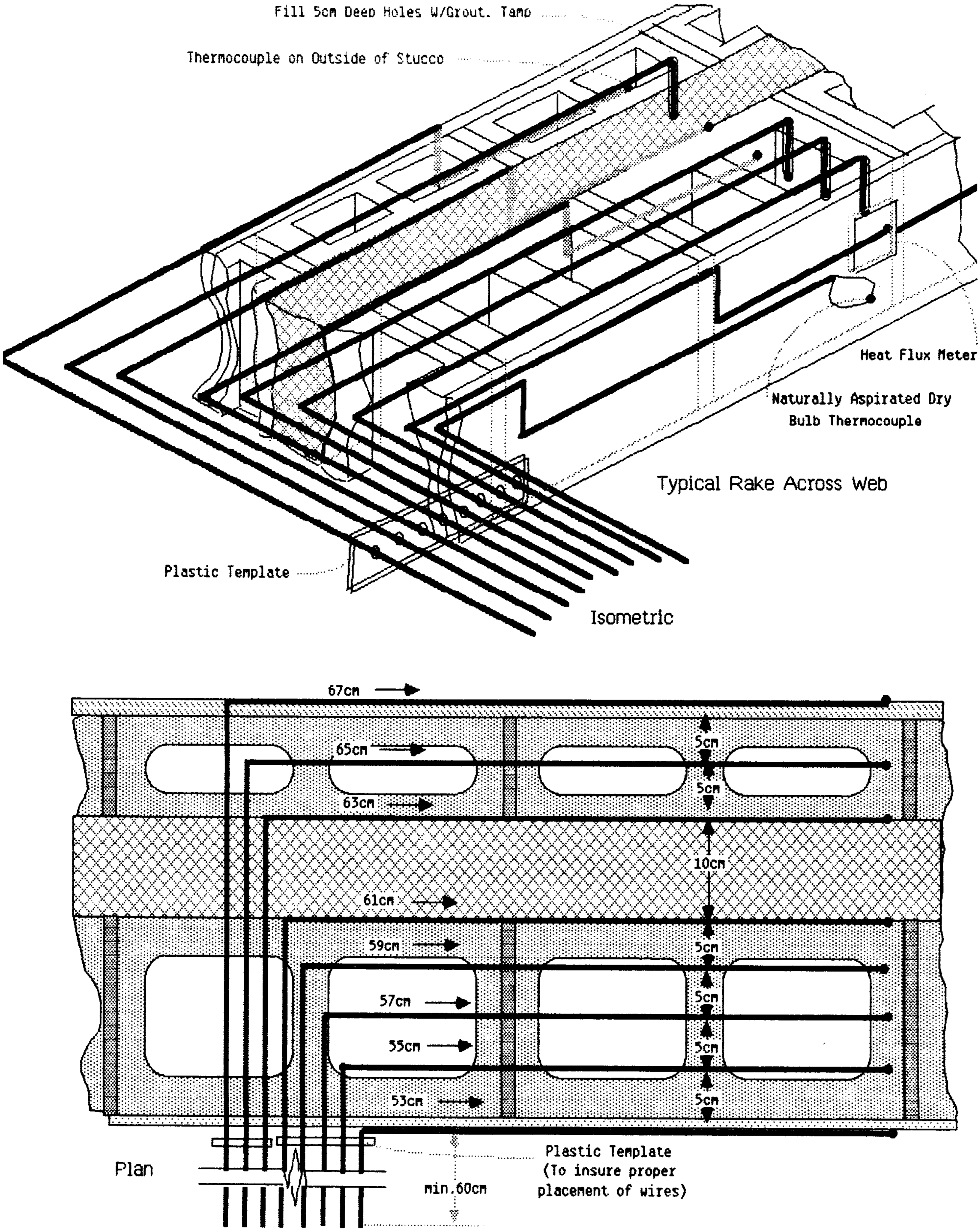


Fig. IX. E. 17 Thermocouple Rake Exterior Wall -Thru Web

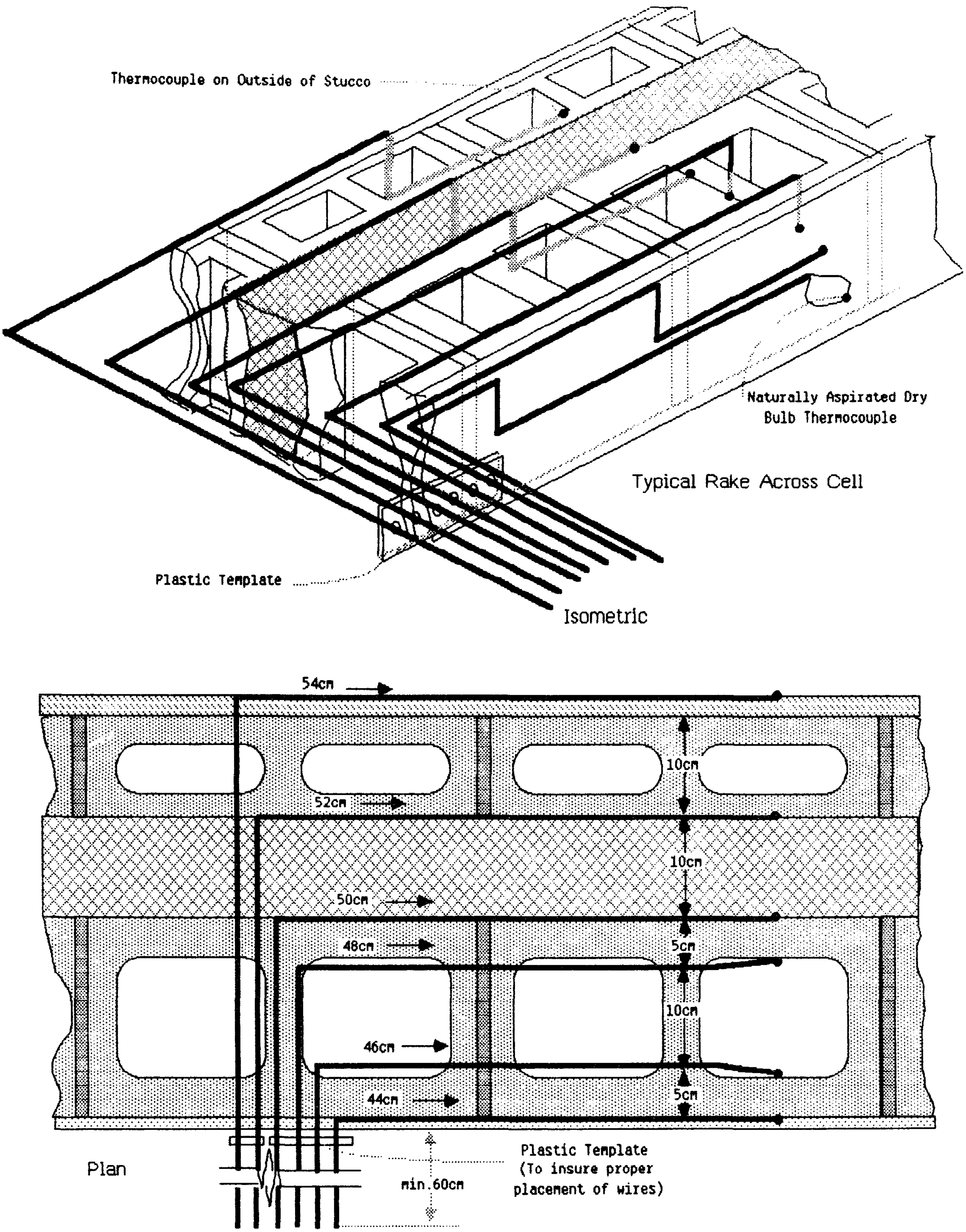


Fig. IX. E. 18 Thermocouple Rake Exterior Wall -Thru Cell

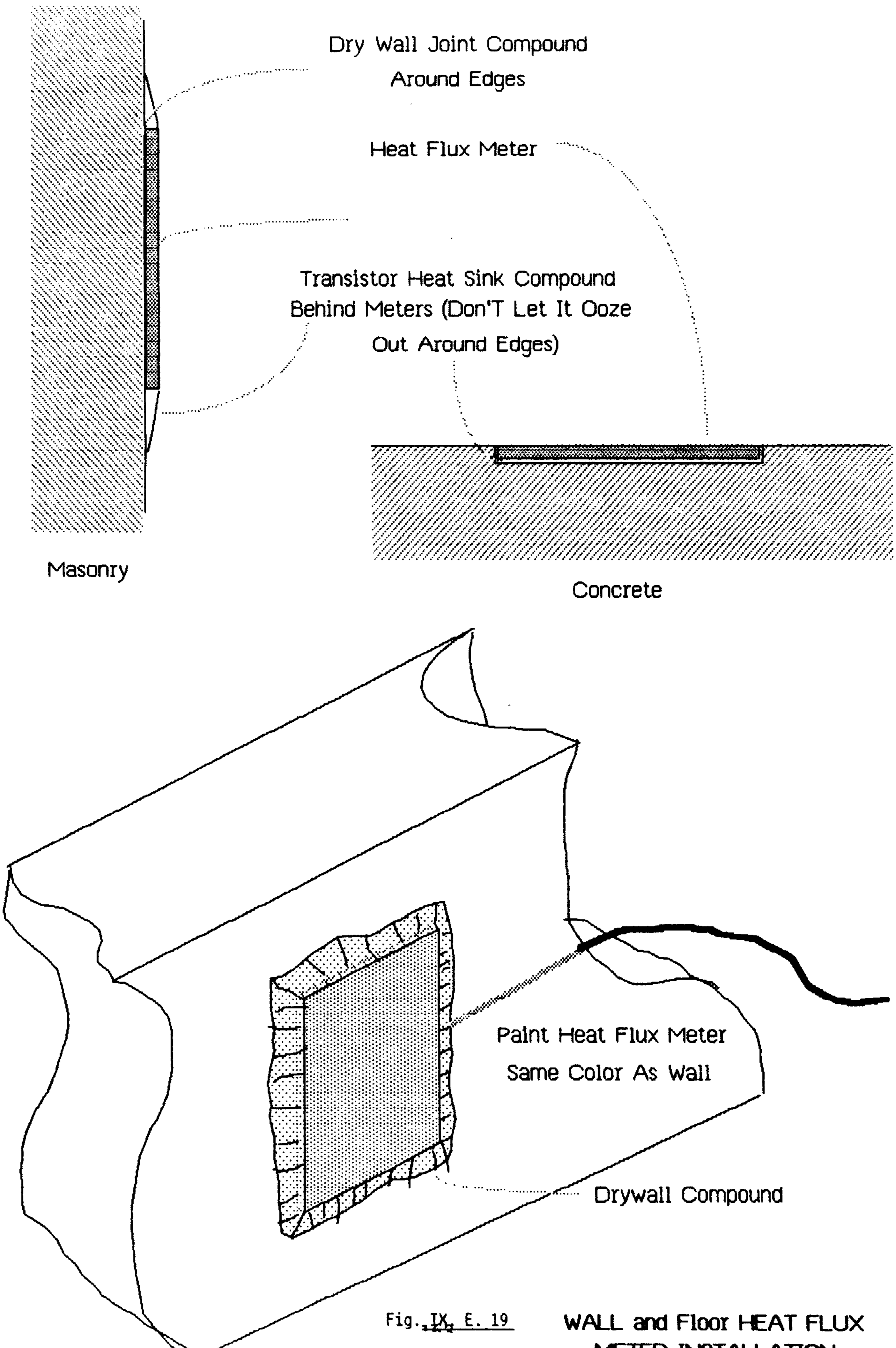
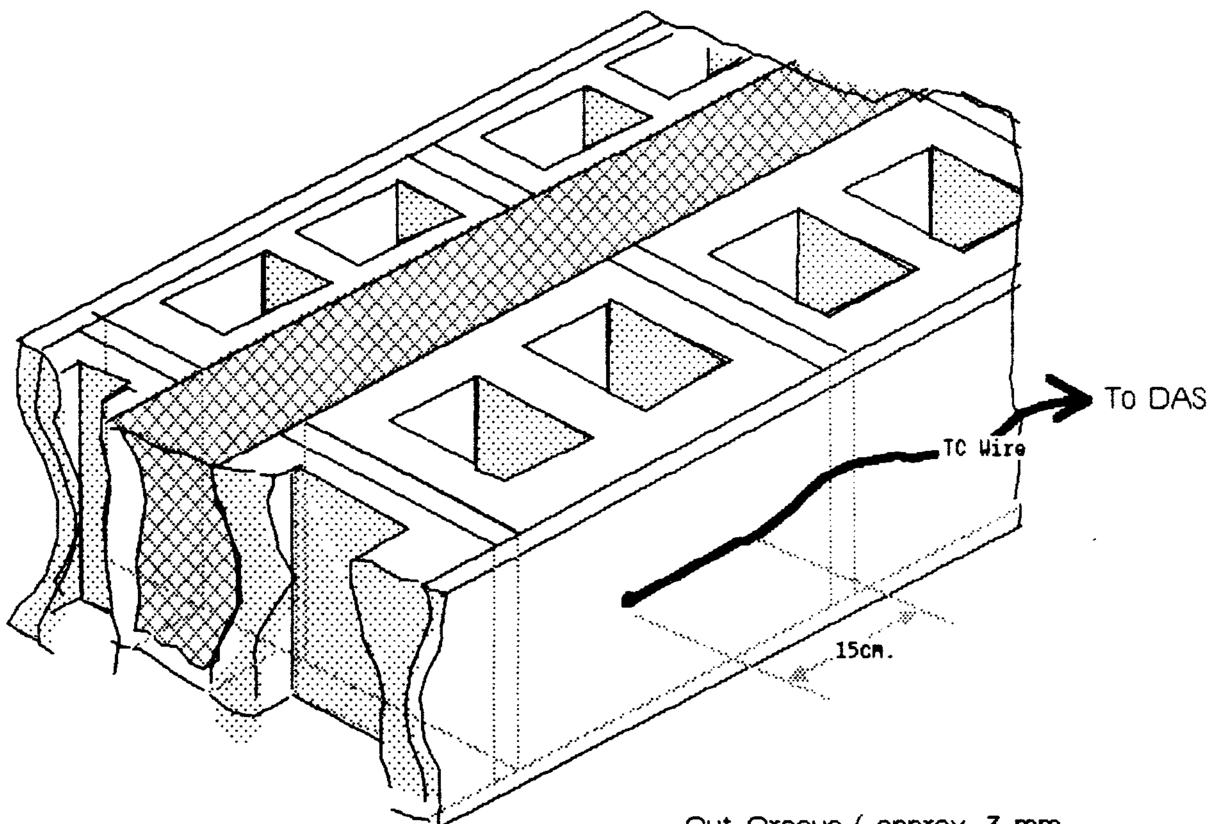


Fig. IX. E. 19 WALL and Floor HEAT FLUX METER INSTALLATION



Cut Groove (approx. 3 mm
Deep) in Masonery, Cement
In Thermocouple & Wire
Using a Portland Cement-Acrylic
Glue Mixture. Paint the Same Color
as Wall. Locate Over Block Core.

Fig. IX. E. 20 **Surface Temperature Thermocouple Installation**

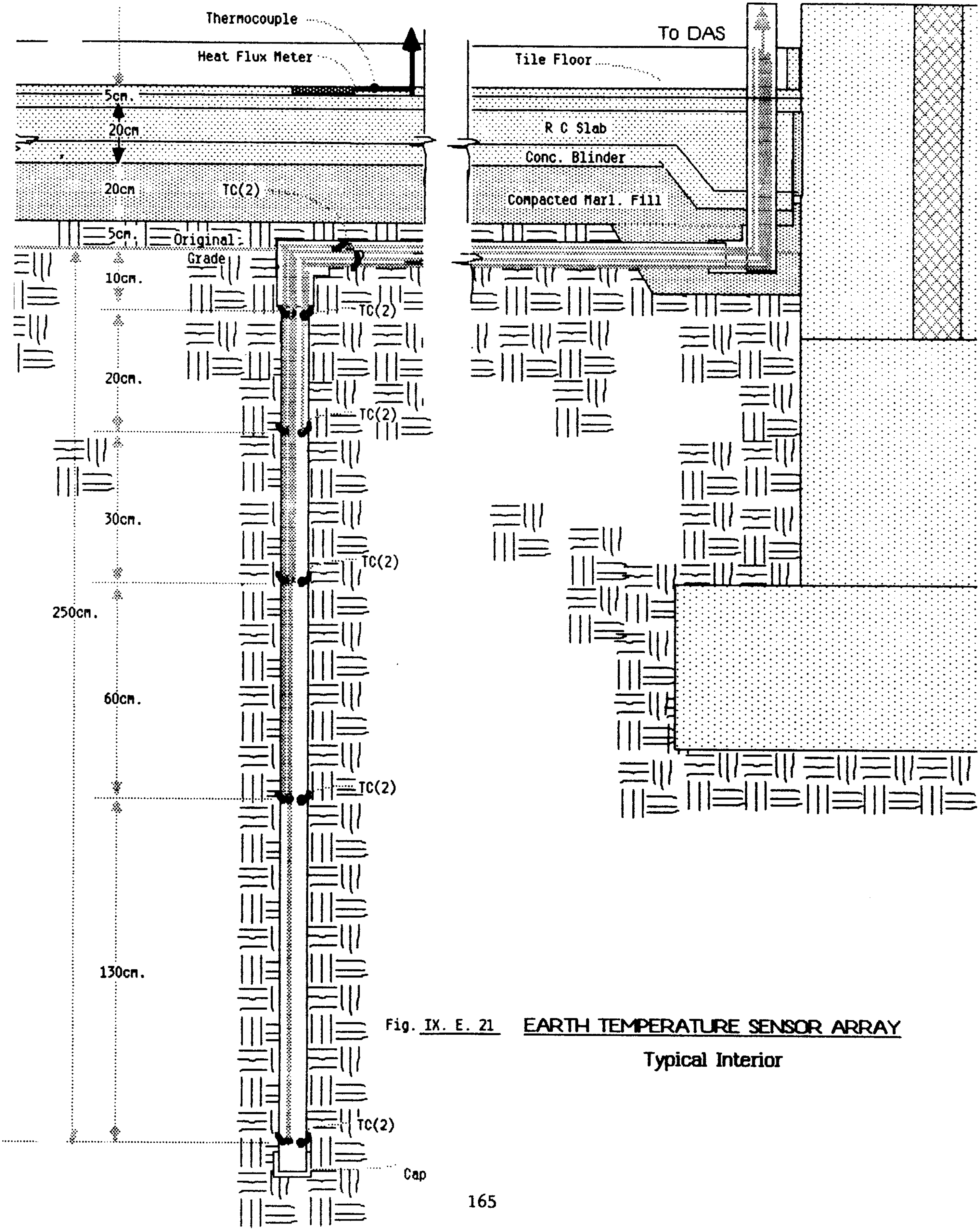
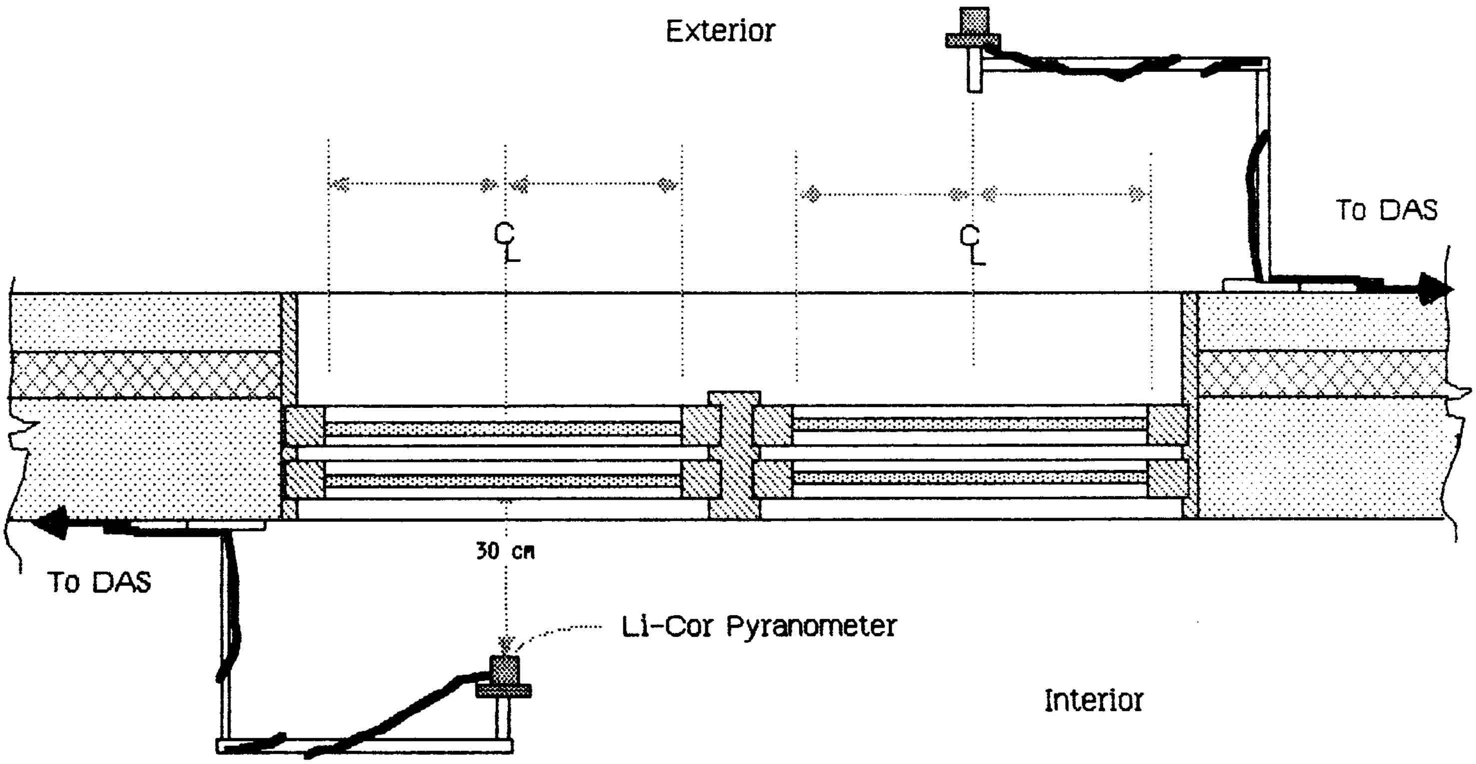


Fig. IX. E. 21 **EARTH TEMPERATURE SENSOR ARRAY**

Typical Interior



PLAN SECTION

Note: Locate Pyranometer 30 cm. From Glass and at the Mid-Point of A Single Pane Of Glass.

Fig. IX. E. 22 TYPICAL LI-COR PYRANOMETER INSTALLATION

The dry and wet bulb temperature of air leaving the evaporative cooling tower will be measured utilizing ERL aspirated temperature stations. The air velocity will also be measured at these points. Eight air velocity measurement points will be actively sampled and six temperature points as detailed in Figures IX.E.3 - IX.E.5. Air velocity measurements will be taken by semi-portable EII air velocity sensors as required by the experimental plan. Eight sensors are required for these experiments. These eight sensors will be relocated from the tower inlets and comfort sensing stations that are not part of the experiment. A total of 17 EII air velocity sensors are required.

b. Refrigerated air

During periods of AC use the supply and return air wet and dry bulb temperatures from each fan coil unit will be measured with ERL aspirated temperature stations. These sensors will be moved from their location at the wind tower inlets to the fan coil units.

Typical air flows will be measured and entered into the DAS.

7. Electrical Power Usage

a. Watt-hour meters

Watt-hour meters will be installed on every major power draw, such as AC units, pumps and fans. Individual totalizing watt-hour meters will be installed on each AC condenser unit and on the domestic water pump.

b. Watt transducers

For remote access and integration into the overall data base remote watt transducers will be installed on the AC condensers and will be integrated into the DAS (see Appendix IX for details).

8. Water Usage

The water used to operate each mode of cooling using water will be measured with a Recorall #15 totalizing flow meter, read manually and entered into the DAS. The water usage will be for the evaporative cooling tower mode, both with Celdek and spray system.

9. Miscellaneous Measurements

a. Solar Domestic Hot Water System Performance

Eight thermocouples to be installed on the hot water system piping per Figure IX.E.23. These sensors will be clamped to the pipe.

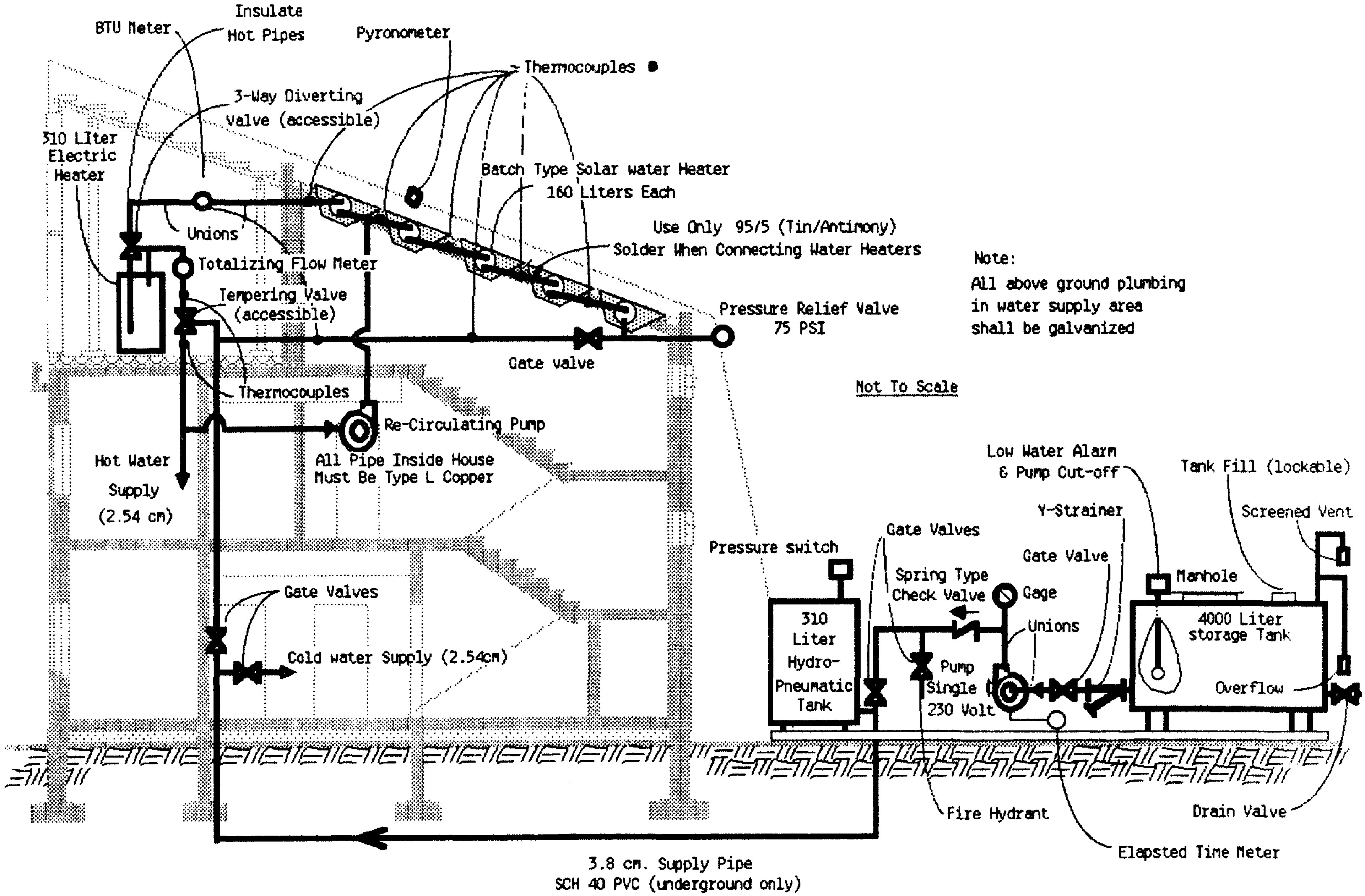


Fig. IX. E. 23 PASSIVE SOLAR DOMESTIC WATER SYSTEM

b. BTU Meter

One BTU meter (Appendix IX) will be installed in the hot water line of the solar collectors.

10. Wiring Chases

In order to route the sensor wiring to the data room 8 cm conduit chases need to be installed at ceiling height connecting the rooms together see Figure IX.E.24 for details. A vertical wire chase will need to be installed connecting the ground floor to the first floor. This chase can be located in the ground floor bathroom. The chase should be 20cm diameter conduit (see Fig. lX.E.24). A 20 cm wire chase will need to be installed connecting the garage to the ground floor bathroom at ceiling height. All the wiring will be routed at ceiling height or in the drop ceiling where possible. A 20 cm wire chase will need to be routed from the ground floor bathroom to the closet ceiling on the first floor (see fig. 19j). Wire chases will be terminated with a panel box as indicated on the drawings.

An 8 cm conduit will need to be installed on the roof of the main house. This will provide a wiring chase for the wires from the solar instruments which will be mounted on the roof. This should be installed by the contractor. See Figures IX.E.3 - IX.E.5 for the location of the solar sensors.

Wind speed and direction sensors will be intalled on a tower on the North side of the building, a 5 cm conduit will need to be installed connecting the sensors to the data room/garage. The conduit should be buried. See Figure IX.E.2 for the location of the wind sensor tower.

11. Power Requirements

The data system will require 115/120 VAC single phase power. At least a 30 amp branch circuit is required with a GFI. In addition the entire building should be positively grounded with a lighting arrestor. At positions indicated on figures IX.E.3 - IX.E.5, ceiling height 115/120 VAC duplex outlets will need to be mounted.

F. CALIBRATION OF INSTRUMENTS

1. Ambient Weather Instruments

a. Dry and wet bulb temperature. These temperatures will be checked periodically with a mercury thermometer calibrated with a calorimeter thermometer accurate to .2°F.

b. The Eppley PIR pyrgeometer used as the basis for calculating the effective sky radiation temperature will be calibrated each year by Eppley Laboratories, in accordance with their specifications.

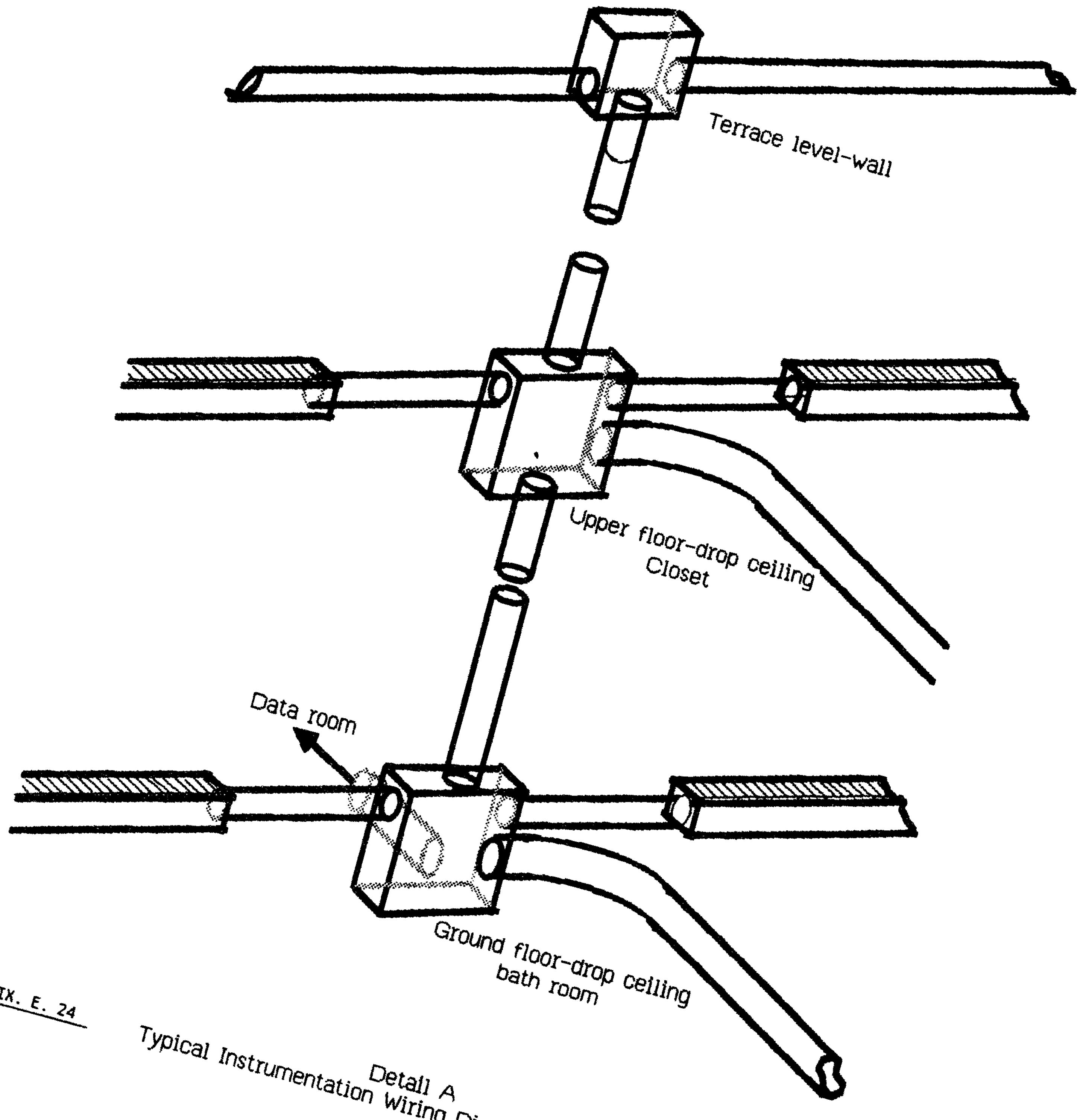


Fig. IX. E. 24

Detail A
Typical Instrumentation Wiring Distributation detail

c. The Eppley PSP pyranometer will be calibrated by Eppley Laboratories each year.

d. The wind velocity measuring instruments will be checked periodically against an EII anemometer calibrated by EII.

   The wind direction will be checked periodically with a compass, corrected for the magnetic declination.

e. Two thermocouples will be used at each point to measure earth temperatures. One set will be connected to the data logger. Once a month, the earth temperature at each point will be checked with the other set of thermocouples, using a portable millivolt meter.

2. Comfort Station Instruments

   a. The wet and dry bulb temperatures will be checked weekly as in section IV A-1.

   b. A globe thermometer with a mercury bulb thermometer calibrated against a calorimeter thermometer will be used to check each globe thermometer periodically.

   c. An Environmental Instruments Inc. (EII) anemometer used to measure fan driven air velocities will be calibrated annually by the factory.

      Single range EII meters used to measure natural draft air velocities will be checked periodically against the multirange EII anemometer mentioned above.

3. Heat Flow Measurements

   a. Heat flux meters will be calibrated by the factory. On a frequent basis standard heat flux meters used only for calibration and painted the same color as the wall will be thermally connected to the wall with transistor heat sink compound and compared with the heat flux meter permanently affixed to the wall.

   b. Dual thermocouples will be installed at each wall location, and the spare set checked monthly against the set used for data logging.

   c. The LiCor pyranometer in each window will be compared periodically to an identical sensor used for error detection only.

4. Wind Instruments

5. Cooling Effectiveness Measuring Instruments

   The airflow measuring instruments and the thermocouples will be checked as described previously.

6. The watt transducers will be checked against the installed watt-hour meters.

G. DATA ACQUISITION SYSTEM SPECIFICATION

1. Computers for Data Acquisition System:

The system consists of three computers, one unit is used to collect the data and control the home based on this data. The second unit is used to analyze the data, format it for archival storage, and develop analytical models. The final unit is located in a public demonstration area and is used to display information for visitors.

The data collection and control computer and the analysis computer are set up exactly the same so that if the controlling computer fails for hardware reasons, the analysis unit can be exchanged. The data acquisition is set up to use the RS-232 serial communications to allow the sytem to switch from one to the other. (See Appendix IX for manufacturers' specifications)

a. COMPUTERS: Data collection/control and analysis

Qty	Description
2	IBM XT PC Mainframe with 10 megabyte hard disk, 256K memory, keyboard, IBM disk drive controller, 2 1/2 height drives.
2	IBM graphics card
2	AST Megaplus I/O card: 2 serial ports, printer port 256K RAM, clock
2	IBM Cluster terminal controller card
2	Software
1	Cable
2	Amdek Model 300A amber monitor and cables
2	OKIDATA u92 printer and cable spare print ribbons, box of paper
1	IBM SNA communications package, synchronous serial card and support software
2	Tape drive system for backup and media transfer of data TALLGRASS or equiv. 10 megabyte tape system (1 unit to be located at ERL-UofA site)

b. COMPUTER: Demonstration:

Qty	Description
1	IBM PC with 256K RAM, 2 disk drives
1	IBM graphics card
1	AST Megaplus I/O card: 2 serial ports, printer
1	IBM Cluster terminal controller card
1	Software
1	Cable
1	IBM Color monitor and cable

c. COMPUTERS: Software

Qty	Description
3	DOS 2.11 Operating system
3	IBM BASIC Programming language IBM Compiled BASIC
3	FORTRAN Compiler

d. MISCELLANEOUS:

Qty	Description
1	Line conditioner system 2000 VA unit, SOLA or equivalent.

2. Data Acquisition System

The data acquisition system is based on a Hewlet Packard HP-3497A system. This system contains a 5-1/2 digit voltmeter and an intelligent controller system. A series of input/output cards are added to support mv inputs, thermocouples, digital inputs and digital outputs.

a. DAS:

Qty	Description	
1	3497A Mainframe	
1	3497A DVM	
1	Option 232	RS-232 I/O
	Option 231	Time
	Option 316	120 VAC, 60 HZ
	Option 910	Documentation
3	Option 298	3498A Epander box and cable
4	Option 908	Rack mounting kit
25	Option 020	20 Thermocouple Input Relay multiplexor
7	Option 010	20 Relay multiplexor
2	Option 110	16 Channel digital output
1	Option 050	16 Channel digital input
1	50 HZ crystal to install in DVM to convert to 50 HZ power. Part #0410-1225	

b. EQUIPMENT CABINET: Accent Vertical Cabinet - Scientific Atlanta OPTIMA Division

Qty	Description	
1	A2-701930 Double bay cabinet module, double wide rack, 75 inches tall, 30 inches deep. Includes top, bases, two exterior side panels, front decorative trim	
	Color: Black bezel and base, Light charcoal panels, top panel, corner members	
5	P-7	7" panel
2	P-10	10" panel
1	P-17	17" panel
1	P-24	24" panel
	Color: All panels are white	
2	R-081930	Drawer units
2	HW-68	Leveling feet
6	SA-30	Support Angels
1	PO-0848	Power outlet strip

c. MISCELLANEOUS:

Qty	Description
4	Panels to mount female thermocouple jacks. Omega 19" Jack panel #19MJP-4-120-T (Copper-constantan)
2	Panels to mount female millivolt jacks. Omega 19" Jack panel #19MJP-3-90-U (Copper)
1	Panels to mount female millivolt jacks. Omega 19" Jack panel #19MJP-2-60-U (Copper)
1	Panels to mount female millivolt jacks. Omega 19" Jack panel #19MJP-2-32-K (Chromel-Alumel)
480	Omega Type T Miniature Panel Jacks (to be mounted in above panels) MPJ-T-F
150	Omega Type U Miniature Panel Jacks (to be mounted in above panels) MPJ-U-F
32	Omega Type K Miniature Panel Jacks (to be mounted in above panels) MPJ-K-F
40	Omega Type T Miniature Panel Jacks - spares
40	Omega Type U Miniature Panel Jacks - spares
10	Omega Type K Miniature Panel Jacks - spares
600	Omega Type T Miniature Plug - NMP-T-M
225	Omega Type U Miniature Plug - NMP-U-M
40	Omega Type K Miniature Plug - NMP-K-M
20	Omega Type T Miniature connectors - pair (MF) NMP-T-MF
10	Omega Type U Miniature connectors - pair (MF) NMP-U-MF
5	Omega Type K Miniature connectors - pair (MF) NMP-K-MF

3. Weather Measurements:

The wind measurement equipment consists of instruments to measure wind speed and direction, temperature, atmospheric pressure, and relative humidity. The equipment is mounted on a 10m tower and requires power supplies and electronics to linearize the analog signals.

a. WIND: R.M. Young Company Wind Sensors

Qty	Description
3	Model No. 35003 Gill Propeller Vane
1	Model No. 23403 Power supply translator - three control modules (50HZ)
3	Model No. 16106 Retractable Mounting Arm - 6 ft
1	Model No. 27230 Calibrating unit - 1800 RPM
1	Model No. 17221 Vane Angle Fixture - AZ
1	Model No. 08261 Sensor mounted azimuth protractor
800ft	9 conductor AWG 20 shielded cable (R.M. Young)

b. RELATIVE HUMIDITY and BAROMETRIC PRESSURE: WEATHERtronics

Qty	Description
1	WEATHERtronics Model No. 5131 Relative Humidity Probe
1	WEATHERtronics Model No. 5139 Modular Humidity Translator and Power Supply.
1	Model No. 7155 Solid state analog output barometer
1	WEATHERtronics Model No. 1715 Signal conditioning module
400ft	9 conductor AWG 20 shielded cable

c. MISCELLANEOUS:

Qty	Description
1	WEATHERtronics Instrument Shelter Weather Service Type
1	33' Rohn Model 25G guyed tower designed for Zone B wind loading per E.I.A. Standard RS-222-C

4. Sensors and Instruments:

Several different types of sensors as detailed in previous sections will need to be installed throughout the building. The majority of these sensors are temperature measurement devices. Thermocouples were chosen to provide these measurements. It is extremely important to acquire the thermocouple wire from the same lot number so as to assure consistency of calibration.

a. TEMPERATURE MEASUREMENT: Type T Thermocouples

Qty	Description
7000ft	Omega Cat No. EXPP-T-20 Extension grade copper/constantan AWG No. 20.
2000ft	Omega Cat No. 24TX20PP 24 conductor extension copper/constantan cable AWG No. 20.
3000ft	Omega Cat No. EXTT-T-24 Extension grade copper/constantan AWG No. 24.

b. AIR VELOCITY MEASUREMENT: Environmental Instruments Inc.

Qty	Description
17	EII 300 Series Model 302 Omnidirectional Precision Air Flow Sensor.
1	AC to DC Power Supply 110/220 VAC/50/60 Hz to run 17 units

c. RADIATION MEASUREMENTS:

Qty	Description
1	Eppley Precision Pyranometer Model PSP to measure total horizontal insolation.
1	Eppley Black and White Pyranometer Model 8-48 to be used with shadowband for measurement of diffuse insolation.
1	Eppley Shadowband fixture.
1	Eppley Precision Infared Radiometer (Pyrgeometer) Model PIR.
20	Li-Cor Model 200SB Pyranometers with cal-connectors.

d. HEAT FLUX MEASUREMENT:

Qty	Description
30	HY-CAL Engineering BI-7 SENSABLE Heat Flow Transducers.

e. POWER MEASUREMENTS:

Qty	Description
5	110/220 VAC Watthour meters
5	Current Transformer - Square D 2N500
5	Rochester Instrument Systems PCE-15 Watt Transducers No. P-2-EO-C5-X1-F50-WO-ZO-A2

f. SOIL MOISTURE SENSORS:

Qty	Description
5	Soil Moisture Sensors - Soiltest MC-371 Soil Cells
5	Soiltest MC-313 Soil Cell Calibration Box

g. WATER USAGE:

Qty	Description
3	Recorall Totalizing Water Meter Model 15 Badger Water Meter Co. or equivalent.

5. Miscellaneous Hardware

Qty	Description
3	Recorall Model 15, Badger water meters
10	24VAC Switching Relay
100ft	2" PVC Pipe
20ft	1 1/2" PVC Pipe
130ft	1" PVC Pipe
13	1" PVC Caps
6	1" PVC 90x Elbow
20ft	2" Copper Pipe
20ft	1 1/2" Copper Pipe
20ft	1/2" Copper Pipe

22	Dayton 2C782 15cfm blower
250ft	16/3 SJ Wire
10	6" Copper Ball
10	Bolts 3/8" x 3"
10	Terminal Strips
13	Super Glue Tubes
13	Epoxy Glue (Ross 179)
5000ft	Belden No. 8759, 1 pair, AWG 20 shielded wire
2000ft	Belden No. 8778, 6 pair, AWG 20 shielded wire
400ft	PANDUIT Plastic Wiring Duct Cable Ties
	Solder
	Paint
	Miscellaneous hardware

6. Portable Equipment

In order to perform measurements, experiments, calibrations and checkouts independently of the installed DAS the following handheld portable instrumentation is required:

Qty	Description
1	Multimeter (HP-3468A) or equivalent Autoringing Multimeter
1	Omega Temperature Logger Model OM-202-10MP5 10 channel
1	Li-Cor Portable Pyranometer Model LI-175 or equivalent
1	EII portable Air Flow meter EII Model 310

7. Tool Kit

It is essential to have a well supplied tool kit and power tools for the laboratory. These tools will facilitate the installation of sensors, reconfiguration of experiments and repairs.

Qty	Description	
1	7 Drawer mobile tool cart (Dayton 6X310 or equivalent.	
1	24x8.5x9.5 inch portable tool box (Dayton 2W211 or equivalent.	
2	Trouble lights	
2	Flash lights	
1	Solder gun	
2	Soldering irons	
1	3/8" Electric Drill	
1	3/4 hp Electric router	
1	Electric Sabre saw	
1	Electric circular saw	
1	4 1/2" Electric grinder	
1	Portable vise	
1	7 Piece combination wrench set: 3/8 - 3/4"	
10	Gloves	
	Screw Drivers:	STUBxLength
1		3/16"x6"
1		3/16"x4"
1		1/4"x6"
1		5/16"x6"
1		3/8"x8"
	Screw Driver: Phillips	
1		#1
1		#2
1		#3

1	#4
1	STUBBY #2
2	Self Holding Screwdriver
1	Chalk Line & blue chalk
1	Level Torpedo
1	Level (24")
	Nut Drivers:
1	3/16"
1	1/4"
1	5/16"
1	11/32"
1	3/8"
1	7/16"
1	1/2"
1	Keyhole saw
1	Combination square
1	Carpenters square
3	Measuring tapes: 100' - 16' - 12'
1	Rule (6' inside read)
2	Utility knife & blades
1	Awl
1	Hacksaw & blades
2	Tubing cutters: 1/8 x 1 1/8
1	Pliers: Longnose: 6" - 4"
1	Channel Locks: 6" - 9" - 12"
1	General Purpose: 6"
1	Oblique 8" Klein D 248-8 plastic dipped
1	Lineman's
1	Needlenose
3	Aviation snips: Left, Right & Center
1	Rasp: half round
4	Files: Flat - round - square & taper

1	Center punch
2	Trimmers: 6" - 8"
2	Putty knife
2	Broad knife
1	3/8" Socket Drive
1	Drill sets: 1/16 - 1/2 & #1-60
1	1/4 - 9/32 masonry bits
1	1/4" - 1 1/2" wood bits
2	Hammers
2	Wire Brushes
1	Wire strippers
1	Hole saw set
3	Extension cords: 25' - 50' - 100'

8. DAS Computer Software

Software must be developed for the Data Acquisition System. The following software elements must be developed:

Data Collection
Data Checking
Data Archiving
Data Analysis
Graphics
Communications - Networking
Setpoint controls

This software development will require approximately 500 man-hours.

In addition a sophisticated level of software must be developed for the HVAC control experiments proposed in Chapter X. This software while as yet undefined should require at least another 200-300 man-hours.

Specific software required for data analysis as specified in the experimental plan would be in addition to the simple analysis programs of the DAS. These specialized analysis programs would be stand-alone programs geared for the solution of specific problems.

H. INSTALLATION TIMING AND PROCEDURES

It is expected that all the sensors and electronic hardware necessary for this phase will be initially set up and verified at the Environmental Research Laboratory prior to shipment to King Faisal University. This effort is covered in another document. Specialized fixtures, earth arrays, comfort sensing stations and wall thermocouple rakes will also be fabricated at ERL prior to the construction phase.

In order to assure the timely installation of the Data Acquisition System a Timing Plan needs to be developed. The following plan outlines the necessary steps and procedures required to install, check out and initialize the data system.

The DAS consists of three basic subsystems: Sensors, Multi-channel Analog/Digital Multiplexer, Computer. Each of these subsystems must be installed in a certain order.

The sensors should be installed according to the following timing plan:

1. Construction Phase

   In order to interface KFU/ERL research and technical staff with the contractor the following Construction Alert Document is provided. This alerts the contractor to the necessary sensor installation timing. (Note the time required is for actual site installation and not for the shop fabrication of the sensor fixtures or attachments.)

   During the construction phase certain activities will occur; first: the wall rake sensors will be installed into the masonry units and then the units will be installed into the building. Concurrent activities may occur.

CONSTRUCTION ALERT, SENSOR INSTALLATION

a. After site preparation, before slab poured

   Install one vertical earth array per instrument plan. (See Figure IX.H.1)

   Time required: 8 hours

b. After ground floor exterior walls are 60 cm high above finished floor

   Install 10 thermocouple rakes in the walls per instrument plan. (See Figure IX.H.2)

   Time required: 30 hours

c. After ground floor exterior walls are 180 cm high above finished floor

Install 10 thermocouple rakes in the walls per instrument plan. (See Figure IX.H.2)

Time required: 30 hours

d. After first floor exterior walls are 60 cm high above finished floor

Install 8 thermocouple rakes in the walls per instrument plan. (See Figure IX.H.2)

Time required: 24 hours

e. After first floor exterior walls are 180 cm high above finished floor

Install 8 thermocouple rakes in the walls per instrument plan. (See Figure IX.H.2)

Time required: 24 hours

f. After completion of building envelope

Install remaining sensors and wiring per instrument plan including pulling wires and installation of plastic wiring duct.

Time required: 400 hours

g. After completion of building sensor installation

Install exterior weather station sensors on 10 meter Rohn tower and in weather station enclosure, pull wires to data room.

Time required: 80 hours

2. After Construction

This phase of the installation can be performed during the final finishing stages of the building construction.

a. After sensors installed

Check out wiring

Wire equipment racks

Time required: 950 hours

(Note: Part of this time required will be for pre-wiring the equipment racks at ERL prior to shipment to KFU. In addition a preliminary wiring and system check will be performed.)

b. After DAS is wired

Install computer equipment and check out

Time required: 120 hours.

c. After DAS hardware installation

Install and check out Data Acquisition System Software (To be supplied by ERL).

Time required: 40 hours

d. After DAS software installed

Perform a complete channel verification of all sensors

Time required: 100 hours

e. After channel verification

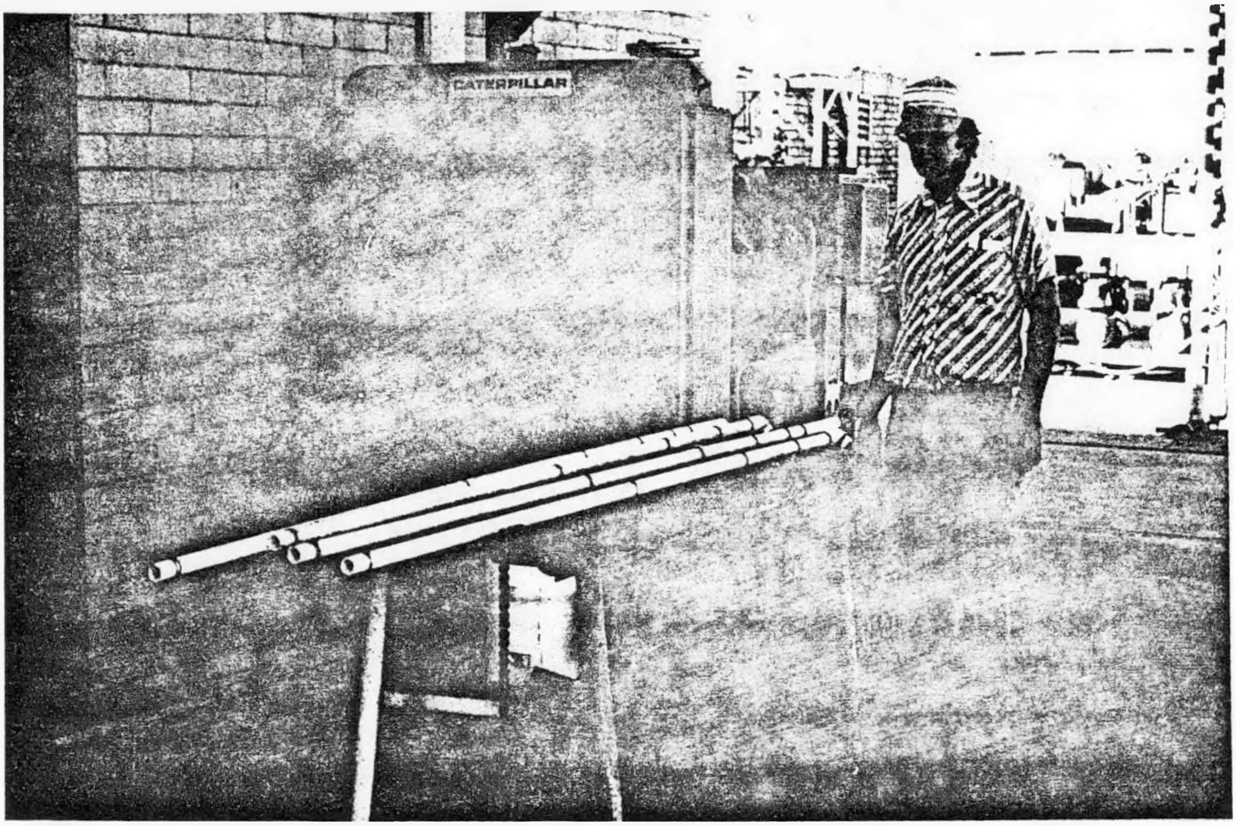
Perform insitu calibration of those sensors which can be physically accessed. (Note: prior to shipment of instrumentation from ERL to KFU all sensors will be calibrated in the laboratory.)

Time required: 200 hours

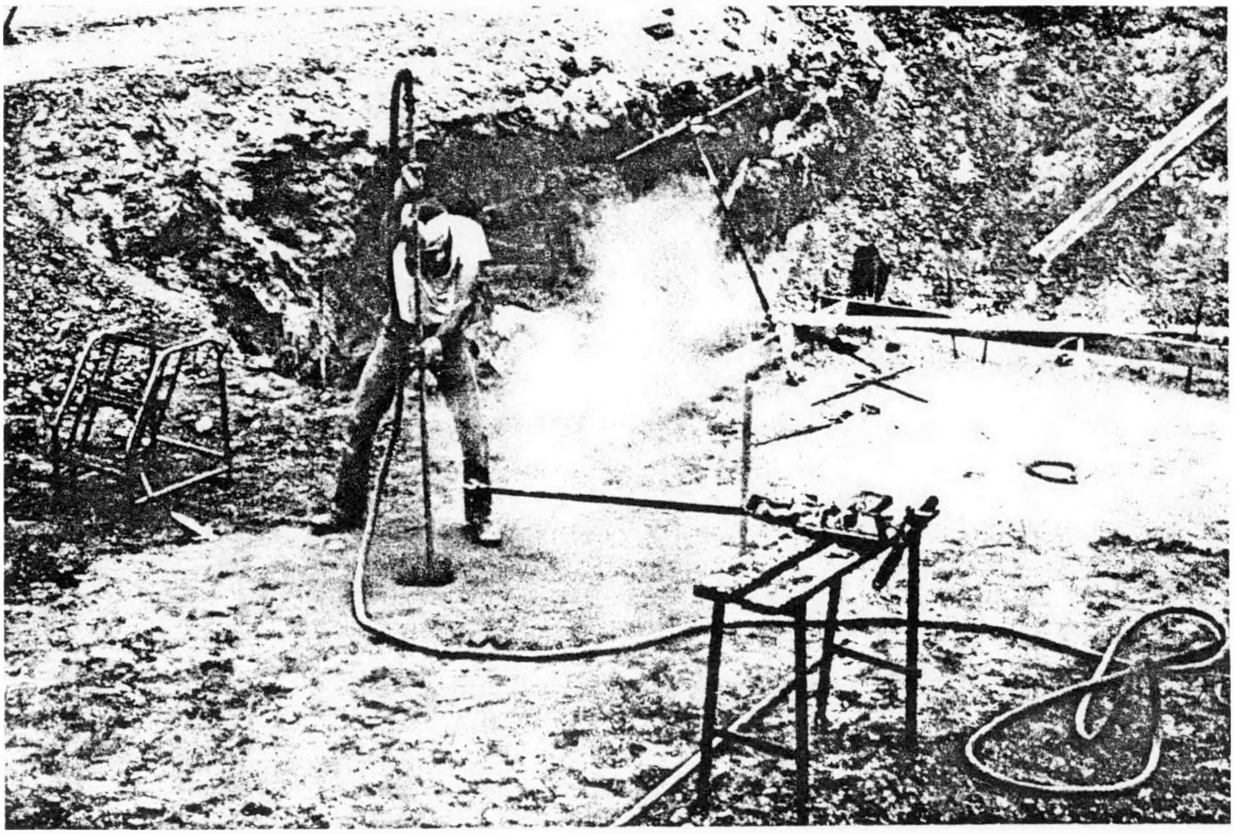
f. After calibration

System is ready for data collection.

A total of 2006 hours is required to install and check out the Data Acquisition System at KFU. This time reflects only the time required for actual installation.



Earth temperature arrays ready for installation



Digging hole for earth temperature array

X. EXPERIMENTAL PLAN

A. CRITERIA FOR PLAN DEVELOPMENT

The criteria used in development of this plan are the following:

1. The plan shall specify a schedule for testing the selected set of cooling options which permits the evaluation of the maximum number of systems during the summer season of the first year of operations.

2. The plan shall emphasize cooling options in order of their anticipated ability to produce interior comfort improvements and the likelihood that each option will be utilized in new construction and/or retrofit applications.

3. The plan shall address the ability of the proposed experiments to definitively characterize the cooling potential of each option selected for testing.

B. THE STRUCTURE

It is very difficult or even impossible to test comfort enhancement techniques such as mass, and sources of coolth such as ventilation and evaporation in just one reconfigurable structure. However, the building structure proposed will allow the performance of a large number of passive cooling techniques to be evaluated and characterized. The essential features of the structure are:

1. High-mass interior and exterior walls suitable for testing cooling techniques that can only be used at night, or that perform best at night.

2. Elevated terraces/porch to test the effect of roof deck shading and ventilations.

3. Cross-ventilation of rooms can be tested due to window shapes and size.

4. Wind tower cooling and ventilation.

5. Effects of window treatments (i.e., reflective films) be tested in controlled zones.

6. High-mass and active refrigeration system suitable for testing various thermostat control strategies.

C. CHARACTERIZING THE COOLING POTENTIAL OF EACH OPTION

The fundamental measurements made in each structure will be the variables which affect comfort, that is the dry-bulb temperature, the wet-bulb temperature, the mean radiant temperature (the globe thermometer temperature as modified by the air velocity), and the air velocity. These will be used to calculate the Fanger Predicted Mean Vote (PMV) (Appendix X) at various locations. The fraction of the time that each comfort category is attained during each test will be calculated.

The ambient weather data to be measured are the dry-bulb temperature, wet-bulb temperature, solar radiation on a horizontal plane, effective sky radiation temperature and wind velocity. Additionally, the earth temperature in an open area will be measured at various depths. These climate variables are the primary limits of the three fundamental passive sources of passive cooling available to this structure, which are:

Ventilation - Dry-bulb temperature

Nocturnal Radiation - Effective sky radiation temperature

Evaporation - Wet-bulb temperature

By comparing the principal climate variables with the comfort in the structures the upper limits of effectiveness for the various passive cooling processes can be determined.

Additionally, input temperatures, output temperatures, and airflow rates will be measured for various sources of coolth. These measurements can be used to determine the cooling output of various cooling methods.

As the weather becomes more severe during the summer, tests of the more powerful methods of passive cooling will be initiated as the comfort provided by less powerful methods deteriorates. Thus we will systematically determine the most severe climate conditions where each of the passive cooling options, including their numerous combinations and permutations with comfort enhancement techniques, will perform adequately.

These tests will also be used to verify computer models. Measuring all the heat flowing in and out of various building components will be difficult. The number of such measurements will have practical limitations, particularly in regard to windows. Heat flux plates and temperature sensors will be placed on and in main wall areas, so that heat flow, thermal capacitance, and thermal conductivity can be determined. Additionally, low cost pyranometers will be placed adjacent to typical windows to measure the insolation passing through the windows.

D. EXPERIMENTAL PLAN IMPLEMENTATION

The following section deals with the implementation of the experimental plan. In order to fully utilize the experimental facility a detailed set of experiments have been developed to evaluate and quantify the passive cooling potential of the facility. This plan encompasses not only the experiments but the timing, manpower requirements and specialized equipment needed to assure the successful outcome of each experiment. The Experimental Time Line on Figure X.D.1 gives the timing for each experiment. It is expected that the facility will be operational in June of 1985 and the first experiments will begin in June. Due to the uncertainty of SOLERAS involvement past Dec. 1985 an alternative source of funding would need to be established. The experimental plan presented assumes the possibility of some form of continued support. There are a number of experiments which would require at least two years to properly quantify the results.

Table X.D.1 presents a summary of each experiment objective and expected results. There is no significance to the experiment numbering system. Some experiments are baseline experiments which are necessary in order to characterize the building thermal envelope. These experiments are similar to those suggested by the document in Appendix X "Performance Evaluation of Passive/Hybrid Solar Heating and Cooling - System Performance Evaluation at the Class A Level".

Table X.D.2 gives the manpower required for each experiment for the operational phase and analysis phase. This manpower requirement is categorized by profession: Architect, Engineer, Computer Specialist, etc. It has been assumed that this manpower will be available as required.

As can be seen from Table X.D.2 there is a requirement for at least 1400 hours of architect time, 1700 hours of engineer time, 700 hours of computer specialist time, and 800 hours of technician time in order for this plan to work.

Table X.D.3 details the specialized equipment that is required for each experiment. This equipment is over and above the installed DAS. Most of the equipment, such as the wind tower will need to be fabricated locally.

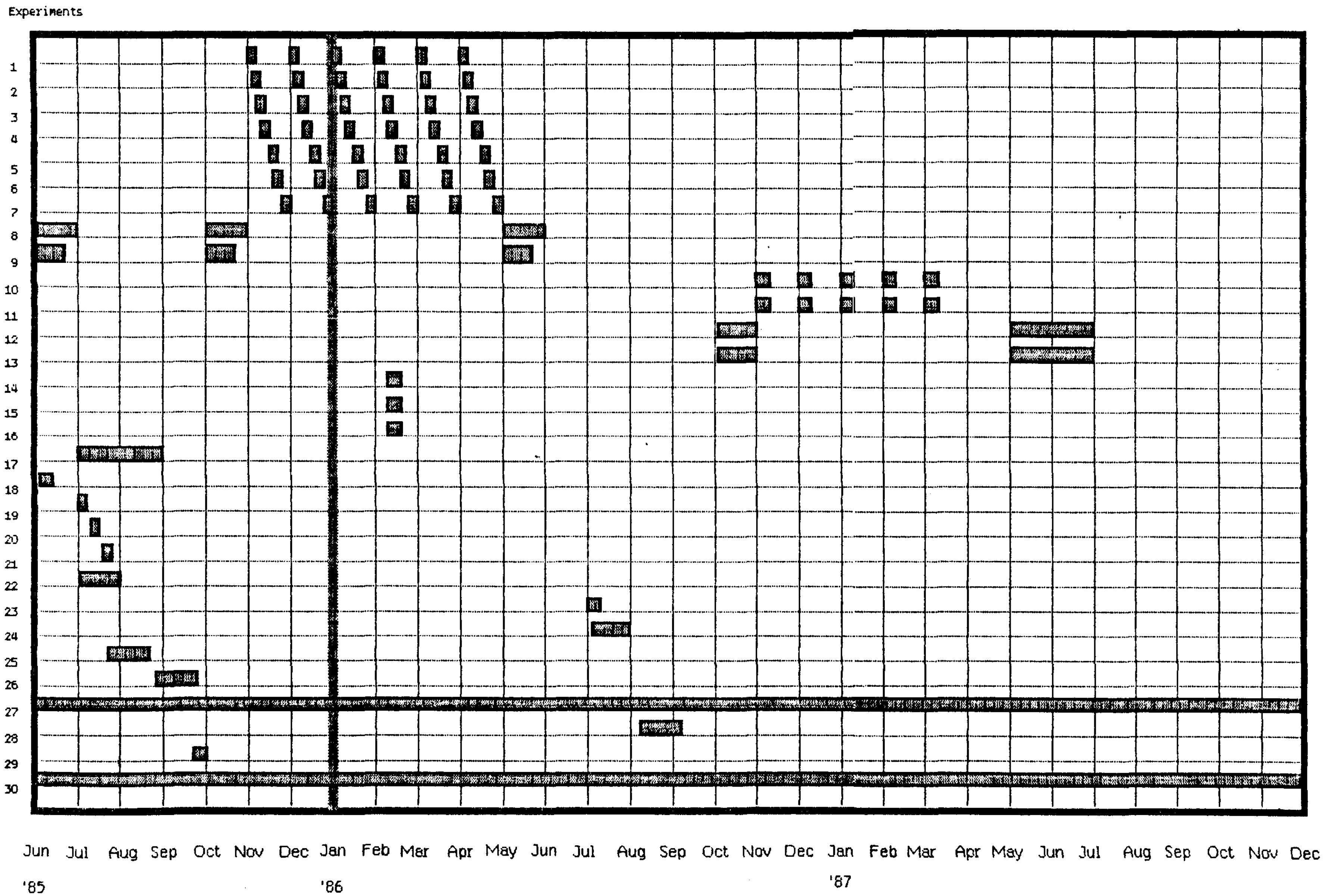


Figure X.A.1 . Experimental Plan Time Line

Table X.D.1. Summary of Experiments

Exp. No.	Description
1	RECONFIGURABLE WALLS/DRUM LOUVER TESTS: To determine the effectiveness of a drum-louver type of inlet/outlet device in directing, maintaining and controlling wind-driven cross-ventilation.
2	RECONFIGURABLE WALLS, DOUBLE-HUNG WINDOWS PLUS DEFLECTOR LOUVER TESTS: To determine the effectiveness of deflector louvers when used in conjunction with standard double-hung windows, in directing, maintaining and controlling wind-driven cross-ventilation.
3	WING-WALL TESTS: To determine the effectiveness of wing-walls in directing, maintaining and controlling wind-driven cross-ventilation.
4	CHEVRON LOUVER TESTS: To determine the effectiveness of a "chevron" louver type inlet/outlet device in creating potential wind-driven cross-ventilation through two adjacent single-orientation rooms.
5	LOUVERED TRANSOMS & DOORS TEST: To determine the effectiveness of fixed louver-transomed doorways plus louvered folding doors as inlet/outlet devices in creating potential wind-driven cross-ventilation through two adjacent single-orientation rooms.
6	WIND TOWER DUCTED-SUPPLY VENTILATION/INLET ALTERNATE #1/YEAR 1: To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.
7	WIND TOWER DIRECT-SUPPLY VENTILATION/INLET ALTERNATE #1/YEAR 1: To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.
8	WIND TOWER DUCTED-SUPPLY EVAPORATIVE COOLING MODE/INLET ALTERNATE #1/YEAR 1: To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.
9	WIND TOWER DIRECT-SUPPLY EVAPORATIVE COOLING MODE/INLET ALTERNATE #1/YEAR 1: To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.

10 WIND TOWER DUCTED-SUPPLY VENTILATION/INLET ALTERNATE #2/YEAR 2: To determine the effectiveness of a 2-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.

11 WIND TOWER DIRECT-SUPPLY VENTILATION/INLET ALTERNATE #2/YEAR 2: To determine the effectiveness of a 2-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone.

12 WIND TOWER DUCTED-SUPPLY 2-STAGE EVAPORATIVE COOLING MODE/INLET ALTERNATE #2/YEAR 2: To determine the effectiveness of a wind tower in maintaining wind-driven 2-stage evaporative cooling and thermal comfort in the occupied zone.

13 WIND TOWER DIRECT-SUPPLY 2-STAGE EVAPORATIVE COOLING MODE/INLET ALTERNATE #2/YEAR 2: To determine the effectiveness of a wind tower in maintaining wind-driven 2-stage evaporative cooling and thermal comfort in the occupied zone.

14 BUILDING LOSS COEFFICIENT: This experiment determines the Building loss coefficient. This is the building envelope transmission and infiltration loss coefficient not including the passive apertures.

15 OVERALL LOSS COEFFICIENT: This experiment determines the Overall loss coefficient (L). Simultaneously the infiltration rate should be measured (see Exp. 16)

16 AIR INFILTRATION: Measurement of the air infiltration rate utilizing a tracer gas technique (SF6).

17 BASELINE THERMAL PERFORMANCE (as built): This experiment establishes the baseline thermal performance of the building during the overheated period (i.e. air conditioning required).

18 AIR FLOW RATE MEASUREMENTS: Measure the volumetric air flow rate for discharge vents, circulation fans, appliance exhaust fans, etc..

19 PASSIVE SOLAR BATCH TYPE WATER HEATER COLLECTOR EFFICIENCY PERFORMANCE (#2): This experiment determines the Batch type water heater collector efficiency utilizing the "drain down" method.

20 PASSIVE SOLAR BATCH TYPE WATER HEATER COLLECTOR EFFICIENCY PERFORMANCE (#2): This experiment determines the Batch type water heater collector efficiency utilizing the BTU meter method.

21 ENERGY STORAGE EFFICIENCY OF THE SOLAR WATER HEATERS: To determine the 24-hour heat loss rate of the batch type solar water heating system.

22 THE EFFECT OF CHANGING THE THERMOSTAT SETPOINT ON ENERGY CONSUMPTION: The objective of the experiment is to study the effect of changing the thermostat on energy consumption of the HVAC system.

23 DUTY CYCLING OF AIR CONDITIONING EQUIPMENT, OPTIMUM START-STOP & BUILDING TIME CONSTANT: To evaluate the energy savings realized by shutting off the cooling system for 10-15 minutes every hour.

24 ROOM TEMPERATURE RESPONSE TO A SUDDEN HEAT DISTURBANCE INPUT: The objective of the experiment is to study the reaction of the control system to a sudden application of load (i.e. people, lights, etc).

25 OFF-PEAK COOLING: The objective is to compare energy requirements, energy cost, comfort levels of off-peak cooling to full-day cooling.

26 DE-RATED AIR CONDITIONING CAPACITY: The objective is to run the air conditioning equipment at a reduced capacity to determine if the cooling energy requirement will be reduced.

27 WINDOW FILMS: The objective is to compare the HVAC energy consumption of the building with and without reflective window films.

28 THE EFFECT OF COOLING THERMOSTAT HYSTERESIS ON REQUIRED COOLING ENERGY: To evaluate the cooling system energy requirements with different amounts of hysteresis on the cooling thermostat.

29 ROOM TEMPERATURE RESPONSE OF BUILDING WITH SYSTEM OFF ("FLOAT TEMPERATURE"): To determine the steady-state temperature response of the building with no cooling provided.

30 EFFECTS OF LOUVERED ROOF SHADING: To determine the effectiveness of the louvered roof shading system for both building load reduction and increased comfort of the roof terrace.

Exp No.	Manpower Requirements							
	Operations				Analysis			
	Arch	Eng	Comp	Tech	Arch	Eng	Comp	Tech
1	24	12	18	24	64	40	20	2
2	24	12	18	24	64	40	1	2
3	24	24	36	4	64	40	1	2
4	24	12	18	24	64	40	20	2
5	24	12	18	24	64	40	20	2
6	24	12	18	30	64	40	20	2
7	24	12	18	30	64	40	20	2
8	24	12	18	48	64	40	20	2
9	24	12	18	48	64	40	20	2
10	24	12	18	24	64	40	20	2
11	24	12	18	24	64	40	20	2
12	24	12	18	32	64	40	20	2
13	24	12	18	32	64	40	20	2
14	0	0	0	0	0	1	0	0
15	8	24	2	24	2	8	2	0
16	12	24	0	2	10	40	5	40
17	20	20	5	10	20	80	5	40
18	10	24	0	24	0	8	0	0
19	10	20	2	80	10	40	5	2
20	15	50	2	2	5	40	5	2
21	2	5	1	3	1	15	1	2
22	5	10	5	15	10	60	20	10
23	1	3	8	20	2	35	5	2
24	1	2	1	8	2	40	1	2
25	4	10	2	12	5	40	4	2
26	4	10	1	50	20	100	20	2
27	4	12	12	30	30	100	40	2
28	20	50	10	10	20	50	20	10
29	5	10	2	2	5	60	10	2
30	10	30	2	30	4	24	16	0
TOT	443	472	307	690	978	1261	456	106

NOTE: These times do not include preparation of final reports and other documents suitable for public disemination. In addition the above times do not reflect any significant software or model development.

Table X.D.2 Manpower Requirements

Exp No.	Qty	Specialized Equipment/Supplies
1	5	Adjustable stands (50 cm to 175 cm)
	28	Standard Revolve-O-Vent units
	8	Non-standard (16in) Revolve-O-Vent units
	3dz	one minute white smoke candles
2	6	Sets of adjustable aluminum window wind deflectors.
3-7	2	Sets of window wing walls.
8&9	30m2	CelDek Pads
	1	Fog Spray System: Candidates: Air system High Pressure Ultra Sonic
10&11	1	Alternate 2 sided wind tower
12&13	1	Two stage evaporative cooling system: Cooling Tower Low pressure drop heat exchanger (Considerable design effort required)
14-16	8	Electric heaters (1 Kwe)
		Sulfur-Hexifluride tracer gas and sample containers
	11	SF6 gas
	20	50.0 ml syringes - for injecting SF6 into building
	60	5.0 ml syringes - for taking samples
	1	Column for gas chromagraph
		Gas Chromatograph - (equipment and analysis available at ERL)
19&20	1	Drain valve
	1	20 liter graduated, insulated container
	1	Hose, 2cm x 10m
	5	Plywood/foam covers for solar collectors
23&28	1	HVAC computer control system
		Software: (considerable effort required to develope the control algorithims and integrate them into the overall DAS software.)
	600m	Control wiring
	10	Solenoids/switching relays (one per coil unit)
27	400m2	Reflective films for windows

Table X.D.3. Specialized Equipment/Supplies

DETAILED EXPERMENTS
FOR THE
KING FAISAL UNIVERSITY
PASSIVE COOLING EXPERIMENTAL FACILITY

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: 1

Start Date: ________ Time: ________ Stop Date: ________ Time: ________

Name of Experiment: Reconfigurable Walls/Drum Louver Tests

Location: G5 & U6

Duration (months, days, hours): January through April; November & December (3 days in each of 6 months)

Objectives:

To determine the effectiveness of a drum-louver (Revolv-O-Vent) type type of inlet/outlet device in directing, maintaining and controlling wind-driven cross-ventilation (air movement) within the occupied zone (approximately 45 to 180 cm. above finished floor) of a typical residential-scale double-orientation room (windows on both sides). Two different types of drum-louver configurations have been suggested, allowing a more thorough exploration of these types of devices.

Experimental Procedure (how to achieve objectives):

a. Install two different types of drum louvers (Fig. X.J.1) in the reconfigurable window walls of G5 & U6: small-scale type in the ground floor room, large-scale type in the upper floor room.

b. Close wind tower air supply inlets in G5 & U6.

c. Observe, and record photographically (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

d. Measure air velocities, at 3 different heights and at 5 different points on plan in G5 & U6, (Fig. X.J.2) with all drum louvers fully open. Measure at lowest height (53 cm.) for 24 hours; at middle height (114 cm.) for 24 hours; then at top height (175 cm.) for 24 hours. To ensure comparability of data, the same start/stop times should be used for each 24-hour period.

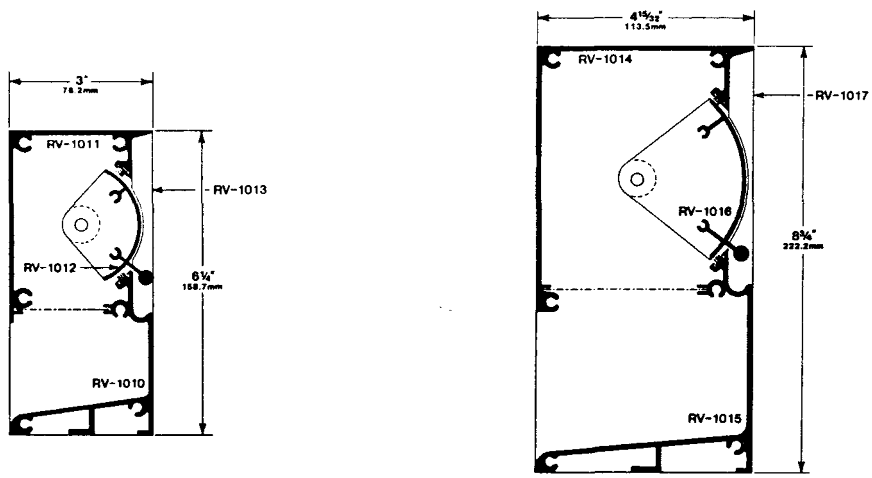
e. Make simultaneous measurements of outdoor wind speed and wind direction, together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature.

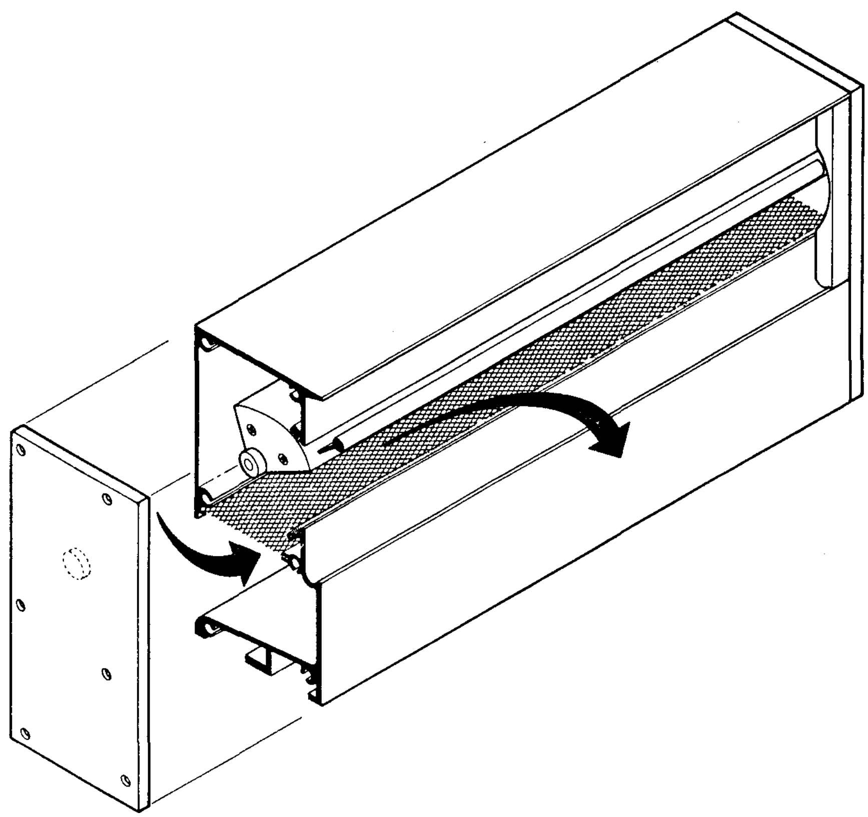
f. Reduce data to assess resulting comfort levels achieved in each room, during the "ventilation-critical" months of the year, and with the two different types of drum louvers.

g. Experiments should be run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc. Attempt to ru

REVOLV-O-VENT™

SCALE- 1/4 SIZE



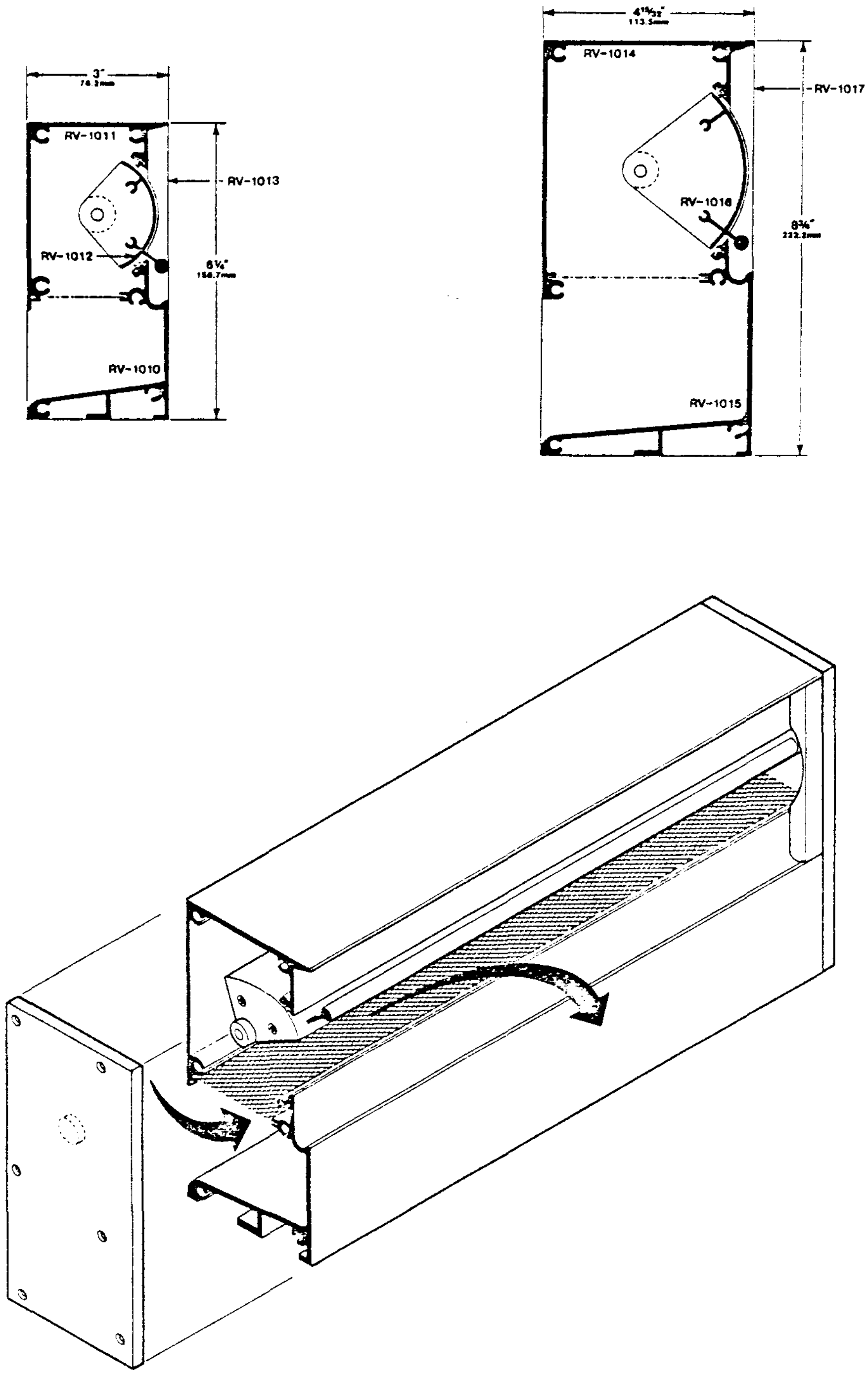


The REVOLV-O-VENT from HOWMET is designed for maximum fresh air flow. It can be used with most flush glaze and curtain wall products. It's available in 3" & 4-1/2" widths.

FIG. X.J.1 : DRUM LOUVER PROTOTYPE

REVOLV VENT™

SCALE- 1/4 'ZE



The REVOLV-O-VENT from HOWMET is designed for maximum fresh air flow. It can be used with most flush glaze and curtain wall products. It's available in 3" & 4-1/2" widths.

FIG. X.J.1 : DRUM LOUVER PROTOTYPE

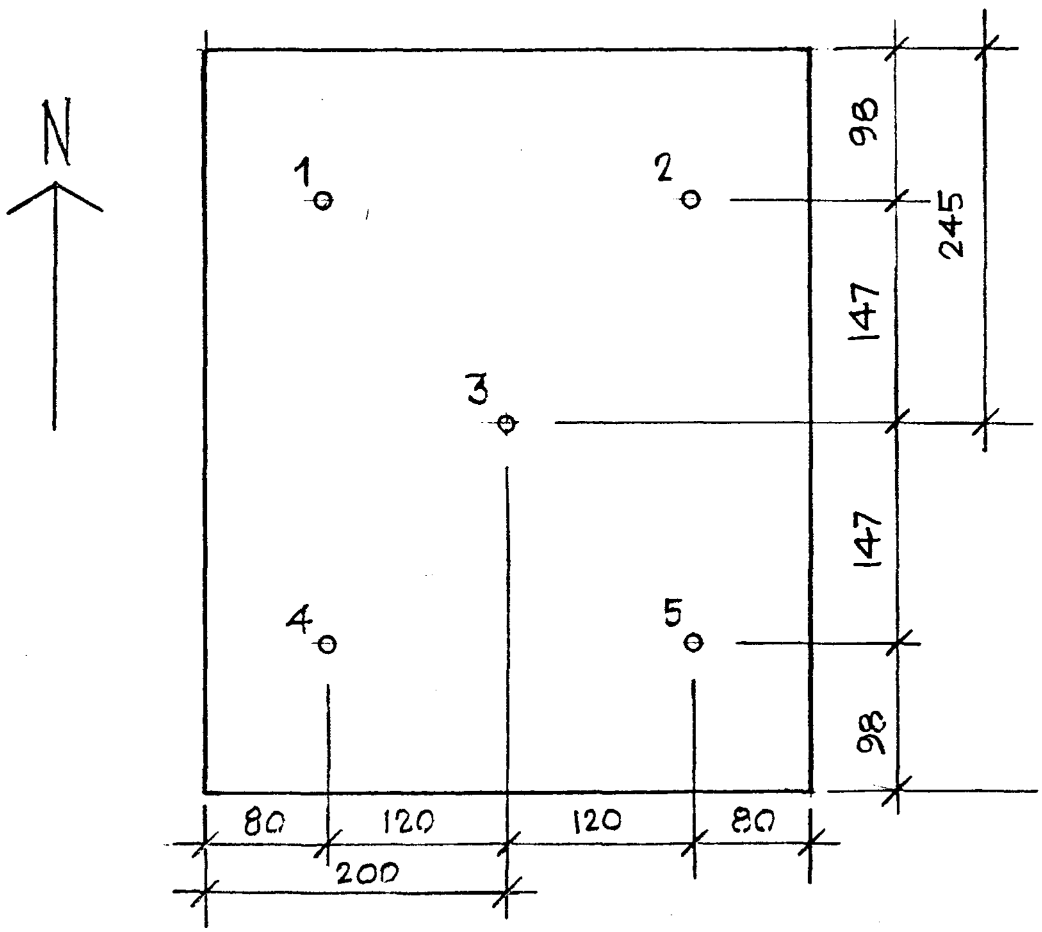


FIG. X.J.2 : PLAN OF G5/U6 SHOWING AIRFLOW SENSOR GRID

this experiment, insofar as possible, under NE wind direction conditions.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Install fixed glazing above drum louver stacks (immediately below window heads). Glazing to measure 64.4 cm. high above "small-scale" stack (G5) and 60 cm. high above "large-scale" stack (U6).
Other operable openings (doors, louvers etc):

a. "Small-scale" configuration in G5: Fourteen 4 1/2" (11.4 cm.) wide Revolv-O-Vent (Howmet Aluminum Co.) units each 6'-4 3/4" (195 cm.) long, stacked 7 high starting at finished floor level.

b. "Large-scale" configuration in U6: Four 16" (41.5 cm.) wide Revolv-O-Vent (Howmet Aluminum Co.) units each 6'-4 3/4" (195 cm.) long, stacked 2 high starting at finished floor level.

Status of inoperative components that affect experiment:

Drum louver units can be utilized with or without integral insect screens. Use of screens will reduce average air movement velocity levels.

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points: at 5.3 m. height (= centerline of upper floor windows) and at 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx. 45 meters) directly north of the north facade of the building.

Wind Direction:

Two points, same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points: see Figure X.J.2 for locations and heights.

Radiant Temperature (incl. globe temperature):

One point, at the center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air velocity sensors: adjustable to heights of from 50 to 175 cm. above finished floor. 28 standard (4 1/2") Revolv-O-Vent (Howmet Aluminum Co.) units; 8 nonstandard (16") Revolv-O-Vent units, refabricated from standard 4 1/2" units. Station #3 (at center of room) also supports other required instrumentation ("comfort station"). 3 dozen 1 minute white smoke candles.

Description:

Cost:

For "Small-scale" configuration (drum louvers only): two sets of 14 standard (4 1/2") Revol-O-Vent units, at approximately $130.00 per section = $1820.00 x 2 = $3640.00 plus cost of frame and upper glazed sections.

For "Large-scale" configuration (drum louvers only): two sets (one per wall) of 4 standard (4 1/2") Revolv-O-Vent units, approximately 4 x $130.00 = $520.00 x 2 = $1040.00 plus cost of refabrication to large scale units (approximately $1600.00) plus cost of frame and upper glazed sections. Four 1 minute white smoke candles: $18.50 per dozen x 3 dozen = $55.50.

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-ups [monthly installation and teardown of air velocity sensor grid plus two sensor-height changes per month]: 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 24 hours.

Reconfiguration [one change of window wall components]: 8 hours per day x 3 days = 24 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sectors (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No: 2

State Date: ________ Time: ________ Stop Date: ________ Time: ________

Name of Experiment: Reconfigurable Walls, Double-Hung Windows plus Deflector Louver Tests

Location: G5 & U6

Duration (months, days, hours): January through April; November & December (3 days in each of 6 months)

Objectives:

To determine the effectiveness of deflector louvers when used in conjunction with standard double-hung windows, in directing, maintaining and controlling wind-driven cross-ventilation (air movement) and maintaining thermal comfort within the occupied zone (approx. 45 to 180 cm. above finished floor level) of a typical residential-scale double-orientation room (windows on both sides).

Experimental Procedure (how to achieve objectives):

a. Install deflector louver arrays on outrigger frames, in front of lower half of double-hung windows on north side of rooms G5 & U6 (similar to installation shown in Figs. IV.A.1 &IV.A.2 except without the wing walls).

b. Close wind tower air supply inlets in G5 &U6.

c. Install air velocity, dry bulb, wet bulb and radiant temperature sensors in rooms G5 & U6 per schedule shown below.

d. Adjust angle of adjustable deflector louvers for maximum air velocity reading at grid station 3 (at center of room). Record angle of adjustment.

e. Observe and record (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

f. With lower half of double-hung windows open, measure air velocities at three different heights and at 5 different points on plan (53, 114, & 175 cm. above finished floor level) in G5 & U6, (Fig. X.J.2). Record velocity at lowest height (53 cm.) for 24 hours, at middle height (114 cm.) for 24 hours, and at top height (175 cm.) for 24 hours. The three 24-hour periods should be consecutive, with one hour allowed for sensor height-change. To ensure comparability of data, the same start/stop times should be used for each 24-hour period.

g. Simultaneously record outdoor wind speed and wind direction, together with indoor dry bulb temperature,, wet bulb temperature and radiant (globe) temperature.

h. Reduce data to assess resulting comfort levels achieved in each room during the "ventilation-critical" months of the year.

i. Experiments should be run in coordination with local weather forecasts to avoid acquiring data during highly "atypical" weather conditions, e.g., to avoid measurements, if possible, during the passage of exceptional frontal weather systems.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Install deflector-louver arrays, utilizing outrigger frames (see Fig. 9) for support devices, to lower half of double-hung windows of G5 & U6.

Other operable openings (doors, louvers etc):

Adjust angle of deflector-louvers to maximize air velocity at grid station 3 (center of room).

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points: 5.3 m. height (= centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows) at a location 150 feet (approx. 45 meters) N of the north facade of the building.

Wind Direction:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points: see Fig. X.J.2 for locations and height.

Radiant Temperature (incl. globe temperature):

One point, at the center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air velocity sensors, and other required instrumentation (see Experiment 1). 6 sets of adjustable aluminum deflector-louvers, (each louver 15 cm. wide by 90 cm. long typ.) supported by aluminum outrigger frames, attachable to window walls of G5 & U6. White smoke candles (see Experiment 1).

Description:

Cost:

Set of adjustable deflector-louvers with outrigger support frames: approximately $350 per set x 3 sets = $1,050.00

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-up [initial set-up of deflector-louvers; monthly installation and teardown of velocity sensor grid plus 2 sensors height-changes per month]: 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 24 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measuements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sectors (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV'S (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
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PASSIVE SOLAR COOLING PROJECT

Experiment No.:____3____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Wing Wall Tests

Location: G2 & U1

Duration (months, days, hours): January through April; November & December (6 days in each of 6 months)

Objectives:

To determine the effectiveness of wing-walls in maintaining wind-driven cross-ventilation (air movement) within the occupied zone (approx. 45 to 180 cm. above furnished floor) of a typical residential-scale single-orientation room (windows on one side only). Two different wing-wall widths have been suggested for testing. This allows a more thorough investigation of the potential of this device.

Experimental Procedure (how to achieve objectives):

a. Install 65 cm. wide wing-walls in window wall of G2 and 130 cm. wide wing-walls in window wall of U1. Install air velocity sensor grid.

b. Adjust angle of adjustable deflector louvers (Fig. IV.A.1) for maximum reading of air velocity at grid station 5 (at center of room). Record angle of adjustment.

c. Close wind tower air supply inlets in G2 & U1.

d. Observe and record photographically (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

e. With lower half of double-hung windows only in panels a, b, e & f open (see Figs. IV.A.1) and with windows in panels c & d closed, measure air velocities at 3 different heights and at 5 different points on plan (53, 114 & 175 cm.) in G2 & U1, (Fig. X.J.3). Record velocity at lowest height (53 cm.) for 24 hours, at middle height (114 cm.) for 24 hours, and at top height (175 cm.) for 24 hours. To ensure comparability of data, the same start/stop times should be used for each 24-hour period.

f. Simultaneously record outdoor wind speed and wind direction, together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature.

g. Reduce data to assess resulting comfort levels achieved in each room during the "ventilation-critical" months of the year, using each of the two different widths of wing walls, and under varying wind direction conditions.

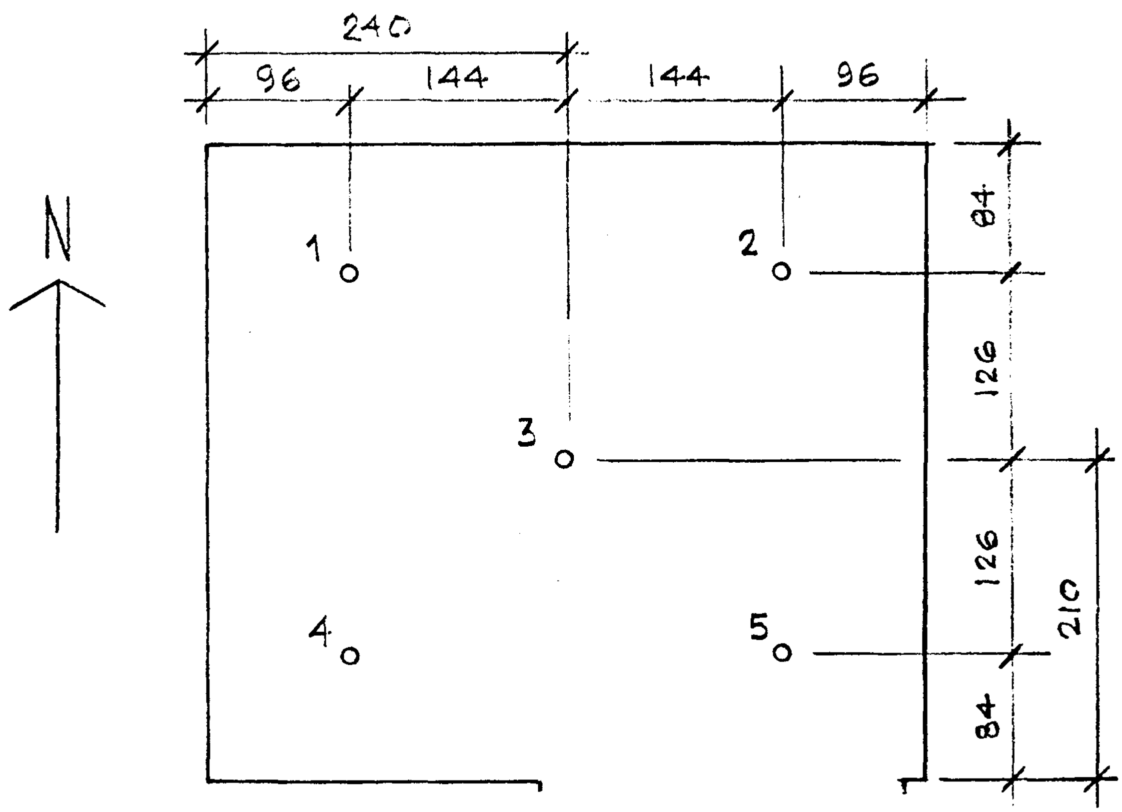

FIG. X.J.3 : PLAN OF G2/U1 SHOWING AIRFLOW SENSOR GRID

h. Remove wing walls from G2 and U1. Readjust angle of deflector-louvers, if necessary, to maximize air velocity readings at grid station 5 (center of room). Record new angle of adjustment, if adjustment is necessary.

i. Repeat steps c) through e) above for new "no wind walls" configuration.

j. Experiments should be run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., avoid measurements, if possible, during the passage of exceptional frontal weather systems.

Configuration

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc.):

Windows:

Attach 65 cm. wide wing walls to window wall of G2, and 130 cm. wide wing walls to window wall of U1 using diagonal aluminum diaphragm-braces (as shown in Figs. IV.A.1 & IV.A.2)

Other operable openings (doors, louvers etc.):

Adjust angle of external deflector-louvers to maximize air velocity at grid station 3 (center of room).

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Hunidity:

Wind Speed:

Two points: 5.3 m. height (=centerline of upper floor windows) and 2.425 c. height (=centerline of round floor windows), at a location 150 feet (approx. 45 meters) directly N of the north facade of the building.

Wind Direction:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points: see Fig. X.J.3 for locations.

Radiant Temperature (incl. globe temperature):

One point, at the enter of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air velocity sensors and other required instrumentation (see Experiment 1)

One set (two) or 65 cm. wide x 210 cm. high foam-filled sheet aluminum wing walls with aluminum diaphragm braced. 65 cm. wing walls approximately $250.00 per set.

One set (two) of 130 cm. wide x 210 cm. high foam-filled sheet aluminum wing walls with aluminum diaphragn braces. 130 cm. wing walls approximately $300.00 per set. White smoke candles (see Experiment 1).

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-up [initial set-up of deflector louvers; monthly installation and teardown of velocity sensor-grid plus 5 sensor height changes per month]: 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 5 changes per month x 6 months (height changes) = 42 hours. Reconfiguration [one removal of wing walls]: 8 hours per day x 1/2 day = 4 hours.

Computer Analyst/Programmer:

6 hours per month x 6 months = 36 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sector (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
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Experiment No.: ____4____

Start Date: _____ Time: _____ Stop Date: _____ Time: _____

Name of Experiment: Chevron Louver Tests

Location: U1 & U9

Duration (months, days, hours): January through April; November & December (3 days in each of 6 months)

Objectives:

To determine the effectiveness of a "chevron" louver type inlet/outlet device in creating potential wind-driven cross-ventilation (air movement) through two adjacent single-orientation (windows in one wall only) residential-scale rooms (one upwind, one downwind); to measure the effectiveness of such a device in providing an adequate outlet for air movement within the occupied zone (approx. 45 to 180 cm. above finished floor) of the windward or upwind room; and to measure the effectiveness of such a device in directing and maintaining a sufficient level of "borrowed" air movement within the occupied zone of the leeward or downwind room.

Experimental Procedure (how to achieve objectives):

a. Open fully vertical control louvers on both sides of chevron louver-bank beneath the closet between rooms U1 & U9.

b. Install air velocity sensor grid and other instruments in U1 & U9.

c. Close wind tower supply inlets in U1 and U9.

d. Observe and record photographically (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

e. Open lower half of all double-hung windows in U1 and U9.

f. Measure air velocity in U1 and U9 at 5 different points on plan (see Fig. X.J.4) and at 3 different heights, with all operable window sections in both rooms fully open. Measure at lowest height (53 cm.) for 24 hours; at middle height (114 cm.) for 24 hours; then at top height (175 cm.) for 24 hours. To ensure comparability of data, the same start/stop times should be used for each 24-hour period.

g. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature.

h. Reduce data to assess resulting comfort levels achieved in each room, during the "ventilation-critical" months of the year.

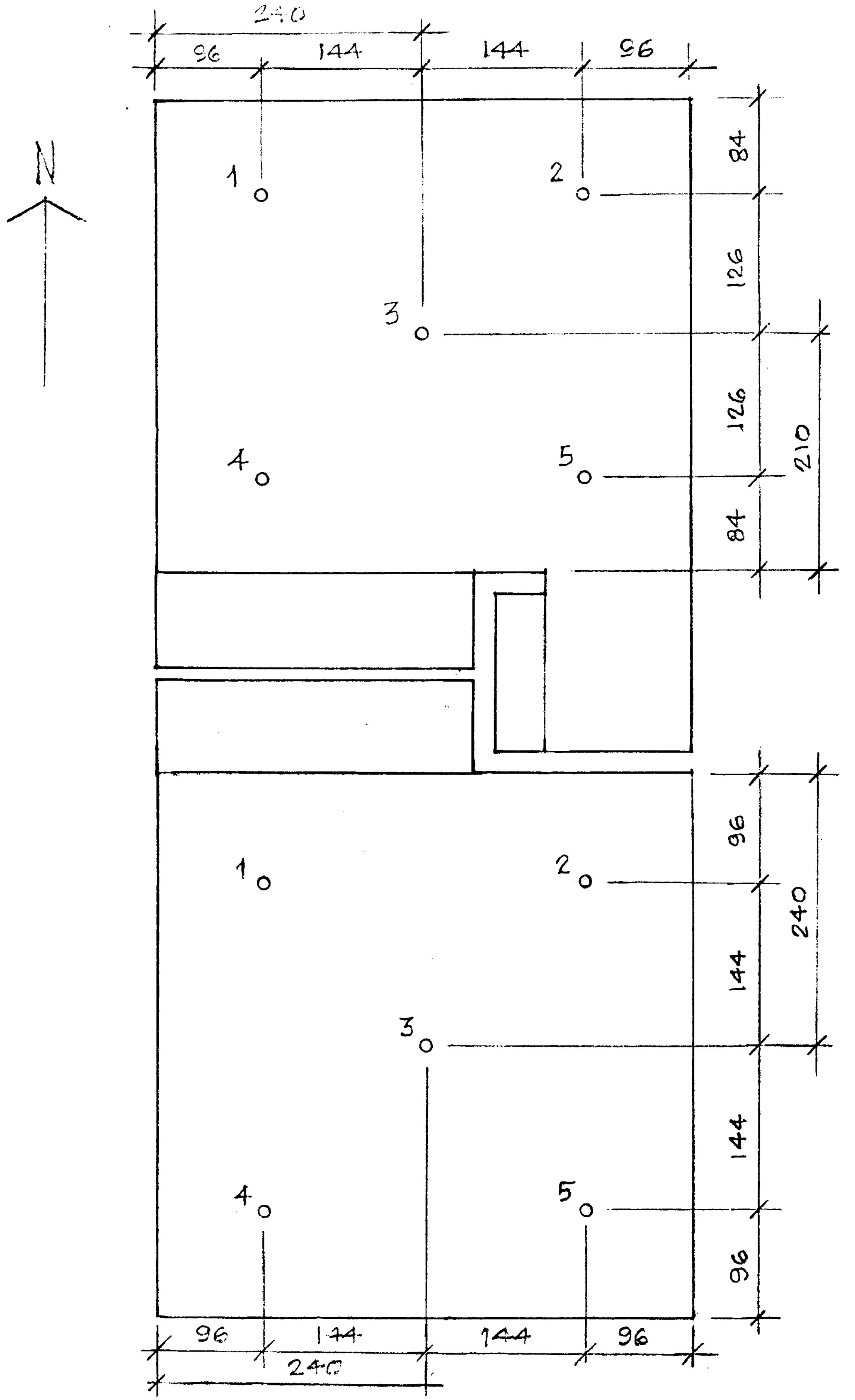

FIG. X.J.4 : PLAN OF U1/U9 SHOWING AIRFLOW SENSOR GRID

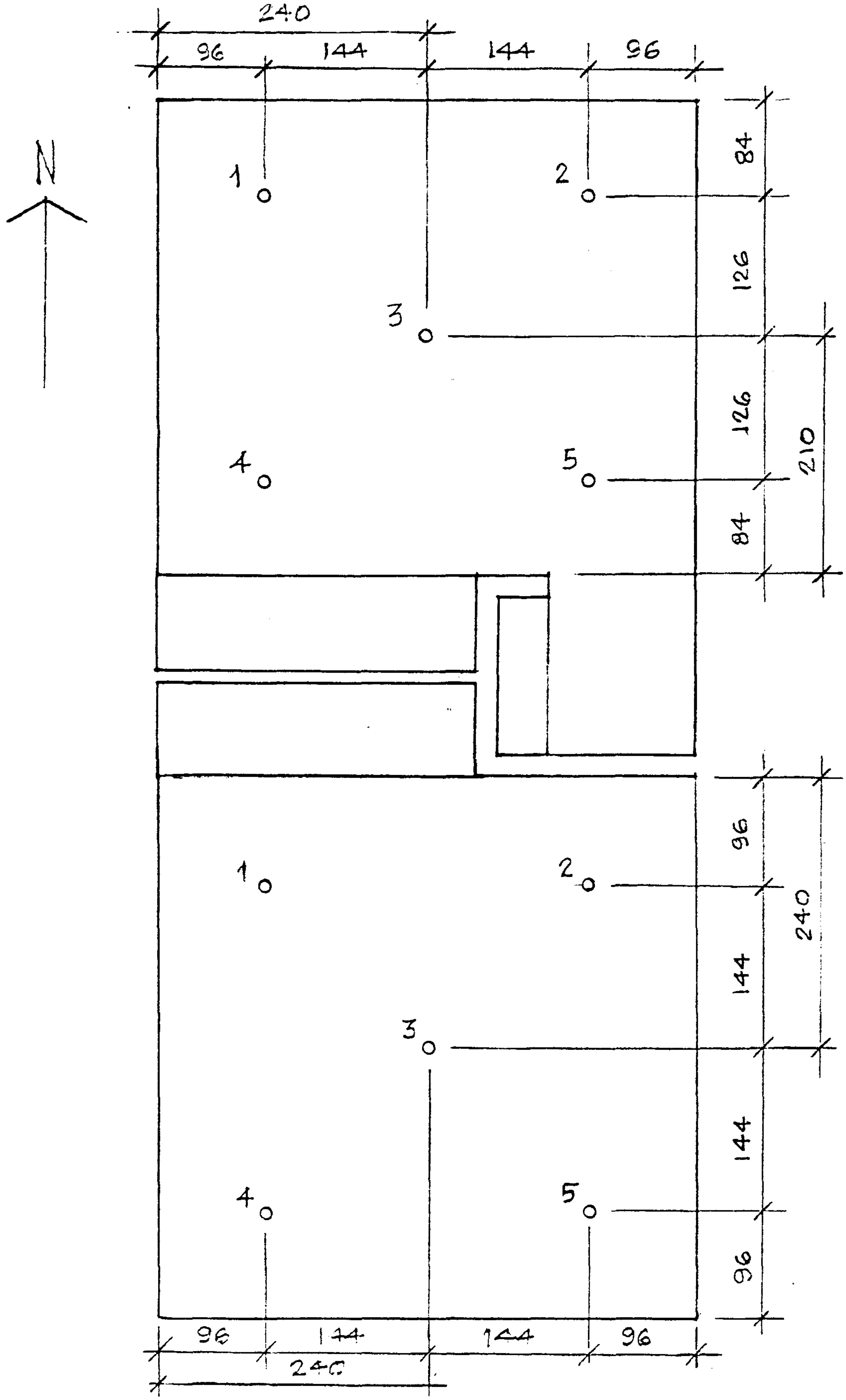

FIG. X.J.4 : PLAN OF U1/U9 SHOWING AIRFLOW SENSOR GRID

i. Experiments to run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Other (please specify):

Status of inoperative components that affect experiments:

Measurements Required (For each measurement enter the number of the data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points; 5.3 m. height (= centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx. 45 meters) north of the north facade of the building.

Wind Direction:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.4. for locations.

Radiant Temperature, (incl. globe temperature):

One point, at the center of room, 45 cm. above finished floor.

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air veloctiy sensors and other required instrumentation (see Experiment 1).
White smoke candles (see Experiment 1).

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-ups [monthly installation and teardown of air velocity sensor grid plus two sensor-height changes per month]: 1 hour per day x 2 days per month x 6 months (height changes) = 24 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sector (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours:

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____5____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Louvered Transoms & Doors Test

Location: G2 & G8

Duration (months, days, hours): January through April; November & December (3 days in each of 6 months)

Objectives:

To determine the effectiveness of fixed louver-transomed doorways plus louvered folding doors as inlet/outlet devices in creating potential wind-driven cross-ventilation (air movement) through two adjacent single-orientation (windows in one wall only) residential-scale rooms (one upwind, one downwind); to measure the effectiveness of such devices in providing an adequate outlet for air movement within the occupied zone (approx. 45 to 180 cm. above finished floor) of the windward or upwind room; and to measure the effectiveness of such devices in directing and maintaining a sufficient level of "borrowed" air movement within the occupied zone of the leeward or downwind room.

Experimental Procedure (how to achieve objectives):

a. Close both sets of folding louvered doors between G2 & G8 (see Fig. IV.A.4). Install air velocity sensor grid and other instruments in G2 & G8.

b. Close wind tower supply inlets in G2 & G8.

c. Observe and recorf photographically (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

d. Keep lower half of all double-hung windows in G2 & G8 open throughout this experiment.

e. Measure air velocities in G2 & G8 at 5 different points on plan (see Fig. X.J.5) at a height of 114 cm. above finished floor for 24 hours.

f. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperatue, wet bulb temperature and radiant (globe) temperature.

g. Reduce data to assess resulting comfort levels achieved in each room, during the "ventilation-critical" months of the year, with louvered doors closed.

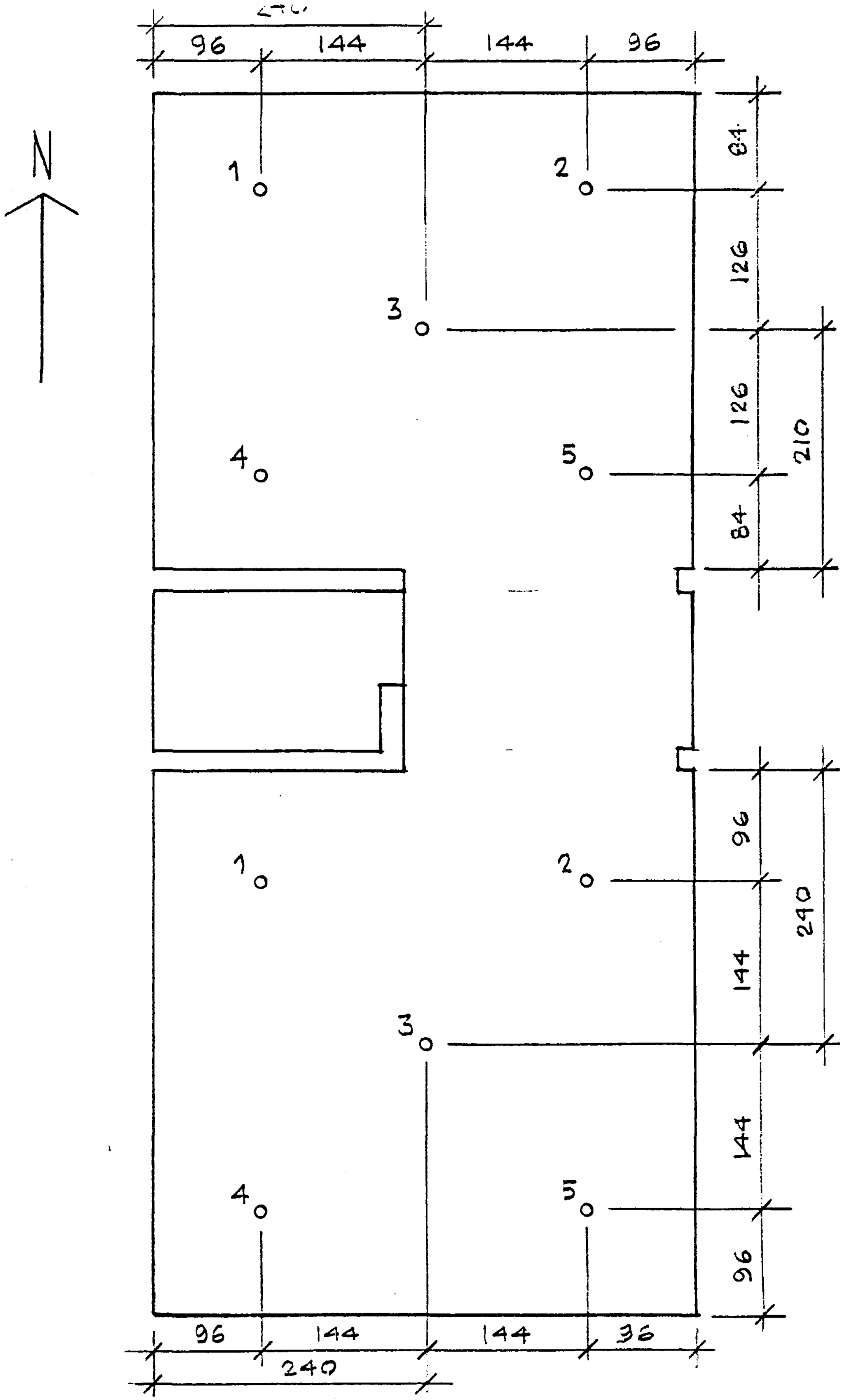

FIG. X.J.5 : PLAN OF G2/G8 SHOWING AIRFLOW SENSOR GRID

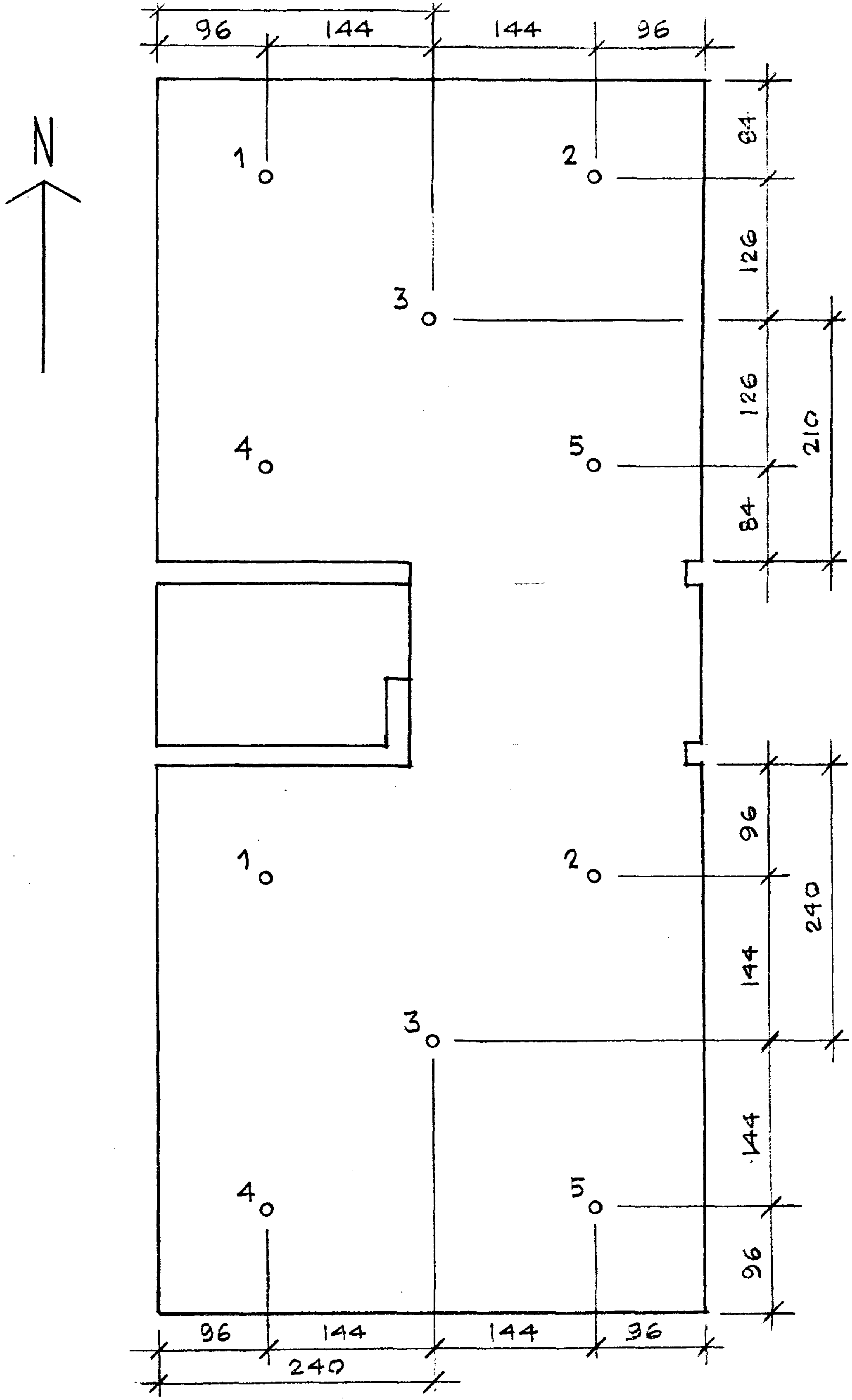

FIG. X.J.5 : PLAN OF G2/G8 SHOWING AIRFLOW SENSOR GRID

h. Open the set of folding doors located on south side of G2, leaving the set of folding doors located on north side of G8 closed.

i. Repeat steps c) through e) above.

j. Open both sets of folding doors between G2 & G8 completely.

k. Repeat steps c) through e) above.

l. Experiments should be run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc);

Windows:

Other operable openings (doors, louvers etc):

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points; 5.3 m. height (= centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx. 45 meters) directly north of the north facade of bulding.

Wind Direction:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperatue:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. aove finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.5 for locations.

Radiant Temperature (incl. globe temperatue):

One point, at the center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air velocity sensors and other required instrumentation (see Experiment 1). White smoke candles (see Experiment 1).

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent experiments:

Manpower requirement (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-ups [monthly installation and teardown of air velocity sensor grid]: 1 hour per day x 2 days per month x 6 months (installation and teardown) = 12 hours.

Reconfiguration [two changes of folding door configuration]: 15 minutes per day x 2 days = .5 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sector (sector width = 22.5°). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration of the folding doors. In addition, average air velocity in the form of m/sec. results should be used to calculate hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: 6

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Wind Tower Ducted-Supply Ventilation/Inlet Alternate #1/Year 1

Location: G8 & U9

Duration (months, days, hours): January through April, November & December (6 days in each of 6 months)

Objectives:

To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone (approx. 45 to 180 cm. above finished floor) of two typical residential-scale, single-orientation (windows in one wall only) rooms, which receive tower air supply through a duct system.

Experimental Procedure (how to achieve objectives):

a. Install Wind Tower Inlet Alternate #1 (Fig. X.J.6)

b. Install air velocity sensor grid and other required instrumentation in G8 & U9.

c. Close all operable windows in G8 & U9.

d. Observe and record (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

e. Adjust louvers on north side of wind tower inlet, plus wind tower extractors (at connection to the supply ducts on both floors) plus deflector vanes at tower air supply inlets in G8 & U9, to maximize air velocity reading at grid station 3 (at center of room). Record all angles of adjustment.

f. Measure air velocities in G8 & U9 at 5 different points on plan (Fig. X.J.7) and at 3 different heights. Measure at lowest height (53 cm.) for 48 hours; at middle height (114 cm.) for 48 hours; and at top height (175 cm.) for 48 hours. To ensure comparability of data, the same start/stop times should be used for each 48-hour period.

g. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature.

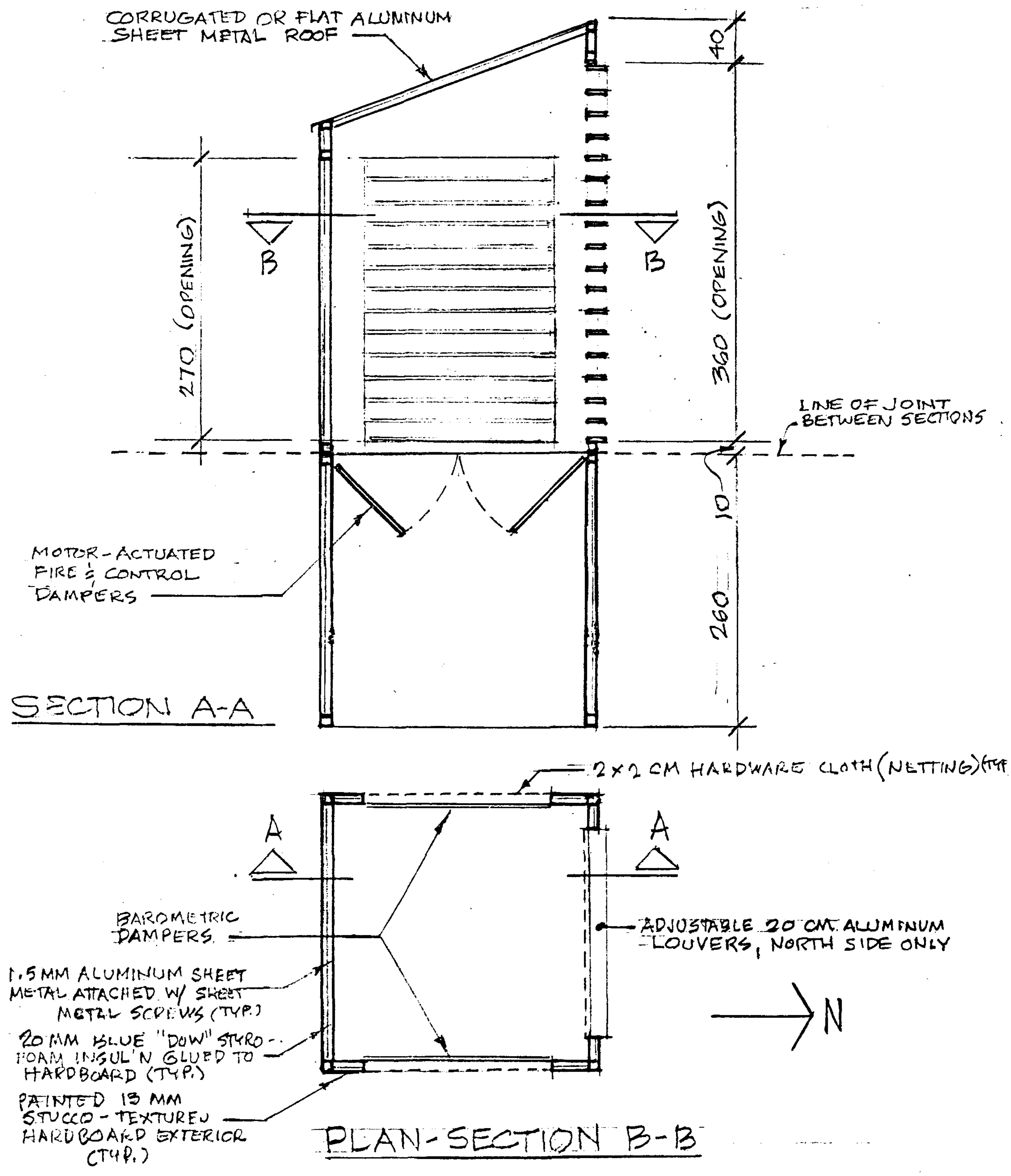

FIG. XJ.6 : WIND TOWER (STEEL-FRAMED SECTION) ALT. #1

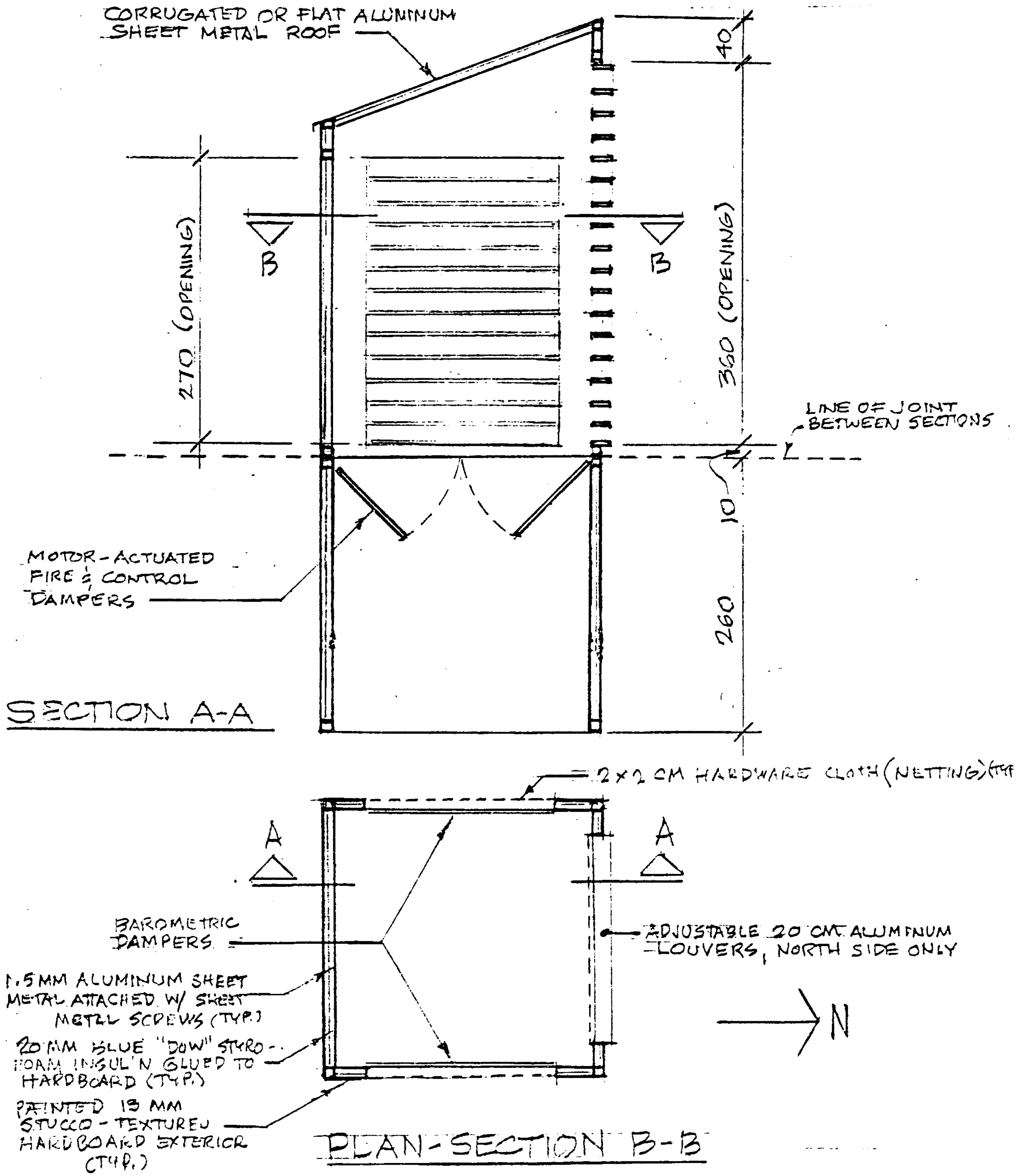

FIG. XJ.6 : WIND TOWER (STEEL-FRAMED SECTION) ALT. #1

h. Reduce data to assess resulting comfort levels achieved in each room, during the "ventilation-critical" months of the year.

i. Experiments to run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc);

Install steel-framed inlet alternate #1 at top of concrete section of wind tower.

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points; 5.3 m. height (= centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx 45 meters) directly north of the north facade of the building.

Wind Direction:

Two points, same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

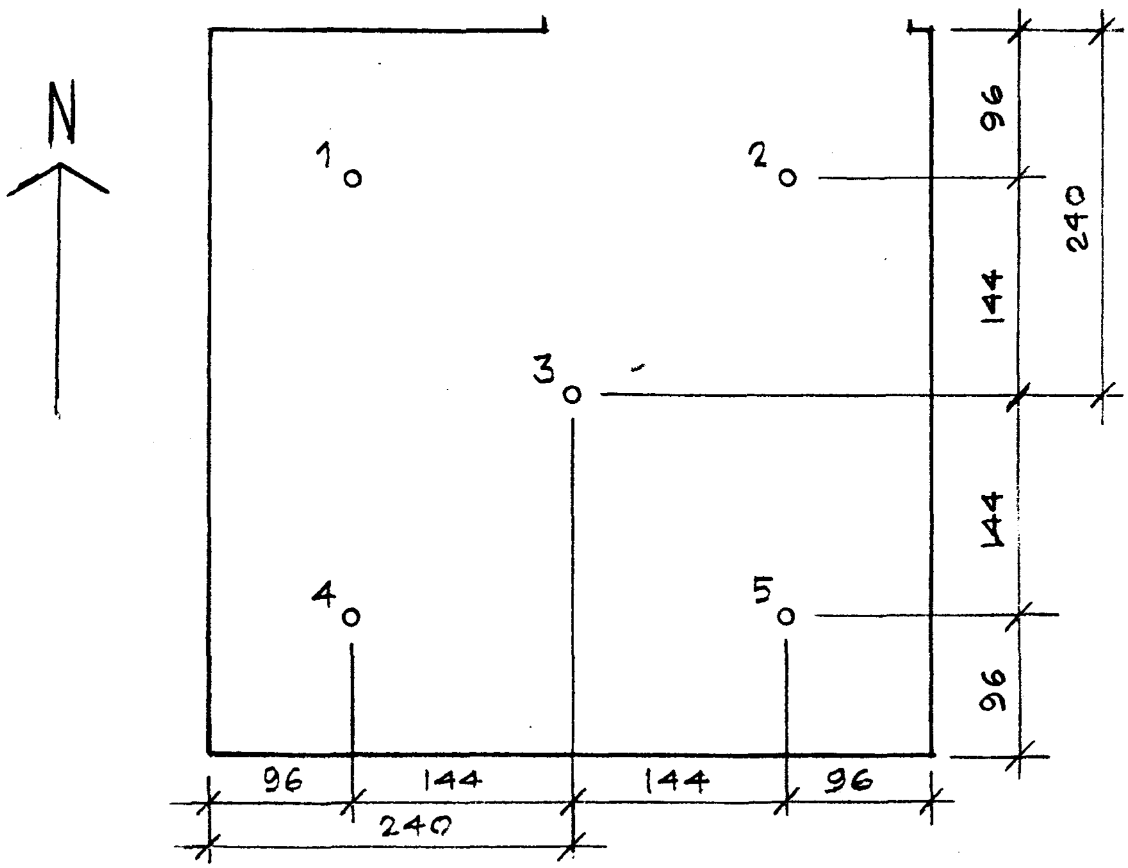

FIG. X.J.7 : PLAN OF G8/U9 SHOWING AIRFLOW SENSOR GRID

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velociy:

Five points; see Figure X.J.7 for locations and heights.

Radiant Temperature (incl. globe temperature):

One point, at the center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air velocity sensors and other required instrumentation: (see Experiment 1).
White smoke candles (see Experiment 1).

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours

Technician:

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____7____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Wind Tower Direct-Supply Ventilation/Inlet Alternate #1/Year 1

Location: G2 & U1

Duration (months, days, hours): January through April; November & December (6 days in each of 6 months)

Objectives:

To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone (approx. 45 to 180 cm. above finished floor) of two typical residential-scale, single-orientation (windows in one wall only) rooms, and which receive tower air supply directly from the tower.

Experimental Procedure (how to achieve objectives):

a. Install Wind Tower Inlet Alternate #1 (Fig. X.J.6)

b. Install air velocity sensor grid and other required instrumentation in G2 & U1.

c. Close all operable windows in G2 & U1.

d. Adjust louvers on north side of wind tower inlet, plus wind tower extractors (at connection to the supply ducts on both floors) plus deflector vanes at tower air supply inlets in G2 & U1, to maximize air velocity readings at grid station 3 (at center of room). Record all angles of adjustment.

e. Observe and record (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracres.

f. Measure air velocities in G2 & U1 at 5 different points on plan (Fig. X.J.8) and at 3 different heights. Measure at lowest height (53 cm.) for 48 hours; at middle height (114 cm.) for 48 hours; and at top height (175 cm.) for 48 hours. To ensure comparability of data, the same start/stop times should be used for each 48-hour period.

g. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry, bulb temperature, wet bulb temperature and radiant (globe) temperature.

h. Reduce data to assess resulting comfort levels achieved in each room, during the "ventilation-critical" months of the year.

Experiment set-ups [initial adjustments, monthly installation and teardown of air velocity sensor grid plus two sensor-height changes per month]: 6 hours (initial adjustments); 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 30 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measuements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sector (sector width = 22.5^{O}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours);

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours.

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

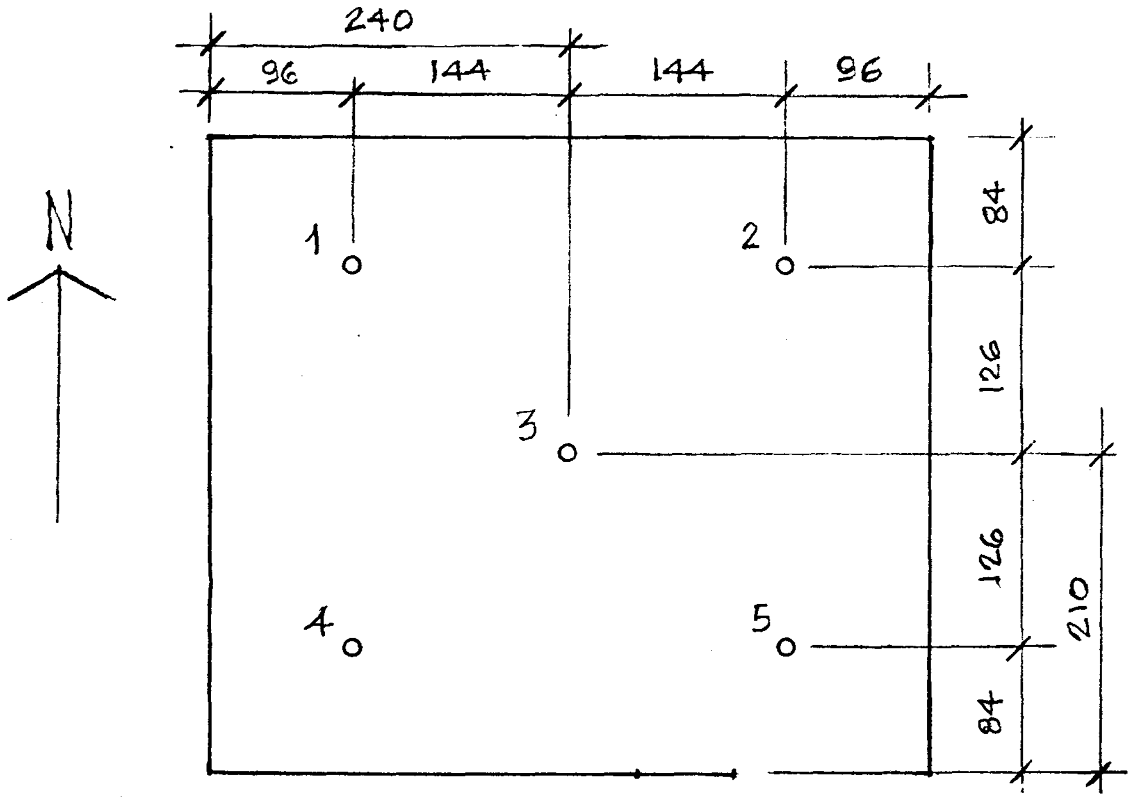

FIG. X.J.8 : PLAN OF G2/U1 SHOWING AIRFLOW SENSOR GRID

i. Experiments to run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration:

General Structure Configuration (system configurations, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Steel-framed Inlet Alternate #1 at top of concrete section of wind tower, as used in Experiment 6.

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points: 5.3 m. height (=centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx. 45 meters) directly north of the north facade of the building.

Wind Direction:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.8 for locations.

Radiant Temperature (incl. globe temperature):

One point, at the center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air velocity sensors and other required instrumentation: (see Experiment 1).
White smoke candles (see Experiment 1).

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours.

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-ups [initial adjustments; monthly installation and teardown of air velocity sensor grid] plus two sensor-height changes per month: 6 hours (initial adjustments); 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 30 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sectors (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours.

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: 8

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Wind Tower Ducted-Supply Evaporative Cooling Mode/ Inlet Alternate #1/Year 1

Location: G8 & U9

Duration (months, days, hours): May, June and October (30/29 days in each of 3 months)

Objectives:

To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven evaporative cooling and thermal comfort in the occupied zone (aprox. 45 to 180 cm. above finished floor) of two typical residential-scale, single-orientation (windows in one wall only) rooms, and which receive tower air supply through a duct system.

Experimental Procedure (how to achieve objectives):

a. Maintain Wind Tower Inlet Alternate #1 in place, (Fig. X.J.6) as used in Experiments 6 & 7.

b. Install Celdek (as wetted medium at top of tower, and as demisters behind each supply inlet (Fig. IV.B.6)

c. Install air velocity sensor grid and other required instrumentation in G8 & U9.

d. Close all operable windows in G8 & U9.

e. Adjust louvers on north side of wind tower inlet, plus wind tower extractors (at connection to the supply ducts on both floors) plus deflector vanes at tower air supply inlets in G8 & U9, to maximize air velocity readings at grid station 3 (at center of room). Record all angles of adjustment.

f. Observe and record (Polaroid flash photos) indoor airflow using white smoke candles as flow tracers.

g. Measure air velocities in G8 & U9 at 5 different points on plan (Fig. X.J.7) and at 3 different heights. Measure at lowest height (53 cm.) for 7 days; at middle height (114 cm.) for 7 days; and at top height (175 cm.) for 7 days. To ensure comparability of data, the same start/stop times should be used for each 48-hour period.

h. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature inside G8 & U9.

i. Reduce data to assess resulting comfort levels achieved in each room during the "evaporative-cooling critical" months of the year.

j. At end of second month (June), remove Celdek wetted medium unit at top of wind tower, and replace with fog nozzles (if nozzles are not already installed).

k. Repeat steps c) through h), while operating fog nozzle system.

l. At end of this experiment, remove <u>all</u> Celdek pads, both wetted media <u>and</u> demisters.

m. Experiments should be run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

<u>Configuration</u>: <u>General Structure Configuration (system configuration, openings etc.)</u>

<u>Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc)</u>:

<u>Windows</u>:

<u>Other operable openings (doors, louvers etc)</u>:

Maintain steel-framed inlet alternate #1 (see Fig. X.J.6) at top of concrete section of wind tower, as used in Experiments 6 and 7.

<u>Other (please specify)</u>:

<u>Status of inoperative components that affect experiment</u>:

<u>Measurements Required (For each measurement enter the number of data points and locations for each.)</u>

<u>Barometric Pressure</u>:

<u>Relative Humidity</u>:

<u>Wind Speed</u>:

Two points; 5.3 m. height (= centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx. 45 meters) directly north of the north facade of the building.

<u>Wind Direction</u>:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.7 for locations.

Radiant Temperature (incl. globe temperature):

One point, at the center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

a. Five stands to support air velocity sensors and other required instrumentation: (see Experiment 1).

b. Celdek pads, used both as the first of two alternative wetted media near the top of the wind tower; and as demisters located just behind each tower air supply inlet (demisters used only in evaporative cooling modes).

c. Fog Nozzle system, as the second alternative wetted medium system. near the top of the wind tower.

d. White smoke candles (see Experiment 1).

Description:

The Fog Nozzle system will be developed from existing technology specifically for Experiments 8, 9, 12 & 13.

The Celdek wetted media system will be developed from existing technology specifically for Experiments 8, 9, 12 & 13.

Cost:

Fog Nozzle system: approximately $8,000 in materials.
Celdek wetted media system: approximately $2,000 in materials.

Labor:

Fog Nozzle system: approximately $8,000 (design and fabriction).
Celdek wetted media system: approximately $2,000 (design and fabrication).

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

This experiment is to run concurrently with Experiment 9.

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-ups [initial set up; monthly installation and teardown of air velocity sensor grid plus two sensor-height changes per month]: 6 hours (initial set-up) plus 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 40 hours.

Reconfiguration [one change of Celdek for Fog Nozzles]: 8 hours per day x 1 day = 8 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sector (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours.

Computer Analyst/Programmer:

20 hours.

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____9____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Wind Tower Direct-Supply Evaporative Cooling Mode Inlet Alternate #1/Year 1

Location: G2 & U1

Duration (months, days, hours): May, June & October (18 days in each of 3 months)

Objectives:

To determine the effectiveness of a 3-sided wind tower in maintaining wind-driven evaporative cooling and thermal comfort in the occupied zone (approx. 45 to 180 cm. above finished floor) of two typical residential-scale, single-orientation (windows on one wall only) rooms, and which receive tower air supply through a duct system.

Experimental Procedure (how to achieve objectives):

a. Maintain Wind Tower Inlet Alternate #1 in place (Fig. X.J.6) as used in Experiments 6, 7 & 8.

b. Maintain Celdek (as wetted medium at top of tower, and as demisters behind each supply inlet (Fig. IV.B.6)

c. Install air velocity sensor grid and other required instrumentation in G2 & U1,

d. Close all operable windows in G2 & U1.

e. Adjust louvers on north side of wind tower inlet, plus wind tower extractors (at connection to the supply ducts on both floors) plus deflector vanes at tower air supply inlets in G2 & U1, to maximize air velocity readings at grid station 3 (at center of room). Record all angles of adjustment.

f. Observe and record (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

g. Measure air velocities in G2 & U1 at 5 different points on plan (Fig. X.J.8) and at 3 different heights. Measure at lowest height (53 cm.) for 7 days; at middle height (114 cm.) for 7 days; and at top height (175 cm.) for 7 days. To ensure comparability of data, the same start/stop times should be used for each 48-hour period.

h. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature, inside G2 & U1.

i. Reduce data to assess resulting comfort levels achieved in each room, during the "evaporative cooling critical" months of the year.

j. At end of second month (June), remove Celdek wetted medium unit at top of wind tower, and replace with fog nozzles (if nozzles are not already installed).

k. Repeat steps c) through h), while operating fog nozzle system.

l. At end of this experiment, remove all Celdek pads, both wetted media and demisters.

m. Experiments to run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration:

General Structure Configuration (system configuration, openings etc.):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Maintain steel-framed inlet alternate #1 at top of concrete section of wind tower, as used in Experiments 6, 7, and 8.

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative humidity:

Wind Speed:

Two points; 5.3 m. height (= centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx 45 meters) directly north of the north facade of the building.

Wind Direction:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.8 for locations.

Radiant Temperature (incl. globe temperature):

One point, at center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

a. Five stands to support air velocity sensors and other required instrumentation: see Experiment 1.

b. Celdek "pads", used both as the first of two alternative wetted media near the top of the wind tower; and as demisters located just behind each tower air supply inlet (demisters used only in evaporative cooling modes).

c. A Fog Nozzle system, as the second alternative wetted medium system, near the top of the wind tower.

d. White smoke candles (see Experiment 1).

Description:

The Fog Nozzle system will be developed from existing technology specifically for Experiments 8, 9, 12 & 13.

The Celdek wetted media system will be developed from existing technology specifically for Experiments 8, 9, 12 &13.

Cost:

Fog Nozzle System: approximately $5,000 in materials.
Celdek wetted media system: approximately $2,000 in materials.

Labor:

Fog Nozzle System: approximately $5,000 (design and fabrication).
Celdek wetted media system: approximately $2,000 (design and fabrication).

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

This experiment is to run concurrently with Experiment 8.

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours.

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours.

Technician:

Experiment set-ups [initial set up; monthly installation and teardown of air velocity sensor grid plus two sensor-height changes per month]: 16 hours (initial set up) plus 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 40 hours.

Reconfiguration [One change of Celdek for Fog Nozzles]: 8 hours per day x 1 day = 8 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sectors (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____10____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Wind Tower Ducted-Supply Ventilation/Inlet Alternate #2/Year 2

Location: G8 & U9

Duration (months, days, hours): January through April, November & December (6 days in each of 6 months)

Objectives:

To determine the effectiveness of a 2-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone (approx. 45 to 180 cm. above finished floor) of two typical residential-scale, single-orientation (windows one wall only) rooms, and which receive tower air supply through a duct system.

Experimental Procedure (how to achieve objectives):

a. Remove Wind Tower Inlet Alternate #1, and Install Wind Tower Inlet Alternate #2 (Fig. X.J.9 & X.J. 10).

b. Install air velocity sensor grid and other required instrumentation in G8 & U9.

c. Close all operable windows in G8 & U9.

d. Adjust louvers on north side of wind tower inlet, plus wind tower extractors (at connection to the supply ducts on both floors) plus deflector vanes at tower air supply inlets in G8 & U9, to maximize air velocity reading at grid station 3 (at center of room). Record all angles of adjustment.

e. Observe and record (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

f. Measure air velocities in G8 & U9 at 5 different points on plan (Fig. X.J.7) and at 3 different heights. Measure at lowest height (53 cm.) for 7 days; at middle height (114 cm.) for 7 days; and at top height (175 cm.) for 7 days. To ensure comparability of data, the same start/stop times should be used for each 7-day period.

g. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature.

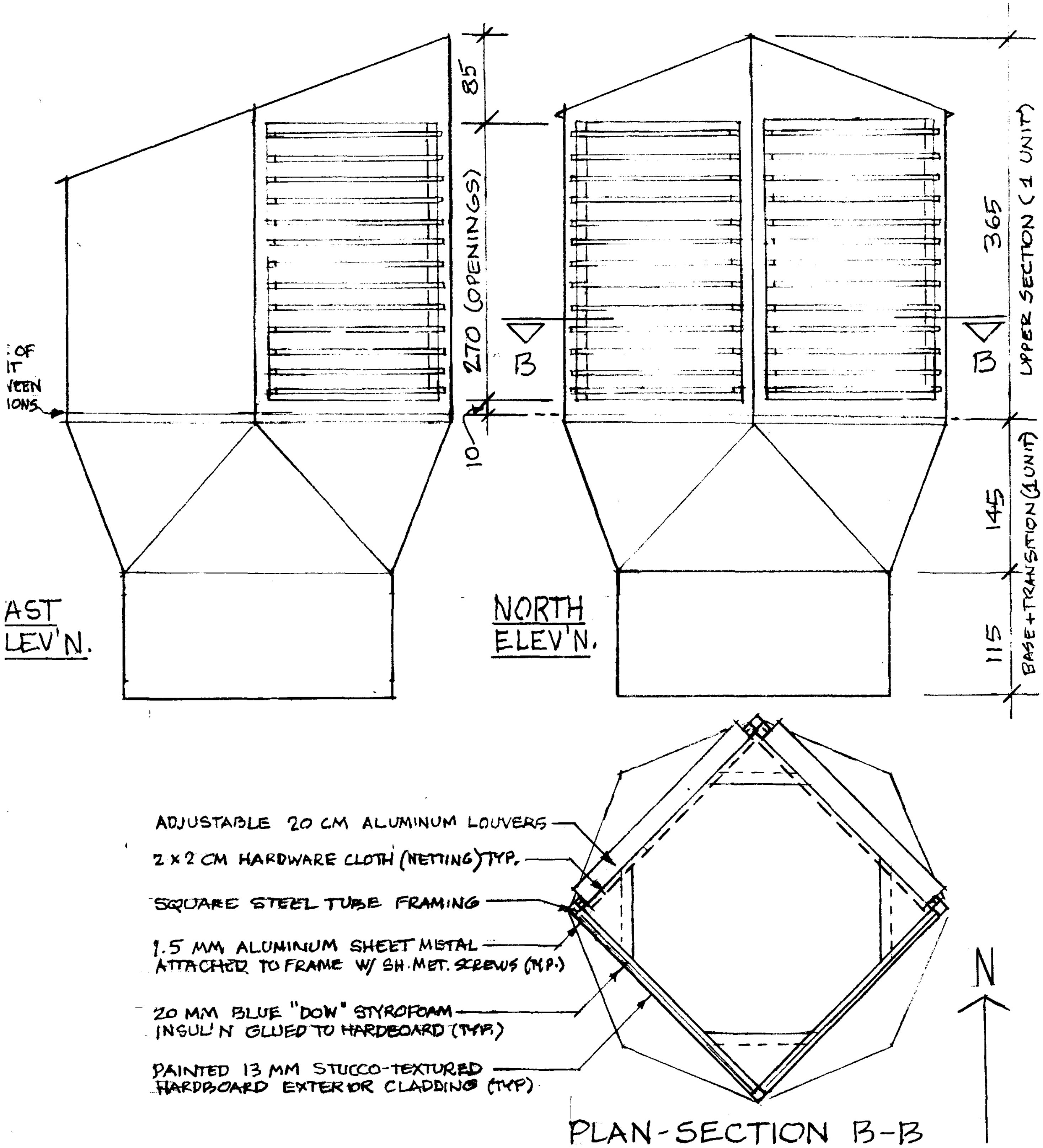

FIG. X.J.9 : WIND TOWER (STEEL-FRAMED SECTIONS) ALT. #2

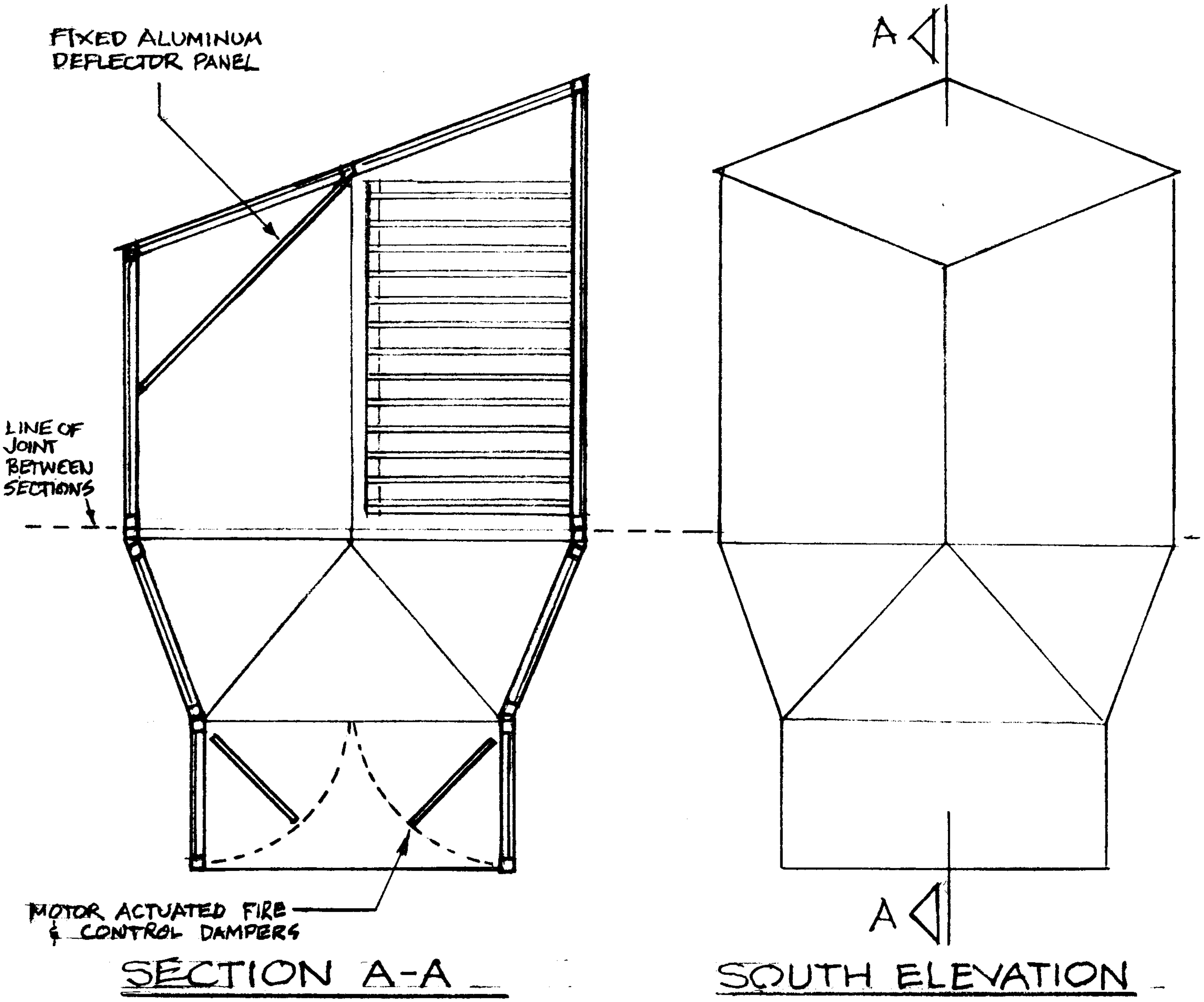

FIG. X.J.10 : WIND TOWER (STEEL-FRAMED SECTIONS) ALT. #2

h. Reduce data to assess resulting comfort levels achieved in each room, during the "ventilation-critical" months of the year.

i. Experiments should be run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc);

Install steel-framed Inlet Alternate #2 (see Fig. XII.10.0) at top of concrete section of wind tower.

Other (please specify):

Status of inoperative components that affect experiments:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points: 5.3 m. height (= centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx. 45 meters) directly north of the north facade of the building.

Wind Direction:

Two points: same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.7 for locations.

Radiant Temperature (incl. globe temperature):

One point, at center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air velocity sensors and other required instrumentation: (see Experiment 1).

White smoke candles (see Experiment 1).

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

This experiment is to run concurrently with Experiment 11.

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours.

Architect:

Supervision: 4 hours per month x 6 months = 24 hours.

Technician:

Experiment set-ups [initial set up; monthly installation and teardown of air velocity sensor grid plus two sensor-height changes per month]: 16 hours (initial set up) plus 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 days per month x 6 months (height changes) = 24 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sectors (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____11____

Start Date: _____ Time: _____ Start Date: _____ Time: _____

Name of Experiment: Wind Tower Direct-Supply Ventilation/Inlet Alt. #2/Year 2

Location: G2 & U1

Duration (months, days hours): January through April; November & December (6 days in each of 6 months)

Objectives:

To determine the effectiveness of a 2-sided wind tower in maintaining wind-driven air movement and thermal comfort in the occupied zone (approx. 45 to 180 cm. above finished floor) of two typical residential-scale, single-orientation (windows in one wall only) rooms, and which receive tower air supply directly from the tower.

Experimental Procedure (how to achieve objectives):

a. Maintain Wind Tower Inlet Alternate #2 (Fig. X.J.9 & X.J.10).

b. Install air velocity sensor grid and other required instrumentation in G2 & U1.

c. Close all operable windows in G2 & U1.

d. Adjust louvers on north side of wind tower inlet, plus the wind tower extractors (at connection to the supply ducts on both floors) plus the deflector vanes at tower air supply inlets in G2 & U1, to maximize air velocity reading at grid station 3 (at center of room). Record all angles of adjustment.

e. Observe and record (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

f. Measure air velocities in G2 & U1 at 5 different points on plan (Fig. X.J.8) and at 3 different heights. Measure at lowest height (53 cm.) for 6 days; at middle height (114 cm.) for 6 days; and at top height (175 cm.) for 6 days. To ensure comparability of data, the same start/stop times should be used for each 6-day period.

g. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature.

h. Reduce data to assess resulting comfort levels aachieved in each room, during the "ventilation-critical" months of the year.

i. Experiments to run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speed, air flow rate, controls used, time on/off etc:

Windows:

Other operable openings (doors, louvers etc):

Maintain Steel-Framed Inlet Alternate #2 (see Fig. XII.10.1) at top of concrete sections of wind tower, as used in Experiment 10.

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points: 5.3 m. height (=centerline of upper floor windows) and 2.425 m. height (=centerline of ground floor windows), at a location 150 feet (approx 45 meters) directly north of the north facade of the building.

Wind Direction:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.8 for locations.

Radiant Temperature (incl. globe temperature):

One point, at the center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Five stands to support air velocity sensors and other required instrumentation: (see Experiment 1).

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

This experiment is to run concurrently with Experiment 10.

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision and smoke tests: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-ups [monthly installation and teardown of air velocity sensor grid] plus two sensor-height changes per month: 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 24 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sectors (sector width = 22.5°). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____12____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Wind Tower Ducted-Supply 2-Stage Evaporative Cooling Mode/Inlet Alternate #2/Year 2

Location: G8 & U9

Duration (months, days, hours): May, June, and October (30/31 days in each of 4 months)

Objectives:

To determine the effectiveness of a wind tower in maintaining wind-driven 2-stage evaporative cooling and thermal comfort in the occupied zone (approx. 45 to 180 cm. above finished floor) of two typical residnetial-scale single-orientation (windows one wall only) rooms, and which receive tower air supply through a duct system when using a two-sided wind tower inlet ("Wind Tower Inlet Alternate #2) and comparing results with those obtained with the three-sided type of tower inlet (utilized in Experiments 6, 7, 8 and 9).

Experimental Procedure (how to achieve objectives):

a. Maintain Wind Tower Inlet Alternate #2 (Fig. X.J.9 & X.J.10).

b. Install Celdek (as wetted medium at top of tower, and as demisters behind each supply inlet (Fig. IV.B.6).

c. Install air velocity sensor grid and other required instrumentation in G8 & U9.

d. Close all operable windows in G8 & U9.

e. Adjust louvers of wind tower inlet, plus wind tower extractors (at connection to the supply ducts on both floors) plus deflector vanes at tower air supply inlets in G8 & U9, to maximize air velocity reading at grid station 3 (at center of room). Record all angles of adjustment.

f. Observe and record (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

g. Measure air velocities in G8 & U9 at 5 different points on plan (Fig. X.J.7) and at 3 different heights. Measure at lowest height (53 cm.) for 2 months; at middle height (114 cm.) for 2 months; and at top height (175 cm.) for 2 months. To ensure comparability of data, the same start/stop times should be used for each 2-month period.

h. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature, inside G8 & U9.

i. Reduce data to assess resulting comfort levels achieved in each room, during the "evaporative cooling-critical" months of the year.

j. At end of second month (June), remove Celdek wetted medium unit at top of wind tower, and replace with fog nozzles (if nozzles are not already installed).

k. Repeat steps c) through h), while operating fog nozzle system.

l. At end of this experiment, remove all Celdek pads both wetted media and demisters.

m. Experiment should be run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Maintain Steel-Framed Inlet Alternate #2 (see Fig. XII.10.1) at top of concrete section of wind tower, as used in Experiments 10 and 11.

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points: 5.3 m. height (= centerline of upper floor windows) and 2.425 m. height (= centerline of ground floor windows), at a location 150 feet (approx. 45 meters) directly north of the north facade of the building.

Wind Direction:

Two points, same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.7 for locations.

Radiant Temperature (incl. globe temperature):

One point, at center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

a. Five stands to support air velocity sensors and other required instrumentation (see Experiment 1).

b. "Celdek" pads, used both as the first of two alternative wetted media near the top of the wind tower; and as demisters located just behind each tower air supply inlet (used only in evaporative cooling modes).

c. A fog nozzle system, as the second alternative wetted medium system, near the top of the wind tower.

d. A two-stage evaporative cooling system.

e. White smoke candles (see Experiment 1).

Description:

The fog nozzle system will be developed from existing technology specifically for Experiments 12 & 13.

The two-stage evaporative cooling system contains the following components: A first stage, consisting of a low pressure-drop, low-friction heat exchanger, located near the top of the tower in a steel-framed tower expansion section, to be designed and developed from existing technology specifically for experiments 12 & 13, plus a second stage, located directly beneath the first stage, utilizing the "Celdek" or fog nozzle systems discussed above as wetted media.

Cost:

Fog Nozzle System: approximately $8,000 in materials

First stage of 2-stge Evaporative Cooling System: approximately $5,000 in materials.

Labor:

Fog Nozzle System: approximately $8,000 (design and fabrication)

First stage of 2-stage Evaporative Cooling System: approximately $12,000 (design and fabrication).

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

This experiment is to run concurrently with Experiment 13.

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours

Architect:

Supervision: 4 hours per month x 6 months = 24 hours

Technician:

Experiment set-ups [monthly installation and teardown of air velocity sensor grid plus two sensor-height changes per month]: 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 24 hours.

Reconfiguration [one change of Celdek for Fog Nozzles]: 8 hours per day x 1 day = 8 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sectors (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect

8 days (= 64 hours)

Technician

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No: ____13____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Wind Tower Direct-Supply 2-stage Evaporative Cooling Mode/Inlet Alternate #2/Year 2

Location: G2 & U1

Duration (months, days, hours): May, June & October (30/31 days in each of 4 months)

Objectives:

To determine the effectiveness of a wind tower in maintaining wind-driven 2-stage evaporative cooling and thermal comfort in the occupied zone (approx. 45 to 180 cm. above finished floor) of two typical residential-scale, single-orientation (windows one wall only) rooms, and which receive tower air supply directly from the wind tower when using a two-sided wind tower inlet ("Wind Tower Inlet Alternate #2") and comparing results with those obtained with the three-sided type of tower inlet (utilized in Experiments 6, 7, 8 and 9).

Experimental Procedure (how to achieve objectives):

a. Maintain Wind Tower Inlet Alternate #2 (Fig. X.J.9 & X.J.10).

b. Install Celdek (as wetted medium at top of tower, and as demisters behind each supply inlet (Fig. IV.B.6).

c. Install air velocity sensor grid and other required instrumentation in G2 & U1.

d. Close all operable windows in G2 & U1.

e. Adjust louvers of wind tower inlet plus wind tower extractors (at connection to the supply ducts on both floors) plus deflector vanes at tower air supply inlets in G2 & U1, to maximize air velocity reading at grid station 3 (at center of room). Record all angles of adjustment.

f. Observe and record (Polaroid flash photos) indoor airflow pattern using white smoke candles as flow tracers.

g. Measure air velocities in G8 & U9 at 5 different points on plan (Fig. X.J.8) and at 3 different heights. Measure at lowest height (53 cm.) for 2 months; at middle height (114 cm.) for 2 months; and at top height (175 cm.) for 2 months. To ensure comparability of data, the same start/stop times should be used for each 2-month period.

h. Make simultaneous measurements of outdoor wind speed and wind direction together with indoor dry bulb temperature, wet bulb temperature and radiant (globe) temperature, inside G8 & U9.

i. Reduce data to assess resulting comfort levels achieved in each room, during the "evaporative cooling-critical" months of the year.

j. At end of second month (June), remove Celdek wetted medium unit at top of wind tower, and replace with fog nozzles (if nozzles are not already installed).

k. Repeat steps c) through h), in July and October, while operating fog nozzle system.

l. At end of this experiment, remove all Celdek pads, both wetted media and demisters.

m. Experiments should be run in coordination with local weather forecasts, to avoid acquiring data during "atypical" weather conditions, e.g., during the passage of exceptional frontal systems, etc.

Configuration

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Maintain Steel-Framed Inlet Alternate #2 (see Fig. XII.10.1) top of concrete section of wind tower, as used in Experiments 10,11 and 12.

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each).

Barometric Pressure:

Relative Humidity:

Wind Speed:

Two points: 5.3 m. height (= centerline of upper floor windows) and 2.425 hm. height (= centerline of ground floor windows), at a location 150 geet (approx. 45 meters) directly north of the north facade of the building.

Wind Direction:

Two points; same as above.

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Wet Bulb Temperature:

One point, at center of room, 45 cm. above finished floor.

Heat Flux:

Light:

Air Velocity:

Five points; see Figure X.J.8 for locations.

Radiant Temperature (incl. globe temperature):

One point, at center of room, 45 cm. above finished floor.

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

a. Five stands to support air velocity sensors and other required instrumentation (see Experiment 1).

b. "Celdek" pads, used both as the first of two alternative wetted media near the top of the wind tower; and as demisters located just behind each tower air supply inlet (used only in evaporative cooling modes).

c. A fog nozzle system, as the second alternative wetted medium system, near the top of the wind tower.

d. A two-stage evaporative cooling system.

e. White smoke candles (see Experiment 1).

Description:

The fog nozzle system will be developed from existing technology sepcifically for Experiments 12 & 13.

The two-stage evaporative cooling system contains the following components: A first stage consisting of a low pressure-drop low-friction heat exchanger, located near the top of the tower in a steel-framed tower expansion section, to be designed and developed from existing technology specifically for experiments 12 & 13, plus second stage, located directly beneath the first stage, utilizing the "Celdek" or fog nozzle system discussed above as wetted media.

Cost:

Fog Nozzle System: approximately $5,000 in materials.

First Stage of 2-stage Evaporative Cooling System: approximately $5,000 in materials.

Labor:

Fog Nozzle System: approximately $5,000 (design and fabrication.

First Stage of 2-stage Evaporative Cooling System: approximately $8,000 (design and fabrication).

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

This experiment is to be run concurrently with Experiment 12.

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per month x 6 months = 12 hours.

Architect:

Supervision: 4 hours per month x 6 months = 24 hours.

Technician:

Experiment set-ups [monthly installation and teardown of air velocity sensor grid plus two sensor-height changes per month]: 1 hour per day x 2 days per month x 6 months (installation and teardown) plus 1 hour per day x 2 changes per month x 6 months (height changes) = 24 hours.

Reconfiguration [one change of Celdek for Fog Nozzles]: 8 hours per day x 1 day = 8 hours.

Computer Analyst/Programmer:

3 hours per month x 6 months = 18 hours.

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Correlate air velocity measurements over the period of the experiment with outdoor wind speed and direction at the same level above ground as the respective indoor measurements. Correlations should take the form of speed ratios or velocity coefficients, grouped by wind direction sectors (sector width = 22.5^{o}). These results should then be averaged over the period of the experiment, to obtain average speed ratios for each wind sector, and for each configuration at each floor of the building. In addition, average air velocity in the form of m/sec. results should be used to calculate average hourly PMV's (comfort levels) for these two rooms, for the period of the experiment.

Manpower requirements (hours):

Engineer:

5 days (= 40 hours)

Architect:

8 days (= 64 hours)

Technician:

30 minutes per day x 3 days = 1.5 hours

Computer Analyst/Programmer:

20 hours

Computer Requirements:

Data reduction, data anlaysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____14____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Building Loss Coefficient Determination

Location: Entire Building

Duration (months, days, hours): 72 hours (mid-winter)

Objectives:

Determine the building overall heat transfer loss coefficient for the building.

Experimental Procedure (how to achieve objectives):

The overall loss coefficient, L, should be measured by electric coheating at least at the beginning of the monitoring period (mid-winter) with simultaneous measurement of infiltration, I, using a tracer gas technique.

For electric coheating measurement of loss coefficient, the building furnace is shut off, circulating fans left running and heating temporarily assumed by thermostatically, metered portable electric convection heaters distributed throughout the house. The building should be unoccupied, with as little light and appliance gain as possile and have been held at a constant temperature for several days to reduce thermal storage effects. The tests should be performed on a night whose temperature is at least 14C lower than the interior temperature and fairly constant.

Determine the building loss coefficient (or envelope transmission and infiltration loss coefficient not including passive apertures). (see Appendix X for more details).

Configuration:

General Structure Configuration (system configuration, openings etc):

All closed.

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

HVAC system off.
Circulation fan on.

Windows: All closed

Other operable openings (doors, louvers etc): All closed

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity: 1 data point at weather station

Wind Speed: 6 data points from weather towers

Wind Direction: 6 data points from weather towers

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature: All temperature sensing stations

Wet Bulb Temperature:

Heat Flux:

Light: All windows

Air Velocity:

Radiant Temperature (incl. globe temperature):

Flow:

Power: Electric heaters

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Thermostatically controlled and metered portable electric convection heaters. (8 Kwe) (8 unit heaters @1 Kwe/unit)

Description:

Heaters should be thermostatically controlled, separately metered and distributed throughout the building.

Cost: $500

Labor: Installation performed in Experiment 15

Experimental Operation (incl. setup and reconfiguration):

Experiment 15, Overall Loss Coefficient
Experiment 16, Infiltration measurement with tracer gas.

Manpower Requirements (hours):

Engineer:

Architect:

Technician:

Computer Analyst/Programmer:

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Based upon the inside and outside temperatures, wind velocity and electric power consumption of the heaters determine the overall loss coefficient. L = (total metered energy)/(Tinside - Toutside)

Manpower requirements (hours):

Engineer: 1 man hour

Architect:

Technician:

Computer Analyst/Programmer:

Computer Requirements: data reduction and calculations

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____15____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Overall Loss Coefficient Determination

Location: Entire Building

Duration (months, days, hours): 72 hours (mid-winter)

Objectives:

Determine the overall heat transfer loss coefficient for the building.

Experimental Procedure (how to achieve objectives):

The overall loss coefficient, L, should be measured by electric coheating at least at the beginning of the monitoring period (mid-winter) with simultaneous measurement of infiltration, I, using a tracer gas technique.

For electric coheating measurement of loss coefficient, the building furnace is shut off, circulating fans left running and heating temporarily assumed by thermostatically, metered portable electric convection heaters distributed throughout the house. The building should be unoccupied, with as little light and appliance gain as possible and have been held at a constant temperature for several days to reduce thermal storage effects. The tests should be performed on a night whose temperature is at least 14C lower than the interior temperature and fairly constant. (see Appendix X for more details).

Configuration:

General Structure Configuration (system configuration, openings etc):

All closed.

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

HVAC heat off
Circulation fan on

Windows: All closed

Other operable openings (doors, louvers, etc): All closed

Other (please specify):

Status of inoperative components that affect experiment:

Measured Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity: 1 data point at weather station

Wind Speed: 6 data points from weather towers

Wind Direction: 6 data points from weather towers

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature: All temperature sensing stations

Wet Bulb Temperature:

Heat Flux:

Light: All windows

Air Velocity:

Radiant Temperature (incl. globe temperature):

Flow:

Power: Electric heaters

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Thermostatically controlled and metered portable electric convection heaters. (8 Kwe) (8 unit heaters @1 Kwe/unit)

Description:

Heaters should be thermostatically controlled, separately metered and distributed throughout the building.

Cost: $500

Labor: 10 man hours for installation

Experimental Operation (incl. setup and reconfiguration):

Experiment 14, Building Loss Coefficient
Experiment 16, Infiltration measurement with tracer gas

Manpower requirements (hours):

Engineer: 24 hours

Architect: 8 hours

Technician: 24 hours

Computer Analyst/Programmer: 2 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Based upon the inside and outside tempertures, wind velocity and electric power consumption of the heaters determine the overall loss coefficient. L = (total metered energy)/(Tinside - Toutside).

Manpower requirements (hours):

Engineer: 8 man hours

Architect: 2 hours

Technician:

Computer Analyst/Programmer: 2 hours

Computer Requirements: data reduction and calculations.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____16____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Air Infiltration

Location: Entire Building

Duration (months, days, hours): 72 hours (mid-winter)

Objectives:

Determine the air infiltration rate of the building utilizing tracer gas dilution techniques (see Appendix X).

Experimental Procedure (how to achieve objectives):

Appendix X contains detailed step by step procedures for this experiment. (see Appendix X for details).

Configuration:

General Structure Configuration (system configuration, openings etc):

All closed

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

HVAC heat off
Circulation fan on

Windows: All closed

Other operable openings (doors, louvers etc): All closed

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each:

Barometric Pressure: Measure atmospheric

Relative Humidity: 1 data point at weather towers

Wind Speed: 6 data points from weather towers

Wind Direction: 6 data points from weather towers

Sky Radiation:

Earth Temperature:

Dry Bulb Temperature: All temperature sensing stations

Wet Bulb Temperature:

Heat Flux:

Light: All windows

Air Velocity:

Radiant Temperature (incl. globe temperature):

Flow:

Power: Electric heaters

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

1 liter SF6 gas
50 ml syringes - for injecting SF6 into building
5 ml syringes - for taking samples
plastic valves to seal syringes
column for gas chromagraph
Gas Chromatograph (available at ERL)

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Experiment 14, Building Loss Coefficient
Experiment 15, Overall Loss Coefficient

Manpower requirements (hours):

Engineer: 24 hours

Architect: 12 hours

Technician: 2 hours

Computer Analyst/Programmer:

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Concentrations of SF6 in the air sample will be analyzed by gas chroatography using an electron capture detector. According to the ASTM Standard, the gas analyzer needs to be calibrated—either by the manufacturer or by using standard mixtures of at least two different concentrations. From the results the air infiltration rate can be calculated utilizing least squares regression techniques. This analysis can be performed at the ERL Fleischman Laboratory utilizing the gas chromatograph equipment.

Manpower requirements (hours):

Engineer: 40 hours

Architect: 10 hours

Technician: Lab Technician: 40 hours

Computer Analyst/Programmer: 5 hours

Computer Requirements: data reduction and calculations

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____17____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Baseline Thermal Performance

Location: Entire Building

Duration (months, days, hours): 2 months (July and August)

Objectives:

To determine the baseline, to operate in the as designed mode for the backup AC system. Adjust thermostat to the 15C setpoint and allow the AC to track the temperture setpoint. Isolate the building from all uncontrollable external influences.

Configuration:

General Structure Configuration (system configuration, openings ets):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

HVAC system on
Circulation fan on

Windows: All closed

Other operable openings (doors, louvers etc): All closed

Other (please specify):

Status of inoperative components that affect experiments:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure: Measured

Relative Humidity: 1 data point at weather station

Wind Speed: 3 data points from weather towers

Wind Direction: 3 data points from weather towers

Sky Radiation: Measured

Earth Temperature:

Dry Bulb Temperature: All temperature sensing stations

Wet Bulb Temperature: All stations

Heat Flux: All stations

Light: All windows

Air Velocity: All stations

Radiant Temperature (incl. globe temperature):

Flow:

Power: Electric heaters

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Manpower requirements (hours):

Engineer: 20 hours

Architect: 20 hours

Technician: 10 hours

Computer Analyst/Programmer: 5 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished:

Calculate the Fanger thermal comfort index (PMV) from collected data. Calculate energy required to maintain the thermal comfort and store for future reference for other experiments. Determine HVAC system performance and compare measured loads to loads calculated by BLAST, CALPAS or MICROPAS, and ERL PASSCOOL.

Manpower requirements (hours):

Engineer: 80 hours

Architect: 20 hours

Technician: 2 hours

Computer Analyst/Programmer: 80 hours

Computer Requirements: data reduction and calculations

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____18____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Air Flow Rate Measurements

Location: Entire Building

Objectives:

To determine the volumetric air flow rates of all powered ventilation and circulation fans.

Experimental Procedure (how to achieve objectives):

Utilizing a portable air velocity instrument measure the volumetric air flow rate of all sourcs of powered ventilation and circulation. Where necessary perform traverses across the flow path.

Configuration:

General Structure Configuration (system configuration, openings etc):

All closed

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

HVAC system on as required
Circulation fans on as required

Windows: All closed

Other operable openings (doors, louvers etc): All closed

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure: Measured

Relative Humidity: 1 data point at weather station

Wind Speed: 3 data points from weather towers

Wind Direction: 3 data points from weather towers

Sky Radiation: Measured

Earth Temperature:

Dry Bulb Temperature: All temperature sensing stations

Wet Bulb Temperature: All stations

Heat Flux: All stations

Light: All windows

Air Velocity: All stations

Radiant Temperature (incl. globe temperature):

Flow:

Power: Electric heaters

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Description:

Cost:

Labor:

Experimental Operation (icnl. setup and reconfiguration:

Manpower requirements (hours):

Engineer: 24 hours

Architect: 10 hours

Technician: 24 hours

Computer Analyst/Programmer:

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Develop volumetric air flow curves for all powered ventilation and circulation equipment inorder to determine heat loss/gain due to powered ventilation equipment and also to establish the baseline air velocity due to circulation fans suitable for incorporation in Fanger PMV analysis.

Manpower requirements (hours):

Engineer: 8 hours

Architect:

Technician:

Computer Analyst/Programmer:

Computer Requirements: data reduction and calculations

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____19____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Passive Solar Batch Type Water Heater Collection Efficiency Performance (#1)

Location:

Duration (months, days, hours): 12 hours

Objectives:

The objective is to determine the collection efficiency of the passive batch type solar water heating system for a 10 hour period. This is a difficult task due to the 160 liter storage tanks in each sealed collector. Because of the difficulties involved, standard efficiency tests for batch type units have not yet been devised. This will require ERL to design their own efficiency tests.

Two methods will be discussed to accomplish this objective.

Experimental Procedure (how to achieve objectives):

The collection efficiency can be measured by emptying and refilling the system early in the morning with water of a known temperature, or the collectors can be covered for several days prior to the experiment. Then by running several liters of water through the collectors, the initial temperature can be determined for each collector by using the thermocouple located between each one. In the evening of the same day, the system can be drained to measure the temperature and thus the days energy gain on the array of collectors. This would be accomplished by closing the supply valve, to prevent the system from refilling with water. A correction is necessary with this method because a few liters of water would remain in each tank and be a source of error. If the drained volume were accurately measured, the amount left in each tank could be calculated, and a correction applied.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling deviced (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Other (please specify):

All point-of-use hot water valves to be shut off tightly

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed: Both sensors

Wind Direction: Both sensors

Sky Radiation: Total solar in plane of roof

Earth Temperature:

Dry Bulb Temperature: 8 locations in Solar Domestic Water System

Wet Bulb Temperature: Ambient

Heat Flux:

Light:

Air Velocity:

Radiant Temperature (incl. globe temperature:

Flow:

Power:

Pressure: Water supply pressure

Specialized Equipment Required:

Equipment/Apparatus:

Replace pressure relief valve with a drain valve; certified thermometer (or calibrated thermometer); graduated, insulated, catchment device (20 liter capacity).

2 cm. hose x 10 m
5 - plywood or canvas covers for the collectors.

Description: Collectors should be covered 4 days prior to experiment.

Cost: $200

Labor: Technician, 4 hours

Experimental Operation (incl. setup and reconfiguration):

Setup:

Collectors should be covered 4 days prior to experiment, unless they are drained and refilled with water of a known temperature during the early morning before the experiment is run.

Concurrent Experiments:

Any of the HVAC experiments can be run concurrently with this one.

Manpower requirements (hours):

Engineer: 4 hours/test x 5 tests = 20 hours

Architect: 2 hours/test x 5 tests = 10 hours

Technician: 16 hours x 5 tests = 80 hours

Computer Analyst/Programmer: 2 hours

Analysis of Experimental Results:

Description (how the analysis is to be acomplished):

Compare available solar insolation with energy collected and correct for water left in the system. Derive efficiency. Efficiency should vary as a function of ambient temperature and solar insolation. This experiment could be run 4 or 5 times under varying conditions to determine this relationship.

Manpower requirements (hours):

Engineer: 5 tests x 8 hours = 40 hours

Architect: 40 hours

Technician: 5 hours

Computer Analyst/Programmer:

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____20____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Passive Solar Batch Type Water Heater Collection Efficiency Performance (#2)

Location:

Duraction (months, days, hours):

Objective:

The objective is to determine the efficiency of the Passive Batch Type Solar Water Heating System for a 10 hour collection period. This is a difficult task due to the 160 liter storage tanks in each sealed collector. Because of the difficulties involved, standard efficiency tests for batch type units have not yet been devised. This will require ERL to design their own efficiency tests.

Two methods will be discussed to accomplish this objective.

Experimental Procedure (how to achieve objectives):

A BTU meter or a flow meter connected to the data acquisition system can be used to measure the useful energy collected by the system. The BTU meter has a multi-wing turbine flow meter and two temperature probes. The flow rate and temperature change is converted electronically into BTU's.

At the end of the solar day, 800 liters or more of water would be drawn from the system. Meter readings will indicate the BTU's taken out of the storage tanks. The efficiency can then be determined by comparing this to the insolation for that day. Although this procedure does not require draining the system, the collectors should be covered for four days prior to the experiment and the initial collector temperatures noted. If collectors cannot be covered during the 4 days prior to the test, then drain the system and refill with water of a known temperature before beginning the experiment.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used time on/off etc:

Windows:

Other operable openings (doors, louvers etc):

Shut all hot water valves tightly. (kitchen, bathrooms, washing machine, etc.)

Other (please specify):

Three way diverting valve near backup hot water heater set to bypass the water heater. Water heater turned off.

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed: Both locations

Wind Direction: Both locations

Sky Radiation: Total solar radiation in plane of collectors

Earth Temperature:

Dry Bulb Temperature: 8 locations in solar domestic water system

Wet Bulb Temperature: Ambient

Heat Flux:

Light:

Air Velocity:

Radiant Temperature (incl. globe temperature):

Flow:

Totalizing flow meter in domestic hot water system.

Power:

Pressure:

Water system pressure (above main pump)

BTU Meter: Read hourly

Specialized Equipment Required:

Equipment/Apparatus: 5 covers for solar collectors

Description: Collectors should be covered 3 days prior to experiment. The system can be drained through the relief valve if necessary.

Cost: $100 - covers

$440 - BTU meter

Labor: Technician - 3 hours

Experimental Operation (incl. setup and reconfiguration):

Setup:

Collectors should be covered 3 days prior to experiment, unless they are drained and refilled with water of a known temperature during the early morning before the experiment is run.

Concurrent Experiments:

Any HVAC type experiment can run concurrently with this experiment.

Manpower requirements (hours):

Engineer: 10 hours/test x 5 tests = 50 hours

Architect: 3 hours/test x 5 tests = 15 hours

Technician: 2 hours

Computer Analyst/Programmer: 2 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Compare available solar insolation with energy collected and correct for water left in the system. Derive efficiency. Efficiency should vary as a function of ambient temperature and solar insolation. This experiment should be run 4 or 5 times under varying conditions to determine this relationship.

Manpower requirements (hours):

Engineer: 5 tests x 5 hours = 25 hours

Architect: 5 tests x 1 hour = 5 hours

Technician: 2 hours

Computer Analyst/Programmer: 5 hours

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____21____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Energy Storage Efficiency of the Solar Water Heaters

Location:

Duration (months, days, hours): 24 hours

Objectives:

To determine the 24 hour heat loss rate of the batch type solar water heating system. This will be useful to predict how much hot water will be available in the morning, or during cloudy periods, and also to verify the computer program written to simulate this system.

Experimental Procedure (how to achieve objectives):

Once the collection efficiency is known, the useful daily energy gain can be calculated by knowing the insolation. By using one of the methods described in experiment #1 or #2, the remaining energy level of the storage system can be determined for the following morning. The efficiency of the storage depends upon the ambient temperature and the previous days insolation. This test should be done both during the winter and the summer.

Configuration:

General Structure Configuration (system configuration, openings etc):

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Other (please specify): Shut off all hot water valves tightly.

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity:

Wind Speed: Both locations

Wind Direction: Both locations

Sky Radiation: Total solar in plane of collectors

Earth Temperature:

Dry Bulb Temperature: 8 locations in the solar water heating system.

Wet Bulb Temperature: Ambient

Heat Flux:

Light:

Air Velocity:

Radiant Temperature (incl. globe temperature):

Flow: Hot water system

Power:

Pressure: Water system pressure

BTU Meter: Read hourly

Specialized Equipment Required:

Equipment/Apparatus:

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments: 5 hours

Manpower requirements (hours):

Engineer: 5 hours

Architect: 2 hours

Technician: 3 hours

Computer Analyst/Programmer: 1 hour

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Manpower requirements (hours):

Engineer: 15 hours/experiment

Architect: 1 hour

Technician: 2 hours

Computer Analyst/Programmer: 1 hour

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____22____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: The Effect of Changing the Thermostrat Set Point on Energy Consumption.

Location:

Duration (months, days, hours): 20 days

Obejctives:

The object of the experiment is to study the effect of changing the thermostat set temperature on energy consumption by the HVAC system.

Experimental Procedure (how to achieve objectives):

The thermostat set temperture is to be increased and the energy consumption by the HVAC equipment is to be measured and compared to the normal operating set point.

The same thing can be done by using a night set back.

Configuration:

General Structure Configuration (system configuration, openings etc):

Windows, wind tower, doors, all shut

Fans, Cooling devices (locations, speeds, air flow rate, controls used time on/off etc):

Thermostats set progressively from 68 to 78 in 2^{o} increments. Run building at each setting for at least 4 days.

Windows: Shut

Other operable openings (doors, louvers etc):

Other (plese speacify):

Status of inoperative components that affect experiment:

No internal loads

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity: Each room and outside ambient

Wind Speed: Hourly

Wind Direction: Hourly

Sky Radiation: Total insolation

Earth Temperature: All locations

Dry Bulb Temperature: Each room and outside ambient

Wet Bulb Temperature: Each room and outside ambient

Heat Flux: All sensors

Light:

Air Velocity: All sensors

Radiant Temperature (incl. globe temperature): All sensors

Flow:

Power: Air-conditioning equipment

Pressure:

Specialized Equipment Required:

Equipment/Apparatus: None

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments: Solar hot water system

Manpower Requirements (hours):

Engineer: 10 hours

Architect: 5 hours

Technician: 3 hours/experiment x 5 = 15 hours

Computer Analyst/Programmer: 5 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Compare energy usage for the various setpoints by normalizing the data to the load.

Manpower Requirements (hours):

Engineer: 60 hours

Architect: 10 hours

Technician: 10 hours

Computer Analyst/Programmer: 20 hours

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____23____

Start Date: _____ Time: _____ Stop Date: _____ Time: _____

Name of Experiment: Duty Cycling of Air-Conditioning Equipment, Optimum Start-Stop & Building Time Constant

Location:

Duration (months, days, hours): 10 days

Objectives:

To evaluate the energy savings realized by shutting off the cooling system for 10-15 minutes every hour (is this practical in a house?). Evaluate any changes in comfort.

Also could investigate optimum start-stop.

Duty cycling is done in commercial buildings to keep peak loads lower, which can lower electric costs, depending on the rate structure.

Experimental Procedure (how to achieve objectives):

Connect the air-conditioning systems to a timing device that will turn off some or all of the four units periodically each hour. Record energy consumption during the test and discuss the rate structure with the local utility to see if such a strategy could benefit the user or the power company.

Configuration:

General Structure Configuration (system configuration, openings etc):

Windows shut, wind tower shut

No internal loads

Fans, Cooling devices (locations, speeds, air flow rate, controls used time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity: Each room and outside ambient

Wind Speed: Hourly

Wind Direction: Hourly

Sky Radiation: Total solar insolation

Earth Temperature: All locations

Dry Bulb Temperature: Each room and outside ambient

Wet Bulb Temperature: Each room and outside ambient

Heat Flux: All sensors

Light:

Air Velocity:

Radiant Temperature (incl. globe temperature): All locations

Flow:

Power: AC units

Pressure:

Special Equipment Required:

Equipment/Apparatus:

A timer to control thermostats or a computer program if the system is computer controlled.

Description:

Room thermostats can be wired in series with a timer to lock out the AC system during an off duty cycle, or the computer can open a relay instead of using an additional timer.

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Operate building AC system in the duty-cycle mode for at least 48 hours; a week would be better.

Manpower Requirements (hours):

Engineer: 3 hours

Architect: 1 hour

Technician: 20 hours

Computer Analyst/Programmer: 8 hours - (more if a control program has not yet been written).

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Determine the amount by which the cooling energy cost could be reduced by duty cycling. Determine the effect this has on the comfort of the occupants by the PMV method.

Manpower Requirements (hours):

Engineer: 35 hours

Architect: 2 hours

Technician: 2 hours

Computer Analyst/Programmer: 5 hours

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____24____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Room Temperature Response to a Sudden Heat Disturbance Input

Location:

Duration (months, days, hours):

Objectives:

The objective of the experiment is to study the reaction of the control system to a sudden application of load. This sudden disturbance input might be people, lights, change in outside conditions, etc. The temperature in the room will change also (float).

Experimental Procedure (how to achieve objectives):

A sudden heat disturbance can be applied using portable electric heaters. The temperature in the room is to be measured at different time intervals and a plot of temperature versus time can be obtained. Also, the power consumption of the HVAC system can be measured and compared to normal operation conditions.

Configuration:

General Structure Configuration (system configuration, openings etc):

System in normal air-conditioning mode of operation.

Fans, Cooling Devices (locations, speeds, air flow rate, controls used, time on/off etc):

Air-conditioner on auto thermostat

Windows: Closed

Other operable openings (doors, louvers etc): Closed

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity: Each room and ambient

Wind Speed: Hourly

Wind Direction: Hourly

Sky Radiation: Hourly

Earth Temperature:

Dry Bulb Temperature: Hourly at each temperature station.

Wet Bulb Temperature: Hourly at each temperature station.

Heat Flux: Each location

Light: Hourly at each temperature station

Air Velocity: Hourly at each temperature station

Radiant Temperature (incl. globe temperature): Hourly

Flow:

Power: Hourly supply to cooling system

Pressure:

Specialized Equipment Required:

Equipment/Apparatus: Electric resistance heaters

Description: The electric heaters will be used to apply a sudden and controlled load to the HVAC system.

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments: Solar hot water heating system

Manpower Requirements (hours):

Engineer: 2 hours

Architect: 1 hour

Technician: 8 hours

Computer Analyst/Programmer: 1 hour

Anslysis of Experimental Results:

Description (how the analysis is to be accomplished):

Use PMV method to evaluate comfort levels before, during and after the disturbance. Determine building response.

Manpower Requirements (hours):

Engineer: 40 hours

Architect: 2 hours

Technician: 2 hours

Computer Analyst/Programmer: 1 hour

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No. ____25____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Off Peak Cooling

Location:

Duration, (Months, days, hours):

Objectives:

The objective is to compare energy requirements, energy cost, and comfort levels of off peak cooling to full day cooling. Off peak cooling is the practice of running the cooling equipment only during the evening and nighttime (5 p.m. until 8 a.m.). Many utilities offer reduced rates for usage during these hours, because it reduces their peak generating capacity and increases their base load.

This strategy is feasible in a high mass building because it has a high thermal storage capacity, and will attenuate temperature swings. Ceiling fans may be used during afternoon hours to increase comfort and enhance convection from the cool walls.

Experimental Procedure (how to achieve objectives):

Run AC equipment at full capacity (all units) only during the hours of 5 p.m. until 8 a.m. Thermostats may need to be set a few degrees below normal controll setpoint. Monitor the energy consumption during an experimental period of at least 5 days.

Configuration:

General Structure Configuration (system configuration, openings, etc):

Unoccupied Building.
No internal loads.

Fans, Cooling devices (locations, speeds, air flow rate, controls used time on/off etc):

All air conditioners turned off during the hours of 8 a.m. to 5 p.m.

Windows:

Closed

Other operable openings (doors, louvers etc):

Wind tower dampers closed

Doors closed

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number or data points and locations for each.)

Barometric Pressure:

Relative Humidity: Ambient and each zone

Wind Speed: Both locations

Wind Direction: Both locations

Sky Radiation: Total solar

Earth Temperature: All sensors

Dry Bulb Temperature: Ambient and each zone

Wet Bulb Temperature:

Heat Flux:

Light:

Air Velocity:

Radiant Temperature (incl. globe temperature): Each zone

Flow:

Power: AC system

Pressure:

Speciualized Equipment Required:

Equipment/Apparatus: None

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer: 10 hours

Architect: 4 hours

Technician: 12 hours

Computer Analyst/Programmer: 2 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished:

Compare cooling energy consumption of controll period to off peak cooling period. The energy consumption must be normalized to the climatic load conditions. Energy comparisons should then be made on a KW per BTU basis.

Manpower requirements (hours):

Engineer: 40 hours

Architect: 5 hours

Technician: 2 hours

Computer Analyst/Programmer: 4 hours

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No. ____26____

Start Date: _____ Time: _____ Stop Date: _____ Time: _____

Name of Experiment: Derated AC Capacity

Location:

Duration (months, days, hours):

Objectives:

The objective is to run the air conditioning equipment at a reduced capacity to determine if the cooling energy requirement will be reduced. Reducing the capacity will cause the air conditioning equipment to run longer but at a lower electrical energy input. Cooling efficiency should be increased due to less cycling, and the high mass of the the building will prevent large temperatures savings. Another objective is to determine the proper amount of derating to cause the compressors to run 24 hours per day; and keep the building within the comfort range.

Experimental Procedure (how to achieve objectives):

Derating the total building cooling capacity can be accomplished by selectively turning off various fan-coil units throughout the building. The cooling energy is to be measured for a period of at least 5 days, for various amounts of derating (5 tons, 4 tons, 3 tons), and comparing this to a time period of equal length when the system was running at full capacity (6 tons).

Congifuration:

General Structure Configuration (system configuration,openings etc):
Building unoccupied

Fans, Cooling devices (locations, speeds, air flow rate, controls uses, time on/off etc):

All ceiling fans and other air circulating equipment on. Various individual fan coil units turned off (one in kitchen, one in main entry, etc.) Thermostats at the same setting as during the full capacity controll segment of this experiment.

Windows: Closed

Other operable openings (doors, louvers etc):

Wind tower dampers shut

Other (please specify):

Status of inoperative components that affect experiment:

Turn off all internal loads.

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity: Each location

Wind Speed: Both locations

Wind Direction: Both locations

Sky Radiation: Total solar

Earth Temperature: All locations

Dry Bulb Temperature: Ambient and each zone

Wet Bulb Temperature: Ambient and each zone

Heat Flux:

Light:

Air Velocity:

Radiant Temperature (incl. globe temperature): Each zone

Flow:

Power: Air conditioning equipment

Pressure:

Specialized Equipment Required:

Equipment/apparatus: None

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer: 10 hours

Architect: 4 hours

Technician: 10 hours x 5 experiments = 50 hours

Computer Analyst/Programmer: 1 hour

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Compare energy consumption of each derating to the control run. This must be normalized using the ambient temperatures and solar gain. The wind speed should also be used to determine infiltration. Comparisons between the various load deratings should be made on a KW per BTU basis.

Manpower requirements (hours):

Engineer: 20 hours/run x 5 = 100 hours

Achitect: 20 hours

Technician: 2 hours

Computer Analyst/Programmer: 4 hours/run x 5 = 20 hours

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____27____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Window Film

Location:

Duration (months, days, hours): 2 years

Objectives:

The objective is to compare the HVAC energy consumption of the building with and without reflective window films. The building would first be operated for a year without window films, noting the energy usage for both the heating and cooling season. Then during the second year add a reflective film and compare the buildings energy consumption to the first year.

Experimental Procedure (how to achieve objectives:

Seasonal energy consumption will be acquired for a year both before and after the window films are applied. Due to changes in weather from year to year, a direct comparison of energy consumption will not be accurate. The data will need to be normalized using average ambient temperature, and total solar radiation.

The window films are applied to the inside surface of the glass.

Congifuration:

General Structure Configuration (system configuration, openings etc):

The building should be operated for a period of four weeks during both the winter and summer without opening any windows, or using the wind tower.

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

HVAC system turned on and set to a fixed temperature for that season. If adjustable differential thermostats are in use, it is important to record the differential and not change it at any time during the experiment.

Windows: Closed

Other operable openings (doors, louvers etc):

Wind tower damper closed

Other (please specify):

Status of inoperative components that affect experiments:

Internal loads (lights, appliances, people) should be kept to a minimum which requires an unoccupied building. An accurate log of lights, appliances, occupants, etc., needs to be kept.

Measurements Required (For each measurement enter the numbr of data points and locations for each.)

Barometric Pressure:

Relative Humidity: Ambient, each zone of building

Wind Speed: Both locations

Wind Direction: Both locations

Sky Radiation: Total solar

Earth Temperature:

Dry Bulb Temperature: Ambient, each zone of building

Wet Bulb Temperature: Ambient, each zone of building

Heat Flux:

Light: Solar gain at each window

Air Velocity: Each zone of building.

Radiant Temperature (incl. globe temperature): Each zone of building

Flow:

Power: Air conditioning and heating energy consumed

Pressure:

Specialized Equipment Required:

Equipment/Apparatus: Reflective window films applied to each window.

Description: The applied window films should have the following Optical Properites:

Solar Energy

Directly Transmitted 19%
Reflected. 50%
Absorbed 31%
Total Solar Energy Rejected. 75%

Visible Light Transmitted. 24%
Emissivity 27

Total U Value

Median	.76 $BTU/hr/ft^2/^oF$	3.7 $Kcal/hr/m^2/^oC$
Design	.84 $BTU/hr/ft^2/^oF$	4.1 $Kcal/hr/m^2/^oC$
Summer	.85 $BTU/hr/ft^2/^oF$	4.15 $Kcal.hr/m^2/^oC$

Cost: $3.00/square foot installed x 150 square feet = $450

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer: 12 hours

Architect: 4 hours

Technician: 30 hours

Computer Analyst/Programmer: 12 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Unless climatic conditions are very close to the same for the experimental period during each year; the data must be normalized by using the average ambient temperature and the total solar radiation which would affect the heating and cooling loads.

Manpower requirements (hours):

Engineer: 100 hours

Architect: 30 hours

Technician: 2 hours

Computer Analyst/Programmer: 40 hours

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____28____

Start Time: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: The Effect of Cooling Thermostat Hysteresis on Required Cooling Energy

Location: Entire building

Duration (months, days, hours): 5 days at each of 5 different settings

Objective:

To evaluate the cooling system energy requirements with different amounts of hysteresis on the cooling thermostat.

Experimental Procedure (how to achieve objectives):

This experiment is based on having a thermostat (or other means of control such as a differential controller) which allows variation of the hysteresis (i.e., the temperature difference below the cooling setpoint to which the system will cool the space before shutting off). The system should be operated for a period of several days at each setting, with hysteresis values of $0^{o}F$, $1^{o}F$, $2^{o}F$, $3^{o}F$, and $4^{o}F$. The total cooling energy consumption, system on-off times, and selected other parameters should be recorded and analyzed. It is expected that the system will perform better at higher values.

Configuration:

General Structure Configuration (system configuration, openings etc):

System in normal cooling operation, with hysteresis adjusted accordingly. All doors and windows shut with wind tower sealed off. No internal Load, (lights, water heater, appliances, people, etc.).

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows: Closed

Other operable openings (doors, louvers etc): Doors closed.

Other (please specify):

Status of inoperative components that affect experiment:
No internal loads

Measurements Required (For each measurement enter the number of data points and locations for each):

Barometric Pressure:

Relative Humidity: Indoor and outdoor

Wind Speed: Both locations

Wind Direction: Both locations

Sky Radiation: Total solar

Earth Temperature: Probes under building

Dry Bulb Temperature: Indoor and outdoor, possibly coil temperatures

Wet Bulb Temperature: Indoor and outdoor

Heat Flux:

Light:

Air Velocity: All zones

Radiant Temperature (incl. globe temperature): All indoor sensors

Flow:

Power: Hourly readings of cooling system power and total energy requirements for duration of experiment

Pressure:

Cooling System On/Off Control Signal: Continuously monitored and recorded on strip chart or mag tape

Specialized Equipment Required:

Equipment/Apparatus:

May require a special thermostat or suitable control device which will allow adjustment of the hysteresis. Computer control would be the most ideal for this experiment.

Description:

Cost: 10 controllable differential thermostats @ $150 each = $1,500.

Labor:

Technician: 5 hours/setting x 5 settings = 25 hours

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments:

Manpower requirements (hours):

Engineer:

Supervision: 2 hours per day x 5 days x 5 settings = 50 hours

Architect: 20 hours

Technician: 10 hours

Computer Analyst/Programmer: 2 hours per/setting 2 x 5 = 10 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Compare the energy use over a fixed period of time for each hysteresis setting, and develop a relationship. Consideration should be given to:

- thermal time lag associated with high building mass
- system operation at part-load
- sacrifice in comfort by allowing up to $4^{o}F$ variation in room temp
- benefit in morning daylight hours (~6-12 noon) if building is cooled up to $4^{o}F$ below set point before the external load gets too high. The system should stay off considerably longer, and when it comes on it should operate more efficiently at a higher load.

Manpower requirements (hours):

Engineer: 50 hours

Architect: 20 hours

Technician: 10 hours

Computer Analyst/Programmer: 20 hours

Computer Requirements: Data reduction, data analysis and computer modeling.

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____29____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Room Temperature Response of Building With System Off ("Float Temperature")

Location: Entire building

Duration (months, days, hours): 10 days in summer

Objectives:

To determine the steady-state temperature response of the building with no cooling provided. This includes:

1. Time of occurrence of peak room temperature for each room
2. Magnitude of peak temperature for each room
3. Plot of temperature versus time for each room

Experimental Procedure (how to achieve objectives):

Monitor and record room temperatures, and other desired data, at least hourly while system is off. Building should have windows, doors and wind tower closed, with no internal load.

Configuration:

General Structure Configuration (system configuration, openings etc):

Windows, doors and wind tower closed.

AC system off for several days before experiment to allow building to reach equilibrium.

No internal load.

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

Windows:

Other operable openings (doors, louvers etc):

Other (please specify):

Status of inoperative components that affect experiment:

Weather conditions: total solar insolation, wind speed and direction, ambient temperature.

Curtains

Landscaping (shade, ground reflectivity)

Color of building exterior and roof

Month of the year (earth temperatures vary seasonally)

Measurements Required (For eah measurement enter the number of data points and locations for each.)

Barometric Pressure:

Relative Humidity: Hourly. Each room and outside ambient.

Wind Speed: Hourly

Wind Direction: Hourly

Sky Radiation: Total solar insolation

Earth Temperature: All locations

Dry Bulb Temperature: Hourly. Each room and outside ambient.

Wet Bulb Temperature: Hourly. Each room and oustide ambient.

Heat Flux: All locations

Light:

Air Velocity: All locations

Radiant Temperature (incl. globe temperature): All locations

Flow:

Power:

Pressure:

Specialized Equipment Required:

Equipment/Apparatus: None

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Concurrent Experiments: Solar Water Heaters

Manpower Requirements (hours):

Engineer: 10 hours

Architect: 5 hours

Technician: 2 hours

Computer Analyst/Programmer: 2 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Note the time of occurrence of peak loads for each room and try to characterize the "time lag" of the building.

Note if there are any significant differences between rooms and try to explain the differences.

Look for a very flat profile (i.e., very little difference in high and low temperature during the day).

Manpower Requirenents (hours):

Engineer: 60 hours

Architect: 5 hours

Technician: 2 hours

Computer Analyst/Programmer: 10 hours

Computer Requirements: Data reduction

EXPERIMENTAL PLAN
KING FAISAL UNIVERSITY
PASSIVE SOLAR COOLING PROJECT

Experiment No.: ____30____

Start Date: ______ Time: ______ Stop Date: ______ Time: ______

Name of Experiment: Effects of Louvered Roof Shading

Location: Entire Building

Duration (months, days, hours): 4 months (July and August - 1985 & 1986)

Objectives:

To determine the thermal and comfort effects of the louvered roof shade.

Experimental Procedure (how to achieve objectives):

Measure the thermal comfort (Fanger PMV) of the terrace area both with the roof shade and without. In addition calculate and measure the building performance both with the roof shade and without. During July and August 1985, with the roof shade installed, and in July and August 1986, with roof shade removed.

Configuration:

General Structure Configuration (system configuration, openings etc):

All closed

Fans, Cooling devices (locations, speeds, air flow rate, controls used, time on/off etc):

HVAC system on as required
Circulation fans on as required

Windows: All closed

Other operable openings (doors, louvers etc): All closed

Other (please specify):

Status of inoperative components that affect experiment:

Measurements Required (For each measurement enter the number of data points and locations for each.)

Barometric Pressure: Measured

Relative Humidity: 1 data point at weather station

Wind Speed: 3 data points from weather towers

Wind Direction: 3 data points from weather towers

Sky Radiation: Measured

Earth Temperature:

Dry Bulb Temperature: All temperature sensing stations

Wet Bulb Temperature: All stations

Heat Flux: All stations

Light: All windows

Air Velocity: All stations

Radiant Temperature (incl. globe temperature):

Flow:

Power: Electric heaters

Pressure:

Specialized Equipment Required:

Equipment/Apparatus:

Description:

Cost:

Labor:

Experimental Operation (incl. setup and reconfiguration):

Manpower requirements (hours):

Engineer: 30 hours

Architect: 10 hours

Technician: 30 hours

Computer Analyst/Programmer: 2 hours

Analysis of Experimental Results:

Description (how the analysis is to be accomplished):

Calculate the Fanger PMV comfort index for the roof terrace areas, determine the energy performance of the building, both with and without roof shade.

Engineer: 24 hours

Architect: 4

Technician:

Computer Analyst/Programmer: 16

Computer Requirements: data reduction and calculations

X REFERENCES

1. Peck, John, et al., Final Report, Passive Cooling Experimental Facility Hot/Arid Zone, DOE Contract No. DE-AC03-80SF-10816, University of Arizona Environmental Research Laboratory, Tucson, AZ, August 1983.