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EVALUATION OF AIR-FLOW WINDOWS: FINAL REPORT

Kurt Brandle and Robert F. Boehm

May 1981

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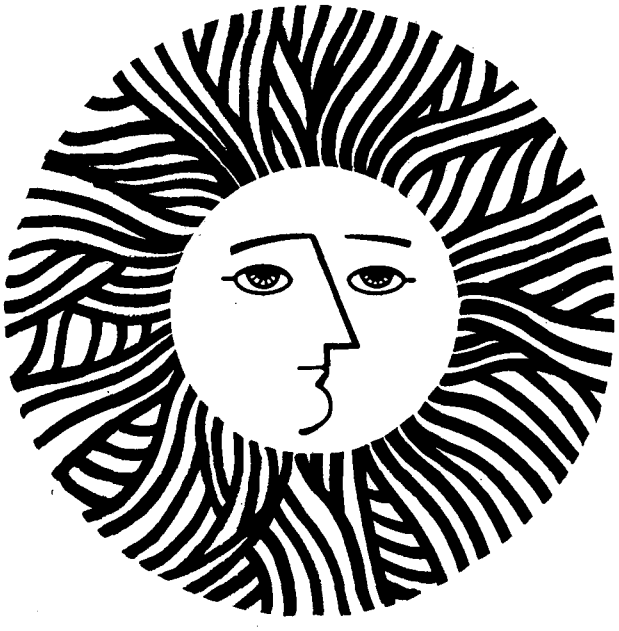

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EVALUATION OF AIR-FLOW WINDOWS:

FINAL REPORT

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EVALUATION OF AIR-FLOW WINDOWS

ABSTRACT

Air-flow windows, which originated in Europe, are being considered for development and applications in this country. Heat losses and gains are reduced by room air flowing through the cavity between the inner and outer glass panes of the windows.

In order to obtain parametric data for the assessment of performance, testing on two air-flow window types (exhaust-air and return-air) was undertaken over the course of more than one year. A conventional reference window was tested simultaneously. Several testing procedures were explored. From the test results, descriptive performance parameters were determined. Based on the test results, computerized energy balance modeling was done hourly for the course of a whole year. The modeling also included the influence of make-up air replacing exhaust-air or the discarded portion of return-air. Scenarios for various seasonal conditions and window air flow rates were developed. A proposal for a demonstration project is outlined. The Appendix includes a report on European air-flow window installations.

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NOMENCLATURE

EVALUATION OF AIR-FLOW WINDOWS - FINAL REPORT

1. INTRODUCTION

1.1. Short History of Air-Flow Windows

Air-flow windows use air from conditioned spaces to temper the impact of climate and weather on the interior environment. The air flows through the window cavity between the inner and outer glass panes. It strongly reduces the energy exchange between the two glass surfaces. Vertical or horizontal blinds act as shading devices and absorbers of solar energy. This energy is removed by the air stream.

Air-flow windows are used increasingly in central and northern Europe. They originated in Sweden where a related patent was filed in 1956. The first large-scale installation dates back to 1967 when the city of Helsinki used air-flow windows designed by the EKONO Company, in its Building Department Offices.

Since the energy crisis of 1973, the energy savings potential of these windows has resulted in many applications; mostly in office buildings. There are at least 50 large buildings and numerous small ones with air-flow windows. The windows are known in Europe variously as climate windows, extract-air windows, or exhaust-air windows.

A separate report, see Appendix A, describes several air-flow window systems as presently used in Europe. Recent applications in retrofit and new construction are shown. Most of these systems use the return-air principle. Air is extracted from the room, flows through the window cavity and is then returned to the central mechanical equipment room. One system, however, is of the exhaust-air type. The air is not returned, but directly exhausted to the outside.

1.2. Problem Statement

Very little information on the performance of air-flow windows is accessible. Available literature usually shows the reduction in U-values and, to a lesser extent, shading coefficients compared to conventional windows. Such data is insufficient for the development of conclusions on energy efficiency and trade-offs between higher first costs versus life-cycle costs of air-flow windows compared with conventional windows.

As air-flow windows appear to be a promising alternative to conventional window systems, especially in regions with high solar radiation levels, the need for testing for the U. S. market was recognized. Air conditioning of buildings is a major use of energy in this country. Air-flow windows offer an excellent possibility for the integration of sun shading devices and, therefore, a reduction in cooling load.

The authors proposed to test air-flow window samples from European manufacturers and simultaneously test a high quality reference window as typically used in the U. S. The Building Environment and Energy Laboratory, University of Utah, was chosen for tests in a setting close to actual building applications. The results of the tests were to be generalized so that they could be applied in building design considerations.

1.3 Test and Modeling Program

The main objective of the work was to establish parameters and performance data of air-flow windows influencing heating and cooling loads. In addition, the performance of air-flow windows over a year's time was to be modeled based on the obtained data.

The purpose for establishing the parameters and test data, as described in Section 4, is to provide architects and engineers with information for performing heat gain/heat loss calculations in applications with air-flow windows. The purpose of the performance modeling, as described in Section 6, is to develop the energy balance of air-flow windows versus conventional windows over a year's time.

2. THE TEST COMPONENTS AS WINDOW TYPES

2.1. Air-Flow Windows

Air-flow windows typically consist of a fixed, double-glazed outer sash and an operable, single-glazed inner sash which generally is opened only for cleaning purposes. Some systems allow for an operable outer sash also which permits window cleaning from inside. A single-glazed outer sash seems possible for installations in very moderate or warm climates. The authors are not aware, however, of any such installations. The two sashes are typically of aluminum and are separated by a thermal break similar to those found in many presently used window systems. At least one system consists of wood sashes and a solid wood frame.

Either venetian or vertical louver blinds are located in the air cavity between the outer and inner glazing. The blinds are operated manually at each window by simple pull or turning mechanisms. Sometimes centralized and motorized control is used in large buildings. Such control, though expensive, has considerable advantages for energy conservation, as continuous adjustment of the blinds in response to solar radiation is possible. Building occupants seldom operate shading devices in an optimal fashion, which is especially true for weekend and holiday periods.

2.1.1. Return-Air Window Return-air windows introduce room air at the bottom frame. The opening at this frame typically is the width of the operable sash. The air flows upward through the cavity and returns via a duct system to the central HVAC equipment. The window, therefore, can be considered the first component of a conventional return duct system. Depending on fresh air requirements for building occupancy, part or all of this air is discarded and is replaced by outside air.

The test window consists of a medium-bronze colored aluminum frame with thermal break. It is glazed with clear 1/4 inch double pane insulating glass outside and 1/4 inch clear single glass inside. White venetian blinds were installed in the window cavity. The window was provided by the Wausau Metals Corporation, Wausau, Wisconsin, and built according to drawings by one of the authors. All extrusions were from stock items. Sections of this window are shown in Figure 2.1, its specifications are given in Appendix B.

2.1.2. Exhaust-Air Window Only one system is is known to be of the exhaust-air type. Room air is introduced at the top frame, flows downward through the window cavity and is exhausted at the bottom frame to the outside. The openings at the top and bottom typically are the width of the operable sash.

In order to avoid outside air from entering the cavity, a check valve is located just inside the exhaust opening. It consists of a neoprene strip which closes the exhaust opening under back pressure from wind.

The test window consists of natural color aluminum frames with thermal break. It is glazed with clear 1/4 inch double pane insulating glass outside and 1/4 inch clear single glass inside. A vertical, white, opaque plastic louver blind with adjustability from inside is installed in the window cavity. The unit was provided by the Protecta-

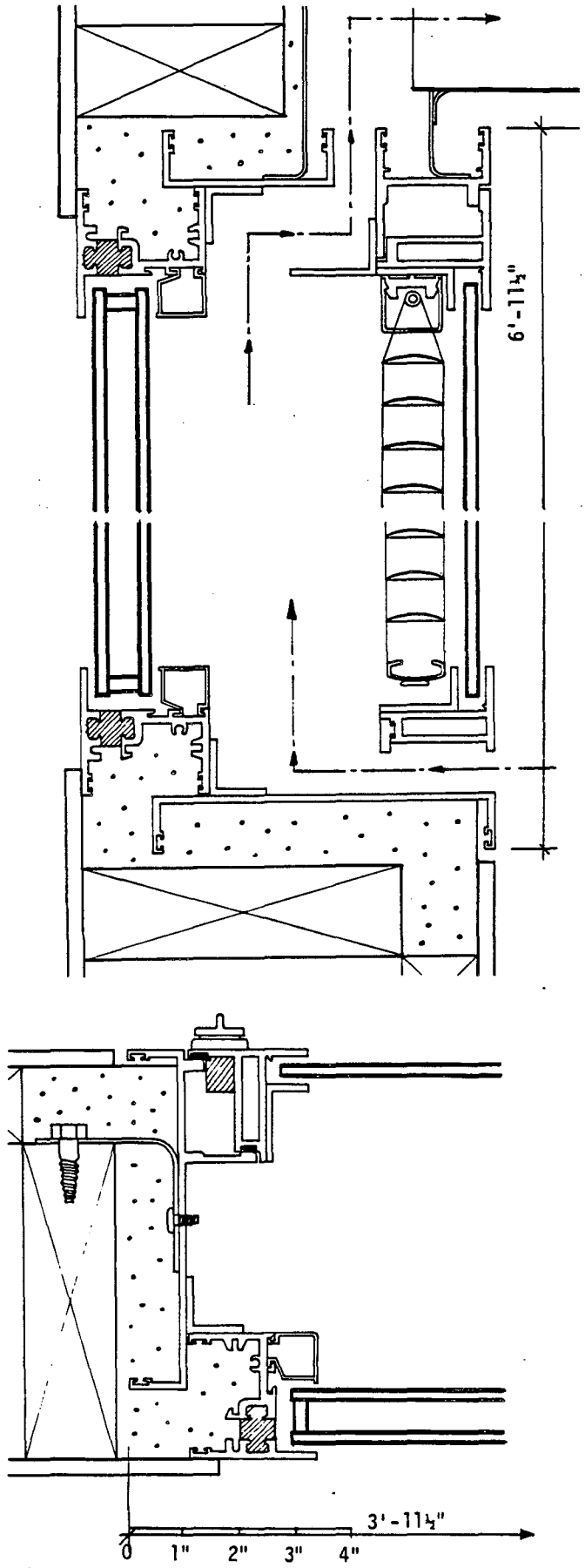

Figure 2.1. Vertical and horizontal section of return-air test window.

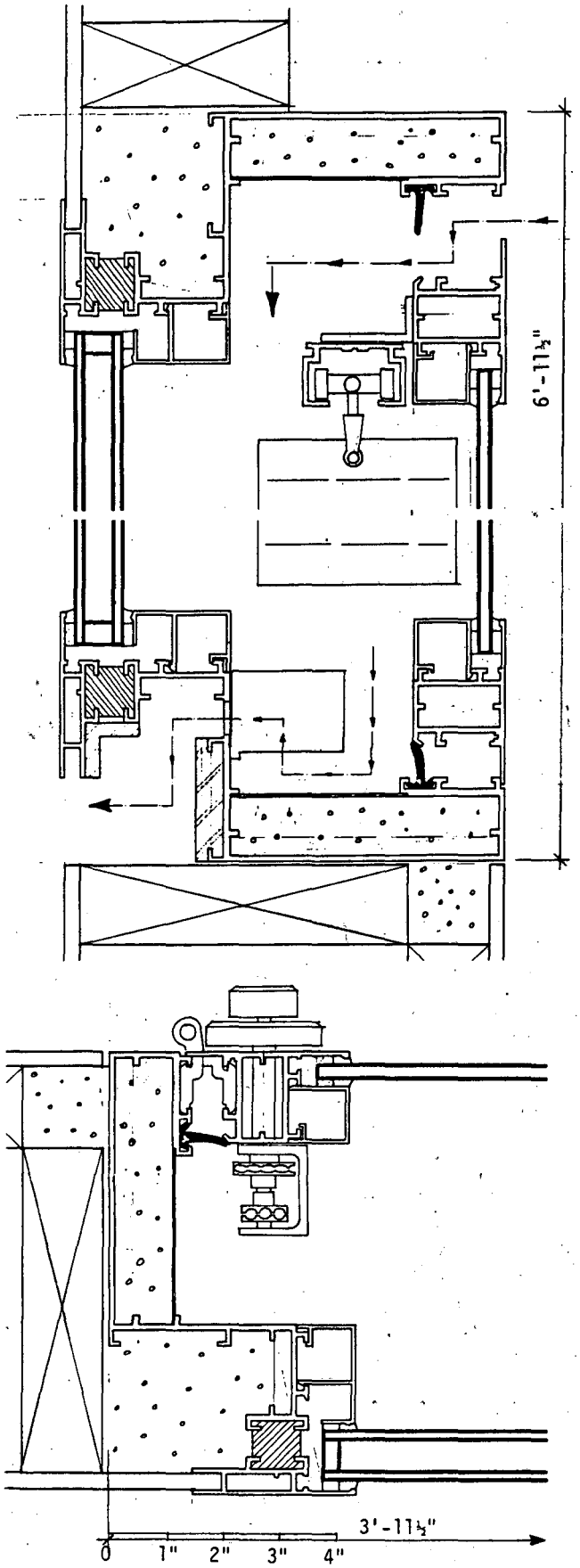

Figure 2.2 Vertical and horizontal section of exhaust-air test window.

Sol Company, Staefa, Switzerland. Sections of this window are shown in Figure 2.2, its specifications are given in Appendix B.

2.2. Reference Window

As air-flow windows have been used mostly in commercial buildings, a commercial type, fixed unit was installed as a reference window. It has a medium-bronze colored aluminum frame with thermal break and clear 1/4 inch double pane insulating glass. An interior white venetian blind was installed at about a 2 inch distance from the inside glass surface. This window was also provided by the Wausau Metals Corporation. Sections of this window are shown in Figure 2.3, its specifications are given in Appendix B.

2.3. Utilization of Test Units

All of the following data and results on the air-flow window type are from the return-air window, unless otherwise noted. Nearly all of the summer testing and most of the winter testing was done with this window installed. Tests run with the exhaust-air window yielded very similar results which are shown also in this report. The reference window was permanently installed and was always tested simultaneously when tests for the air-flow were performed.

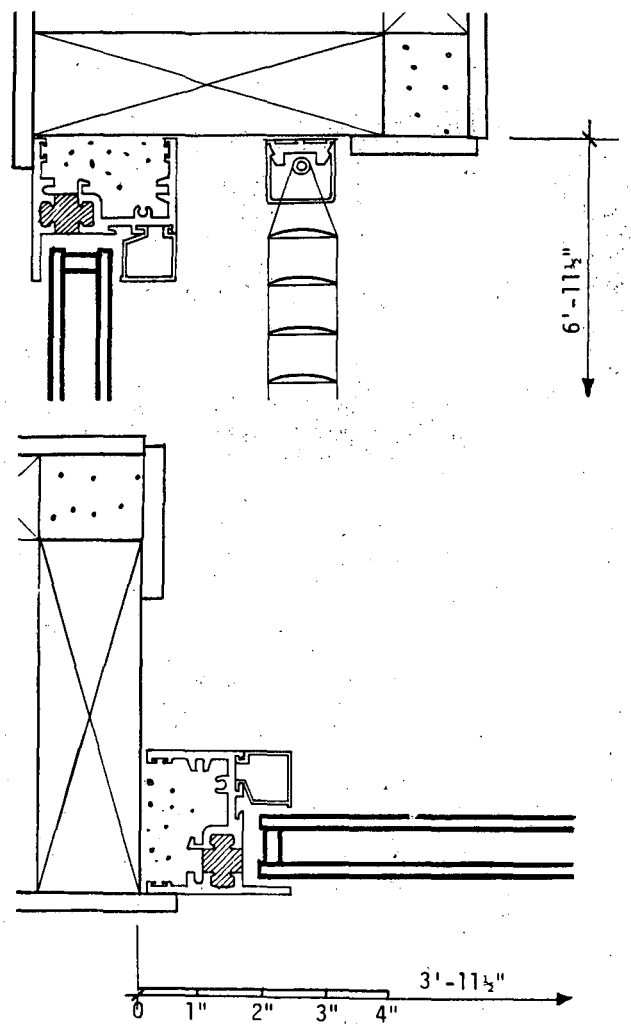

Figure 2.3. Vertical and horizontal section of reference window.

3. TESTING PROCEDURES

3.1. Objectives

The testing procedures were guided by a primary objective: performance comparisons between air-flow windows and conventional windows were to be made side-by-side in the same environment. Sufficient experimental data was to be gathered to generalize the performance of the windows so that they might later be evaluated in other applications and climates.

3.2. Test Facility

The testing program took place in a facility at the University called the Building Environment and Energy Laboratory (BEE Lab). This facility, actually a test rig, is a 20 ft x 20 ft x 10 ft high steel frame box elevated from the ground approximately 3 ft on a rotatable crane base. Rotation of the BEE Lab on its base allows for easy changes of up to 360° of orientation. A photograph of the facility is shown in Figure 3.1 and its location is shown in Figure 3.2.

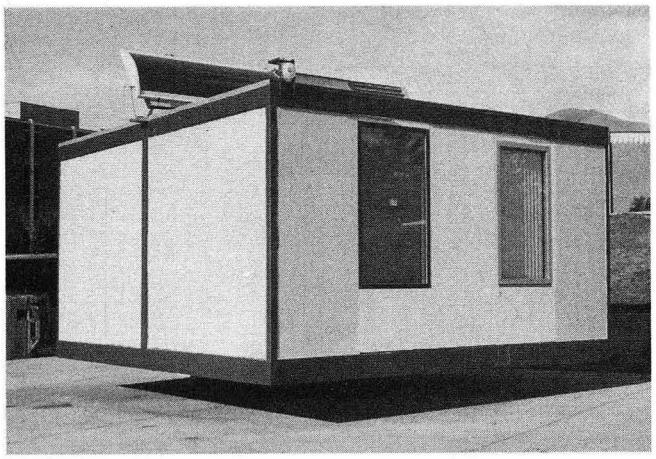

Figure 3.1. The Building Environment and Energy Laboratory, University of Utah, with air-flow window at right and reference window at left. XBB 823-2714

The bulk of the thermal envelope of the BEE Lab consists of polyurethane panels 6 in (15.24 cm) thick, with a 12 in (30.48 cm) thick glass fiber insulated floor. The polyurethane panels are attached by a bolt/clip arrangement so that they can easily be rearranged for evaluation of virtually any kind of components pertinent to a building's skin. Considerable effort has been expended to caulk virtually all infiltration possibilities. A double-doored entry way is used to cut down on infiltration losses also. A vent in the middle of the floor can be opened to furnish makeup air when an exhaust-air window is being used.

The BEE Lab is outfitted with a through-the-wall type two-ton air conditioner, located over the door of the facility. Cold air from the air conditioner can be either diffused to the space uniformly or directed to specific locations by wire reinforced foil hoses. Control of the air conditioner is accomplished by a conventional thermostat.

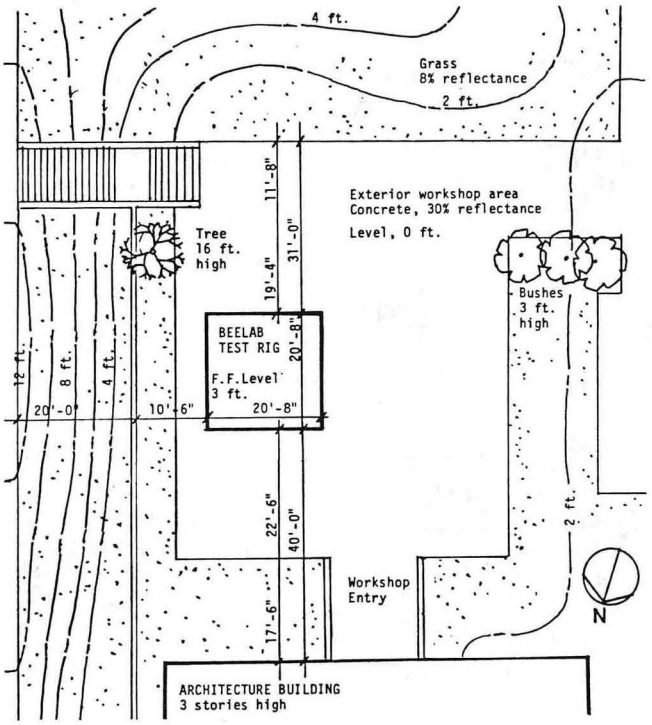

Figure 3.2. Location of Building Environment and Energy Laboratory, University of Utah.

Heating of the BEE Lab is accomplished by small electric resistance area heaters with integral fans. Two of these units were usually used. Typically one was set with its thermostat about 1°C lower than the other. This allowed more uniform operating conditions during periods of small heat loss from the lab.

As can be seen in Figure 3.1, the windows were mounted side-by-side in one facade of the Lab 4 ft apart. An insulating wall panel was used between the windows so that various types of experimental equipment could be mounted on each without interference with the other.

Because of its thermal characteristics, the BEE Lab provides a very stable interior environment. The laboratory itself, however, is not part of the testing apparatus beyond providing this environment and easy changes in solar exposure.

Shortly after the windows were installed, a heat balance was performed on the Lab. The UA (overall heat transfer coefficient times overall area product) was found to be 81.1 Btu/°F, including the windows, but with no air flow. At no-flow the UA factor for the windows (flow and reference added together) alone was calculated to account for 23.4 Btu/°F of that total (more than 25% of the total

loss can be attributed to the windows).

It was decided that by use of the test building itself an overall heat balance approach to testing, would not yield sufficient accuracy. At this point it was decided that separate measurements on each window would be used.

Several types of instrumentation are mounted in and around the Lab. Included are thermocouples, pyranometers and watt-hour meters. Thermocouples of the iron constantan type are located at several locations outside and inside the Lab to establish both inside and outside ambient temperatures. The outside ambient temperature was monitored by a thermocouple located underneath the lab shaded from solar insolation. Inside ambient temperatures were monitored by a shaded thermocouple at the midpoint of the window. Two Eppley pyranometers are used to measure solar insolation. A model 8-48 Black and White pyranometer is used to measure the solar insolation in a horizontal plane at the top of the Lab. A model PSP pyranometer is mounted in a vertical plane on the same facade as used for window mounting. The pyranometer location can be seen at the upper left of Figure 3.1. All electrical power used in the Lab is monitored through two conventional watt-hour meters.

3.3. Air-Flow Window Evaluation Techniques

3.3.1. Box Approach Initially a box approach was used to evaluate the air flow window. A box of slightly larger area than the window to be tested and approximately 1 m deep was carefully sealed around the window. A blower and flow measuring device were mounted on the opposite side of the box from the vent into the window. Over the blower inlet to the box a flow diffuser was used to decrease the peak velocity and distribute the flow uniformly inside the box. It was hoped that the sensible heat gain or loss as the air flowed through the box could be used to infer window performance. However, it was found that a serious drawback existed: If the heat gain/loss was large across the window (large overall ΔT), the readings were undesirable because of unreal interior conditions (inside the box). At high solar insolation temperatures of 130 to 150 F were encountered within the box which created undesirable temperature differences in relation to the space.

The box approach was determined to be an improper way to evaluate air-flow windows, primarily because of their low effective overall heat transfer coefficient. However, it was adapted to the evaluation of the reference conventional window with fair success. More discussion is given on this in Section 3.4

3.3.2. Separate Heat Flow Approach Testing of the air-flow window was accomplished with air being forced through the air-flow window from a small centrifugal blower. Air flow was measured with an ASME standard orifice with pressure drop being monitored on a draft gage. Variations in air flow, when desired, were accomplished by an adjustable by-pass following the blower but prior to the orifice. Temperatures were measured at a variety of locations along the air flow path, over the window surface, and in the room and outside, see Figure 3.3. Incident solar flux was measured in the vertical plane with an Eppley model PSP pyranometer. Transmitted solar flux in the vertical plane was measured on the inner pane of the window with a LI-COR, model LI-200S, pyranometer. Because of the non-uniform transmitted radiation pattern due to some settings of the blinds, a translucent diffuser plate was mounted between the glass and the pyranometer, removed from the glass approximately 1 in (2.54 cm). This arrangement was calibrated with the Eppley pyranometer both with and without the diffuser. A cross sectional sketch of the testing apparatus is shown in Figure 3.3. Photographs of the test set-ups are shown in Figures 3.4 and 3.5.

Heat flows through each air-flow window were assessed in the following ways. The sensible heat lost or gained in the window cavity was easily inferred as follows:

$$QEAF = QRA = \dot{m}_1 \cdot C_p \cdot (T_{fx} - T_{fi}) \qquad (3.1)$$

All of the quantities on the right hand side of Equation 1 were measured and logged on time periods varying from 5 minutes to 20 minutes.

How this quantity is interpreted in the energy performance evaluation of the window depends upon the flow type of the window and its operational mode. For example, consider a return-air window where 100% of the flow air is returned to the space. In this case, the energy quantity represented by Equation 3.1 must be added or removed by the HVAC system or compensated by gains or losses in other parts of the building.

A totally different situation exists for exhaust air operation. If all of the air circulated through the window is dumped to the outside, a like quantity of outside air must be conditioned and returned to the space. In this situation, the associated sensible heat quantity is:

$$QFRESH\ 1 = \dot{m}_1 \cdot C_p \cdot (T_o - T_i) \qquad (3.2)$$

The energy quantities represented by Equations 3.1 and 3.2 depend at least implicitly on the insolation, when present, and the overall temperature difference. Examination of these two equations can give some insight into performance of the two types of windows in a variety of operating conditions. Windows of the return-air type, where a portion of the air is exhausted, will demonstrate a proportion of each of the two energy flow quantities shown above.

Solar energy transmitted directly through the window assembly as short wave length (1.5 μm) radiation was measured by the LI-COR pyranometer. Incident solar energy in almost the same plane was compared to the Eppley measurement. A transmissivity for the window was easily formed from these two measurements.

Measurement of the combined re-emitted radiation and natural convection from the inside of the window to the room caused considerable problems. Several approaches were attempted and rejected, including the use of a heat flux transducer (heat

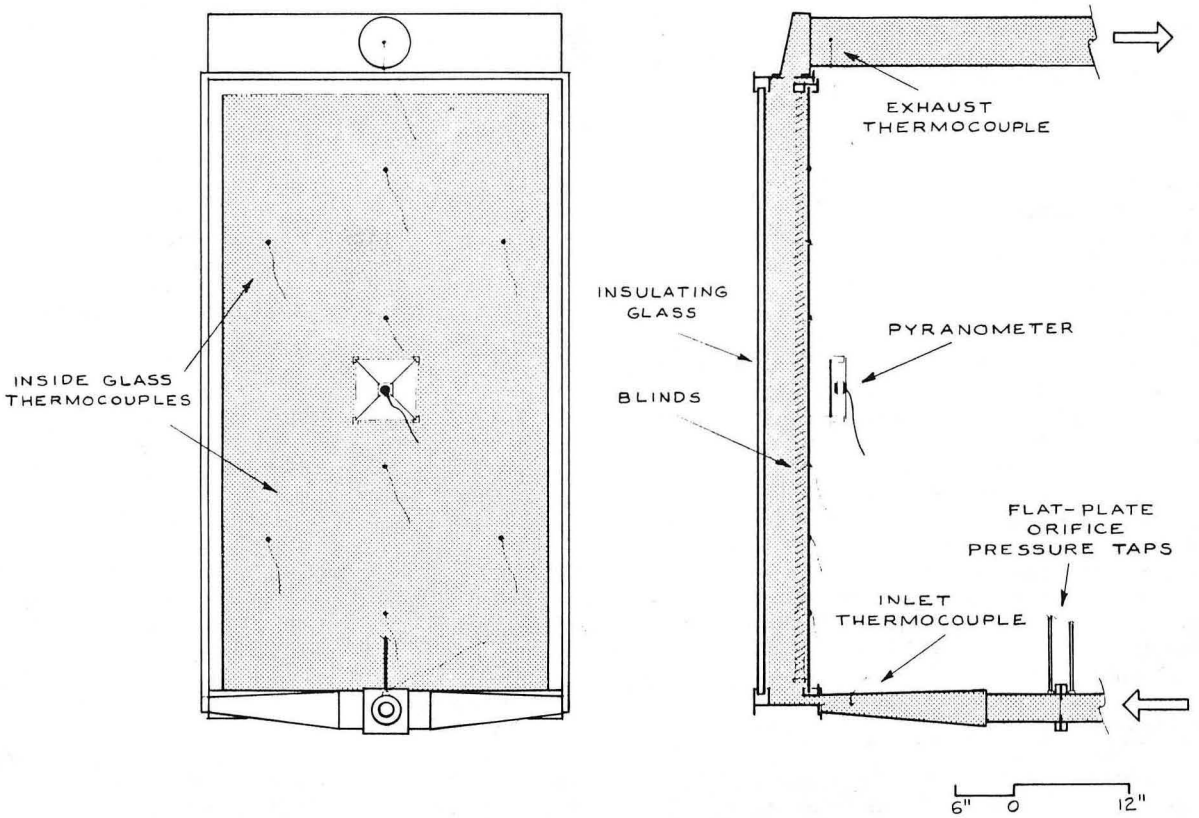

Figure 3.3. Testing Apparatus for Return-Air Window

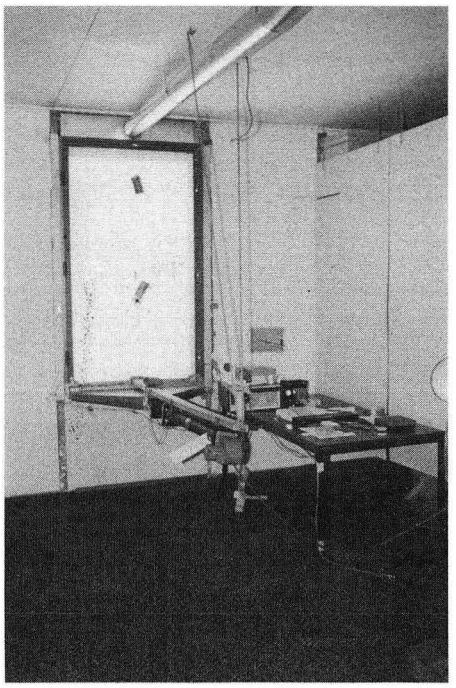

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Figure 3.4. Test Set-up for Return-Air Window

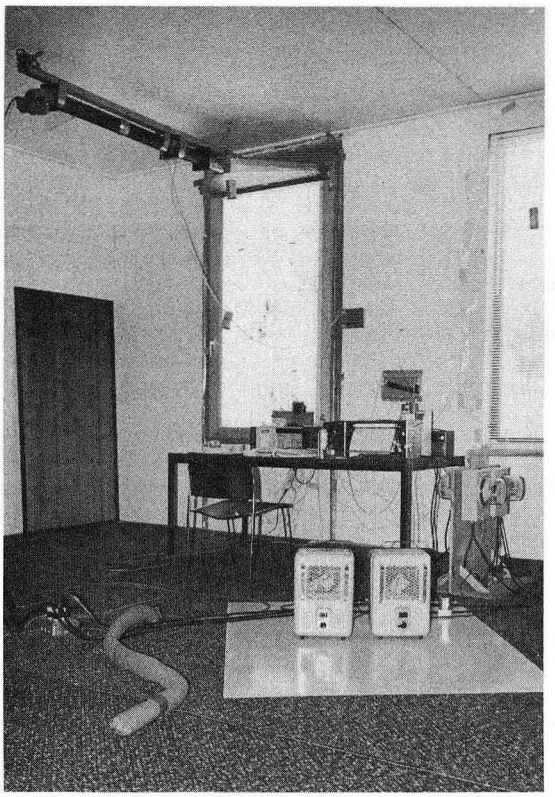

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Figure 3.5. Test Set-up for Exhaust-Air Window

flows were too low for devices of this type that were available) and an insulated flow box mounted over the window (too much thermal inertia relative to the heat flows here, but see more on this approach in the discussion on the reference window testing). A method was finally adopted where calculations of the radiation and natural convection were used as a function of temperature difference, the latter being between the surface temperature of the inner window pane and the room air temperature. In particular Newton's Law of Cooling is used

$$QI = h_{total} \cdot A_g \cdot (T_{wi} - T_i) \qquad (3.3)$$

where

$$h_{total} = f \cdot (T_{wi} - T_i) \qquad (3.4)$$

and is shown graphically in Figure 3.8. A description of the assumptions, equations, and values used is given in the Appendix C.

To check the correlation, several approaches were used. In one case, the flow-box technique was used. Although this approach was rejected for the regular testing of the flow window, it was used to advantage here for calibration purposes. Also, a Hy-Cal heat flux transducer was used. Typical heat flows from the room side of the flow window assembly were much too small for the normal range of the heat flux transducer, but approximated values could be inferred at the higher heat flows. Both approaches led us to believe that Equation 3.3 yielded a maximum error of about 9%, except at low values of $T_{wi} - T_i$. If each of our thermocouple calibrations were in error by approximately 0.5 F (thought to be the case), a potentially large error could exist at very small temperature differences. This was the source of what we believe to be the largest error in this approach.

Great concern was held for the accuracy of the use of a thermocouple to measure the glass surface temperature, particularly in periods of high incident solar flux. However, thermocouples were used and were affixed with small amounts of transparent glue. Temperatures registered from this type of installation were checked periodically with a Barnes Instatherm infrared temperature indicator, and comparisons indicated an accuracy to within 8% in all cases.

Temperatures were measured at several locations using calibrated iron constantan thermocouples (see locations denoted in Figure 3.3) on the inner pane of the windows and in the room. As would be anticipated, some variation with location was found in each of these groups of measurement. This variation ranged up to 3° F at high heat flow conditions. Considerable effort was expended to determine the most reasonable spatial averaging of the various readings. The spatial averaging was performed by taking discrete values of area and the corresponding temperature for two different weather conditions (high and low heat flow). It was found that horizontally aligned measurements checked within the accuracy of the thermocouple calibration, which simplified the spatial averaging process.

From the measurements thus described, generalized parameters describing the flow window performance could be inferred. These are described in Chapter 4.

3.4. Reference Window Evaluation

3.4.1. First Approach Initially the reference window, a conventional double-glazed window, was tested without inside blinds. In this configuration, an approach similar to the one described in Section 3.3.2 could be used. In particular, the transmitted solar flux could be measured. Temperatures on the inside of the glass and in the room could be used to estimate the total re-radiated energy and convection flow to the room. Since shading devices were required by the Scope of Work for the project, this approach was abandoned and a second method (see below) was used.

3.4.2. Second Method To satisfy the Scope of Work for the project interior venetian blinds were used to simulate an actual commercial building installation. Because of the use of interior venetian blinds, a totally different approach was required in evaluating energy flows through the reference window. For this situation, an insulated air flow box was built over the window. Air was forced downward through the box at low velocities to simulate a room-type environment (see Figure 3.6). The test set-up is shown in Figure 3.7.

Heat transfer through the window translates itself as a sensible heat flow to the air flowing through the box. There is a tradeoff here between errors in not representing room conditions accurately because of too high an air flow, (i.e. too high of a velocity across the reference window surface or across the blinds), and errors in possibly too high of an average box temperature (periods of high heat gain) or too low of an average box temperature (periods of high heat loss) at very low air flows. This latter aspect does not allow a good representation of a typical spatial environment. At any rate, an equation of the form of Equation 3.1 is used to infer the heat flow through the glass. Corrections were also made for heat transfer through the polystyrene-insulated-plywood box. This latter correction was relatively small, always below 6% (see more information on this in Section 4.3.4).

Clearly this approach cannot distinguish between overall heat transfer coefficient effects and the solar transmissivity effects. However, comparisons between the flow box technique and traditional values of U (0.58 - 0.65 Btu/ft^2 hr F)* and shading coefficients (0.51)** all gave agreement within ten percent. This was considered excellent for in situ-type measurements.

3.5 Blind Adjustment

An attempt was made to handle the blinds of all windows in a manner similar to how they might be handled in actual installations. It is generally the case that people adjust blinds so that the beam component of the radiation does not penetrate into the room, particularly during bright sunlight con-

* See ASHRAE Handbook of Fundamentals, 1972, p. 370.

** See ASHRAE Handbook of Fundamentals, 1972, p. 402.

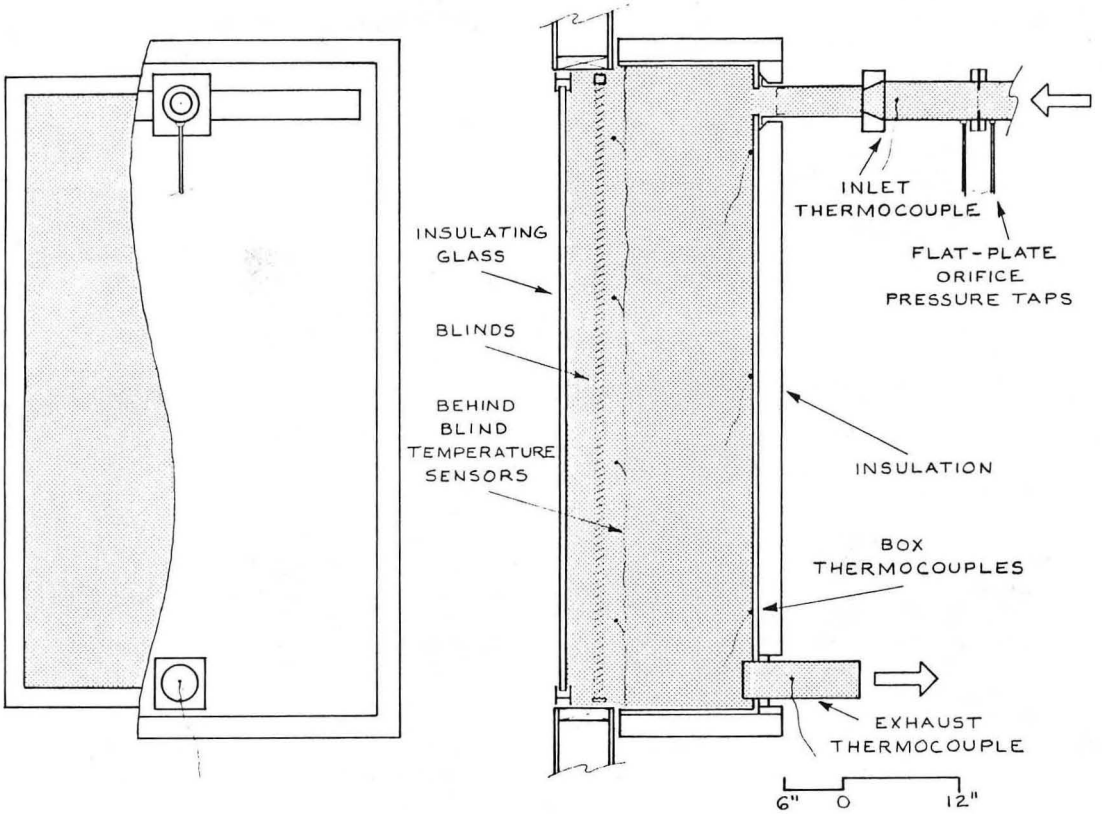

Figure 3.6. Testing Apparatus for Reference Window

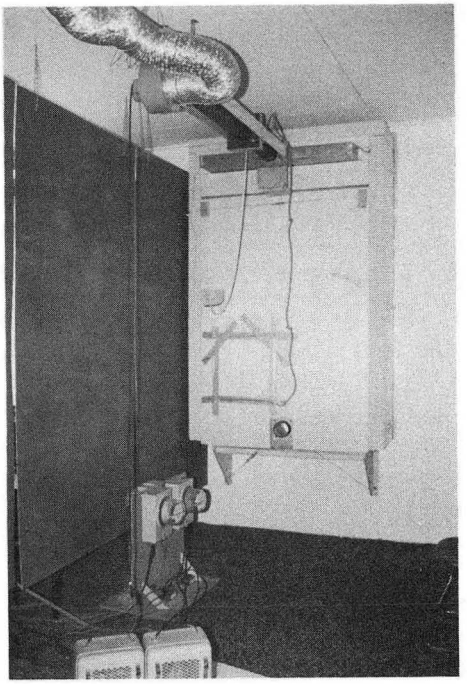

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Figure 3.7. Test Set-up for Reference Window

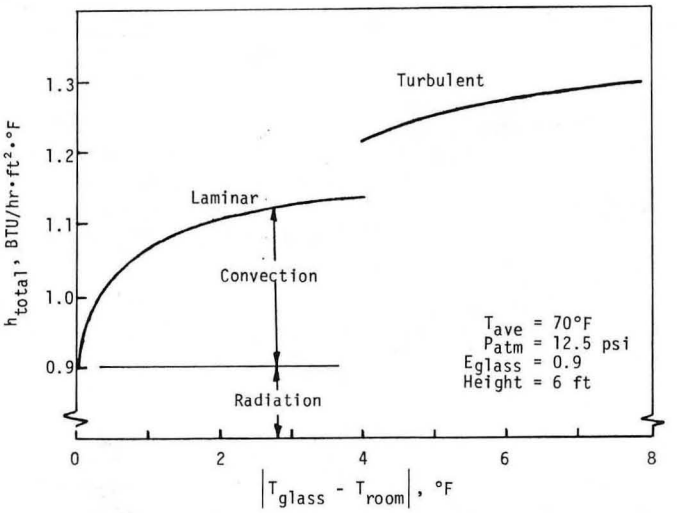

Figure 3.8. Combined Heat Transfer Correlation (used for exchange between inside pane of air-flow windows and room).

ditions. The blinds in the experiments were always adjusted so that this situation prevailed. A few measurements were made in direct bright sunlight with no blinds, or blinds present but open, to establish baseline information.

3.6 Data Logging

A Digitec Datalogger was available for use on a regular basis in the BEE Lab. This particular device has twenty input channels, 15 for iron-constantan thermocouples and 5 for millivolt signals. The datalogger was outfitted with a digital interface so that the data could be wired to the School of Architecture Interdata computer.

Unanticipated problems arose with the Digitec device at some of the least desirable times. Without warning the datalogger would become very irratic, sending totally meaningless data to the computer. The Mechanical Engineering Electronic Technician examined the device several times. Generally it was hypothesized that problems might be initiated because of voltage spikes on the BEE Lab electrical lines. This was considered to be the case because the datalogger performed fine in the computer room or in the Electrical Repair shop, but not in the Lab. The application of the voltage stabilizing device in the Lab proved not to be a satisfactory solution.

At one point the device was returned to the factory. This did not make a permanent improvement in the operation. During malfunctions and for the last part of the project (after the Digitec instrument was finally abandoned) a Fluke Datalogger was used on a loan basis. This device performed flawlessly. Operation in this mode required more effort since data had to be handled by hand, but otherwise had no effect on the test plan and operation.

4. PARAMETERS AND MODELS FOR TESTING

4.1 External and Internal Environmental Conditions

In order to develop conclusions on the performance of air-flow windows for a wide range of climatic conditions, a broad range of test conditions were included. The major ones are variations in outside temperature, inside temperature and solar radiation. A summer and winter testing sequence provided the outside conditions in a natural setting from very high to very low temperature and radiation levels. Climatic data for Salt Lake City is given in Appendix D.

Testing for the influence of wind was not attempted as wind velocities in Salt Lake City are very low and uneven. Average wind velocities in Salt Lake City vary between 7.5 and 9.6 mph. Velocities are generally much lower with occasional strong gusts. Tests were performed when there was no discernable wind velocity (estimated to be less than 2 mph). This situation occurred even more often because the Lab is located in a topographical depression between an earth mound and the Architecture School building. The test results were discarded when (unusual case of) high wind velocities were encountered.

Another important environmental condition is humidity. Although all tests were performed in the local, low humidity climate, temperatures on the inner surface of the double glazing of the air-flow window were measured. These were used to establish conditions at which condensation may occur related to RH levels of the cavity air stream.

Footcandle levels of daylighting on typical days were measured related to the same blind positions as used in the thermal test sequence. The dimensions of the test room were 12 ft x 20 ft x 10 ft with the 4 ft x 7 ft window centered in one of the 12 ft walls. The sill height of 2 ft 8 in equalled the work plane for the fc measurements. The reflectance value on walls and ceilings was 0.75 and on the floor, 0.10.

4.2 Parameters Related to Environmental Controls

The unique nature of air-flow windows required the inclusion of two components which either do not exist in conventional window systems or their impact is considered separately from the function of the window system. These components are the air flow rate through the window cavity and the position of the sun-shading device.

4.2.1. Air Flow Rates and Directions Typical air flow rates used in Europe are 3 to 6 cfm per foot of window width. In typical exterior zones of office buildings with 15 to 20 ft zone depth, three to five feet of window width relate to one occupant (spatial requirement and adequacy of daylighting). Fresh air rates of 10 to 15 cfm per person coincide with these window air flow rates. Three air flow rates were tested in addition to no-flow: 3.9, 5.4 and 7.7 cfm per foot of window width. These values, developed from specifics of measurement, encompassed the full range of normally used air flows.

The exhaust-air window type used in Europe has a downward air flow direction. Nearly all return-air windows use an upward flow direction. No important consequences for the winter and summer performance related to air flow direction were expected. This assumption, however, had to be verified by test runs. An exhaust-air window with downward flow and a return-air window with upward flow were tested under winter and summer conditions.

As with the conventional windows, relative humidity levels of the inside air must be watched with regard to condensation. During the winter season the air flowing through the window cavity is cooled, unless high levels of solar radiation are present. Depending on the air flow direction, condensation may begin to occur in the upper or lower end of the cavity. The inside surface of the insulating glass is the critical surface. Temperatures of this surface were measured at low outside temperatures and at various flow rates in order to determine temperature levels at which condensation may occur. Relative humidity levels at which condensation would occur were not measured but estimated from temperature measurements (see Section 5.4).

4.2.2. Sun Shading Devices A sun shading device in the window cavity can be positioned to reduce the solar radiation directly entering the space. It reflects part of the solar radiation outside and part inside. Another part is absorbed and reradiated outside and inside. With increasing air flow, a major part of the energy is carried away with the air stream.

Venetian blinds have the advantage of excellent solar control and can be retracted completely when no sun shading is needed. They also reflect daylight toward the ceiling which results in improved penetration of daylight into the space. Therefore, a typically available, white venetian blind with one-inch wide slats was chosen for the return-air window tests. The same type of blinds were used for simultaneous testing of the reference window with the same slat angles, but the blind in a typical location of about two inches inside the insulating glass surface. The exhaust-air window was an imported product with integral blinds of vertical white opaque louvers.

The slat angle influenced the thermal and daylighting behavior considerably. Three blind positions were tested in addition to completely retracted blinds: horizontal, 30° and 45°.

Full beam sunlight striking a workplane is generally not a desirable condition. Therefore, the blinds were adjusted into the mentioned positions in such a way that the direct beam component was always intercepted. During periods of significant beam radiation on the windows, the blind slat angles were set according to solar altitude angles for venetian blinds and to azimuth angles for vertical blinds.

The same assumption was made in the computer model of yearly energy balance calculations for the air-flow window and the reference window.

4.2.3. Interdependence of Air Flow and Sun Shading The energy balance of air-flow windows is considerably influenced by the interaction of the air-flow and sun shading device position. In order to develop basic parameters for a year-by-year energy balance analysis, the air flows and shading device positions, noted above, were varied one-by-one. This resulted in 16 testing combinations.

4.2.4. Facade Orientations Five compass orientations were evaluated: S, SW, SE, W, E. A large building directly to the north of the Lab rendered this orientation unrepresentative. The SE and E orientations were shaded by mountains and a tree through the bulk of the morning hours, thus yielding the data very site specific and thus undesirable. For these reasons most of the testing was performed in the S, SW, and W orientations. The generality of the results via the correlations (to be discussed) rendered the orientations used to be sufficient.

These exposures, especially the west exposure, force the frequent manipulation of the venetian or the vertical blind angles in order to achieve only diffuse and reflected light to enter the test room. Test results related to various blind and sun angles were checked with regard to possibly significant variations of the effective shading coefficient as described in Section 4.3.3.

4.3. Algorithms for Testing and Data Reduction

The traditional model for a window's steady state energy balance is:

$$QS = U \cdot (T_o - T_i) \cdot A_w + SC \cdot SHGF \cdot A_g \qquad (4.1)$$

where the U includes both the glazing and the frame. For a given conventional window, the U value is assumed to be constant. The SC value is assumed to be constant also, whether it is related to the shading effect of a particular glass type or shading device, such as a venetian blind. The solar heat gain factors, SHGF, contain the reduction of the irradiation I_o by one pane of 1/8-in sheet glass.

Accounting for the energy flows in the air-flow windows is much more involved than for conventional windows. This is due to the addition of the cavity flow and its potential impact on the space and the mechanical system. To generalize the results requires the definitions of additional parameters, and these are described below.

4.3.1. The Effective U Value, U_1 The U_1 value is an energy transmission property for non-solar radiation conditions. This property is defined to account for the total heat transfer (not including directly transmitted solar radiation) from the inner surface of the window assembly to or from the room. U_1 is determined by nighttime testing:

$$U_1 = h_{total} \cdot (T_{wi} - T_i)/(T_o - T_i) \qquad (4.2)$$

and represents the heat transfer off of the room-side glass surface to the room divided by the temperature across the whole window section. U_1 was determined for each air flow rate and each sun shade position.

Even though U_1 is determined during nighttime, it is used to represent performance during all conditions, so influence of sun shade positions had to be included in the testing.

4.3.2 Energy Loss Coefficient for the Window Air Stream The energy loss or gain by the air stream in the cavity is represented by $m_1 C_p (T_{fx} - T_{fi})$. This quantity is the basis for what is defined here as the pseudo heat transfer coefficient of air-flow windows U_2.

$$U_2 = \dot{m}_1 \cdot C_p \cdot (T_{fx} - T_{fi})/[(T_o - T_i) \cdot A_w] \qquad (4.3)$$

These values were determined also by nighttime testing with the various air flow and sun shading device positions.

4.3.3. The Effective Shading Coefficient The effective shading coefficient is broken down into two parts for the exhaust-air window and into three parts for the return-air window. These are required to represent the complexities of the thermal characteristics of the flow windows.

The ratio of the amount of solar radiation directly transmitted to the room relative to the incident radiation is defined here as RB, most commonly denoted as transmissivity. In addition, there is an amount indirectly transmitted and is defined here as H_1. H_1 is the fraction of I_o re-radiated or convected into the room. A third part, denoted here as H_2, is the amount of heat transferred to the air stream in the window cavity. H_2 is similar to U_2 but accounting for the solar impact.

The amount of solar radiation directly transmitted to the room, RB x I_o, is measured with the inside pyranometer as I_{tr}. Consequently,

$$RB = I_{tr}/I_o. \qquad (4.4)$$

RB is not affected by the air flow rate, so there are only as many values as there are venetian blind settings, that is four (open, horizontal, at 30° and at 45°). RB and H_1 were determined by daytime testing and data reduction. While RB has some variation with incidence angle, this variation was found insignificant in the overall energy balance.

H_1 is defined as the heat transfer off the inside window surface to the room (during anytime) minus the U_1 value effect (defined from nighttime conditions), all divided by the solar irradiation:

$$H_1 = \left[h_{total} \cdot (T_{wi} - T_i) - U_1 \cdot (T_o - T_i)\right] \cdot A_w / I_o \cdot A_g \qquad (4.5)$$

Note that H_1 only has a value during daytime conditions, as Equation 4.5 will be zero at night (see Equation 4.2). H_1 must be evaluated for all air flow and sun shading combinations.

There is a portion of the energy transfer to the cavity air stream which is due to the solar irradiation, beyond that dictated by the temperature difference between the room and the outdoors. This effect can be included in a manner somewhat similar to that used in defining H_1. H_2 is defined as:

$$H_2 = \left\{[\dot{m}_1 \cdot C_p \cdot (T_{fx} - T_{fi})] - U_2 \cdot A_w \cdot (T_o - T_i)\right\} / I_o \cdot A_g \quad (4.6)$$

Note that A_g, the glass area, has been used here, while A_w, the total window area was used to define U_2. This neglects the influence of the frame related to solar radiation transfer, which is very small compared to the heat flow through the frame from other heat transfer modes. H_2 is developed from daytime testing for all air flow and sun shading combinations. H_2 is not of interest for the exhaust-air window as all air is discarded. It is important, however, for evaluating the performance of the return-air window. The portion of air of the return-air window system which is not discarded transports the H_2 of this air to the central HVAC equipment. If heat recovery equipment is used, an additional portion of H_2 can be saved before the exhaust air portion is discarded.

4.3.4. The U Value and the Shading Coefficient of the Reference Window The test conditions for the reference window were chosen as closely as possible resembling typical window applications today. The window was located in the same facade as the air-flow window with four feet of wall in between. Tests for the air-flow and reference window were run simultaneously. The test set-up differed considerably from that of the air-flow window, as described in Section 3.4.

Although U value information for the reference window was available, see Appendix B, tests had to be run to develop data for the conditions on the testing site and for evaluating the performance changes between the various shading device positions for which no data is available. Again, as with the air-flow window, the effect of the various venetian blind positions on the U value must be evaluated because of daytime impact. The overall heat transfer coefficient for the reference window is calculated as:

$$U_r = [\dot{m}_2 \cdot C_p \cdot (T_{rx} - T_{ri}) + U_b \cdot A_b \cdot (T_{box} - T_i)]/[(T_o - T_{bl}) \cdot A_w] \quad (4.7)$$

The second set of terms in the numerator of Equation 4.7 accounts for the heat exchange between the room and the air flowing through the box. A value of 2.75 was used for $U_b \cdot A_b$*. T_{bl} is the average temperature on the box side of the venetian blind. From detailed testing, it was found that T_{bl} differed from T_{box}.

There is also only little information available on the daytime performance of the reference window with interior venetian blinds at various blind settings. Therefore, tests for the reference window were run simultaneously with the air-flow window, both having the same blind setting. The shading coefficient is defined here as:

$$SC = [\dot{m}_2 \cdot C_p \cdot (T_{rx} - T_{ri}) + U_b \cdot A_b \cdot (T_{box} - T_i) - U_r \cdot A_w \cdot (T_o - T_{bl})]/I_o \cdot A_g \quad (4.8)$$

* $U_b \cdot A_b = 0.05 \times 55 = 2.75$ Btu/hr F.

This parameter was evaluated by daytime testing at the various shading device positions. Two air flow rates were used for testing the reference window.

4.4. The Energy Balance of the Air-Flow Windows and the Reference Window

The energy balance of the air-flow windows and the reference window can be calculated by using the parameters as described above. It should be kept in mind that energy balance means the net effect of the window under consideration on the central HVAC equipment which holds the thermal environment of the building in steady state. This implies not only consideration of the window as a barrier between the inside environment and outdoors, but also the impact of the air flow on energy consumption.

The instantaneous energy balance of the air-flow windows related to the barrier between the inside environment and the outdoors, but not including the energy carried with the flow is

$$QS = U_1 \cdot (T_o - T_i) \cdot A_w + (H_1 + RB) \cdot I_o \cdot A_g \quad (4.9)$$

The energy balance of the reference window is

$$QS = U_r \cdot (T_o - T_i) \cdot A_w + SC \cdot I_o \cdot A_g \quad (4.10)$$

While QS for the exhaust-air window and for the return-air window is very similar for the same window dimensions and environmental conditions, their overall performance may vary considerably because of their operational characteristics (exhaust-air versus return-air features).

5. TEST RESULTS AND DISCUSSION

The test period for the windows lasted from January 1980 through April 1981 averaging about 3 days per week. From the large amount of testing the days listed in Appendix H were chosen for data reduction. Two factors influenced this selection: days were eliminated when exterior environmental conditions were highly variable or when there was a malfunction of equipment. Other days were eliminated because of data repetitivity. Sample data is given in Appendix F.

5.1. The U_1 and U_2 Values

The U_1 values (effective U values) decrease with increasing air flows through the window cavity; see Figures 5.1 and 5.2. Reduction of the data was performed as described in Section 4.3.1. The range of values calculated is shown by the error bars. The circle denotes the average of all values for a specific air flow. These values are somewhat lower than those given by CARDA for a 4 ft high window with wooden sash. They are slightly higher than values by Swiss manufacturers for aluminum sash windows of the same 7 ft height as the test windows (see Appendix A, Figures A5.2.6 and A5.1.2).

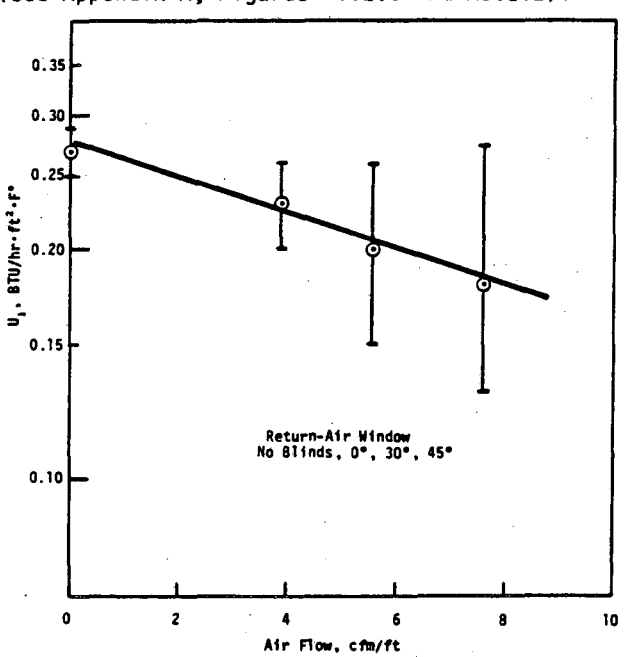

Figure 5.1. Effective U-value U_1 of the Return-Air Window.

At no or very low air flow through the window cavity a somewhat peculiar situation exists.* The window does not behave like a triple glazed window with a U value around 0.35. The low value range around 0.28 may be due to the window cavity being open to the room. Free convection, though small, could occur and produce low-flow rate admission of space air into the cavity. This flow would warm

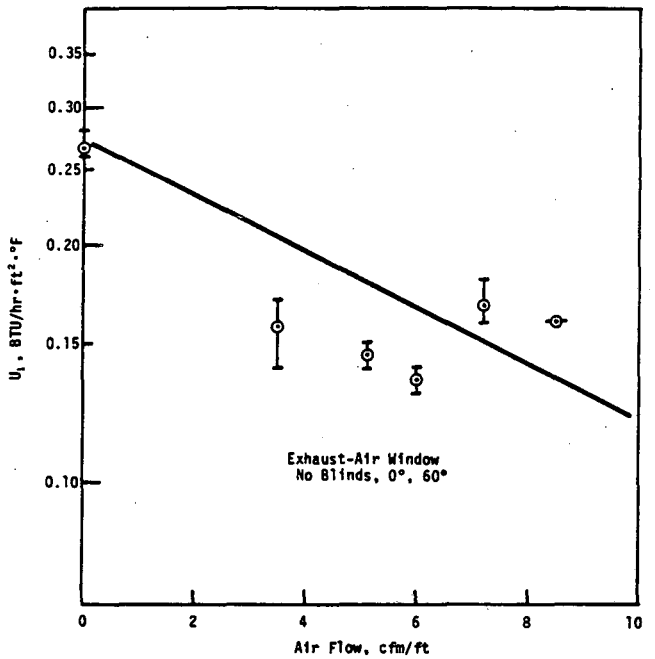

Figure 5.2. Effective U-value U_1 of the Exhaust-Air Window.

the inner glass pane to a higher temperature than the inner glass pane of a conventional triple glazed window would show at the same inside room temperature. This free convection would produce a heat loss. Another possible explanation is the difference in construction, particularly the spacing of the glass panes, of the air flow window compared to conventional triple glazed windows.

The U_2 values, as shown in Figures 5.3 and 5.4, must be considered in the context of effective U values. With decreasing air flow the U_2 value increases while the U_1 values decrease. Increasingly more energy is lost or gained by the air stream.

Although a great deal of data was analyzed related to the four different blind settings, no clear differences in U_1 values could be observed. As soon, however, as the blinds were closed completely, U_1 values between 0.9 and 0.12 developed. It became quite obvious that the radiative exchange between the outer and inner glass panes is appreciably affected only at tightly closed blinds.**

The blinds affected the U_2 values differently than they affected the U_1 values. For U_2, as long as the blinds were in the cavity, the U_2 values were similar, independent of blind angle. When the blinds are retracted, however, the U_2 values are slightly decreased (see Figure 5.3).

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* Such low air flows are not used under typical operational conditions. They may, nevertheless, occur because of reduction in total air flow; for example as an energy conservation measure at time of no occupancy.

** Good tilting closure was possible only with verticle louver blinds in the exhaust air windows. Data for completely closed blinds is not used in any way related to this project and the above mentioned values are given for possible interest beyond this project.

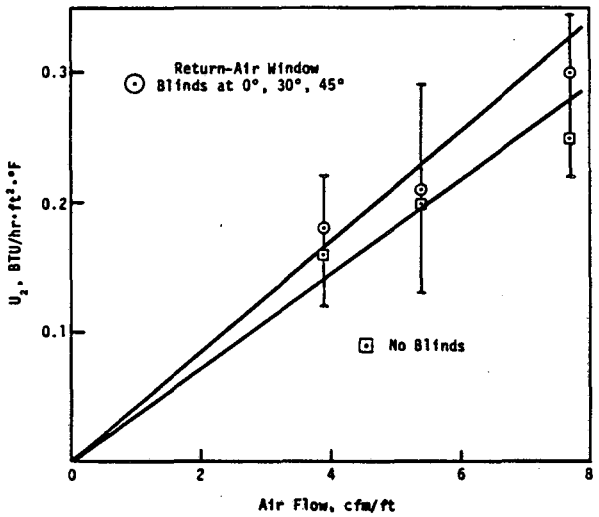

Figure 5.3. Energy Loss or Absorption Coefficient U_2 for the Air Stream of the Return-Air Window.

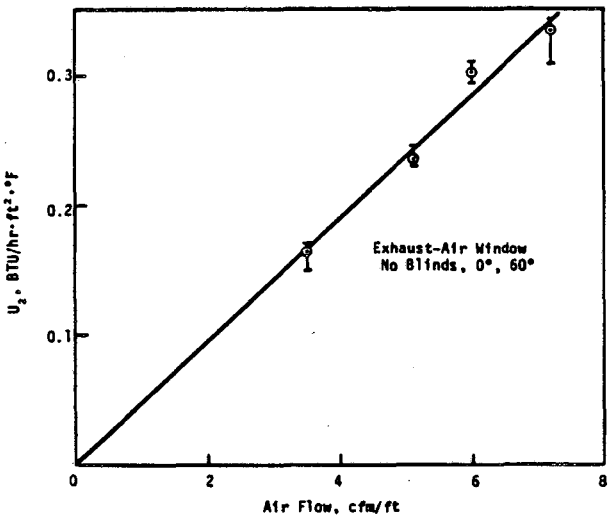

Figure 5.4. Energy Loss or Absorption Coefficient U_2 for the Air Stream of the Exhaust-Air Window.

5.2. The RB, H_1 and H_2 Values

The reduction of irradiation related to the radiation barrier, that is the glass and the shading device, is not influenced by the air flow. Therefore, variations of RB, Figure 5.5, are obtained only for different blind settings. At first glance, these values may appear to be low. They, however, contain only the directly transmitted (not re-radiated) radiation component. They also are averages over typically rather large variations of sun angles with respect to the normal to the glass surface, where transmission tends to decrease rapidly with angle at very large angles of incidence.

The RB values are long term averages at various blind settings. Clearly the tilt position has a strong influence on the results (see Figure 5.5). Although there was scatter in the data, the values did not show a clear tendency related to solar altitude and azimuth angles although there should be some effect here. The diffusing and multi-reflective geometry as created by the blinds guides the solar radiation during clear days to the inside quite independently of the solar angles.

Venetian Blind Setting	RB
Retracted	0.31
at 0° slat angle	0.14
at 30° slat angle	0.10
at 45° slat angle	0.07
Louver Blind Setting	**RB**
Retracted	0.36
at 0° louver angle	0.14
at 60° louver angle	0.09

Figure 5.5. RB Values for Air-Flow Windows with White Venetian Blinds at Various Slat Angles to Horizontal Plane or with White Opaque Vertical Louver Blinds at Various Angles from Normal to Window Plane.

The H_1 values clearly decrease in value with increasing air flow. Various blind positions did not develop a pattern for differentiation. This can be explained from the fact that the surface area of the blinds reached by solar radiation is basically constant, independent of blind setting angles, as long as the blinds are closed enough to block direct radiation. Therefore, absorption and re-radiation of glass and blinds vary little. Again there is some uncertainty for no or very low cavity air flow, similar to what has been said in regard to U_1 values at very low air flows. Here the situation is even less a problem, as such low air flows may occur in daytime only during cutbacks over weekends and holidays.

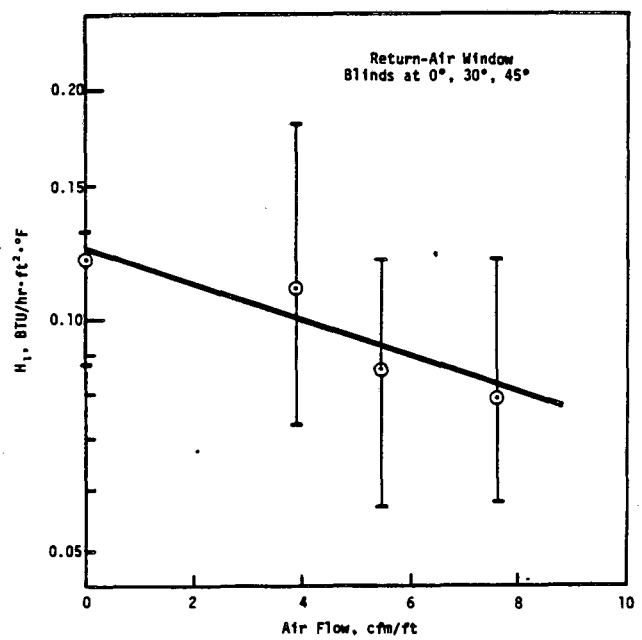

Figure 5.6. Heat Transfer Coefficient H_1 for Return-Air Window.

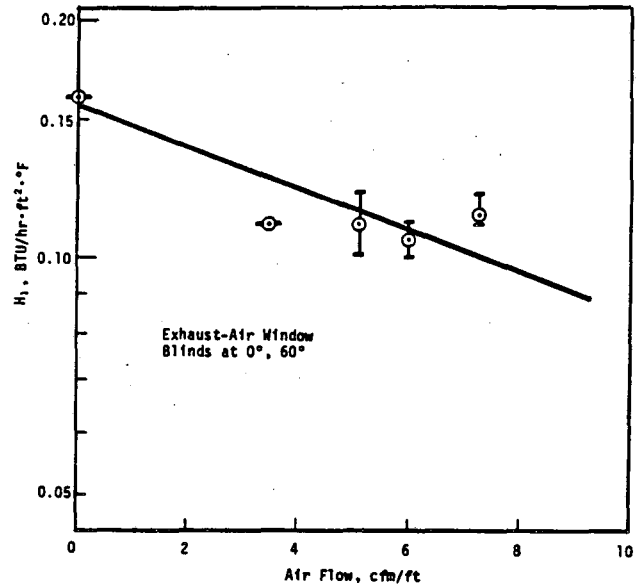

Figure 5.7. Heat Transfer Coefficient H_1 for Exhaust-Air Window.

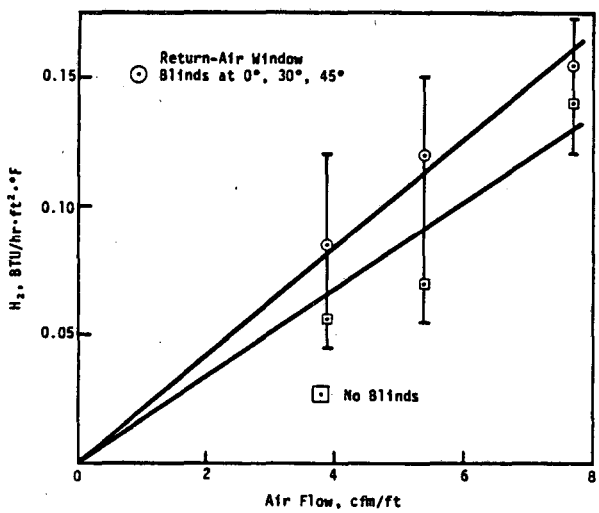

Figure 5.8. Heat Absorption Coefficient H_2 for the Air Stream of the Return-Air Window.

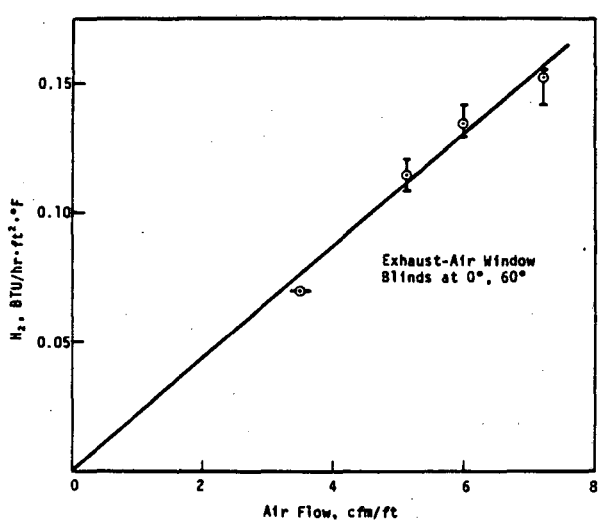

Figure 5.9. Heat Absorption Coefficient H_2 for the Air Stream of the Exhaust-Air Window.

5.3. The U_r and SC Values

The U_r value did not show any appreciable decline with blind opening angle until they were closed as tightly as possible. The U_r for this blind closure was found to be 0.43. The average value for blind settings from open to 45° slat tilt was found to be 0.55 with a scatter between 0.52 and 0.62. This slightly lower value than given in the literature (0.58 for 1/2 inch air space)* and also somewhat lower than test results furnished by the Wausau Metals Corporation (Appendix B) for the reference windows, is due to our test conditions at no or very low wind velocities. U values are generally given for 15 mph wind velocity which is considerably higher than experienced during our tests.

Extensive testing for SC values at all blind settings showed very consistent values for no blinds present, but this condition was used in the testing only during totally overcast conditions. The scatter ranged from 0.52 to 0.64 with the average at 0.57.

The values for the various slat tilts showed scatter from 0.37 to 0.49 with the average at 0.44. Here, similarly to the H_2 values, no clear pattern could be observed in relation to blind slat angles.

The SC value for open blinds is slightly lower and the value for closed blinds is slightly higher than what one would expect in comparison with conventional shading coefficients of double glazed windows.** One must remember in this context that these values are normalized to irradiation of the outside vertical surface and not to radiation after transmission through one pane of glass, as conventionally given in ASHRAE literature.

5.4. Condensation Potential in the Air-Flow Window Cavity

The potential for condensation in the window cavity of the exhaust-air window was evaluated for five air flows: 2.8, 3.9, 5.4, 6.6 and 7.7 cfm/ft of window width. For this purpose three thermocouples were attached to the inside surface of the double glazed, outer window pane in the vertical axis of the test window at a 6 inch distance from the top window frame, at the center and at 6 inches from the bottom frame.

Samples of test data are given for these air flows in Appendix G. The temperature T_{low} is the lowest temperature of the three which was in this case the thermocouple close to the lower frame because of the down-flow air direction.

By establishing a ratio of the total temperature drop across the window and the partial temperature drop to the insulating glass surface

$$\frac{T_i - T_o}{T_i - T_{low}} = CR \qquad (5.1)$$

* See ASHRAE Handbook of Fundamentals, 1972, p. 370.

** See ASHRAE Handbook of Fundamentals, 1972, p. 402.

the level of any temperature on the inside of the glass (T_{low}) can be calculated in relation to various indoor and outdoor temperature conditions. Values of CR for various air flows are also given in Appendix G. Figure 5.10 shows the relative humidity limits of the room air at 65°F for various flow rates and outdoor temperatures. At the areas above the limits fogging or condensation may occur at the inside of the insulating glass surface.

These limits are lower than for conventional double glazing as the cavity air is cooler than the room air. At higher flow rates, than those tested, the glass surface temperatures will approach levels of conventional double glazing at room air condition. This surface temperature drop of air-flow windows increases with the height of windows.

In cold climates, rooms with unusually high relative humidity levels, that is, above about 40 percent, should either receive higher cavity air-flow rates than those tested or triple glazing should be applied for the outer part of the cavity. The latter was specified, for example, for the computer room of the German Texaco Building in Hamburg where a relative humidity of 50 percent was to be maintained.

A Swedish manufacturer* of air-flow windows recommends for their winter conditions and a 1.20 m (4 ft) high window a minimum flow rate of 5 cfm/ft of window width (winter design temperature for Stockholm is 5°F).

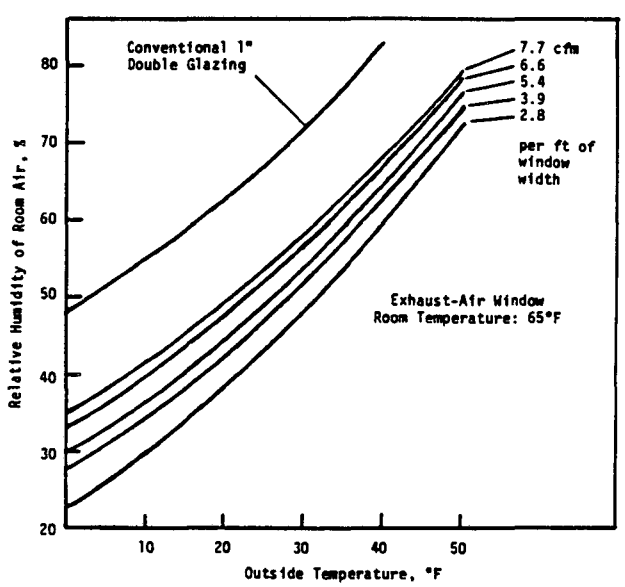

Figure 5.10. Relative humidity limits of room air above which condensation may occur in window cavity on inside of insulating glass pane at outside temperature (T_o) and cavity air flow rate ($\dot{m}$). Exhaust-air window with outer 1" insulating glass, window height 7 ft.

*COMBIVENT Design Manual by CARDA Company.

5.5. Mean Radiant Temperature

The mean radiant temperature (mrt) refers to the equivalent radiant heat exchange between the human body and the surfaces that surround it: for example, a room. An excellent discussion of the mrt, its measurement, and its calculation is given by Fanger.**

Although evaluation of the mrt of the test windows was called for in the contract, this data is of little value in specific. The reason for this is that all surfaces surrounding a human body contribute to the mrt through their temperatures and their radiation shape factors:**

$$T_{mrt} = T_1 F_{p-1} + T_2 F_{p-2} + .. + T_n F_{p-n} \qquad (5.2)$$

If, for example, surface** is the test window, its contribution to the mrt is through the window surface temperature and its shape factor with the person. The shape factor will vary with several characteristics, including the size of the window, its height from the floor, and the distance between the person and the window. The general term $T_i F_{p-i}$ is totally dependent upon the specifics of the application. For this reasoning alone, the conclusion can be drawn that the most critical factor in the mrt determination for any space will be the temperature of the inner (roomside) surface of the window.

An examination of the appropriate methods for measurement of the mrt underlines the conclusion that the inner surface temperature of the window is most critical. Two methods are used for experimental determination of mrt.**

A simple device used for this purpose is the globe thermometer. The globe thermometer consists of a black spherical shell with a thermal sensor located in the center. With the reading from the globe thermometer, the air temperature and the air velocity, the mrt can be calculated. This step is an involved technique and is primarily influenced by the details of the room and only secondarily affected by the window (this can be seen by comparing the shape factor from the body to the window with unity.)

The other approach substitutes some complications for others. In this approach the temperatures of all surfaces in the room are determined. Use is then made of estimates of shape factors to find the mrt, as shown in the equation given above. Shape factors of this type have been tabulated.***

When consideration was given for determination of the mrt in the present testing program, the method using the globe thermometer was rejected as being too site specific. Instead, the surface temperature determination method was used. Surface

** P. O. Fanger, THERMAL COMFORT - ANALYSIS AND APPLICATIONS IN ENVIRONMENTAL ENGINEERING, McGraw-Hill Book Company, 1972, pp. 141-148.

*** P. O. Fanger, op. cit., Chapter 6.

temperature data for the window given as a function of the primary independent variables in the testing program was determined to be the most durable and widely applicable form of the data.

Surface temperatures for the flow window were determined in all experimental runs. This parameter was key in determining window performance, as has been discussed above.* Hence the assumed h_{total} variation coupled with the inferred (from the experimental data) variation of U_1 can be used to "return" values of the inside (roomside) surface temperature. This is done for nighttime conditions in Figure 5.11. As would be expected, the surface temperature (the window contribution to the mrt) increases with increasing air flow for winter nighttime conditions. Comparable results for typical single, double and triple-glazed windows are shown, based upon an assumed constant overall heat transfer coefficient but an inside heat transfer coefficient that varies as shown in Figure 3.8.

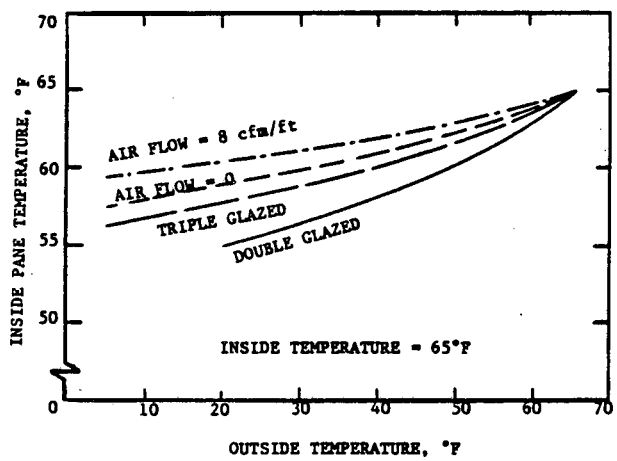

Figure 5.11. Inside pane temperature for nighttime winter conditions, to be used in mean radiant temperature calculation. Inside temperatures other than 65°F can be found by linearly shifting whole curve.

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* Remember that $(T_i - T_{wi})$ was used to find h_{total}, and then, for nighttime testing, $h_T (T_i - T_{wi}) = U_1 (T_i - T_o)$ was used to find U_1.

6. PERFORMANCE MODELING

The test results, as described in Chapter 5 can be used in many practical applications. Most importantly, however, is the potential impact on energy consumption determinations. In the following section, the considerations for performance modeling are outlined. Following that, results for year long modeling for a range of operating parameters in Salt Lake City are given. The performance modeling program is listed in Appendix H.

6.1. Description of Modeling Technique

6.1.1. Energy Balance of the Air-Flow Windows

The instantaneous energy balance of the air-flow windows relative to the barrier between the inner and outer ambient conditions, but neglecting the energy in the air flow was noted in Section 4.4. It is repeated here:

$$QS = U_1 (T_o - T_i) \cdot A_w + (H_1 + RB) \cdot I_o \cdot A_g \quad (6.1)$$

The air used to achieve the reduction in energy transfer across the air-flow windows must be replaced, if discarded, or it must be conditioned, if returned to the central HVAC system. In case of the exhaust-air window, all cavity air is discarded and replaced by fresh air. In case of the return-air window, the option exists to only partially discard. The air not discarded will have to be treated before recycling.

The instantaneous heat loss or gain of the return air in the cavity is defined as:

$$QRT = \dot{m}_1 \cdot C_p \cdot (T_{fx} - T_{fi}) \quad (6.2)$$

The amount to be treated is 1-FR, where FR is the fresh air fraction which replaces part of the return air. The energy required to treat the recycled air can be expressed by

$$QRC = (1\text{-}FR) \cdot QRT = (1\text{-}FR) \cdot [U_2 \cdot (T_o - T_i) \cdot A_w + H_2 \cdot I_o \cdot A_g] \quad (6.3)$$

The energy losses and gains from the fresh air flow (balancing the exhaust air) are defined in the following section.

6.1.2. Energy Balance of the Reference Window

As outlined in Section 4.4, the energy balance on the reference window is established by using the overall heat transfer coefficient and the shading coefficient

$$QS = U_r \cdot (T_o - T_i) \cdot A_w + SC \cdot I_o \cdot A_g \quad (6.4)$$

6.2. Energy Content of Exhaust-Air

While evaluating the efficiencies of air-flow windows versus conventional systems it is important to consider the "fate" of the air after it leaves the window cavity. In the case of the exhaust-air window all air is discarded to the outside. In the case of the return-air window all, none, or part of the air is discarded. Only in very special cases none of this return air may be discarded which implies total reconditioning.

Discarded air must be made up from fresh outside air. Minimum fresh air requirements must be considered. For the conditioning of the fresh air, energy is needed to provide the desired sensible and latent components of a steady state room air condition.

Fresh air requirements are generally expressed in cfm per person. Here, for easier comparison, fresh air requirements are expressed in cfm per ft of window width. The sensible energy content of make-up air for a particular requirement is then

$$Q_{FR1} = FR \cdot CFM \cdot WW \cdot 0.92 \cdot (T_o - T_i) \quad (6.5)$$

where 0.92 represents the product of air density, specific heat and 60 minutes per hour (0.064 x 0.24 x 60). The latent energy content of make-up air is

$$Q_{FR2} = FR \cdot CFM \cdot WW \cdot 3.84 \, [(1070 + 0.45 \cdot TM) \cdot WO - (1070 + 0.45 \cdot T_i) \cdot WI] \quad (6.6)$$

where 3.84 represents the product of air density and 60 minutes per hour (0.064 x 60). The sum of $1070 + 0.45 \cdot T_i$ relates to the enthalpy levels at the monthly mean outside temperatures (TM) and the inside temperatures (T_i). The mean outside temperatures, the inside temperatures and the related humidity ratios for Salt Lake City as used for the performance modeling are given in the Appendix L.

6.3. Hourly Insolation and Temperature Determination

As is discussed in the next section an hourly time step is used for the modeling of the windows to determine their year-long performance. Hence it is very critical to have representative values for the two most important climatic variables: temperature and insolation.

There are two extremes that can be considered in modeling these two parameters. In one, long-term (e.g. month) averages can be used. This can be a very inaccurate approach in modeling items that respond to variability. In another, virtually instantaneous weather records for a large number of years can be used. Two drawbacks exist in this approach: weather records of this type are quite limited (at best, hourly values are available from the SOLMET system for some of their stations), and the computer time and capability required for this type of calculation is far beyond the reach of most architectural and engineering firms.

Experience, primarily related to solar system simulation developed at the University of Utah* has shown that there are procedures whereby the

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* S. R. Swanson and R. F. Boehm, "Experimental Measurements and Systems Implications of Performance of Flat Plate Solar Collector Configurations," ASME Paper 76-WA/Sol-14, 1976.

S. R. Swanson and R. F. Boehm, "Calculation of Long Term Solar Collector Heating System Performance," SOLAR ENERGY, 19, 2, 1977, pp. 129-138.

variability of the weather can be handled approximately. This variability is so important to the modeling of systems like the ones considered here, and can be handled approximatley with little loss in accuracy but with a great deal of simplification of the weather records and computer capability required.

The technique used in the present work is described briefly here and in somewhat greater detail in Appendix M. Accuracy of the simulation is difficult to assess in absolute terms because there are relatively few simulations published that have used very detailed data and are considered to be highly accurate. We have compared the very detail calculations for solar system performance performed at LASL with agreement within 4% maximum error, but more typically 1-2%.** What is critical is that the approach does include variability of weather parameters in an approximately realistic fashion and it is within the computer capabilities of many firms. Since both the flow windows and the reference window are modeled with the same code, the comparisons given here should be relatively valid.

In the weather modeling (described in more detail in Appendix M), base data required for input are (all for the location of interest):

1. Long term average monthly maximum and minimum temperatures
2. A specific yeart daily maximum and minimum temperatures
3. Long term average monthly insolation on a horizontal surface
4. A specific year*** daily insolation on a horizontal surface.

These data are readily found in U. S. Weather Bureau records.

The daily insolations are normalized so that the monthly sums of the daily values correspond to the long term monthly averages. A similar procedure is performed on the temperatures. In this manner, a data set reflecting specific year variability but with long term average equivalence is generated.

In typical solar radiation modeling fashion, the daily, horizontal, total radiation values are separated into beam and diffuse components. The beam component is then varied hourly via the physical variations of the sunshine so lucidly described by many authors. This is the same as "clear sky" condition calculations, but with a modified intensity due to the degree of cloud cover present on a particular day. As is the real situation, the modeling scheme does not allow any beam radiation on extremely overcast days (this is shown specifically in Appendix M). The total and diffuse variations through the day are handled by empirical relations and these are given in Appendix M also.

The ambient temperature is varied with time sinusoidally between the maximum value for the day and the minimum value for the day. A slight delay past solar noon of the occurrence of the maximum value is taken to more closely simulate what normally is measured.

More details on the calculation procedure for the temperatures and the insolation are given in the Appendix M and I.

R. F. Boehm and S. R. Swanson, SOLAR SYSTEM DESIGN HANDBOOK FOR UTAH, Utah Engineering Experiment Station, 1978.

T. Newell, S. Swanson and R. Boehm, "Mass Flow Considerations for Solar Air Heating Systems," PROCEEDINGS OF THE INTERNATIONAL SOLAR ENERGY SOCIETY, 1979, pp. 857-861.

T. Newell, S. Swanson and R. Boehm, "The Effect of Auxiliary Load Management Strategy on Solar System Performance," PROCEEDINGS OF THE INTERNATIONAL SOLAR ENERGY SOCIETY, 1979, pp. 2143-2147.

R. Rudloff, S. Swanson and R. Boehm, "Computer Simulation Results for Planar Reflectors and Flat Plat Solar Collectors," JOURNAL OF SOLAR ENERGY ENGINEERING, May 1980, pp. 166-172.

T. Newell, "Parametric Studies of Active Residential Solar Heating Systems," M.S. Thesis, University of Utah 1980.

** See Boehm and Swanson, 1978, in previous footnote.

*** While a specific year's data is used, the particular year is not important because of the normalized procedure used in the calculations.

7. MODELING RESULTS AND DISCUSSION

7.1. Monthly Performance Results

Figures 7.1 through 7.24 show monthly performance modeling results for two cavity air flows (4 and 6 cfm/ft of window width) over the course of a year. These results are sums of hourly calculations by a computer program which is listed in Appendix H. The external environment input is the reference year data on radiation and temperatures of Salt Lake City as described in Section 6.3 and listed in Appendix I. The window input data is based on the test results as shown in Figures 5.1, 5.3, 5.5, 5.6 and 5.8. The data is given in four blocks per month which represent the south, east, west and north orientations. This data is listed in Btu per month and is for reference and air-flow window sizes of 4 ft width and 7 ft height.

Only heat gain or heat loss will happen across a window during a particular hour. Over the course of a day or a month, however, times of heat gain and heat loss will occur. These loads should not be traded-off against each other, as considerable distortions of actual performance would develop.* Therefore, all performance modelling results are shown as simulations of positive and negative hourly energy balances (heat gains and losses).

The first four values of each block give the heat gain and heat loss for the reference window and air-flow windows: QREF and QEAF.

Positive values represent heat gain, negative values represent heat loss. The simulations are based on the assumption that the heat gains and heat losses of the exhaust-air window and return-air window are the same, that is QEAF = QRA; the fate of the exhaust air or return air and the associated energy not being considered.

The first two lines of the FR columns give the energy QRC which is required to treat with HVAC equipment that part of the air which is recirculated (not exhausted). If FR = 1, all air is exhausted and QRC = 0. This happens in the case of exhaust-air windows or when all air in a return-air window system is exhausted. With decreasing FR less and less air is exhausted. The recirculated air must be treated.

The last four lines of every block refer to the energy which is necessary to treat the fresh air, that is the air replacement for the exhaust-air window or the return-air window. These values decrease with decreasing FR. They are the same in each block, as they are the same for each orientation.

Figure 7.43 shows the sample output of the hourly performance over one day at 4 cfm/ft of window width (7th of August). Figure 7.44 gives the key for understanding these values.

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* Special HVAC systems may accept functions which allow trade-off, for example through energy shifting in buildings, when heat gains and losses occur simultaneously, or through energy storage.

Since there are several components of the various energy flows, an understanding of the numerical results of the Energy Balance Simulation Program is somewhat involved.

Figures 7.25 through 7.42, therefore, show some of the same data in graphic form for transmission gains and losses on south and west orientations, for energy required to treat recycled air and for energy required to treat make-up air.

For the following discussion reference is made to the graphs from Figure 7.25 onward through 7.42. Two units on the vertical scale of these graphs equal 0.1×10^6 Btu per month. Figure 7.25 shows the performance of the test window (QEAF or QRA) and the reference window (QREF) for the south orientation at 4 cfm/ft of window width. The graph shows an improvement for the air-flow window versus the reference window of about 60 percent for heating and about 55 percent for cooling during all year. Heat losses and heat gains are separated as totals are not representative of window energy balance.

An increase of cavity air-flow from 4 to 6 cfm/ft improves this efficiency slightly more. This difference is small, however, and that it is hardly noticeable in the graph (Figure 7.34). These decreases of QEAF+ and QEAF- are for January: $0.104 \times 10^6 - 0.101 \times 10^6 = 0.003 \times 10^6$ Btu for heat gain and $-0.113 \times 10^6 + 0.100 \times 10^6 = -0.013 \times 10^6$ Btu for heat loss (see Figures 7.1 and 7.13). For October, with the largest heat gain, the improvement is $0.252 \times 10^6 - 0.240 \times 10^6 = 0.012 \times 10^6$ (Figures 7.10 and 7.22). These differences represent improvements of 12 percent for the largest heating load and 5 percent for the largest cooling load at south orientation.

Figure 7.28 shows the performance for west orientation at 4 cfm/ft. The performance in heating is obviously very similar to that found for the south orientation. The improvement in performance of the air-flow window versus the reference window related to cooling load is about 58 percent.

The impact of the increase in cavity air flow from 4 to 6 cfm/ft again is hardly noticeable in the graph. During the peak month of July it yields a reduction of $0.238 \times 10^6 - 0.227 \times 10^6 = 0.011 \times 10^6$ Btu (Figures 7.7 and 7.19), that is about 4.5 percent.

The values described above are the heat gains and losses to and from the interior environment, not considering energy in the air flow. In this regard the exhaust-air and return-air system perform equally: therefore the notation of QEAF = QRA in the discussed graphs.

If the cavity air flow is larger than the fresh air requirement of the exterior building zone, then gains and losses for treating fresh air beyond comfort requirements must be included in the energy balance of the exhaust air windows, Figures 7.31 through 7.33. These graphs are shown with fresh air fractions of 1.0, 0.75, 0.5 and 0.25. At fresh air fraction equal to zero, all cavity air is recycled. It is obvious that the potential for savings exists, especially in winter, if the fresh air flow is less than the cavity air flow. A

return-air window would be chosen over an exhaust-air window, as the exhaust air window always has the maximum a fresh air fraction of 1.0.

In case of the return-air window with a fresh air fraction smaller than 1.0 must add the energy required (QRC) to treat that part of the cavity air which will be recycled, Figures 7.26 and 7.27, 7.29 and 7.30. The energy needed for treating this air is in this case (Salt Lake City) in winter considerably smaller than the energy needed for treating fresh air. Not so in summer, however. It is noted that during summer months when there is no heating required, there are small negative values, representing heat loss. This is due to the static temperature setting in the computer model of 78°F during the summer months. Salt Lake City experiences considerable temperature swings during summer and temperatures often fall below 78°F. The winter setting is at 68°F which may contribute to small gains when the outside temperature is above this level. For consideration of the comparative overall performance of the windows these small losses and gains are of negligible concern.

7.2. Monthly Summary Samples Including Fresh Air Impact

For a better understanding of overall window performance the loads from window heat gain/heat loss, from treatment of recycled air and from treatment of fresh air, are added. For a fresh air fraction, for example, of 0.75 for the return-air window and the reference window the following heating and cooling loads are found (Btu/month).

Exhaust Air Window

January, south, 4 cfm/ft, heat loss (Figure 7.1)

$$SQEAF = QEAF + QFRESH\ 1 + QFRESH\ 2$$
$$= -0.113 \times 10^6 - 0.404 \times 10^6 - 0.113 \times 10^6$$
$$= -0.630 \times 10^6$$

October, south, 4 cfm/ft, heat gain (Figure 7.10)*

$$SQEAF = QEAF + QFRESH\ 1$$
$$= 0.252 \times 10^6 + 0.773 \times 10^3 = 0.253 \times 10^6$$

July, west, 4 cfm/ft, heat gain (Figure 7.7)

$$SQEAF = QEAF + QFRESH\ 1$$
$$= 0.238 \times 10^6 + 0.378 \times 10^5 = 0.276 \times 10^6$$

Return-Air Window

January, south, 4 cfm/ft, 0.75 fresh air, heat loss:

$$SQRA = QEAF + QRC + QFRESH\ 1 + QFRESH\ 2$$
$$= -0.113 \times 10^6 - 0.199 \times 10^5 - 0.303 \times 10^6 - 0.849 \times 10^5$$
$$= -0.521 \times 10^6$$

October, south, 4 cfm/ft, 0.75 fresh air, heat gain:

$$SQRA = QEAF + QRC + QFRESH\ 1$$
$$= 0.252 \times 10^6 + 0.264 \times 10^5 + 0.580 \times 10^3$$
$$= 0.279 \times 10^6$$

July, west, 4 cfm/ft, 0.75 fresh air, heat gain:

$$SQRA = QEAF + QRC + QFRESH\ 1$$
$$= 0.238 \times 10^6 + 0.239 \times 10^5 + 0.284 \times 10^5$$
$$= 0.290 \times 10^6$$

Reference Window

January, south, 4 cfm/ft, 0.75 fresh air, heat loss:

$$SQREF = QREF + QFRESH\ 1 + QFRESH\ 2$$
$$= -0.309 \times 10^6 - 0.303 \times 10^6 - 0.849 \times 10^5$$
$$= -0.697 \times 10^6$$

October, south, 4 cfm/ft, 0.75 fresh air, heat gain:

$$SQREF = QREF + QFRESH\ 1$$
$$= 0.629 \times 10^6 + 0.580 \times 10^3$$
$$= 0.687 \times 10^6$$

July, west, 4 cfm, 0.75 fresh air, heat gain:

$$SQREF = QREF + QFRESH\ 1$$
$$= 0.551 \times 10^6 + 0.284 \times 10^6$$
$$= 0.580 \times 10^6$$

These values show large energy savings for the air flow windows versus the reference windows. Because of the fresh air fraction assumed to be 0.75, the return-air window performs considerably better than the exhaust-air window in January (heat loss), but not as well in October (south, heat gain) and July (west, heat gain). For October, this is due to the utilization of outside air which has a lower temperature level than the inside air. For July, the difference between the outside air and the inside air is smaller than the difference between the return air from the return-air window and the inside air, resulting in larger energy consumption for treatment than for cooling fresh air from outside.

The sample of hourly data for the 7th of August (Figure 7.43) clearly shows the cooling load contributions of the various energy flows. The reduction in performance for the room cooling load from reference window to air-flow window for west orientation is nearly 60 percent: $0.255 \times 10^4 - 0.106 \times 10^4 = 0.149 \times 10^4$ Btu/hr.

At a fresh air fraction of 0.75 the recycled air would bring a cooling load of 0.118×10^3 (QRCD in computerized data) and the fresh air a cooling load of 0.136×10^3 (QFR1). The negative sign of QFR2 indicates moisture loss to the outside at the assumed inside relative humidity level of 30 percent.

---

* A latent heat gain component (QFRESH 2) does not appear in the heat gain calculations because of the low relative humidity levels in Salt Lake City.

January

```
SO.

QREF+
 0.285E 06
QREF-
-0.309E 06
QEAF+
 0.104E 06
QEAF-
-0.113E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.105E 05  0.209E 05  0.314E 05
QRC -
 0.000E 00 -0.199E 05 -0.398E 05 -0.598E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.404E 06 -0.303E 06 -0.202E 06 -0.101E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.113E 06 -0.849E 05 -0.566E 05 -0.283E 05

EAST

QREF+
 0.480E 05
QREF-
-0.336E 06
QEAF+
 0.230E 05
QEAF-
-0.119E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.118E 04  0.236E 04  0.353E 04
QRC -
 0.000E 00 -0.222E 05 -0.445E 05 -0.667E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.404E 06 -0.303E 06 -0.202E 06 -0.101E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.113E 06 -0.849E 05 -0.566E 05 -0.283E 05

WEST

QREF+
 0.709E 05
QREF-
-0.333E 06
QEAF+
 0.325E 05
QEAF-
-0.118E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.194E 04  0.387E 04  0.581E 04
QRC -
 0.000E 00 -0.219E 05 -0.438E 05 -0.657E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.404E 06 -0.303E 06 -0.202E 06 -0.101E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.113E 06 -0.849E 05 -0.566E 05 -0.283E 05

NO.

QREF+
 0.324E 04
QREF-
-0.358E 06
QEAF+
 0.884E 04
QEAF-
-0.124E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QRC -
 0.000E 00 -0.239E 05 -0.477E 05 -0.716E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.404E 06 -0.303E 06 -0.202E 06 -0.101E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.113E 06 -0.849E 05 -0.566E 05 -0.283E 05
```

February

```
SO.

QREF+
 0.516E 06
QREF-
-0.250E 06
QEAF+
 0.202E 06
QEAF-
-0.934E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.202E 05  0.404E 05  0.606E 05
QRC -
 0.000E 00 -0.157E 05 -0.314E 05 -0.470E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.346E 06 -0.259E 06 -0.173E 06 -0.865E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.929E 05 -0.697E 05 -0.465E 05 -0.232E 05

EAST

QREF+
 0.136E 06
QREF-
-0.275E 06
QEAF+
 0.571E 05
QEAF-
-0.977E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.476E 04  0.953E 04  0.143E 05
QRC -
 0.000E 00 -0.181E 05 -0.362E 05 -0.544E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.346E 06 -0.259E 06 -0.173E 06 -0.865E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.929E 05 -0.697E 05 -0.465E 05 -0.232E 05

WEST

QREF+
 0.189E 06
QREF-
-0.272E 06
QEAF+
 0.750E 05
QEAF-
-0.976E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.690E 04  0.138E 05  0.207E 05
QRC -
 0.000E 00 -0.178E 05 -0.356E 05 -0.534E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.346E 06 -0.259E 06 -0.173E 06 -0.865E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.929E 05 -0.697E 05 -0.465E 05 -0.232E 05

NO.

QREF+
 0.360E 04
QREF-
-0.298E 06
QEAF+
 0.101E 05
QEAF-
-0.102E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.220E 01  0.439E 01  0.659E 01
QRC -
 0.000E 00 -0.201E 05 -0.403E 05 -0.604E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.346E 06 -0.259E 06 -0.173E 06 -0.865E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.929E 05 -0.697E 05 -0.465E 05 -0.232E 05
```

Figures 7.1 and 7.2. Monthly performance data for cavity air flow of 4 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100×10^6).

March

SO.

QREF+
0.436E 06
QREF-
-0.240E 06
QEAF+
0.185E 06
QEAF-
-0.889E 05

FR:	1.0	.75	.50	.25
QRC +	0.000E 00	0.167E 05	0.335E 05	0.502E 05
QRC -	0.000E 00	-0.154E 05	-0.309E 05	-0.463E 05
QFRESAH1 +	0.406E 03	0.305E 03	0.203E 03	0.102E 03
QFRESAH1 -	-0.340E 06	-0.255E 06	-0.170E 06	-0.851E 05
QFRESH2 +	0.000E 00	0.000E 00	0.000E 00	0.000E 00
QFRESH2 -	-0.876E 05	-0.657E 05	-0.438E 05	-0.219E 05

EAST

QREF+
0.193E 06
QREF-
-0.257E 06
QEAF+
0.903E 05
QEAF-
-0.920E 05

FR:	1.0	.75	.50	.25
QRC +	0.000E 00	0.671E 04	0.134E 05	0.201E 05
QRC -	0.000E 00	-0.170E 05	-0.341E 05	-0.511E 05
QFRESAH1 +	0.406E 03	0.305E 03	0.203E 03	0.102E 03
QFRESAH1 -	-0.340E 06	-0.255E 06	-0.170E 06	-0.851E 05
QFRESH2 +	0.000E 00	0.000E 00	0.000E 00	0.000E 00
QFRESH2 -	-0.876E 05	-0.657E 05	-0.438E 05	-0.219E 05

WEST

QREF+
0.261E 06
QREF-
-0.255E 06
QEAF+
0.113E 06
QEAF-
-0.918E 05

FR:	1.0	.75	.50	.25
QRC +	0.000E 00	0.952E 04	0.190E 05	0.285E 05
QRC -	0.000E 00	-0.168E 05	-0.335E 05	-0.503E 05
QFRESAH1 +	0.406E 03	0.305E 03	0.203E 03	0.102E 03
QFRESAH1 -	-0.340E 06	-0.255E 06	-0.170E 06	-0.851E 05
QFRESH2 +	0.000E 00	0.000E 00	0.000E 00	0.000E 00
QFRESH2 -	-0.876E 05	-0.657E 05	-0.438E 05	-0.219E 05

NO.

QREF+
0.271E 05
QREF-
-0.274E 06
QEAF+
0.338E 05
QEAF-
-0.951E 05

FR:	1.0	.75	.50	.25
QRC +	0.000E 00	0.210E 03	0.420E 03	0.630E 03
QRC -	0.000E 00	-0.188E 05	-0.376E 05	-0.565E 05
QFRESAH1 +	0.406E 03	0.305E 03	0.203E 03	0.102E 03
QFRESAH1 -	-0.340E 06	-0.255E 06	-0.170E 06	-0.851E 05
QFRESH2 +	0.000E 00	0.000E 00	0.000E 00	0.000E 00
QFRESH2 -	-0.876E 05	-0.657E 05	-0.438E 05	-0.219E 05

April

SO.

QREF+
0.299E 06
QREF-
-0.199E 06
QEAF+
0.132E 06
QEAF-
-0.715E 05

FR:	1.0	.75	.50	.25
QRC +	0.000E 00	0.114E 05	0.227E 05	0.341E 05
QRC -	0.000E 00	-0.132E 05	-0.264E 05	-0.395E 05
QFRESAH1 +	0.109E 03	0.815E 02	0.543E 02	0.272E 02
QFRESAH1 -	-0.285E 06	-0.214E 06	-0.143E 06	-0.713E 05
QFRESH2 +	0.000E 00	0.000E 00	0.000E 00	0.000E 00
QFRESH2 -	-0.178E 06	-0.134E 06	-0.891E 05	-0.446E 05

EAST

QREF+
0.233E 06
QREF-
-0.198E 06
QEAF+
0.114E 06
QEAF-
-0.710E 05

FR:	1.0	.75	.50	.25
QRC +	0.000E 00	0.826E 04	0.165E 05	0.248E 05
QRC -	0.000E 00	-0.135E 05	-0.269E 05	-0.404E 05
QFRESAH1 +	0.109E 03	0.815E 02	0.543E 02	0.272E 02
QFRESAH1 -	-0.285E 06	-0.214E 06	-0.143E 06	-0.713E 05
QFRESH2 +	0.000E 00	0.000E 00	0.000E 00	0.000E 00
QFRESH2 -	-0.178E 06	-0.134E 06	-0.891E 05	-0.446E 05

WEST

QREF+
0.303E 06
QREF-
-0.197E 06
QEAF+
0.135E 06
QEAF-
-0.708E 05

FR:	1.0	.75	.50	.25
QRC +	0.000E 00	0.112E 05	0.224E 05	0.336E 05
QRC -	0.000E 00	-0.132E 05	-0.264E 05	-0.396E 05
QFRESAH1 +	0.109E 03	0.815E 02	0.543E 02	0.272E 02
QFRESAH1 -	-0.285E 06	-0.214E 06	-0.143E 06	-0.713E 05
QFRESH2 +	0.000E 00	0.000E 00	0.000E 00	0.000E 00
QFRESH2 -	-0.178E 06	-0.134E 06	-0.891E 05	-0.446E 05

NO.

QREF+
0.538E 05
QREF-
-0.202E 06
QEAF+
0.563E 05
QEAF-
-0.705E 05

FR:	1.0	.75	.50	.25
QRC +	0.000E 00	0.677E 03	0.135E 04	0.203E 04
QRC -	0.000E 00	-0.145E 05	-0.290E 05	-0.435E 05
QFRESAH1 +	0.109E 03	0.815E 02	0.543E 02	0.272E 02
QFRESAH1 -	-0.285E 06	-0.214E 06	-0.143E 06	-0.713E 05
QFRESH2 +	0.000E 00	0.000E 00	0.000E 00	0.000E 00
QFRESH2 -	-0.178E 06	-0.134E 06	-0.891E 05	-0.446E 05

Figures 7.3 and 7.4. Monthly performance data for cavity air flow of 4 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100 x 10^6).

May

SO.

```
QREF+
 0.259E 06
QREF-
-0.183E 06
QEAF+
 0.121E 06
QEAF-
-0.642E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.982E 04  0.196E 05  0.295E 05
QRC -
 0.000E 00 -0.122E 05 -0.245E 05 -0.367E 05
QFRESAH1 +
 0.100E 04  0.751E 03  0.501E 03  0.250E 03
QFRESAH1 -
-0.255E 06 -0.191E 06 -0.127E 06 -0.637E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.158E 06 -0.119E 06 -0.792E 05 -0.396E 05
```

EAST

```
QREF+
 0.310E 06
QREF-
-0.177E 06
QEAF+
 0.143E 06
QEAF-
-0.628E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.117E 05  0.234E 05  0.351E 05
QRC -
 0.000E 00 -0.120E 05 -0.240E 05 -0.360E 05
QFRESAH1 +
 0.100E 04  0.751E 03  0.501E 03  0.250E 03
QFRESAH1 -
-0.255E 06 -0.191E 06 -0.127E 06 -0.637E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.158E 06 -0.119E 06 -0.792E 05 -0.396E 05
```

WEST

```
QREF+
 0.400E 06
QREF-
-0.175E 06
QEAF+
 0.177E 06
QEAF-
-0.627E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.155E 05  0.310E 05  0.464E 05
QRC -
 0.000E 00 -0.117E 05 -0.234E 05 -0.351E 05
QFRESAH1 +
 0.100E 04  0.751E 03  0.501E 03  0.250E 03
QFRESAH1 -
-0.255E 06 -0.191E 06 -0.127E 06 -0.637E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.158E 06 -0.119E 06 -0.792E 05 -0.396E 05
```

NO.

```
QREF+
 0.100E 06
QREF-
-0.172E 06
QEAF+
 0.803E 05
QEAF-
-0.614E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.177E 04  0.354E 04  0.531E 04
QRC -
 0.000E 00 -0.120E 05 -0.240E 05 -0.360E 05
QFRESAH1 +
 0.100E 04  0.751E 03  0.501E 03  0.250E 03
QFRESAH1 -
-0.255E 06 -0.191E 06 -0.127E 06 -0.637E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.158E 06 -0.119E 06 -0.792E 05 -0.396E 05
```

June

SO.

```
QREF+
 0.260E 06
QREF-
-0.114E 06
QEAF+
 0.123E 06
QEAF-
-0.406E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.107E 05  0.213E 05  0.320E 05
QRC -
 0.000E 00 -0.767E 04 -0.153E 05 -0.230E 05
QFRESAH1 +
 0.904E 04  0.678E 04  0.452E 04  0.226E 04
QFRESAH1 -
-0.148E 06 -0.111E 06 -0.738E 05 -0.369E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.123E 06 -0.925E 05 -0.617E 05 -0.308E 05
```

EAST

```
QREF+
 0.371E 06
QREF-
-0.111E 06
QEAF+
 0.172E 06
QEAF-
-0.402E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.150E 05  0.299E 05  0.449E 05
QRC -
 0.000E 00 -0.729E 04 -0.146E 05 -0.219E 05
QFRESAH1 +
 0.904E 04  0.678E 04  0.452E 04  0.226E 04
QFRESAH1 -
-0.148E 06 -0.111E 06 -0.738E 05 -0.369E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.123E 06 -0.925E 05 -0.617E 05 -0.308E 05
```

WEST

```
QREF+
 0.471E 06
QREF-
-0.109E 06
QEAF+
 0.205E 06
QEAF-
-0.399E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.193E 05  0.386E 05  0.579E 05
QRC -
 0.000E 00 -0.709E 04 -0.142E 05 -0.213E 05
QFRESAH1 +
 0.904E 04  0.678E 04  0.452E 04  0.226E 04
QFRESAH1 -
-0.148E 06 -0.111E 06 -0.738E 05 -0.369E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.123E 06 -0.925E 05 -0.617E 05 -0.308E 05
```

NO.

```
QREF+
 0.188E 06
QREF-
-0.106E 06
QEAF+
 0.111E 06
QEAF-
-0.395E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.566E 04  0.113E 05  0.170E 05
QRC -
 0.000E 00 -0.682E 04 -0.136E 05 -0.205E 05
QFRESAH1 +
 0.904E 04  0.678E 04  0.452E 04  0.226E 04
QFRESAH1 -
-0.148E 06 -0.111E 06 -0.738E 05 -0.369E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.123E 06 -0.925E 05 -0.617E 05 -0.308E 05
```

Figures 7.5 and 7.6. Monthly performance data for cavity air flow of 4 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100 x 10^6).

July

SO.

```
QREF+
 0.354E 06
QREF-
-0.729E 05
QEAF+
 0.163E 06
QEAF-
-0.271E 05
FR:     1.0         .75         .50         .25
QRC +
 0.000E 00  0.156E 05  0.313E 05  0.469E 05
QRC -
 0.000E 00 -0.465E 04 -0.931E 04 -0.140E 05
QFRESAH1 +
 0.378E 05  0.284E 05  0.189E 05  0.946E 04
QFRESAH1 -
-0.797E 05 -0.598E 05 -0.399E 05 -0.199E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.101E 06 -0.759E 05 -0.506E 05 -0.253E 05
```

EAST

```
QREF+
 0.452E 06
QREF-
-0.722E 05
QEAF+
 0.203E 06
QEAF-
-0.270E 05
FR:     1.0         .75         .50         .25
QRC +
 0.000E 00  0.196E 05  0.391E 05  0.587E 05
QRC -
 0.000E 00 -0.456E 04 -0.912E 04 -0.137E 05
QFRESAH1 +
 0.378E 05  0.284E 05  0.189E 05  0.946E 04
QFRESAH1 -
-0.797E 05 -0.598E 05 -0.399E 05 -0.199E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.101E 06 -0.759E 05 -0.506E 05 -0.253E 05
```

WEST

```
QREF+
 0.551E 06
QREF-
-0.715E 05
QEAF+
 0.238E 06
QEAF-
-0.269E 05
FR:     1.0         .75         .50         .25
QRC +
 0.000E 00  0.239E 05  0.479E 05  0.718E 05
QRC -
 0.000E 00 -0.449E 04 -0.898E 04 -0.135E 05
QFRESAH1 +
 0.378E 05  0.284E 05  0.189E 05  0.946E 04
QFRESAH1 -
-0.797E 05 -0.598E 05 -0.399E 05 -0.199E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.101E 06 -0.759E 05 -0.506E 05 -0.253E 05
```

NO.

```
QREF+
 0.245E 06
QREF-
-0.708E 05
QEAF+
 0.138E 06
QEAF-
-0.268E 05
FR:     1.0         .75         .50         .25
QRC +
 0.000E 00  0.902E 04  0.180E 05  0.271E 05
QRC -
 0.000E 00 -0.441E 04 -0.883E 04 -0.132E 05
QFRESAH1 +
 0.378E 05  0.284E 05  0.189E 05  0.946E 04
QFRESAH1 -
-0.797E 05 -0.598E 05 -0.399E 05 -0.199E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.101E 06 -0.759E 05 -0.506E 05 -0.253E 05
```

August

SO.

```
QREF+
 0.412E 06
QREF-
-0.884E 05
QEAF+
 0.179E 06
QEAF-
-0.328E 05
FR:     1.0         .75         .50         .25
QRC +
 0.000E 00  0.183E 05  0.366E 05  0.549E 05
QRC -
 0.000E 00 -0.565E 04 -0.113E 05 -0.169E 05
QFRESAH1 +
 0.253E 05  0.190E 05  0.126E 05  0.632E 04
QFRESAH1 -
-0.102E 06 -0.767E 05 -0.511E 05 -0.256E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.964E 05 -0.723E 05 -0.482E 05 -0.241E 05
```

EAST

```
QREF+
 0.398E 06
QREF-
-0.878E 05
QEAF+
 0.180E 06
QEAF-
-0.327E 05
FR:     1.0         .75         .50         .25
QRC +
 0.000E 00  0.168E 05  0.337E 05  0.505E 05
QRC -
 0.000E 00 -0.559E 04 -0.112E 05 -0.168E 05
QFRESAH1 +
 0.253E 05  0.190E 05  0.126E 05  0.632E 04
QFRESAH1 -
-0.102E 06 -0.767E 05 -0.511E 05 -0.256E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.964E 05 -0.723E 05 -0.482E 05 -0.241E 05
```

WEST

```
QREF+
 0.494E 06
QREF-
-0.876E 05
QEAF+
 0.211E 06
QEAF-
-0.327E 05
FR:     1.0         .75         .50         .25
QRC +
 0.000E 00  0.211E 05  0.422E 05  0.632E 05
QRC -
 0.000E 00 -0.553E 04 -0.111E 05 -0.166E 05
QFRESAH1 +
 0.253E 05  0.190E 05  0.126E 05  0.632E 04
QFRESAH1 -
-0.102E 06 -0.767E 05 -0.511E 05 -0.256E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.964E 05 -0.723E 05 -0.482E 05 -0.241E 05
```

NO.

```
QREF+
 0.168E 06
QREF-
-0.872E 05
QEAF+
 0.108E 06
QEAF-
-0.326E 05
FR:     1.0         .75         .50         .25
QRC +
 0.000E 00  0.547E 04  0.109E 05  0.164E 05
QRC -
 0.000E 00 -0.558E 04 -0.112E 05 -0.167E 05
QFRESAH1 +
 0.253E 05  0.190E 05  0.126E 05  0.632E 04
QFRESAH1 -
-0.102E 06 -0.767E 05 -0.511E 05 -0.256E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.964E 05 -0.723E 05 -0.482E 05 -0.241E 05
```

Figures 7.7 and 7.8. Monthly performance data for cavity air flow of 4 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100 x 10^6).

September

```
SO.

QREF+
 0.414E 06
QREF-
-0.168E 06
QEAF+
 0.180E 06
QEAF-
-0.615E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.170E 05  0.340E 05  0.510E 05
QRC -
 0.000E 00 -0.109E 05 -0.218E 05 -0.326E 05
QFRESAH1 +
 0.264E 04  0.198E 04  0.132E 04  0.661E 03
QFRESAH1 -
-0.219E 06 -0.164E 06 -0.110E 06 -0.548E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.133E 06 -0.999E 05 -0.666E 05 -0.333E 05
EAST

QREF+
 0.246E 06
QREF-
-0.172E 06
QEAF+
 0.116E 06
QEAF-
-0.621E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.959E 04  0.192E 05  0.288E 05
QRC -
 0.000E 00 -0.115E 05 -0.230E 05 -0.345E 05
QFRESAH1 +
 0.264E 04  0.198E 04  0.132E 04  0.661E 03
QFRESAH1 -
-0.219E 06 -0.164E 06 -0.110E 06 -0.548E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.133E 06 -0.999E 05 -0.666E 05 -0.333E 05
WEST

QREF+
 0.314E 06
QREF-
-0.171E 06
QEAF+
 0.139E 06
QEAF-
-0.621E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.125E 05  0.251E 05  0.376E 05
QRC -
 0.000E 00 -0.113E 05 -0.227E 05 -0.340E 05
QFRESAH1 +
 0.264E 04  0.198E 04  0.132E 04  0.661E 03
QFRESAH1 -
-0.219E 06 -0.164E 06 -0.110E 06 -0.548E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.133E 06 -0.999E 05 -0.666E 05 -0.333E 05
NO.

QREF+
 0.571E 05
QREF-
-0.177E 06
QEAF+
 0.503E 05
QEAF-
-0.627E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.126E 04  0.252E 04  0.378E 04
QRC -
 0.000E 00 -0.121E 05 -0.242E 05 -0.362E 05
QFRESAH1 +
 0.264E 04  0.198E 04  0.132E 04  0.661E 03
QFRESAH1 -
-0.219E 06 -0.164E 06 -0.110E 06 -0.548E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.133E 06 -0.999E 05 -0.666E 05 -0.333E 05
```

October

```
SO.

QREF+
 0.629E 06
QREF-
-0.212E 06
QEAF+
 0.252E 06
QEAF-
-0.793E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.264E 05  0.528E 05  0.792E 05
QRC -
 0.000E 00 -0.132E 05 -0.264E 05 -0.396E 05
QFRESAH1 +
 0.773E 03  0.580E 03  0.387E 03  0.193E 03
QFRESAH1 -
-0.260E 06 -0.195E 06 -0.130E 06 -0.651E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.169E 06 -0.127E 06 -0.845E 05 -0.422E 05

EAST

QREF+
 0.225E 06
QREF-
-0.220E 06
QEAF+
 0.969E 05
QEAF-
-0.802E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.884E 04  0.177E 05  0.265E 05
QRC -
 0.000E 00 -0.141E 05 -0.283E 05 -0.424E 05
QFRESAH1 +
 0.773E 03  0.580E 03  0.387E 03  0.193E 03
QFRESAH1 -
-0.260E 06 -0.195E 06 -0.130E 06 -0.651E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.169E 06 -0.127E 06 -0.845E 05 -0.422E 05

WEST

QREF+
 0.300E 06
QREF-
-0.218E 06
QEAF+
 0.124E 06
QEAF-
-0.801E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.120E 05  0.239E 05  0.359E 05
QRC -
 0.000E 00 -0.139E 05 -0.279E 05 -0.418E 05
QFRESAH1 +
 0.773E 03  0.580E 03  0.387E 03  0.193E 03
QFRESAH1 -
-0.260E 06 -0.195E 06 -0.130E 06 -0.651E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.169E 06 -0.127E 06 -0.845E 05 -0.422E 05

NO.

QREF+
 0.298E 05
QREF-
-0.226E 06
QEAF+
 0.293E 05
QEAF-
-0.811E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.473E 03  0.945E 03  0.142E 04
QRC -
 0.000E 00 -0.149E 05 -0.298E 05 -0.447E 05
QFRESAH1 +
 0.773E 03  0.580E 03  0.387E 03  0.193E 03
QFRESAH1 -
-0.260E 06 -0.195E 06 -0.130E 06 -0.651E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.169E 06 -0.127E 06 -0.845E 05 -0.422E 05
```

Figures 7.9 and 7.10. Monthly performance data for cavity air flow of 4 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100×10^6).

November

```
SO.

QREF+
 0.392E 06
QREF-
-0.186E 06
QEAF+
 0.149E 06
QEAF-
-0.691E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.161E 05  0.322E 05  0.483E 05
QRC -
 0.000E 00 -0.118E 05 -0.236E 05 -0.354E 05
QFRESAH1 +
 0.726E 03  0.545E 03  0.363E 03  0.182E 03
QFRESAH1 -
-0.233E 06 -0.174E 06 -0.116E 06 -0.581E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.703E 05 -0.528E 05 -0.352E 05 -0.176E 05

EAST

QREF+
 0.108E 06
QREF-
-0.194E 06
QEAF+
 0.522E 05
QEAF-
-0.702E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.382E 04  0.763E 04  0.114E 05
QRC -
 0.000E 00 -0.127E 05 -0.253E 05 -0.380E 05
QFRESAH1 +
 0.726E 03  0.545E 03  0.363E 03  0.182E 03
QFRESAH1 -
-0.233E 06 -0.174E 06 -0.116E 06 -0.581E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.703E 05 -0.528E 05 -0.352E 05 -0.176E 05

WEST

QREF+
 0.141E 06
QREF-
-0.193E 06
QEAF+
 0.644E 05
QEAF-
-0.703E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.512E 04  0.102E 05  0.154E 05
QRC -
 0.000E 00 -0.125E 05 -0.251E 05 -0.376E 05
QFRESAH1 +
 0.726E 03  0.545E 03  0.363E 03  0.182E 03
QFRESAH1 -
-0.233E 06 -0.174E 06 -0.116E 06 -0.581E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.703E 05 -0.528E 05 -0.352E 05 -0.176E 05

NO.

QREF+
 0.271E 05
QREF-
-0.200E 06
QEAF+
 0.265E 05
QEAF-
-0.714E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.471E 03  0.941E 03  0.141E 04
QRC -
 0.000E 00 -0.133E 05 -0.266E 05 -0.399E 05
QFRESAH1 +
 0.726E 03  0.545E 03  0.363E 03  0.182E 03
QFRESAH1 -
-0.233E 06 -0.174E 06 -0.116E 06 -0.581E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.703E 05 -0.528E 05 -0.352E 05 -0.176E 05
```

December

```
SO.

QREF+
 0.256E 06
QREF-
-0.325E 06
QEAF+
 0.926E 05
QEAF-
-0.119E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.932E 04  0.186E 05  0.280E 05
QRC -
 0.000E 00 -0.209E 05 -0.417E 05 -0.626E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.413E 06 -0.310E 06 -0.207E 06 -0.103E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.108E 06 -0.810E 05 -0.540E 05 -0.270E 05

EAST

QREF+
 0.384E 05
QREF-
-0.352E 06
QEAF+
 0.195E 05
QEAF-
-0.124E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.944E 03  0.189E 04  0.283E 04
QRC -
 0.000E 00 -0.232E 05 -0.464E 05 -0.695E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.413E 06 -0.310E 06 -0.207E 06 -0.103E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.108E 06 -0.810E 05 -0.540E 05 -0.270E 05

WEST

QREF+
 0.549E 05
QREF-
-0.347E 06
QEAF+
 0.271E 05
QEAF-
-0.124E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.152E 04  0.304E 04  0.456E 04
QRC -
 0.000E 00 -0.229E 05 -0.458E 05 -0.687E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.413E 06 -0.310E 06 -0.207E 06 -0.103E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.108E 06 -0.810E 05 -0.540E 05 -0.270E 05

NO.

QREF+
 0.837E 03
QREF-
-0.371E 06
QEAF+
 0.596E 04
QEAF-
-0.128E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QRC -
 0.000E 00 -0.246E 05 -0.492E 05 -0.737E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.413E 06 -0.310E 06 -0.207E 06 -0.103E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.108E 06 -0.810E 05 -0.540E 05 -0.270E 05
```

Figures 7.11 and 7.12. Monthly performance data for cavity air flow of 4 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100 x 10^6).

January

```
SO.

QREF+
 0.285E 06
QREF-
-0.309E 06
QEAF+
 0.101E 06
QEAF-
-0.100E 06
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.157E 05  0.314E 05  0.471E 05
QRC -
 0.000E 00 -0.299E 05 -0.598E 05 -0.896E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.607E 06 -0.455E 06 -0.303E 06 -0.152E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.170E 06 -0.127E 06 -0.849E 05 -0.424E 05

EAST

QREF+
 0.480E 05
QREF-
-0.336E 06
QEAF+
 0.237E 05
QEAF-
-0.105E 06
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.177E 04  0.353E 04  0.530E 04
QRC -
 0.000E 00 -0.333E 05 -0.667E 05 -0.100E 06
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.607E 06 -0.455E 06 -0.303E 06 -0.152E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.170E 06 -0.127E 06 -0.849E 05 -0.424E 05

WEST

QREF+
 0.709E 05
QREF-
-0.333E 06
QEAF+
 0.329E 05
QEAF-
-0.105E 06
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.291E 04  0.581E 04  0.871E 04
QRC -
 0.000E 00 -0.328E 05 -0.657E 05 -0.985E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.607E 06 -0.455E 06 -0.303E 06 -0.152E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.170E 06 -0.127E 06 -0.849E 05 -0.424E 05

NO.

QREF+
 0.324E 04
QREF-
-0.358E 06
QEAF+
 0.101E 05
QEAF-
-0.109E 06
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QRC -
 0.000E 00 -0.358E 05 -0.716E 05 -0.107E 06
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.607E 06 -0.455E 06 -0.303E 06 -0.152E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.170E 06 -0.127E 06 -0.849E 05 -0.424E 05
```

February

```
SO.

QREF+
 0.516E 06
QREF-
-0.250E 06
QEAF+
 0.193E 06
QEAF-
-0.833E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.303E 05  0.606E 05  0.909E 05
QRC -
 0.000E 00 -0.235E 05 -0.470E 05 -0.705E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.519E 06 -0.389E 06 -0.259E 06 -0.130E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.139E 06 -0.105E 06 -0.697E 05 -0.349E 05

EAST

QREF+
 0.136E 06
QREF-
-0.275E 06
QEAF+
 0.561E 05
QEAF-
-0.865E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.715E 04  0.143E 05  0.214E 05
QRC -
 0.000E 00 -0.272E 05 -0.544E 05 -0.816E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.519E 06 -0.389E 06 -0.259E 06 -0.130E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.139E 06 -0.105E 06 -0.697E 05 -0.349E 05

WEST

QREF+
 2.189E 06
QREF-
-0.272E 06
QEAF+
 0.731E 05
QEAF-
-0.865E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.103E 05  0.207E 05  0.310E 05
QRC -
 0.000E 00 -0.267E 05 -0.534E 05 -0.801E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.519E 06 -0.389E 06 -0.259E 06 -0.130E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.139E 06 -0.105E 06 -0.697E 05 -0.349E 05

NO.

QREF+
 0.360E 04
QREF-
-0.298E 06
QEAF+
 0.113E 05
QEAF-
-0.898E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.330E 01  0.659E 01  0.989E 01
QRC -
 0.000E 00 -0.302E 05 -0.604E 05 -0.907E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.519E 06 -0.389E 06 -0.259E 06 -0.130E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.139E 06 -0.105E 06 -0.697E 05 -0.349E 05
```

Figures 7.13 and 7.14. Monthly performance data for cavity air flow of 6 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100×10^6).

March

```
SO.

QREF+
 0.436E 06
QREF-
-0.240E 06
QEAF+
 0.178E 06
QEAF-
-0.791E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.251E 05  0.502E 05  0.753E 05
QRC -
 0.000E 00 -0.231E 05 -0.463E 05 -0.694E 05
QFRESAH1 +
 0.609E 03  0.457E 03  0.305E 03  0.152E 03
QFRESAH1 -
-0.511E 06 -0.383E 06 -0.255E 06 -0.128E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.131E 06 -0.985E 05 -0.657E 05 -0.328E 05

EAST

QREF+
 0.193E 06
QREF-
-0.257E 06
QEAF+
 0.886E 05
QEAF-
-0.816E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.101E 05  0.201E 05  0.302E 05
QRC -
 0.000E 00 -0.256E 05 -0.511E 05 -0.767E 05
QFRESAH1 +
 0.609E 03  0.457E 03  0.305E 03  0.152E 03
QFRESAH1 -
-0.511E 06 -0.383E 06 -0.255E 06 -0.128E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.131E 06 -0.985E 05 -0.657E 05 -0.328E 05

WEST

QREF+
 0.261E 06
QREF-
-0.255E 06
QEAF+
 0.110E 06
QEAF-
-0.815E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.143E 05  0.285E 05  0.428E 05
QRC -
 0.000E 00 -0.252E 05 -0.503E 05 -0.755E 05
QFRESAH1 +
 0.609E 03  0.457E 03  0.305E 03  0.152E 03
QFRESAH1 -
-0.511E 06 -0.383E 06 -0.255E 06 -0.128E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.131E 06 -0.985E 05 -0.657E 05 -0.328E 05

NO.

QREF+
 0.271E 05
QREF-
-0.274E 06
QEAF+
 0.353E 05
QEAF-
-0.840E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.315E 03  0.630E 03  0.945E 03
QRC -
 0.000E 00 -0.282E 05 -0.565E 05 -0.847E 05
QFRESAH1 +
 0.609E 03  0.457E 03  0.305E 03  0.152E 03
QFRESAH1 -
-0.511E 06 -0.383E 06 -0.255E 06 -0.128E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.131E 06 -0.985E 05 -0.657E 05 -0.328E 05
```

April

```
SO.

QREF+
 0.299E 06
QREF-
-0.199E 06
QEAF+
 0.128E 06
QEAF-
-0.635E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.170E 05  0.341E 05  0.511E 05
QRC -
 0.000E 00 -0.198E 05 -0.395E 05 -0.593E 05
QFRESAH1 +
 0.163E 03  0.122E 03  0.815E 02  0.408E 02
QFRESAH1 -
-0.428E 06 -0.321E 06 -0.214E 06 -0.107E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.267E 06 -0.200E 06 -0.134E 06 -0.668E 05

EAST

QREF+
 0.233E 06
QREF-
-0.198E 06
QEAF+
 0.111E 06
QEAF-
-0.629E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.124E 05  0.248E 05  0.372E 05
QRC -
 0.000E 00 -0.202E 05 -0.404E 05 -0.606E 05
QFRESAH1 +
 0.163E 03  0.122E 03  0.815E 02  0.408E 02
QFRESAH1 -
-0.428E 06 -0.321E 06 -0.214E 06 -0.107E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.267E 06 -0.200E 06 -0.134E 06 -0.668E 05

WEST

QREF+
 0.303E 06
QREF-
-0.197E 06
QEAF+
 0.131E 06
QEAF-
-0.628E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.168E 05  0.336E 05  0.505E 05
QRC -
 0.000E 00 -0.198E 05 -0.396E 05 -0.595E 05
QFRESAH1 +
 0.163E 03  0.122E 03  0.815E 02  0.408E 02
QFRESAH1 -
-0.428E 06 -0.321E 06 -0.214E 06 -0.107E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.267E 06 -0.200E 06 -0.134E 06 -0.668E 05

NO.

QREF+
 0.538E 05
QREF-
-0.202E 06
QEAF+
 0.577E 05
QEAF-
-0.624E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.102E 04  0.203E 04  0.305E 04
QRC -
 0.000E 00 -0.217E 05 -0.435E 05 -0.652E 05
QFRESAH1 +
 0.163E 03  0.122E 03  0.815E 02  0.408E 02
QFRESAH1 -
-0.428E 06 -0.321E 06 -0.214E 06 -0.107E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.267E 06 -0.200E 06 -0.134E 06 -0.668E 05
```

Figures 7.15 and 7.16. Monthly performance data for cavity air flow of 6 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100 x 10^6).

May

SO.

```
QREF+
 0.259E 06
QREF-
-0.183E 06
QEAF+
 0.118E 06
QEAF-
-0.567E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.147E 05  0.295E 05  0.442E 05
QRC -
 0.000E 00 -0.184E 05 -0.367E 05 -0.551E 05
QFRESAH1 +
 0.150E 04  0.113E 04  0.751E 03  0.376E 03
QFRESAH1 -
-0.382E 06 -0.287E 06 -0.191E 06 -0.956E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.238E 06 -0.178E 06 -0.119E 06 -0.594E 05
```

EAST

```
QREF+
 0.310E 06
QREF-
-0.177E 06
QEAF+
 0.139E 06
QEAF-
-0.556E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.175E 05  0.351E 05  0.526E 05
QRC -
 0.000E 00 -0.180E 05 -0.360E 05 -0.539E 05
QFRESAH1 +
 0.150E 04  0.113E 04  0.751E 03  0.376E 03
QFRESAH1 -
-0.382E 06 -0.287E 06 -0.191E 06 -0.956E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.238E 06 -0.178E 06 -0.119E 06 -0.594E 05
```

WEST

```
QREF+
 0.400E 06
QREF-
-0.175E 06
QEAF+
 0.171E 06
QEAF-
-0.556E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.232E 05  0.464E 05  0.697E 05
QRC -
 0.000E 00 -0.176E 05 -0.351E 05 -0.527E 05
QFRESAH1 +
 0.150E 04  0.113E 04  0.751E 03  0.376E 03
QFRESAH1 -
-0.382E 06 -0.287E 06 -0.191E 06 -0.956E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.238E 06 -0.178E 06 -0.119E 06 -0.594E 05
```

NO.

```
QREF+
 0.100E 06
QREF-
-0.172E 06
QEAF+
 0.809E 05
QEAF-
-0.545E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.266E 04  0.531E 04  0.797E 04
QRC -
 0.000E 00 -0.180E 05 -0.360E 05 -0.540E 05
QFRESAH1 +
 0.150E 04  0.113E 04  0.751E 03  0.376E 03
QFRESAH1 -
-0.382E 06 -0.287E 06 -0.191E 06 -0.956E 05
QFRESH2 +
 0.200E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.238E 06 -0.178E 06 -0.119E 06 -0.594E 05
```

June

SO.

```
QREF+
 0.260E 06
QREF-
-0.114E 06
QEAF+
 0.119E 06
QEAF-
-0.360E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.160E 05  0.320E 05  0.480E 05
QRC -
 0.000E 00 -0.115E 05 -0.230E 05 -0.345E 05
QFRESAH1 +
 0.136E 05  0.102E 05  0.678E 04  0.339E 04
QFRESAH1 -
-0.221E 06 -0.166E 06 -0.111E 06 -0.554E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.185E 06 -0.139E 06 -0.925E 05 -0.463E 05
```

EAST

```
QREF+
 0.371E 06
QREF-
-0.111E 06
QEAF+
 0.166E 06
QEAF-
-0.357E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.224E 05  0.449E 05  0.673E 05
QRC -
 0.000E 00 -0.109E 05 -0.219E 05 -0.328E 05
QFRESAH1 +
 0.136E 05  0.102E 05  0.678E 04  0.339E 04
QFRESAH1 -
-0.221E 06 -0.166E 06 -0.111E 06 -0.554E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.185E 06 -0.139E 06 -0.925E 05 -0.463E 05
```

WEST

```
QREF+
 0.471E 06
QREF-
-0.109E 06
QEAF+
 0.197E 06
QEAF-
-0.355E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.290E 05  0.579E 05  0.869E 05
QRC -
 0.000E 00 -0.106E 05 -0.213E 05 -0.319E 05
QFRESAH1 +
 0.136E 05  0.102E 05  0.678E 04  0.339E 04
QFRESAH1 -
-0.221E 06 -0.166E 06 -0.111E 06 -0.554E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.185E 06 -0.139E 06 -0.925E 05 -0.463E 05
```

NO.

```
QREF+
 0.188E 06
QREF-
-0.106E 06
QEAF+
 0.109E 06
QEAF-
-0.352E 05
FR:      1.0          .75          .50          .25
QRC +
 0.000E 00  0.849E 04  0.170E 05  0.255E 05
QRC -
 0.000E 00 -0.102E 05 -0.205E 05 -0.307E 05
QFRESAH1 +
 0.136E 05  0.102E 05  0.678E 04  0.339E 04
QFRESAH1 -
-0.221E 06 -0.166E 06 -0.111E 06 -0.554E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.185E 06 -0.139E 06 -0.925E 05 -0.463E 05
```

Figures 7.17 and 7.18. Monthly performance data for cavity air flow of 6 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100 x 10^6).

July

```
SO.

QREF+
 0.354E 06
QREF-
-0.729E 05
QEAF+
 0.156E 06
QEAF-
-0.241E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.235E 05  0.469E 05  0.704E 05
QRC -
 0.000E 00 -0.698E 04 -0.140E 05 -0.209E 05
QFRESAH1 +
 0.567E 05  0.426E 05  0.284E 05  0.142E 05
QFRESAH1 -
-0.120E 06 -0.897E 05 -0.598E 05 -0.299E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.152E 06 -0.114E 06 -0.759E 05 -0.379E 05

EAST

QREF+
 0.452E 06
QREF-
-0.722E 05
QEAF+
 0.194E 06
QEAF-
-0.241E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.294E 05  0.587E 05  0.881E 05
QRC -
 0.000E 00 -0.684E 04 -0.137E 05 -0.205E 05
QFRESAH1 +
 0.567E 05  0.426E 05  0.284E 05  0.142E 05
QFRESAH1 -
-0.120E 06 -0.897E 05 -0.598E 05 -0.299E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.152E 06 -0.114E 06 -0.759E 05 -0.379E 05

JEST

QREF+
 0.551E 06
QREF-
-0.715E 05
QEAF+
 0.227E 06
QEAF-
-0.240E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.359E 05  0.718E 05  0.108E 06
QRC -
 0.000E 00 -0.674E 04 -0.135E 05 -0.202E 05
QFRESAH1 +
 0.567E 05  0.426E 05  0.284E 05  0.142E 05
QFRESAH1 -
-0.120E 06 -0.897E 05 -0.598E 05 -0.299E 05
QFRESH2 +
 0.200E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.152E 06 -0.114E 06 -0.759E 05 -0.379E 05

NO.

QREF+
 0.245E 06
QREF-
-0.708E 05
QEAF+
 0.134E 06
QEAF-
-0.240E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.135E 05  0.271E 05  0.406E 05
QRC -
 0.000E 00 -0.662E 04 -0.132E 05 -0.199E 05
QFRESAH1 +
 0.567E 05  0.426E 05  0.284E 05  0.142E 05
QFRESAH1 -
-0.120E 06 -0.897E 05 -0.598E 05 -0.299E 05
QFRESH2 +
 0.200E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.152E 06 -0.114E 06 -0.759E 05 -0.379E 05
```

August

```
SO.

QREF+
 0.412E 06
QREF-
-0.884E 05
QEAF+
 0.170E 06
QEAF-
-0.292E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.275E 05  0.549E 05  0.824E 05
QRC -
 0.000E 00 -0.847E 04 -0.169E 05 -0.254E 05
QFRESAH1 +
 0.379E 05  0.284E 05  0.190E 05  0.948E 04
QFRESAH1 -
-0.153E 06 -0.115E 06 -0.767E 05 -0.383E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.145E 06 -0.108E 06 -0.723E 05 -0.361E 05

EAST

QREF+
 0.398E 06
QREF-
-0.878E 05
QEAF+
 0.172E 06
QEAF-
-0.292E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.252E 05  0.505E 05  0.757E 05
QRC -
 0.000E 00 -0.839E 04 -0.168E 05 -0.252E 05
QFRESAH1 +
 0.379E 05  0.284E 05  0.190E 05  0.948E 04
QFRESAH1 -
-0.153E 06 -0.115E 06 -0.767E 05 -0.383E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.145E 06 -0.108E 06 -0.723E 05 -0.361E 05

WEST

QREF+
 0.494E 06
QREF-
-0.876E 05
QEAF+
 0.202E 06
QEAF-
-0.292E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.316E 05  0.632E 05  0.948E 05
QRC -
 0.000E 00 -0.829E 04 -0.166E 05 -0.249E 05
QFRESAH1 +
 0.379E 05  0.284E 05  0.190E 05  0.948E 04
QFRESAH1 -
-0.153E 06 -0.115E 06 -0.767E 05 -0.383E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.145E 06 -0.108E 06 -0.723E 05 -0.361E 05

NO.

QREF+
 0.168E 06
QREF-
-0.872E 05
QEAF+
 0.105E 06
QEAF-
-0.291E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.821E 04  0.164E 05  0.246E 05
QRC -
 0.000E 00 -0.837E 04 -0.167E 05 -0.251E 05
QFRESAH1 +
 0.379E 05  0.284E 05  0.190E 05  0.948E 04
QFRESAH1 -
-0.153E 06 -0.115E 06 -0.767E 05 -0.383E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.145E 06 -0.108E 06 -0.723E 05 -0.361E 05
rr
```

Figures 7.19 and 7.20. Monthly performance data for cavity air flow of 6 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100×10^6).

September

```
SO.

QREF+
 0.414E 06
QREF-
-0.168E 06
QEAF+
 0.173E 06
QEAF-
-0.547E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.255E 05  0.510E 05  0.765E 05
QRC -
 0.000E 00 -0.163E 05 -0.326E 05 -0.489E 05
QFRESAH1 +
 0.396E 04  0.297E 04  0.198E 04  0.991E 03
QFRESAH1 -
-0.329E 06 -0.246E 06 -0.164E 06 -0.822E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.200E 06 -0.150E 06 -0.999E 05 -0.500E 05

EAST

QREF+
 0.246E 06
QREF-
-0.172E 06
QEAF+
 0.112E 06
QEAF-
-0.551E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.144E 05  0.288E 05  0.432E 05
QRC -
 0.000E 00 -0.172E 05 -0.345E 05 -0.517E 05
QFRESAH1 +
 0.396E 04  0.297E 04  0.198E 04  0.991E 03
QFRESAH1 -
-0.329E 06 -0.246E 06 -0.164E 06 -0.822E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.200E 06 -0.150E 06 -0.999E 05 -0.500E 05

WEST

QREF+
 0.314E 06
QREF-
-0.171E 06
QEAF+
 0.134E 06
QEAF-
-0.551E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.188E 05  0.376E 05  0.564E 05
QRC -
 0.000E 00 -0.170E 05 -0.340E 05 -0.510E 05
QFRESAH1 +
 0.396E 04  0.297E 04  0.198E 04  0.991E 03
QFRESAH1 -
-0.329E 06 -0.246E 06 -0.164E 06 -0.822E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.200E 06 -0.150E 06 -0.999E 05 -0.500E 05

NO.

QREF+
 0.571E 05
QREF-
-0.177E 06
QEAF+
 0.506E 05
QEAF-
-0.556E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.189E 04  0.378E 04  0.567E 04
QRC -
 0.000E 00 -0.181E 05 -0.362E 05 -0.543E 05
QFRESAH1 +
 0.396E 04  0.297E 04  0.198E 04  0.991E 03
QFRESAH1 -
-0.329E 06 -0.246E 06 -0.164E 06 -0.822E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.200E 06 -0.150E 06 -0.999E 05 -0.500E 05
```

October

```
SO.

QREF+
 0.629E 06
QREF-
-0.212E 06
QEAF+
 0.240E 06
QEAF-
-0.707E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.396E 05  0.792E 05  0.119E 06
QRC -
 0.000E 00 -0.198E 05 -0.396E 05 -0.594E 05
QFRESAH1 +
 0.116E 04  0.870E 03  0.580E 03  0.290E 03
QFRESAH1 -
-0.391E 06 -0.293E 06 -0.195E 06 -0.977E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.253E 06 -0.190E 06 -0.127E 06 -0.633E 05

EAST

QREF+
 0.225E 06
QREF-
-0.220E 06
QEAF+
 0.935E 05
QEAF-
-0.713E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.133E 05  0.265E 05  0.398E 05
QRC -
 0.000E 00 -0.212E 05 -0.424E 05 -0.636E 05
QFRESAH1 +
 0.116E 04  0.870E 03  0.580E 03  0.290E 03
QFRESAH1 -
-0.391E 06 -0.293E 06 -0.195E 06 -0.977E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.253E 06 -0.190E 06 -0.127E 06 -0.633E 05

WEST

QREF+
 0.300E 06
QREF-
-0.218E 06
QEAF+
 0.119E 06
QEAF-
-0.713E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.179E 05  0.359E 05  0.538E 05
QRC -
 0.000E 00 -0.209E 05 -0.418E 05 -0.627E 05
QFRESAH1 +
 0.116E 04  0.870E 03  0.580E 03  0.290E 03
QFRESAH1 -
-0.391E 06 -0.293E 06 -0.195E 06 -0.977E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.253E 06 -0.190E 06 -0.127E 06 -0.633E 05

NO.

QREF+
 0.298E 05
QREF-
-0.226E 06
QEAF+
 0.299E 05
QEAF-
-0.720E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.709E 03  0.142E 04  0.213E 04
QRC -
 0.000E 00 -0.224E 05 -0.447E 05 -0.671E 05
QFRESAH1 +
 0.116E 04  0.870E 03  0.580E 03  0.290E 03
QFRESAH1 -
-0.391E 06 -0.293E 06 -0.195E 06 -0.977E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.253E 06 -0.190E 06 -0.127E 06 -0.633E 05
```

Figures 7.21 and 7.22. Monthly performance data for cavity air flow of 6 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100 x 10^6).

November

```
SO.

QREF+
 0.392E 06
QREF-
-0.186E 06
QEAF+
 0.142E 06
QEAF-
-0.616E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.241E 05  0.483E 05  0.724E 05
QRC -
 0.000E 00 -0.177E 05 -0.354E 05 -0.531E 05
QFRESAH1 +
 0.109E 04  0.817E 03  0.545E 03  0.272E 03
QFRESAH1 -
-0.349E 06 -0.262E 06 -0.174E 06 -0.872E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.106E 06 -0.791E 05 -0.528E 05 -0.264E 05

EAST

QREF+
 0.108E 06
QREF-
-0.194E 06
QEAF+
 0.512E 05
QEAF-
-0.624E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.572E 04  0.114E 05  0.172E 05
QRC -
 0.000E 00 -0.190E 05 -0.380E 05 -0.570E 05
QFRESAH1 +
 0.109E 04  0.817E 03  0.545E 03  0.272E 03
QFRESAH1 -
-0.349E 06 -0.262E 06 -0.174E 06 -0.872E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.106E 06 -0.791E 05 -0.528E 05 -0.264E 05

WEST

QREF+
 0.141E 06
QREF-
-0.193E 06
QEAF+
 0.628E 05
QEAF-
-0.625E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.768E 04  0.154E 05  0.230E 05
QRC -
 0.000E 00 -0.188E 05 -0.376E 05 -0.565E 05
QFRESAH1 +
 0.109E 04  0.817E 03  0.545E 03  0.272E 03
QFRESAH1 -
-0.349E 06 -0.262E 06 -0.174E 06 -0.872E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.106E 06 -0.791E 05 -0.528E 05 -0.264E 05

NO.

QREF+
 0.271E 05
QREF-
-0.200E 06
QEAF+
 0.271E 05
QEAF-
-0.633E 05
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.706E 03  0.141E 04  0.212E 04
QRC -
 0.000E 00 -0.200E 05 -0.399E 05 -0.599E 05
QFRESAH1 +
 0.109E 04  0.817E 03  0.545E 03  0.272E 03
QFRESAH1 -
-0.349E 06 -0.262E 06 -0.174E 06 -0.872E 05
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.106E 06 -0.791E 05 -0.528E 05 -0.264E 05
```

December

```
SO.

QREF+
 0.256E 06
QREF-
-0.325E 06
QEAF+
 0.895E 05
QEAF-
-0.106E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.140E 05  0.280E 05  0.419E 05
QRC -
 0.000E 00 -0.313E 05 -0.626E 05 -0.938E 05
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.620E 06 -0.465E 06 -0.310E 06 -0.155E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.162E 06 -0.122E 06 -0.810E 05 -0.405E 05

EAST

QREF+
 0.384E 05
QREF-
-0.352E 06
QEAF+
 0.203E 05
QEAF-
-0.110E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.142E 04  0.283E 04  0.425E 04
QRC -
 0.000E 00 -0.348E 05 -0.695E 05 -0.104E 06
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.620E 06 -0.465E 06 -0.310E 06 -0.155E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.162E 06 -0.122E 06 -0.810E 05 -0.405E 05

WEST

QREF+
 0.549E 05
QREF-
-0.347E 06
QEAF+
 0.277E 05
QEAF-
-0.109E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.228E 04  0.456E 04  0.684E 04
QRC -
 0.000E 00 -0.344E 05 -0.687E 05 -0.103E 06
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.620E 06 -0.465E 06 -0.310E 06 -0.155E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.162E 06 -0.122E 06 -0.810E 05 -0.405E 05

NO.

QREF+
 0.837E 03
QREF-
-0.371E 06
QEAF+
 0.710E 04
QEAF-
-0.113E 06
FR:      1.0         .75         .50         .25
QRC +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QRC -
 0.000E 00 -0.369E 05 -0.737E 05 -0.111E 06
QFRESAH1 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESAH1 -
-0.620E 06 -0.465E 06 -0.310E 06 -0.155E 06
QFRESH2 +
 0.000E 00  0.000E 00  0.000E 00  0.000E 00
QFRESH2 -
-0.162E 06 -0.122E 06 -0.810E 05 -0.405E 05
```

Figures 7.23 and 7.24. Monthly performance data for cavity air flow of 6 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per month (0.100E 06 = 0.100×10^6).

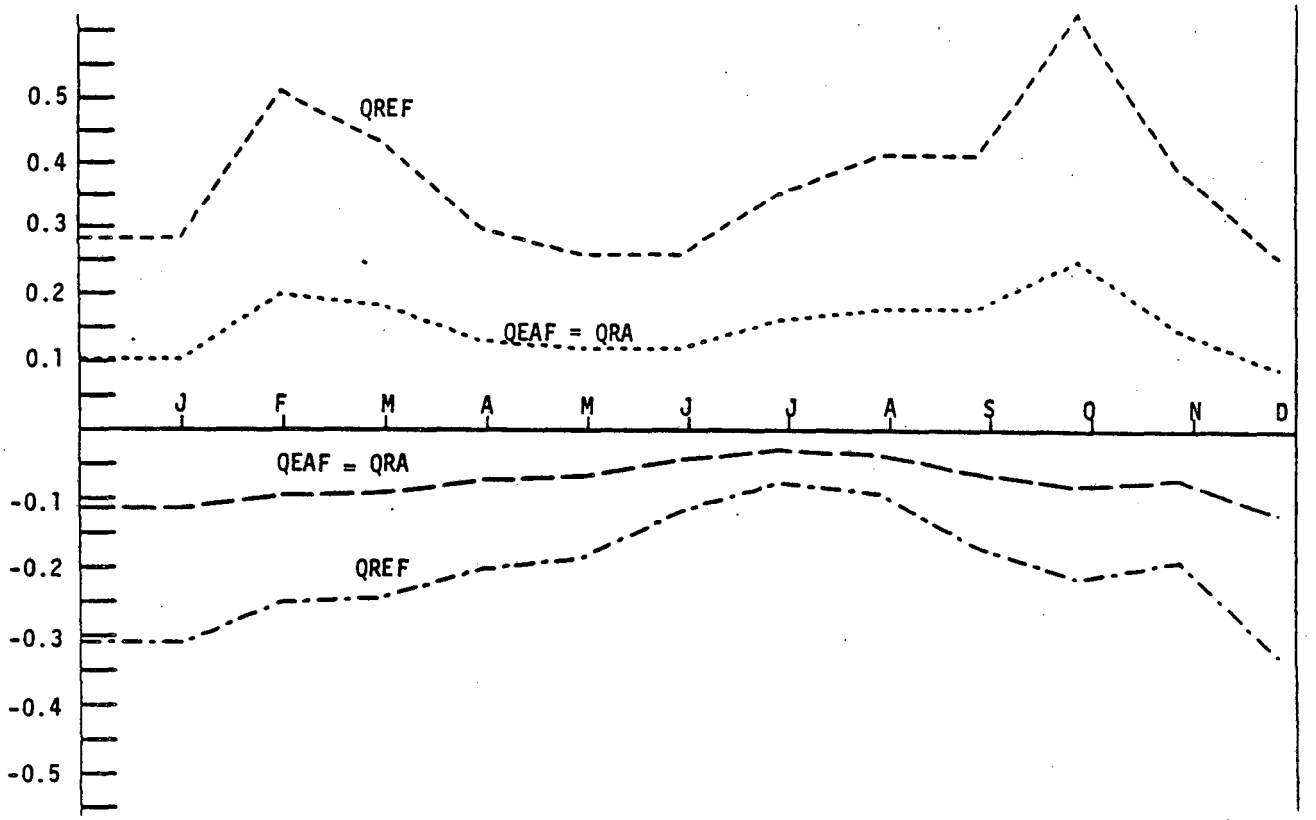

Figure 7.25. Heat gain and heat loss, QREF and QEAF, of reference and air-flow windows with southern orientation. Cavity air flow, 4 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

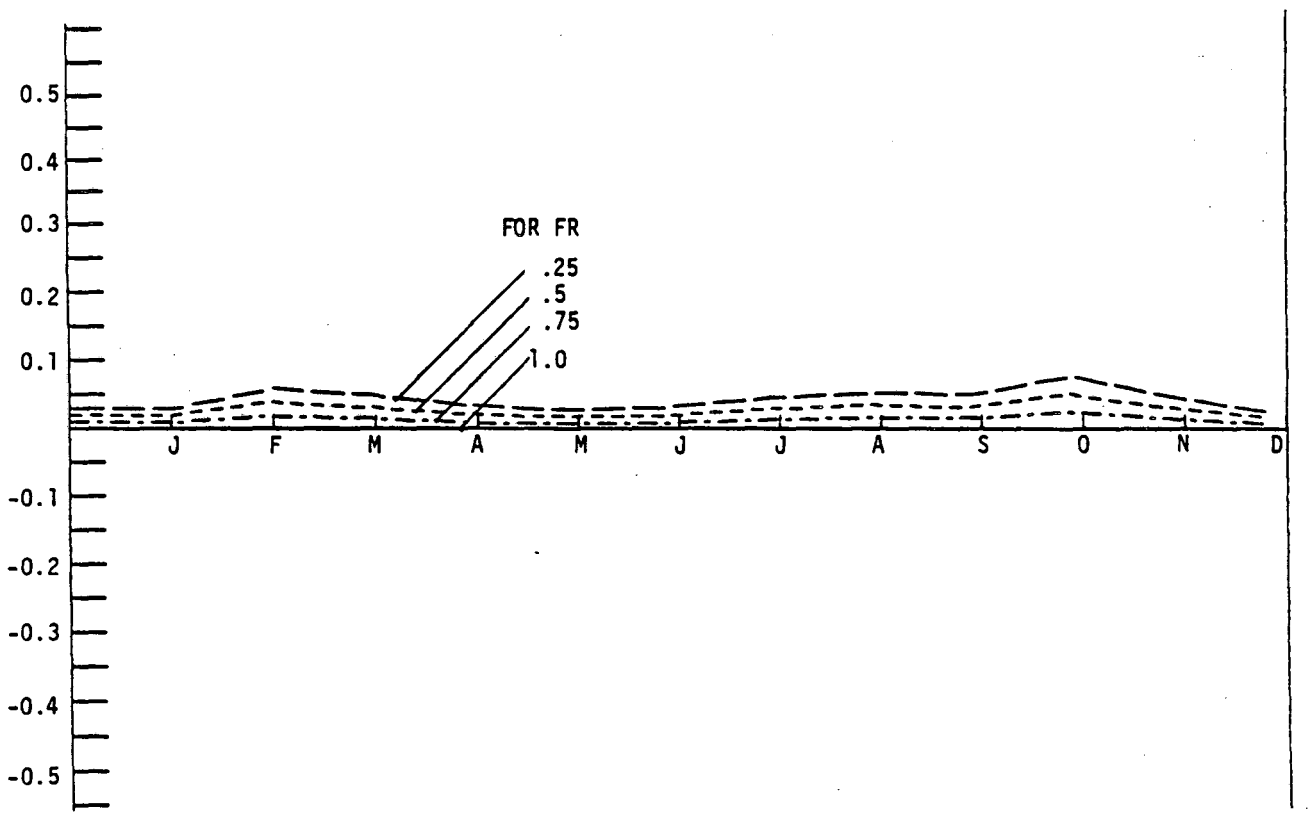

Figure 7.26. Cooling load from recycled air, QRC, at various fresh air fractions, southern orientation. Cavity air flow, 4 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

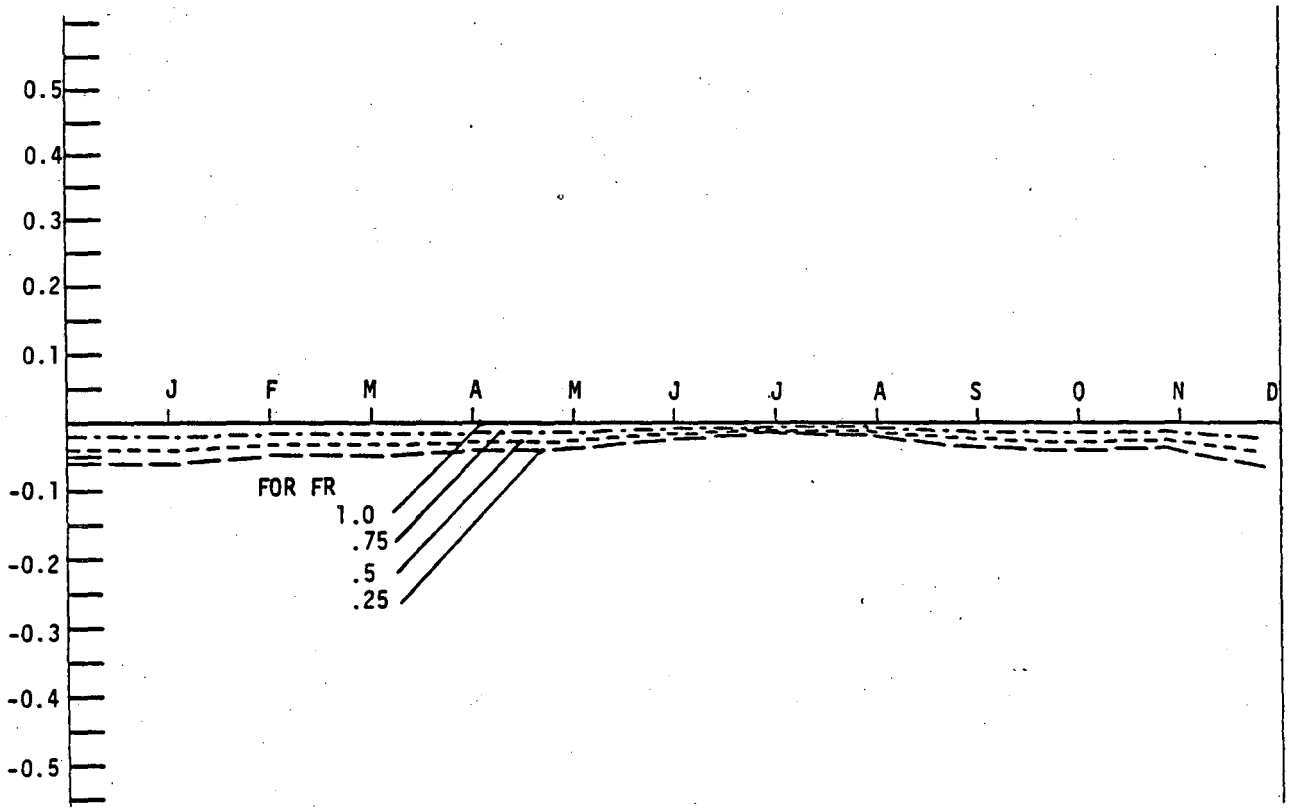

Figure 7.27. Heating load from recycled air, QRC, at various fresh air fractions, southern orientation. Cavity air flow, 4 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

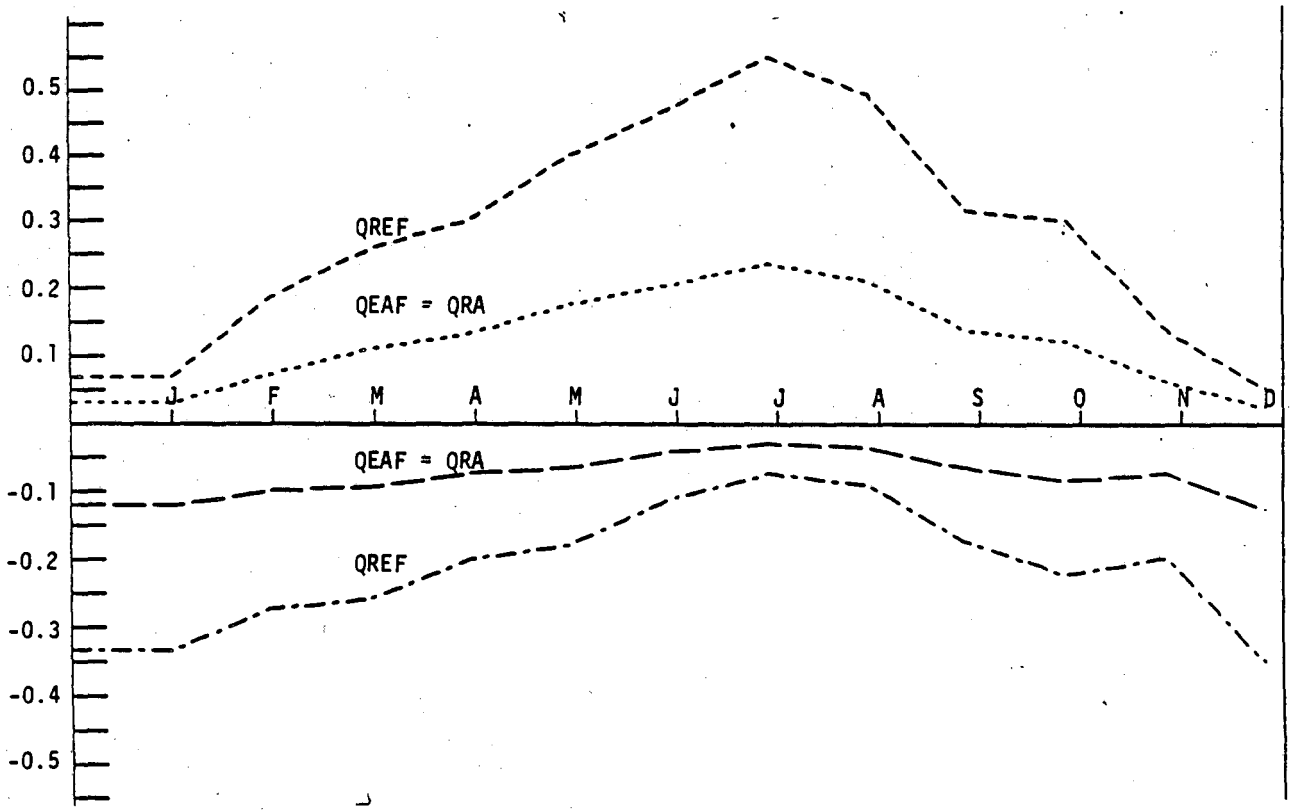

Figure 7.28. Heat gain and heat loss, QREF and QEAF, of reference and air-flow windows, western orientation. Cavity air flow, 4 cvm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

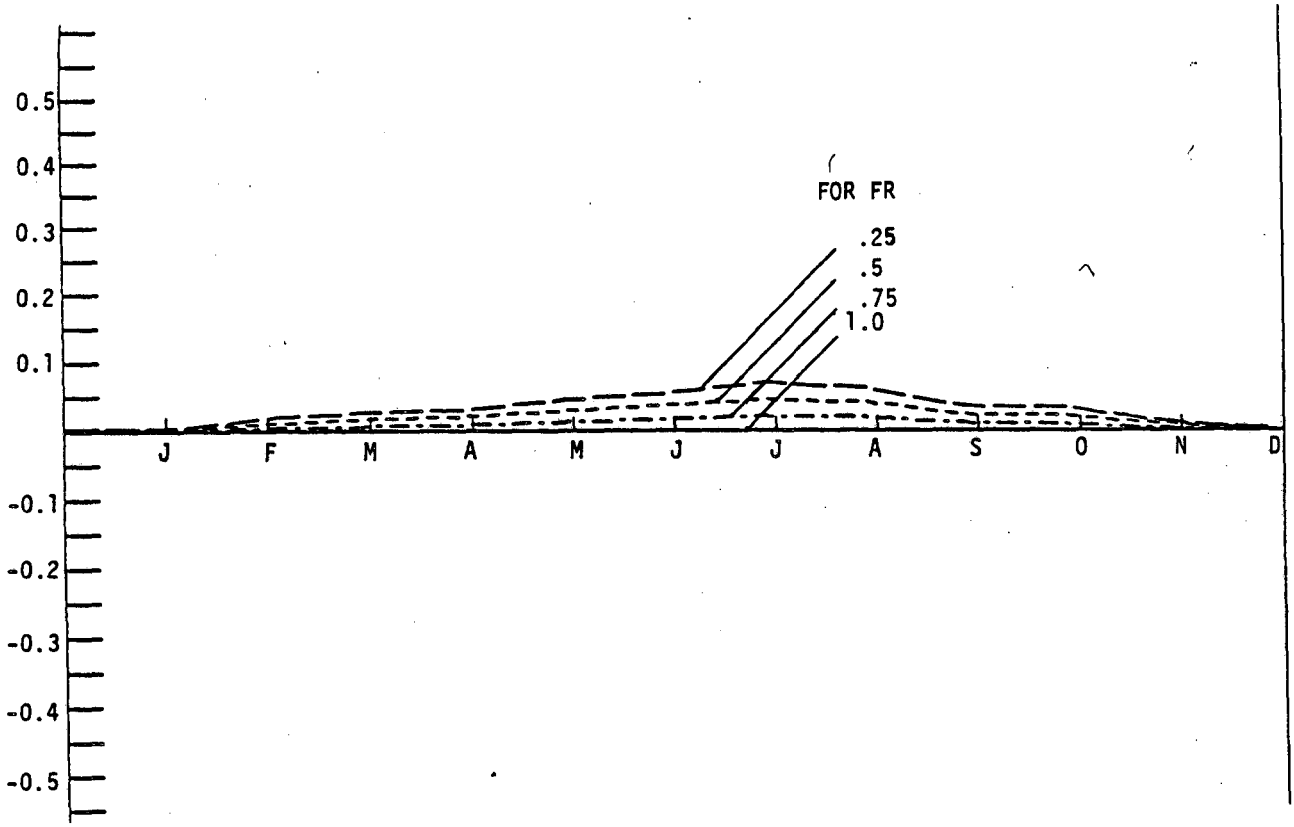

Figure 7.29. Cooling load from recycled air, QRC, at various fresh air fractions, western orientation. Cavity air flow 4 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

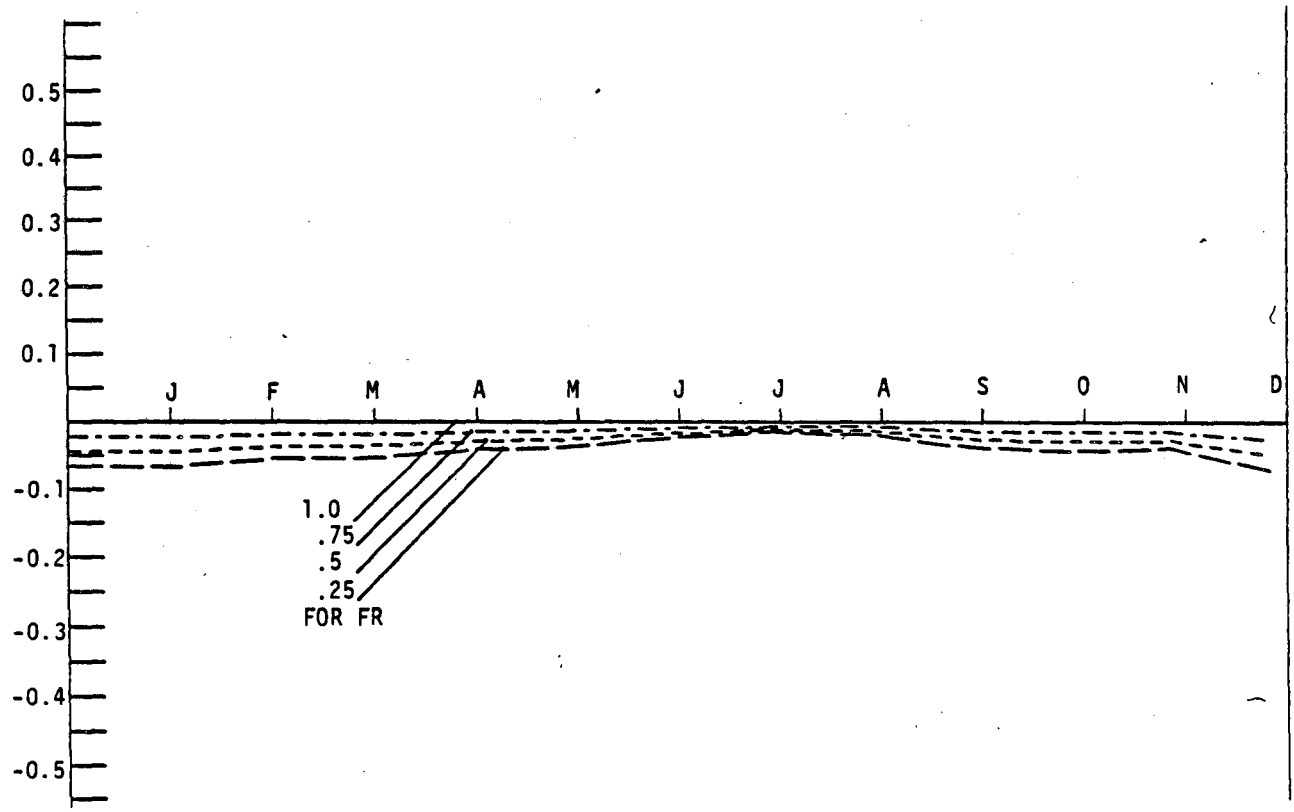

Figure 7.30. Heating load from recycled air, QRC, at various fresh air fractions, western orientation. Cavity air flow, 4 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

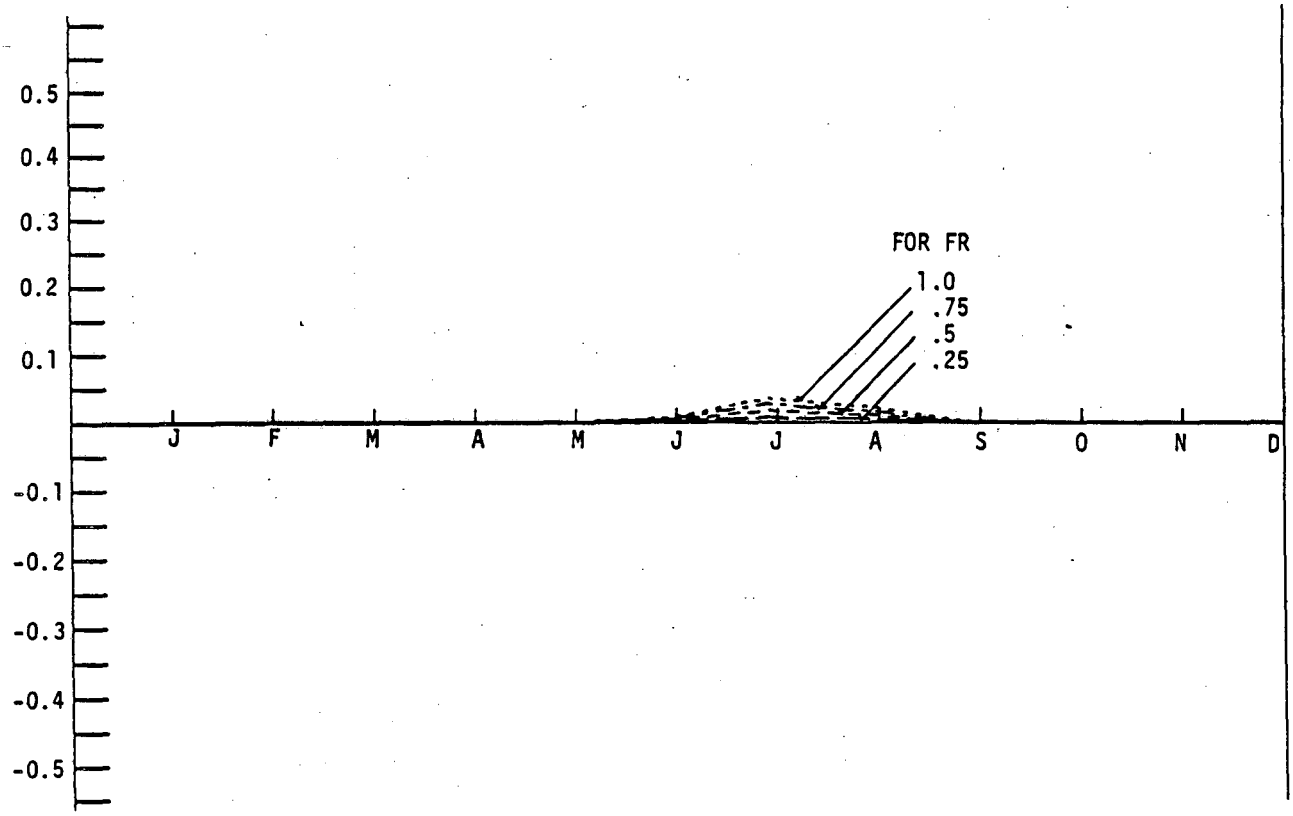

Figure 7.31. Sensible cooling load from fresh air, QFRESH 1, at various fresh air fractions. Cavity air flow, 4 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 BTU.

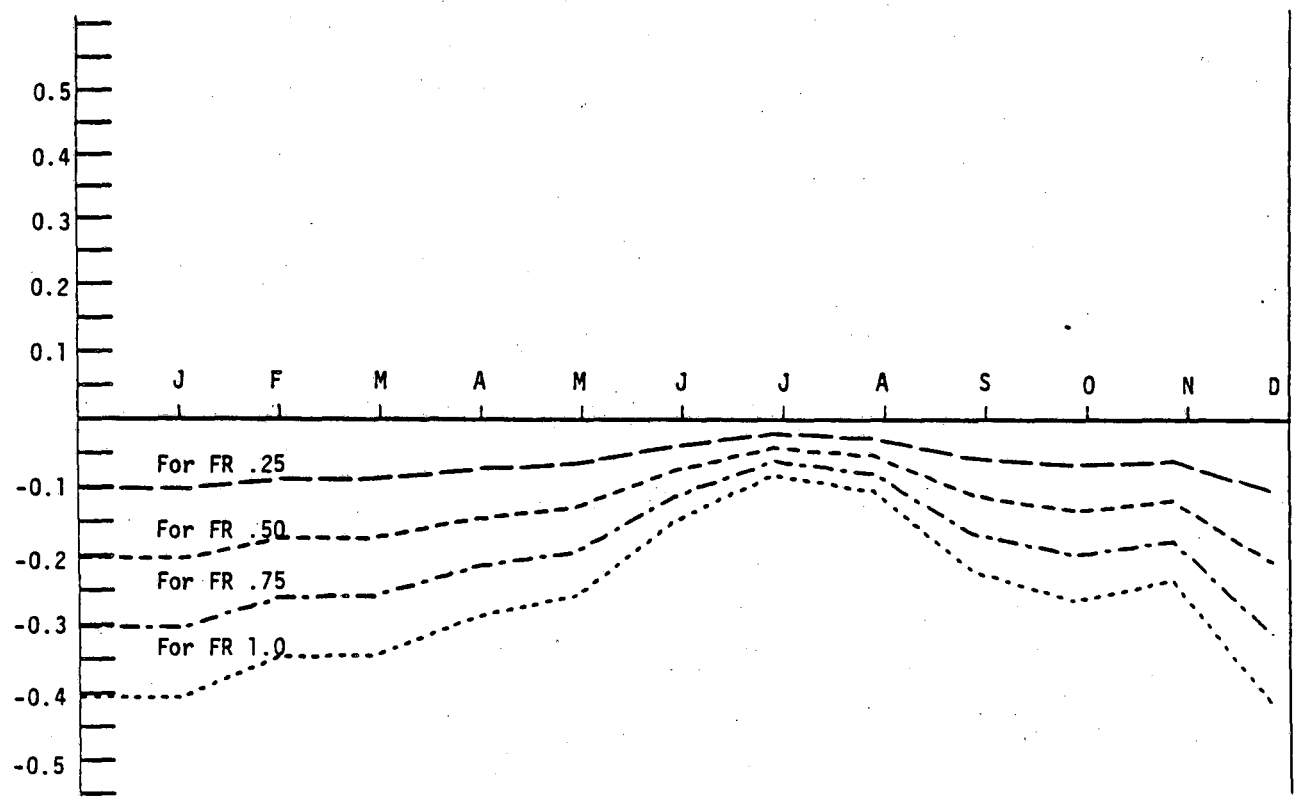

Figure 7.32. Sensible heating load from fresh air, QFRESH 1, at various fresh air fractions. Cavity air flow, 4 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 BTU.

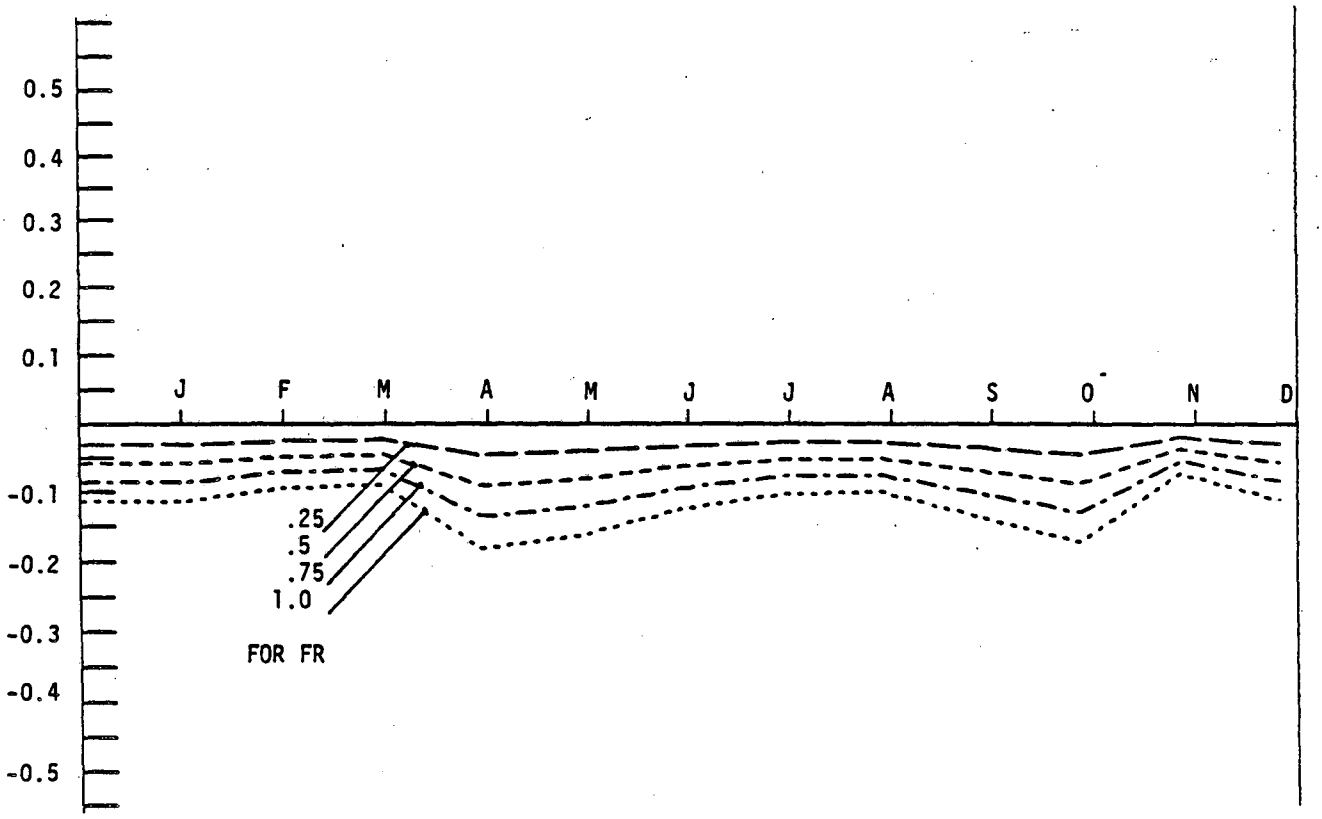

Figure 7.33. Latent energy load (addition of moisture) from fresh air, QFRESH 2, at various freshair fractions. Cavity air flow, 4 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 BTU.

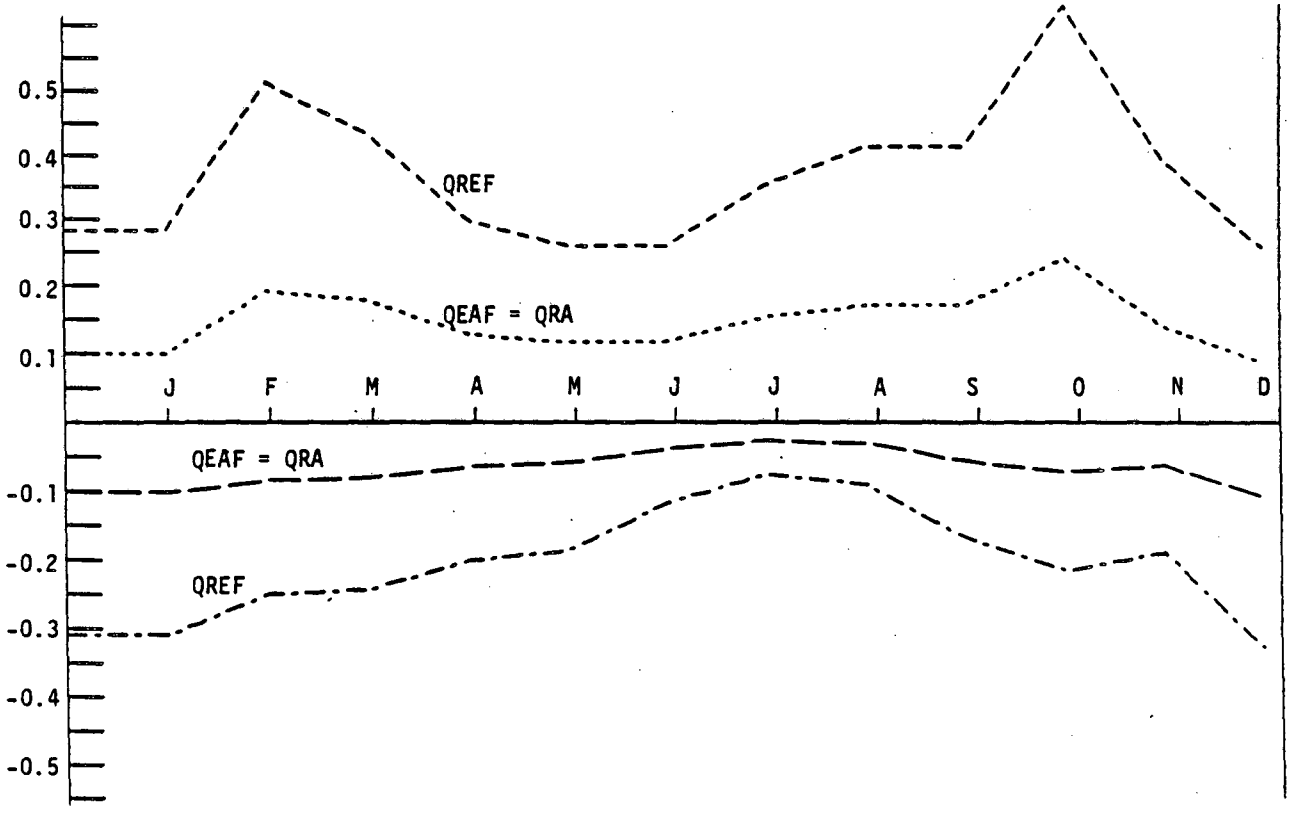

Figure 7.34. Heat gain and heat loss, QREF and QEAF, of reference and air-flow windows, southern orientation. Cavity air flow 6 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

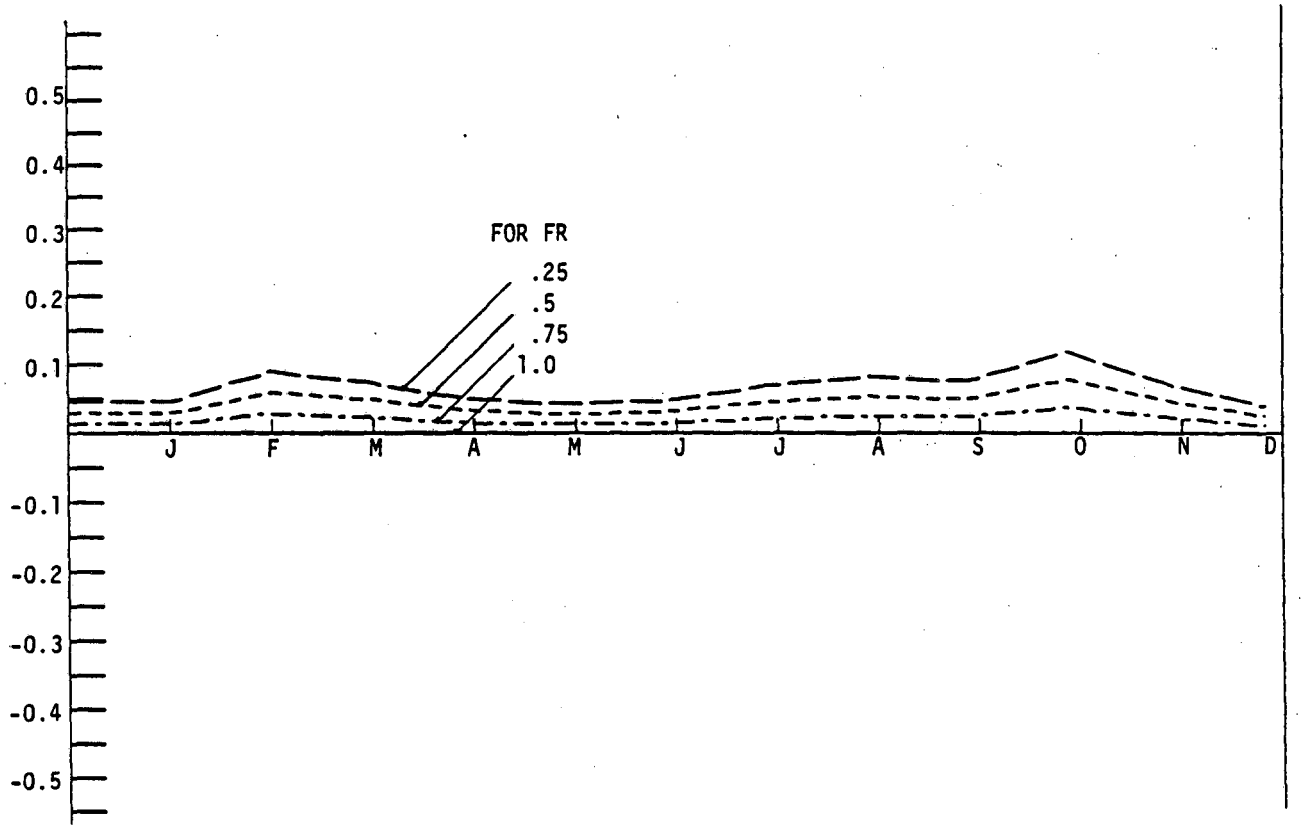

Figure 7.35. Cooling load from recycled air, QRC, at various fresh air fractions, southern orientation. Cavity air flow, 6 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

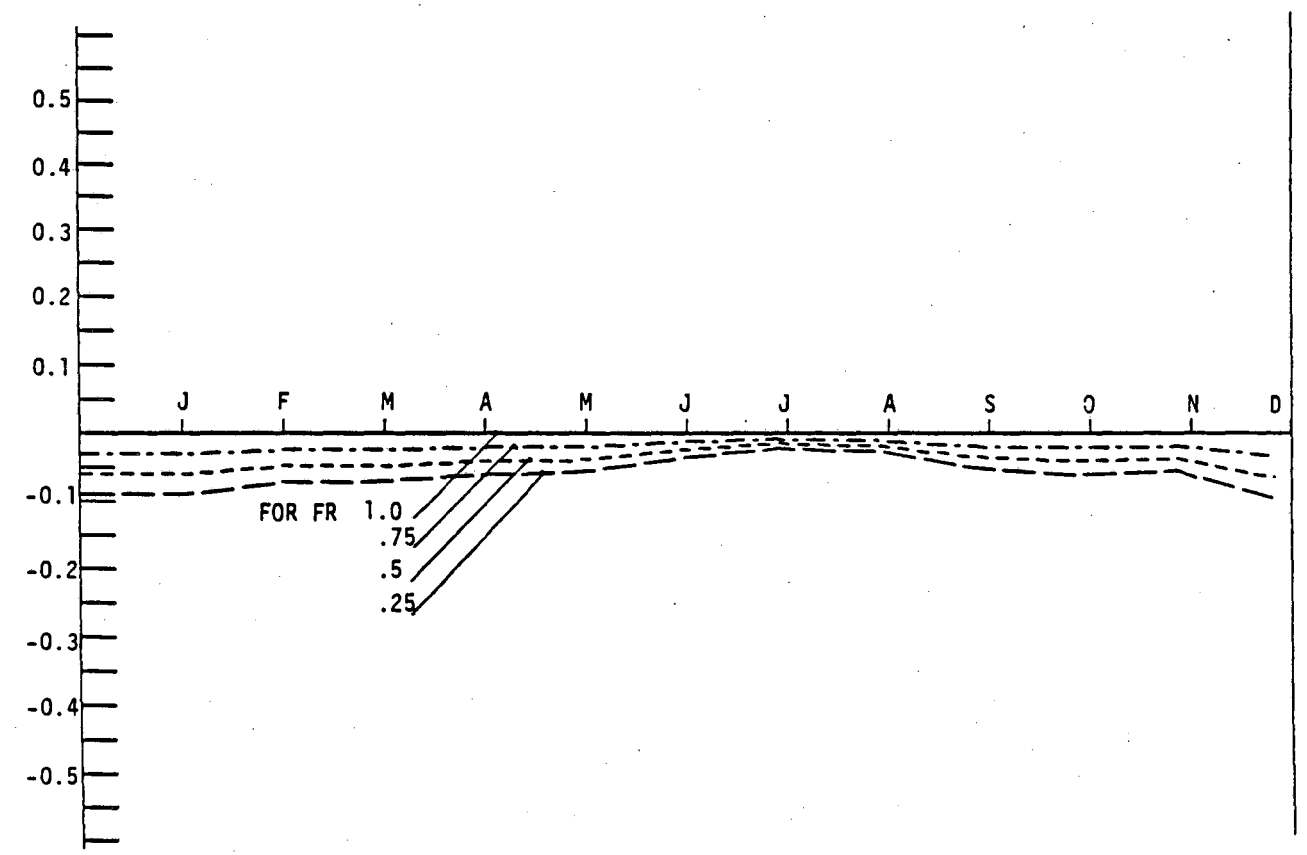

Figure 7.36. Heating load from recycled air, QRC, at various fresh air fractions, southern orientation. Cavity air flow, 6 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

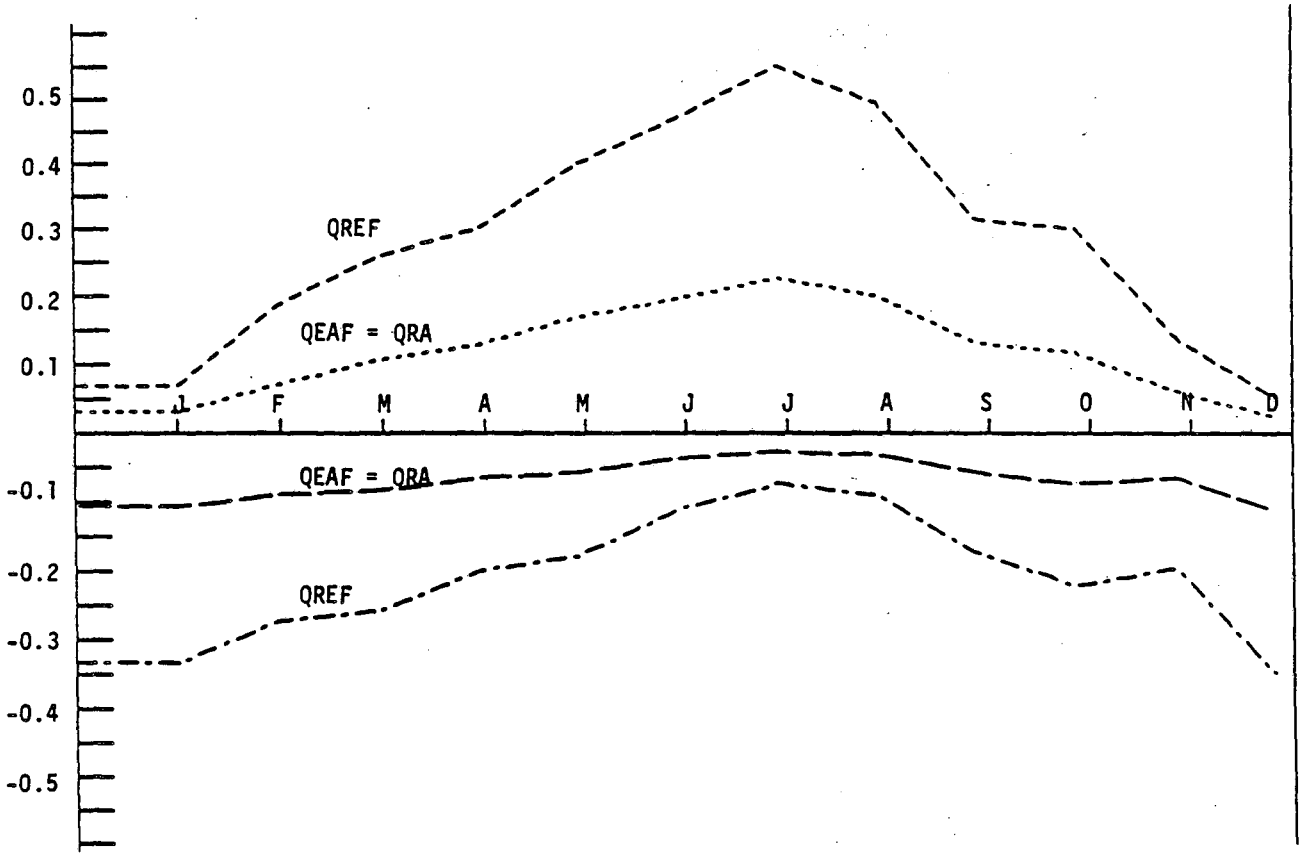

Figure 7.37. Heat gain and heat loss, QREF and QEAF, of reference and air-flow windows, western orientation. Cavity air flow, 6 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

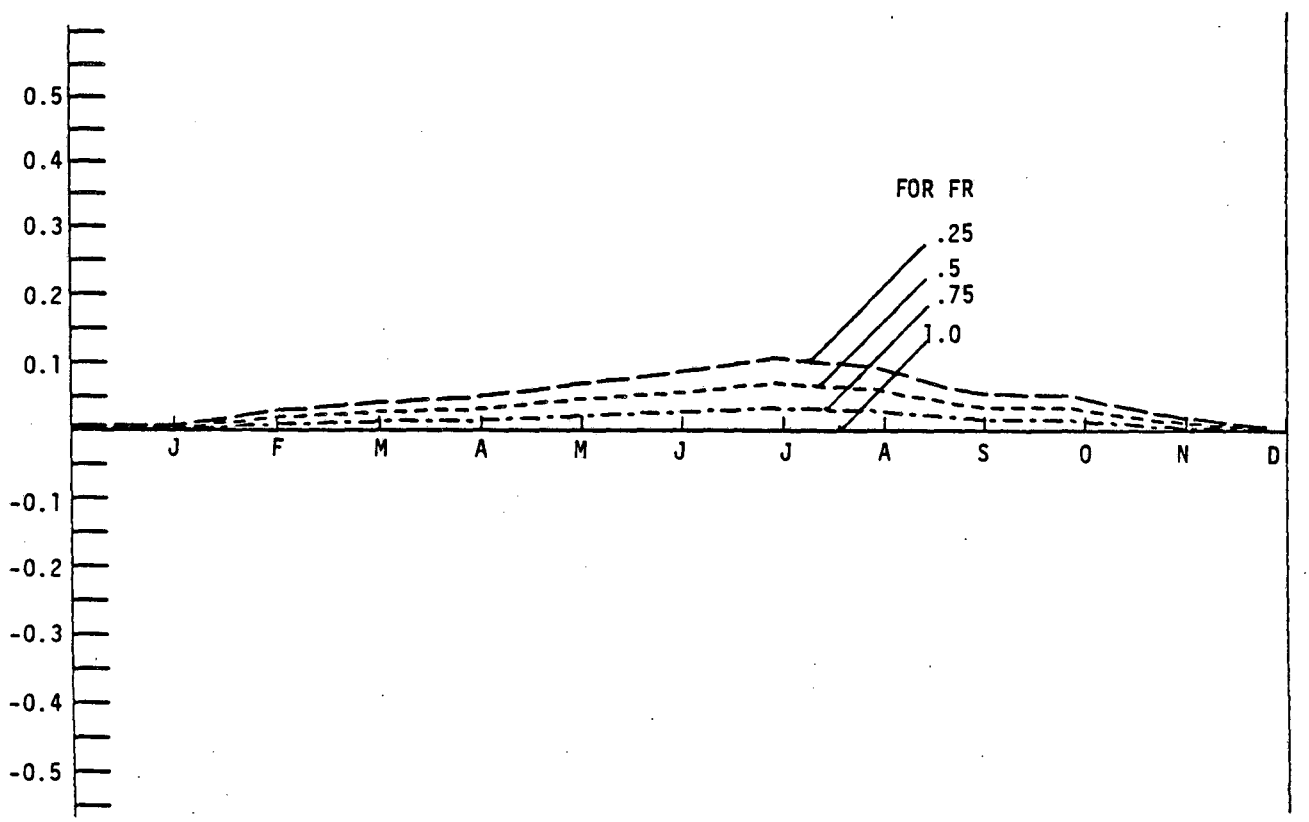

Figure 7.38. Cooling load from recycled air, QRC, at various fresh air fractions, western orientation. Cavity air flow, 6 cfm/ft of window width; window size 4 ft x 7 ft;, in 10^6 Btu.

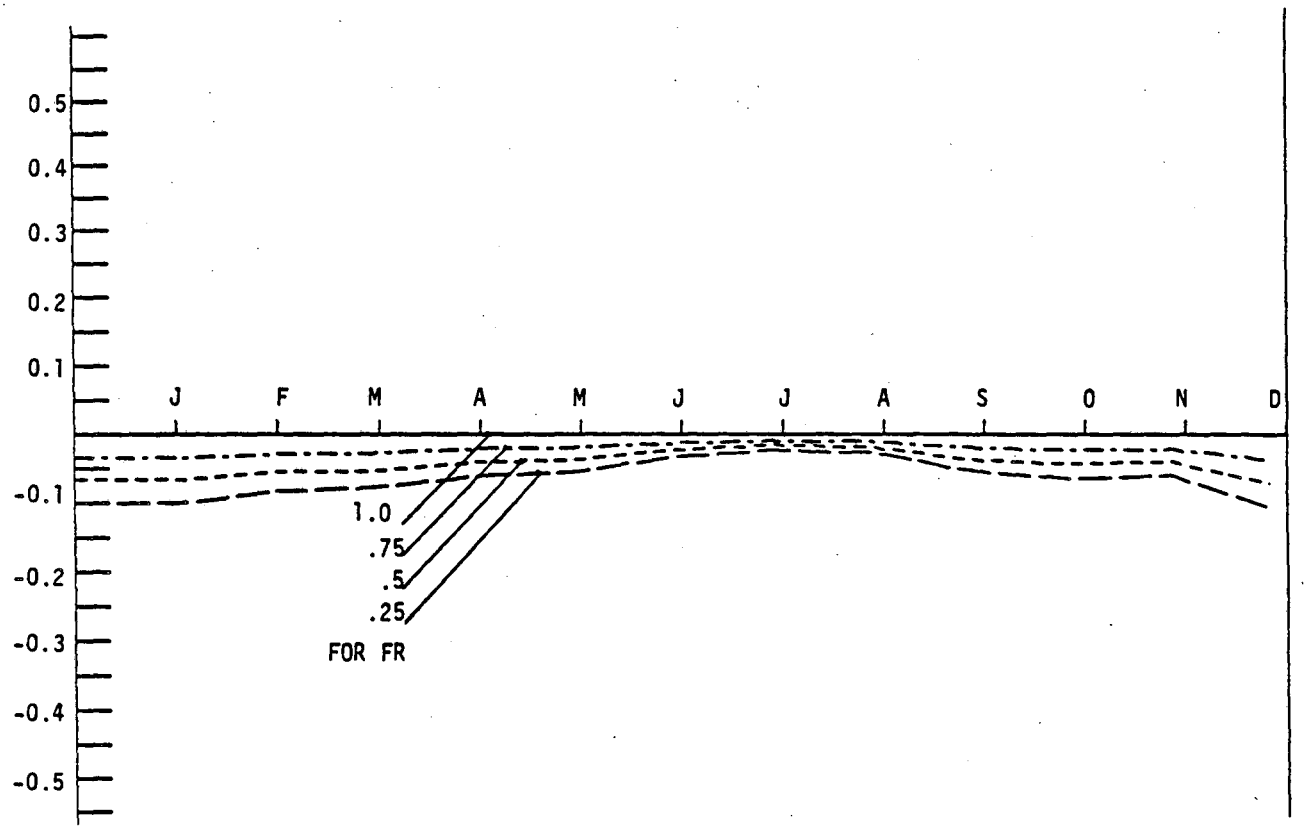

Figure 7.39. Heating load from recycled air, QRC, at various fresh air fractions, western orientation. Cavity air flow, 6 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 Btu.

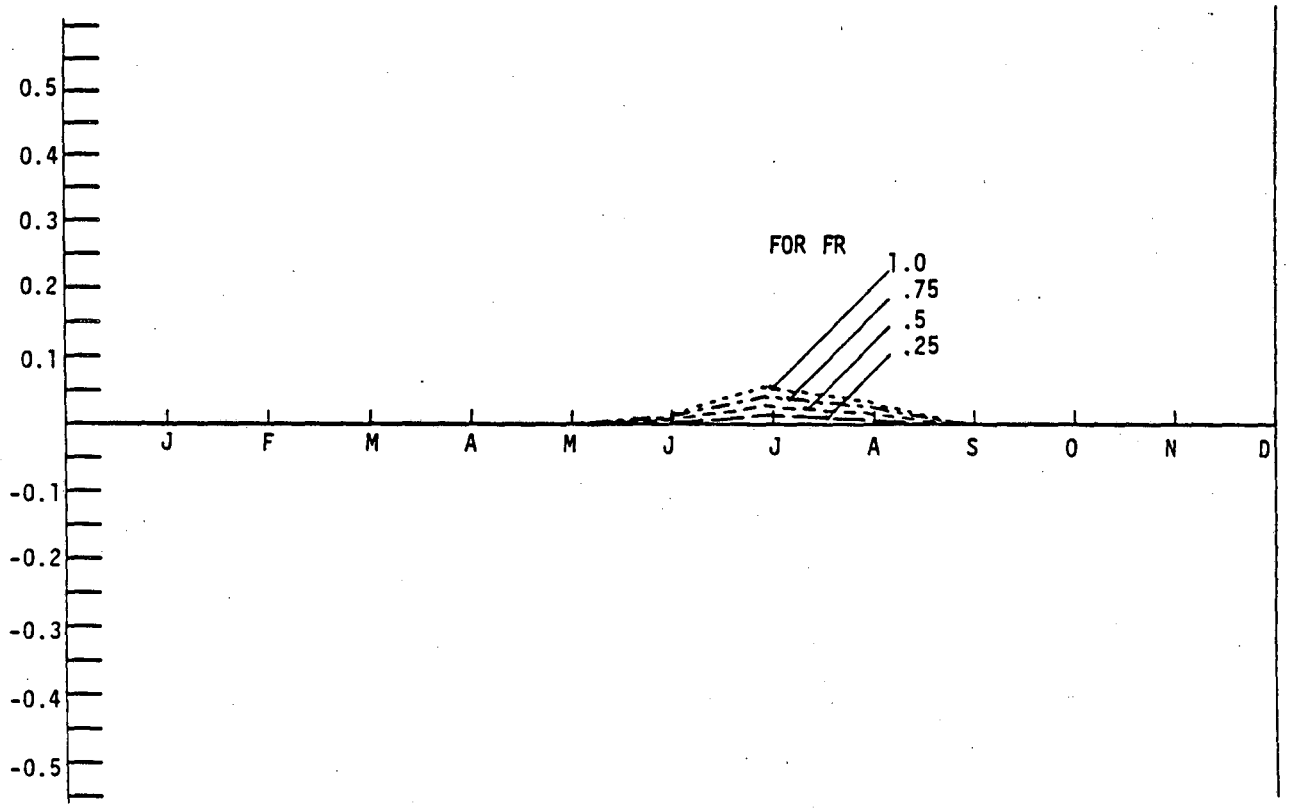

Figure 7.40. Sensible cooling load from fresh air, QFRESH 1, at various fresh air fractions. Cavity air flow, 6 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 BTU.

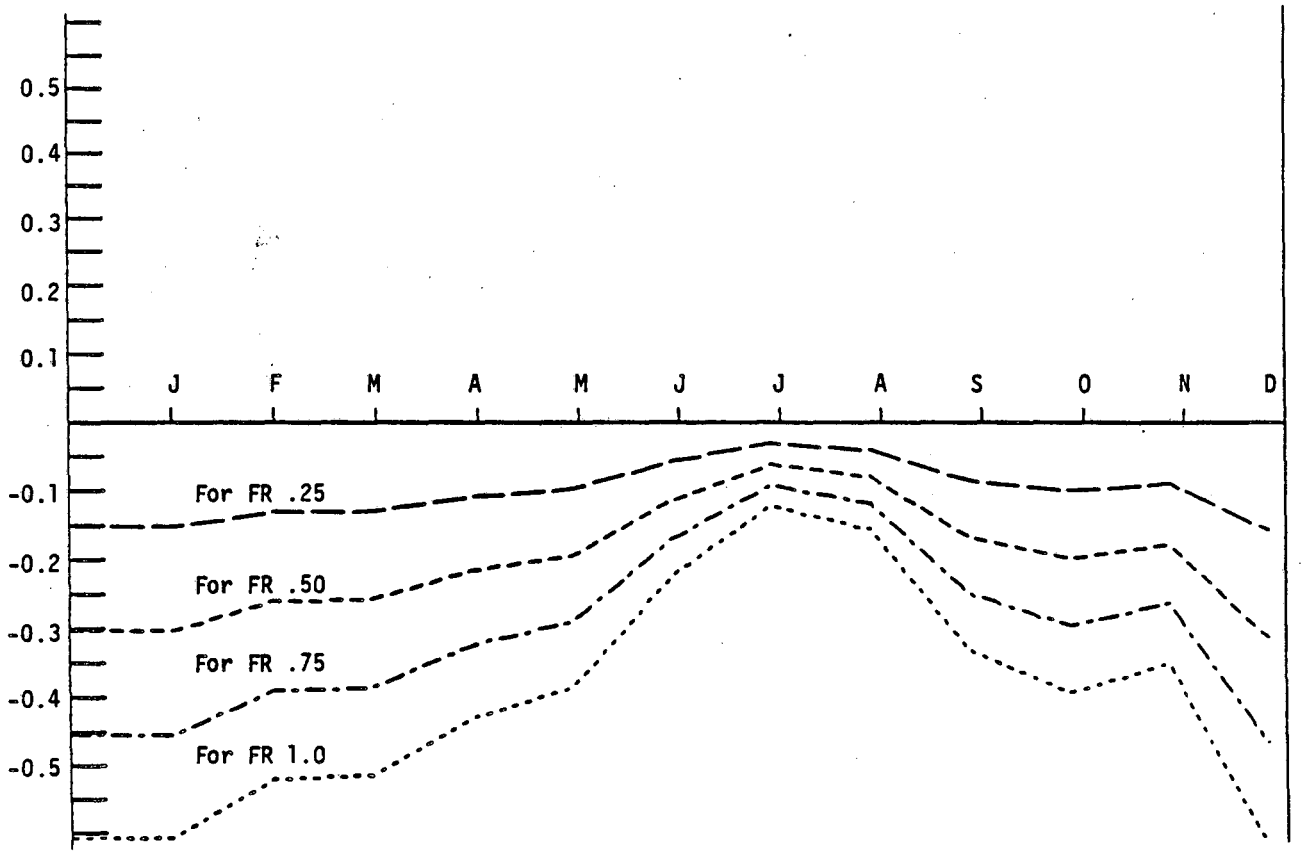

Figure 7.41. Sensible heating load from fresh air, QFRESH 1, at various fresh air fractions. Cavity air flow, 6 cfm/ft of window width, window size 4 ft x 7 ft, in 10^6 BTU.

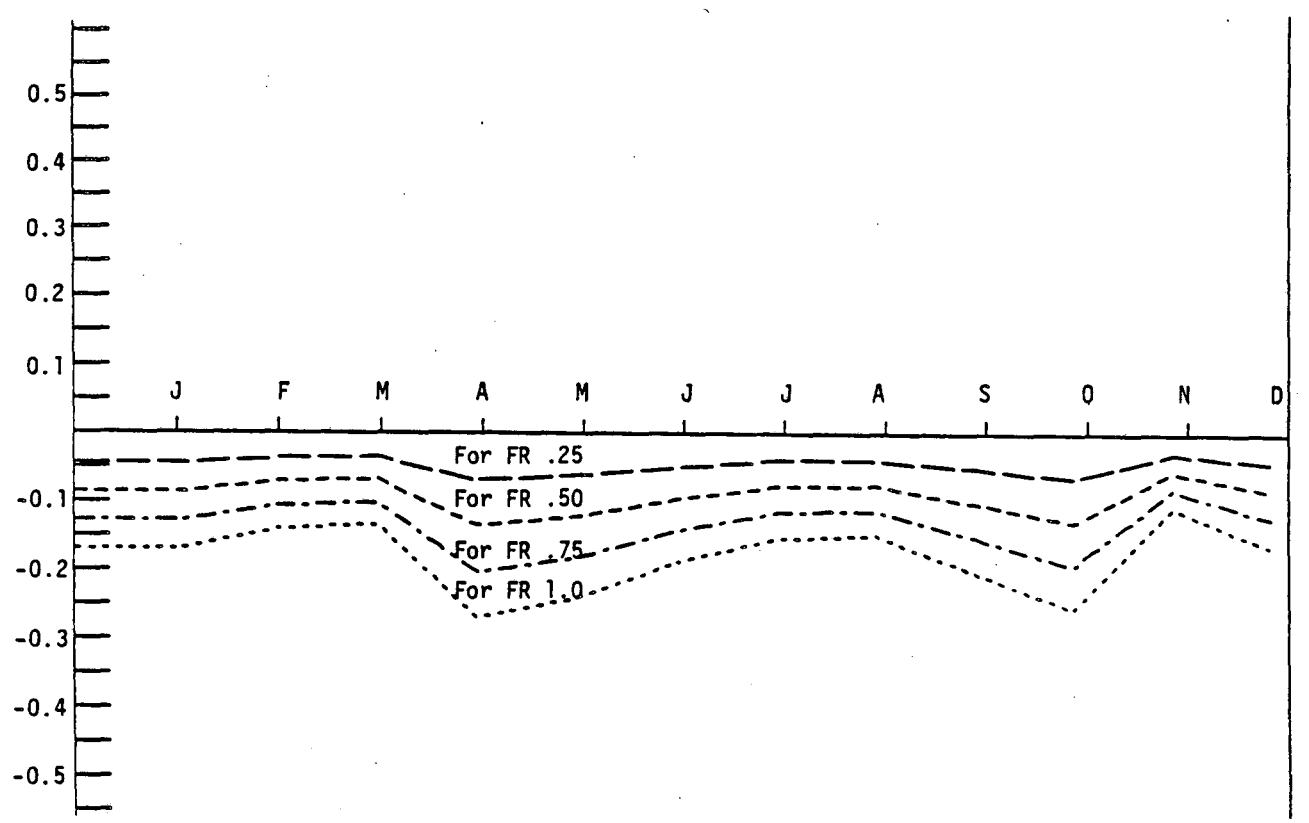

Figure 7.42. Latent energy load (addition of moisture) from fresh air, QFRESH 2, at various fresh air fractions. Cavity air flow, 6 cfm/ft of window width; window size 4 ft x 7 ft, in 10^6 BTU.

Day: August 7

HOUR: 1				
EQAFS	-0.736E 02	-0.736E 02	-0.736E 02	-0.736E 02
QREFS	-0.194E 03	-0.194E 03	-0.194E 03	-0.194E 03
QRCD				
	0.000E 00	-0.118E 02	-0.237E 02	-0.355E 02
	0.000E 00	-0.118E 02	-0.237E 02	-0.355E 02
	0.000E 00	-0.118E 02	-0.237E 02	-0.355E 02
	0.000E 00	-0.118E 02	-0.237E 02	-0.355E 02
QFR1	-0.187E 03	-0.140E 03	-0.935E 02	-0.467E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 2				
EQAFS	-0.660E 02	-0.660E 02	-0.660E 02	-0.660E 02
QREFS	-0.173E 03	-0.173E 03	-0.173E 03	-0.173E 03
QRCD				
	0.000E 00	-0.106E 02	-0.212E 02	-0.318E 02
	0.000E 00	-0.106E 02	-0.212E 02	-0.318E 02
	0.000E 00	-0.106E 02	-0.212E 02	-0.318E 02
	0.000E 00	-0.106E 02	-0.212E 02	-0.318E 02
QFR1	-0.168E 03	-0.126E 03	-0.838E 02	-0.419E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 3				
EQAFS	-0.528E 02	-0.528E 02	-0.528E 02	-0.528E 02
QREFS	-0.139E 03	-0.139E 03	-0.139E 03	-0.139E 03
QRCD				
	0.000E 00	-0.849E 01	-0.170E 02	-0.255E 02
	0.000E 00	-0.849E 01	-0.170E 02	-0.255E 02
	0.000E 00	-0.849E 01	-0.170E 02	-0.255E 02
	0.000E 00	-0.849E 01	-0.170E 02	-0.255E 02
QFR1	-0.134E 03	-0.100E 03	-0.670E 02	-0.335E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 4				
EQAFS	-0.348E 02	-0.348E 02	-0.348E 02	-0.348E 02
QREFS	-0.915E 02	-0.915E 02	-0.915E 02	-0.915E 02
QRCD				
	0.000E 00	-0.560E 01	-0.112E 02	-0.168E 02
	0.000E 00	-0.560E 01	-0.112E 02	-0.168E 02
	0.000E 00	-0.560E 01	-0.112E 02	-0.168E 02
	0.000E 00	-0.560E 01	-0.112E 02	-0.168E 02
QFR1	-0.884E 02	-0.663E 02	-0.442E 02	-0.221E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 5				
EQAFS	-0.133E 02	-0.133E 02	-0.133E 02	-0.133E 02
QREFS	-0.351E 02	-0.351E 02	-0.351E 02	-0.351E 02
QRCD				
	0.000E 00	-0.215E 01	-0.429E 01	-0.644E 01
	0.000E 00	-0.215E 01	-0.429E 01	-0.644E 01
	0.000E 00	-0.215E 01	-0.429E 01	-0.644E 01
	0.000E 00	-0.215E 01	-0.429E 01	-0.644E 01
QFR1	-0.339E 02	-0.254E 02	-0.169E 02	-0.847E 01
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 6				
EQAFS	0.102E 03	0.102E 03	0.848E 03	0.229E 03
QREFS	0.159E 03	0.159E 03	0.239E 04	0.644E 03
QRCD				
	0.000E 00	0.529E 01	0.106E 02	0.159E 02
	0.000E 00	0.529E 01	0.106E 02	0.159E 02
	0.000E 00	0.107E 03	0.213E 03	0.320E 03
	0.000E 00	0.293E 02	0.585E 02	0.878E 02
QFR1	0.259E 02	0.194E 02	0.129E 02	0.647E 01
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 7				
EQAFS	0.186E 03	0.186E 03	0.103E 04	0.353E 03
QREFS	0.308E 03	0.308E 03	0.290E 04	0.547E 03
QRCD				
	0.000E 00	0.115E 02	0.231E 02	0.346E 02
	0.000E 00	0.115E 02	0.231E 02	0.346E 02
	0.000E 00	0.131E 03	0.262E 03	0.393E 03
	0.000E 00	0.182E 02	0.363E 02	0.545E 02
QFR1	0.869E 02	0.651E 02	0.434E 02	0.217E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02

Day: August 7

HOUR: 8				
EQAFS	0.258E 03	0.270E 03	0.108E 04	0.270E 03
QREFS	0.717E 03	0.456E 03	0.305E 04	0.456E 03
QRCD				
	0.000E 00	0.358E 02	0.717E 02	0.107E 03
	0.000E 00	0.177E 02	0.353E 02	0.530E 02
	0.000E 00	0.139E 03	0.278E 03	0.417E 03
	0.000E 00	0.177E 02	0.353E 02	0.530E 02
QFR1	0.145E 03	0.109E 03	0.725E 02	0.362E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 9				
EQAFS	0.524E 03	0.349E 03	0.115E 04	0.349E 03
QREFS	0.127E 04	0.594E 03	0.278E 04	0.594E 03
QRCD				
	0.000E 00	0.619E 02	0.124E 03	0.186E 03
	0.000E 00	0.232E 02	0.465E 02	0.697E 02
	0.000E 00	0.128E 03	0.257E 03	0.385E 03
	0.000E 00	0.232E 02	0.465E 02	0.697E 02
QFR1	0.196E 03	0.147E 03	0.981E 02	0.491E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 10				
EQAFS	0.699E 03	0.406E 03	0.923E 03	0.406E 03
QREFS	0.170E 04	0.695E 03	0.223E 04	0.695E 03
QRCD				
	0.000E 00	0.818E 02	0.164E 03	0.245E 03
	0.000E 00	0.275E 02	0.549E 02	0.824E 02
	0.000E 00	0.106E 03	0.211E 03	0.317E 03
	0.000E 00	0.275E 02	0.549E 02	0.824E 02
QFR1	0.237E 03	0.178E 03	0.119E 03	0.594E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 11				
EQAFS	0.809E 03	0.439E 03	0.642E 03	0.439E 03
QREFS	0.196E 04	0.755E 03	0.156E 04	0.755E 03
QRCD				
	0.000E 00	0.943E 02	0.189E 03	0.283E 03
	0.000E 00	0.301E 02	0.602E 02	0.903E 02
	0.000E 00	0.766E 02	0.153E 03	0.230E 03
	0.000E 00	0.301E 02	0.602E 02	0.903E 02
QFR1	0.266E 03	0.199E 03	0.133E 03	0.664E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 12				
EQAFS	0.895E 03	0.483E 03	0.346E 03	0.483E 03
QREFS	0.217E 04	0.824E 03	0.854E 03	0.824E 03
QRCD				
	0.000E 00	0.104E 03	0.208E 03	0.312E 03
	0.000E 00	0.325E 02	0.650E 02	0.974E 02
	0.000E 00	0.456E 02	0.913E 02	0.137E 03
	0.000E 00	0.325E 02	0.650E 02	0.974E 02
QFR1	0.279E 03	0.209E 03	0.139E 03	0.697E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 13				
EQAFS	0.802E 03	0.582E 03	0.443E 03	0.443E 03
QREFS	0.195E 04	0.142E 04	0.766E 03	0.766E 03
QRCD				
	0.000E 00	0.940E 02	0.188E 03	0.282E 03
	0.000E 00	0.706E 02	0.141E 03	0.212E 03
	0.000E 00	0.308E 02	0.616E 02	0.924E 02
	0.000E 00	0.308E 02	0.616E 02	0.924E 02
QFR1	0.276E 03	0.207E 03	0.138E 03	0.691E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 14				
EQAFS	0.690E 03	0.834E 03	0.414E 03	0.414E 03
QREFS	0.168E 04	0.202E 04	0.716E 03	0.716E 03
QRCD				
	0.000E 00	0.815E 02	0.163E 03	0.244E 03
	0.000E 00	0.968E 02	0.194E 03	0.291E 03
	0.000E 00	0.288E 02	0.576E 02	0.863E 02
	0.000E 00	0.288E 02	0.576E 02	0.863E 02
QFR1	0.258E 03	0.194E 03	0.129E 03	0.645E 02
QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02

Figure 7.43. Hourly performance data for cavity air flow of 4 cfm/ft of window width and various fresh air fractions (window size 4 ft x 7 ft) in Btu per hour (0.100E 04 = 0.100 x 10^4).

Day: August 7

HOUR: 15				
EQAFS	0.521E 03	0.101E 04	0.361E 03	0.361E 03
QREFS	0.127E 04	0.244E 04	0.624E 03	0.624E 03
QRCD				
	0.000E 00	0.626E 02	0.125E 03	0.188E 03
	0.000E 00	0.114E 03	0.229E 03	0.343E 03
	0.000E 00	0.251E 02	0.502E 02	0.753E 02
	0.000E 00	0.251E 02	0.502E 02	0.753E 02
QFR1				
	0.226E 03	0.169E 03	0.113E 03	0.564E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 16				
EQAFS	0.310E 03	0.106E 04	0.285E 03	0.285E 03
QREFS	0.760E 03	0.255E 04	0.494E 03	0.494E 03
QRCD				
	0.000E 00	0.387E 02	0.775E 02	0.116E 03
	0.000E 00	0.118E 03	0.236E 03	0.353E 03
	0.000E 00	0.199E 02	0.399E 02	0.598E 02
	0.000E 00	0.199E 02	0.399E 02	0.598E 02
QFR1				
	0.181E 03	0.136E 03	0.904E 02	0.452E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 17				
EQAFS	0.202E 03	0.783E 03	0.202E 03	0.285E 03
QREFS	0.349E 03	0.220E 04	0.349E 03	0.469E 03
QRCD				
	0.000E 00	0.141E 02	0.281E 02	0.422E 02
	0.000E 00	0.101E 03	0.202E 03	0.303E 03
	0.000E 00	0.141E 02	0.281E 02	0.422E 02
	0.000E 00	0.174E 02	0.348E 02	0.521E 02
QFR1				
	0.127E 03	0.952E 02	0.635E 02	0.317E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 18				
EQAFS	0.118E 03	0.481E 03	0.118E 03	0.334E 03
QREFS	0.202E 03	0.135E 04	0.202E 03	0.511E 03
QRCD				
	0.000E 00	0.792E 01	0.158E 02	0.238E 02
	0.000E 00	0.618E 02	0.124E 03	0.185E 03
	0.000E 00	0.792E 01	0.158E 02	0.238E 02
	0.000E 00	0.166E 02	0.330E 02	0.495E 02
QFR1				
	0.675E 02	0.506E 02	0.338E 02	0.169E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 19				
EQAFS	0.717E 02	0.855E 02	0.717E 02	0.855E 02
QREFS	0.106E 03	0.126E 03	0.106E 03	0.126E 03
QRCD				
	0.000E 00	0.316E 01	0.632E 01	0.947E 01
	0.000E 00	0.371E 01	0.741E 01	0.111E 02
	0.000E 00	0.316E 01	0.632E 01	0.947E 01
	0.000E 00	0.371E 01	0.741E 01	0.111E 02
QFR1				
	0.647E 01	0.486E 01	0.324E 01	0.162E 01
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 20				
EQAFS	-0.205E 02	-0.205E 02	-0.205E 02	-0.205E 02
QREFS	-0.538E 02	-0.538E 02	-0.538E 02	-0.538E 02
QRCD				
	0.000E 00	-0.330E 01	-0.659E 01	-0.989E 01
	0.000E 00	-0.330E 01	-0.659E 01	-0.989E 01
	0.000E 00	-0.330E 01	-0.659E 01	-0.989E 01
	0.000E 00	-0.330E 01	-0.659E 01	-0.989E 01
QFR1				
	-0.520E 02	-0.390E 02	-0.260E 02	-0.130E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 21				
EQAFS	-0.410E 02	-0.410E 02	-0.410E 02	-0.410E 02
QREFS	-0.108E 03	-0.108E 03	-0.108E 03	-0.108E 03
QRCD				
	0.000E 00	-0.659E 01	-0.132E 02	-0.198E 02
	0.000E 00	-0.659E 01	-0.132E 02	-0.198E 02
	0.000E 00	-0.659E 01	-0.132E 02	-0.198E 02
	0.000E 00	-0.659E 01	-0.132E 02	-0.198E 02
QFR1				
	-0.104E 03	-0.780E 02	-0.520E 02	-0.260E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02

Figure 7.43 — Continued.

Day: August 7

HOUR: 22				
EQAFS	-0.575E 02	-0.575E 02	-0.575E 02	-0.575E 02
QREFS	-0.151E 03	-0.151E 03	-0.151E 03	-0.151E 03
QRCD				
	0.000E 00	-0.926E 01	-0.185E 02	-0.278E 02
	0.000E 00	-0.926E 01	-0.185E 02	-0.278E 02
	0.000E 00	-0.926E 01	-0.185E 02	-0.278E 02
	0.000E 00	-0.926E 01	-0.185E 02	-0.278E 02
QFR1				
	-0.146E 03	-0.110E 03	-0.731E 02	-0.365E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 23				
EQAFS	-0.691E 02	-0.691E 02	-0.691E 02	-0.691E 02
QREFS	-0.182E 03	-0.182E 03	-0.182E 03	-0.182E 03
QRCD				
	0.000E 00	-0.111E 02	-0.222E 02	-0.333E 02
	0.000E 00	-0.111E 02	-0.222E 02	-0.333E 02
	0.000E 00	-0.111E 02	-0.222E 02	-0.333E 02
	0.000E 00	-0.111E 02	-0.222E 02	-0.333E 02
QFR1				
	-0.175E 03	-0.132E 03	-0.877E 02	-0.439E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02
HOUR: 24				
EQAFS	-0.748E 02	-0.748E 02	-0.748E 02	-0.748E 02
QREFS	-0.197E 03	-0.197E 03	-0.197E 03	-0.197E 03
QRCD				
	0.000E 00	-0.120E 02	-0.241E 02	-0.361E 02
	0.000E 00	-0.120E 02	-0.241E 02	-0.361E 02
	0.000E 00	-0.120E 02	-0.241E 02	-0.361E 02
	0.000E 00	-0.120E 02	-0.241E 02	-0.361E 02
QFR1				
	-0.190E 03	-0.142E 03	-0.950E 02	-0.475E 02
QFR2				
	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02

PAUSE
PAUSE
X

		South	West	East	North
	HOUR: 6				
	EQAFS	0.102E 03	0.102E 03	0.848E 03	0.229E 03
	QREFS	0.159E 03	0.159E 03	0.239E 04	0.644E 03
		FR=1.0	FR=0.75	FR=0.5	FR=0.25
South	QRCD				
West		0.000E 00	0.529E 01	0.106E 02	0.159E 02
East		0.000E 00	0.529E 01	0.106E 02	0.159E 02
North		0.000E 00	0.107E 03	0.213E 03	0.320E 03
		0.000E 00	0.293E 02	0.585E 02	0.878E 02
	QFR1				
all		0.259E 02	0.194E 02	0.129E 02	0.647E 01
facades	QFR2	-0.130E 03	-0.971E 02	-0.648E 02	-0.324E 02

Nomenclature:
EQAFS same as QRAF, but in Btu per hour
QREFS same as QREF, but in Btu per hour
QRCD same as QRC, but in Btu per hour
QFR1 same as QFRESH1, but in Btu per hour
QFR2 same as QFRESH2, but in Btu per hour

Figure 7.44. Key to Figure 7.43.

7.3. Yearly Summary Samples Including Fresh Air Impact

Discussing this broader context of Section 7.2 and of the following, which goes beyond the window performance itself, one should be aware that it relates to the hot and arid climate of Salt Lake City. In other places, especially where temperature and humidity levels are considerably different, the heating and cooling loads from make-up air will be quite different.

Figure 7.45 shows the yearly heat loss at south orientation for the reference, exhaust-air and return-air windows. For the exhaust-air window or for the return-air window with all return air exhausted and without application of an energy recovery system, the air-flow window systems have at fresh air fraction 1.0 about 22 percent lower heat losses than the reference window. If the return-air exhaust rate is 75 percent (FR = .75), then the exhaust-air window is about 7 percent and the return-air window about 24 percent lower than the reference window. At 50 percent return air exhaust rate the heat loss of the exhaust-air window has a 13 percent higher and the return-air window a 26 percent lower loss than the reference window. The same trend holds for other window orientations.

Figure 7.46 shows the yearly heat gain at south orientation. With a fresh air fraction of 1.0 the air-flow windows have a 59 percent lower heat gain than the reference window. With a fresh air fraction of 0.5 the return-air window is about 12 percent less efficient than the exhaust-air window. Similar relationships exist for other orientations, such as the west orientation, shown in Figure 7.47.

This only slightly better performance of the exhaust-air window versus the return-air window in summer and the considerably better performance of the return-air window in winter, may lead to the decision for application of the return-air system. Considering internal heat gains, however, may change the basis for such a decision.

If one uses the rather low amount of 3 W per sq ft of internal heat gain (people, lighting, equipment), a 20 ft deep exterior building zone will, at 4 ft window width, produce a gain of 240 W or 818 Btu/hr. For 9 work hours and a 5 day work week a gain of 1.914 x 10^6 Btu per year will occur. This load which occurs mostly during daytime will slightly counterbalance the losses in winter, but substantially contribute to summer cooling loads in buildings with the reference or the return-air windows at lower than 1.0 fresh air fraction. The exhaust-air window will directly discard this load with the cavity air.

Yearly Heat Losses*

	QREF		QEAF		QRC		QFR1		QFR2		TOTAL
			at fresh air fraction FR = 1.0								
Reference Window	1.904	+					2.536	+	0.977	=	5.417
Exhaust-Air Window			0.699	+			2.536	+	0.977	=	4.212
Return-Air Window			0.699	+			2.536	+	0.977	=	4.212
			at fresh air fraction FR = 0.75								
Reference Window	1.904	+					1.902	+	0.733	=	4.539
Exhaust-Air Window			0.699	+			2.536	+	0.977	=	4.212
Return-Air Window			0.699	+	0.124	+	1.902	+	0.733	=	3.458
			at fresh air fraction FR = 0.5								
Reference Window	1.904	+					1.268	+	0.489	=	3.661
Exhaust-Air Window			0.699	+			2.536	+	0.977	=	4.212
Return-Air Window			0.699	+	0.247	+	1.268	+	0.489	=	2.703

* including January through May and October through December.

Figure 7.45. Yearly heat losses, south orientation, window cavity air flow 4 cfm/ft of window width, window size 4 ft x 7 ft, in 10^6 Btu per year.

Yearly Heat Gains*

	QREF		QEAF		QRC		QFR1	QFR2**		TOTAL
			at fresh air fraction FR = 1.0							
Reference Window	4.512	+					0.078		=	4.590
Exhaust-Air Window			1.791	+			0.078		=	1.869
Return-Air Window			1.791	+			0.078		=	1.869
			at fresh air fraction FR = 0.75							
Reference Window	4.512	+					0.059		=	4.571
Exhaust-Air Window			1.791	+			0.078		=	1.869
Return-Air Window			1.791	+	0.182	+	0.059		=	2.032
			at fresh air fraction FR = 0.50							
Reference Window	4.512	+					0.039		=	4.551
Exhaust-Air Window			1.791	+			0.078		=	1.869
Return-Air Window			1.791	+	0.264	+	0.039		=	2.094

* including all months
**no latent heat gains because of low relative humidity conditions in Salt Lake City.

Figure 7.46. Yearly heat gains, south orientation, window cavity air flow 4 cfm/ft of window width, window size 4 ft x 7 ft, in 10^6 Btu per year.

Yearly Heat Gains*

	QREF		QEAF		QRC		QFR1	QFR2**		TOTAL
			at fresh air fraction FR = 1.0							
Reference Window	3.550	+					0.078		=	3.628
Exhaust-Air Window			1.541	+			0.078		=	1.619
Return-Air Window			1.541	+			0.078		=	1.619
			at fresh air fraction FR = 0.75							
Reference Window	3.550	+					0.059		=	3.609
Exhaust-Air Window			1.541	+			0.078		=	1.619
Return-Air Window			1.541	+	0.141	+	0.059		=	1.741
			at fresh air fraction FR = 0.5							
Reference Window	3.550	+					0.039		=	3.589
Exhaust-Air Window			1.541	+			0.078		=	1.619
Return-Air Window			1.541	+	0.182	+	0.039		=	1.763

* including all months
** no latent heat gains because of low relative humidity conditions in Salt Lake City.

Figure 7.47. Yearly heat gains, west orientation, window cavity air flow 4 cfm/ft of window width, window size 4 ft x 7 ft, in 10^6 Btu per year.

8. DEMONSTRATION PROJECT OUTLINE

The outline for a demonstration project must address the major assets and liabilities which the application of air-flow windows will bring into various building situations. Therefore, instead of discussing a project in a particular situation, a question-and-answer method was chosen in order to cover the relevant aspects as broadly as possible. The questions and answers are listed in the Appendix N.

Such questions frequently will be asked by architects and engineers when confronted with the choice of using air-flow windows. The answers contain a great deal of information not directly related to the main task of thermal testing, but important for understanding the whole context of air-flow window applications.

In the following, the major features of a demonstration project are outlined. They are developed from the question-answer content. The recommendations are grouped in five areas of consideration: Site Selection and Environmental Conditions, Type of Building, Window Type and Solar Control, HVAC System and Window Integration, and Monitoring for Demonstration.

8.1. Site Selection and Environmental Conditions

The tests and simulations, as described in the previous sections have shown potentially large energy savings through application of air-flow windows in an area, Salt Lake City, with moderate to strong fluctuations in outside temperatures and with high solar radiation levels. Many areas in the United States have similar conditions, except for humidity and wind velocity levels, which are particularly low in Salt Lake City.

In regions with mild climatic conditions the energy conserving features of air-flow windows will not be as obvious. Therefore, a project demonstrating their performance should be located in a metropolitan area with strong temperature variations during the course of the year and high solar radiation levels. Exterior relative humidity levels are not an important consideration for the operation of the windows as the potential for condensation in the window cavity is depending on maintained interior humidity levels. Exterior humidity levels will have to be considered, however, in comparing exhaust-air versus return-air window performance related to make-up air requirements.

In order to allow the study of solar impact under comparable conditions for all orientations, the site should be located in an area as little as possible obstructed by neighboring buildings. For example, the upper floors of a highrise office building would serve this purpose. The building should be oriented in such a way that true South, East, West and North facades are achieved and can be monitored.

8.2. Type of Building

Although air-flow windows have been installed in a variety of building types, such as hospitals and schools, by far the largest number of applications occurred in office structures. Office buildings have typically large window areas and, consequently, large exterior building zones.

The proper functioning of air-flow windows is dependent on sufficient air supply from such exterior zones. Typical space requirements per office occupant range between 50-100 sq ft. Therefore, 3 to 5 ft of facade width is allocated per occupant in exterior zones of buildings at 15 to 20 ft of zone depth. As the minimum fresh air requirements per occupant typically are 10 to 15 cfm per occupant, 2 to 5 cfm per ft of window width are available as window supply air (space exhaust or return air). This is in the functionally effective range of cavity air supply rates. At larger zone depth more supply air may be available.

Office buildings represent a large volume of building in the private and government sector. They lend themselves also for retrofit installations, with application of the return-air window type, by leaving the exterior facade in place and installation of a second window inside which provides the cavity. In most cases the extension of the conventional return duct system to the return-air duct headers above the window can be accomplished within suspended ceilings.

Because of the above mentioned items and because office buildings contain rather uniform space functions (with related uniform monitoring conditions) they appear to represent the best building type for a demonstration project.

8.3. Window Types and Installations

As evident from the results of the yearly performance modeling, the overall energy balances of the exhaust-air and the return-air window vary considerably in dependence on outside environmental conditions, air-flow rates and reconditioning of window cavity air (in the case of return-air windows). In order to demonstrate the operational characteristics and compare the actual performance of the two air-flow window types, it seems advisable to install both systems in the same demonstration project under the same conditions; for example, as two floors of an otherwise conventionally built office building.

A third floor with conventional windows could serve as a reference arrangement for monitoring performance. As the air-flow window contains three panes of glass, the reference window should contain three pane insulating glass. This would yield a considerably improved performance of the reference window for demonstration purposes, especially during winter.

Part of the improvement in performance of air-flow windows versus conventional windows is the integration of shading devices in the window cavity. This difference of performance is especially evident at low solar altitude angles, that is, in the winter half-year for South and in the summer half-year for East and West walls.

White venetian blinds should be installed, in the cavity of the air-flow windows except in the North facade, to reflect part of the radiation to

the outside and to provide increased daylight penetration into the space via ceiling reflections. The shading devices of the reference floor (on the inside of conventional windows with insulating glass) should be of the same type.

The blinds should be automatically controlled on all windows of the test floors in order to achieve comparable results. For latitudes of the United States, with the exception of Alaska, only four adjustments of the blinds over the year's course are necessary: retracted at overcast skies, horizontal, 30 degree and 45 degree positioning of the slats at sun exposure (the latter three blocking the solar beam completely). Such automatic venetian blind controls are on the market in Switzerland and West Germany.

8.4. HVAC System and Window Integration

A separate HVAC and air-distribution system should be installed for each of the three window types. This will allow separate demonstrations and monitoring. It will also allow identification of shifts and tradeoffs in building cost which will occur because of differences in the physical and operational characteristics of the system.

The same functional uses, occupant numbers and lighting levels should be maintained in order to achieve similar heat gains for comparative evaluation. For the same reason, air-flow rates should be maintained at the same levels. The effects of higher heat gains and higher air-flow rates, as encountered in other building types, than offices, and potentially favoring the overall energy balance of one system over another, should not be subject to physical demonstration, but part of energy performance modeling.

Which HVAC and air-distribution system should be chosen depends on many parameters of which the choice of windows and shading devices are only two, although crucial ones. Certain aspects, however, directly related to a demonstration project with air-flow windows need to be emphasized:

1) While the air supply to the exterior zones of the test floor can be achieved by identical distribution systems, the air return (or air exhaust) systems will have to accommodate the particulars of each window type.

2) Pressurization for air flow window operation must be provided. In case of the exhaust-air window the pressure must be exerted on the supply side. For the return-air window this may be accomplished on the supply, on the return or on combined sides.

3) Return duct connections are necessary in case of return-air windows. As return-air windows are typically of the up-flow type, these connections are accomplished by flexible ducting pieces and, to the outside well insulated, sheet metal duct headers connected for the full width openings above the window cavities.

4) Zoning related to the facade orientations should be provided for separate monitoring. This is done most effectively through partitioning with walls. It also implies separation between the core and the outer zones of the test floors.

8.5. Monitoring for Demonstration

Monitoring for the demonstration could be done on two levels, microscopic and macroscopic. Assume that a multifloored office building has been chosen for the discussion here. Each floor might have a different type of window. On the macroscopic basis, the total energy consumption for the floor (heating or cooling) would be determined. This would be done by measuring the total air flow to each floor and by inferring its enthalpy content from temperature and humidity measurements. Care would have to be taken to avoid any gross dissimilarities of loads of the floors.

If some problem exists in the HVAC system of the building such that the floorwise macroscopic measurements cannot be made, a series of semi-macroscopic measurements might be made on a room-by-room approach.

On the microscopic level, some samples of the various types of windows would be selected for detailed studies, temperatures should be measured on the inside (roomside) surface of the inner glazing. This can be used for various demonstrations, such as mean radiant temperature comparisons between windows. Also, temperatures of selectively chosen windows will be measured in more detail to infer condensation possibilities.

An electronic panel display exhibiting instantaneous energy flows and recorded long term performance data of the individual test floors and orientations would help its demonstration purpose.

9. CONCLUSIONS

The major goal of this project was energy performance comparisons of air-flow type windows with the conventional insulating glass window. The project included the development of testing and performance modeling parameters, simultaneous testing of air-flow window and conventional window components, data reduction and computer modeling of window performance. It should be noted that very little testing and performance modeling for air-flow windows had been undertaken and often unusual procedures had to be developed for achieving desired data. The results are shown in Sections 5 and 7. They show considerable energy savings of air-flow windows versus the conventional insulating glass type for most of the environmental and operational conditions, and related to the climate of Salt Lake City. It is important to consider the results within the context of a particular building. The examples of monthly and yearly heat losses and heat gains in Section 7 reinforce this comment.

The following items are the major conclusions from this project:

1. The energy balance across the windows, that is transmission losses or gains between the outside and the exterior zones of a building, is, on a yearly basis, 30 to 60 percent in favor of air-flow windows.

2. The air-flow window principle is effective in reducing heat losses and heat gains. It is, however, crucial to consider the disposal/reutilization mode of cavity air with regard to its impact on the energy balance combined with transmission losses. Both the sensible and the latent heat content of the exhaust-air/return-air must be considered.

3. The exhaust-air window often shows large heat losses in winter, compared with the return-air window, in situations where only part of the return-air is replaced by fresh air.

4. The performance of air-flow windows related to transmission losses and gains improves with increasing cavity air flow rates. The improvement rate is strong for air flows up to about 6 cfm/ft of window width but is small beyond this level.

5. A general statement regarding the choice between return-air window versus exhaust-air window cannot be made, based on window testing alone. Other factors related to a particular building's functions and HVAC system, such as occupancy load, artificial lighting level, air change rate, energy recovery equipment, will play important roles in the decision process between the two window types.

6. The mean radiant temperatures in spaces with large window walls will be favorably influenced in winter and summer by installation of air-flow windows, as the inside surface temperatures will be considerably closer to room air temperatures than double glazed, or even triple glazed, windows would yield.

7. Condensation from humidity of room air may occur on the cavity side of the outer insulating glass pane of air-flow windows at slightly higher room air temperatures than on the room side of conventional insulating glass.

8. A simulation procedure has been developed which can be adapted to any location where long term averages of solar insolation and maximum and minimum temperatures are available.

9. Considerations are given for the definition of a demonstration project where full scale applications of flow windows can be made.

10. ACKNOWLEDGEMENT

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APPENDIX A

Air-Flow Window Applications in Europe

This report describes the state of the art of air-flow windows as developed from a literature search and from visits to air-flow window installations in Germany, Sweden and Switzerland.

1. Introduction

The air-flow window which is increasingly used in central and northern Europe has originated in Sweden. A related Swedish patent was filed on September 27, 1956. The first large-scale installation dates back to 1967 when the city of Helsinki used air-flow windows, designed by the EKONO Company in its Building Department offices.

Since the energy crisis of 1973, the energy savings potential of these windows has resulted in a strong interest in their application. There are at least 50 large buildings and numerous small ones in Europe with air-flow window installations. The components are known in Europe as exhaust-air windows or climate windows.

2. Window Type

The air-flow windows use return or exhaust air from conditioned spaces to temper the impact of climate and weather on the interior environment. The air flows through the window cavity between the inner and outer glass panes. It strongly reduces the energy exchange between the two surfaces. Vertical or horizontal blinds act as shading devices and absorbers of solar energy. Some of this energy is removed by the air stream.

The air flow direction is generally upwards. At least one system, however, is based on downflow. This system allows space air to enter the window cavity through the top frame and exhausts the air through the lower frame directly to the outside. All other systems return the air from the window cavity to the central air-conditioning equipment. The space air is introduced to the window cavity at sill height, that is, just below the window frame. In some installations, the air enters a few inches above floor level and is ducted via spandrel panel duct to the window cavity.

The inner window frame is always operable for cleaning the cavity and the blinds. In large air-conditioned buildings, the outer frame is generally fixed. It is often an integral part of the curtain wall. Some systems provide an operable outer sash, allowing cleaning of the outside glass surface from the interior space.

The air in the up-flow windows is returned by means of a manifold-type duct above the windows or by individual return ducts. No return connection exists for the direct exhaust-air window type.

Although the excellent thermal properties of these windows have been the major force behind their application, the potential for reducing sound transmission has been more important in certain situations. The "double skin" nature of these windows allows for efficient acoustical separation and absorption (cavity box lining). Typical applications are in offices and hotels with heavy automobile traffic outside and in buildings close to airports.

The principle of the air-flow window is similarly utilized by all manufacturers. The details, however, vary widely; not only between manufacturers, but from installation to installation by the same manufacturer. The two major groups of applications are curtain-wall-integrated components and individual windows, which are also used in retrofit situations.

3. Window and Blind Materials

All wood, all aluminum, and aluminum-wood combinations have been used. In the latter case, aluminum is generally applied as exterior cladding material. The aluminum windows have thermal breaks between the outer and inner frames. The frame sections are generally deep, resulting in cavity space dimensions between the glass panes of four to eight inches.

The blinds are either aluminum venetian blinds in various colors or vertical, white, nylon blinds. The blinds are either manually operated or motorized with central controls and solar irradiation sensing equipment.

4. Technical Discussion

There are three major considerations for justifying the application and higher cost of air-flow windows compared with conventional fenestration:

a. Architectural design, comfort conditions, and space utilization;
b. Building and maintenance costs;
c. Energy consumption.

4.1. Architectural Design, Comfort Conditions and Space Utilization

The appearance of air-flow windows and facades is basically the same as for conventional ones, with the exception of sun shading. The location of sun-shading devices between the glass panes of conventional windows is generally not advisable. Under the impact of solar radiation, the shading devices act as absorbers and radiators, increasing the surface temperatures of windows. The exterior shading devices which should be used in conventional fenestration influence the appearance of buildings considerably. In air-flow window systems, sun-shading devices are generally placed between the glass panes. The solar energy absorption is a desired effect in this case, allowing convective transport of the collected solar energy directly to the outside or to the central HVAC equipment. The building exterior is not influenced by the shading devices.

Air-flow windows have excellent thermal properties. The effective U-values are 25 to 50 percent

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* This report was initially submitted as part of the milestone reporting procedures of the LBL contract in January 1980; that is, before any window testing under this contract had been done.

of those of double insulating glass windows. They vary with the air-flow rate through the window cavity. The effective shading coefficients are as low as .2 and are variable by adjustment of the blinds. Low shading coefficients are also achieved in some installations by heat absorbing or reflecting glass.

These thermal properties establish very favorable comfort conditions, even close to the window surface. At a room temperature of 68°F, an outside temperature of 5°F, the typical air-flow rates from 6 to 15 cfm per foot of window width, temperature drops of only 5 to 9°F below room temperature are experienced. The mean radiant temperature of the space is considerably improved, especially in spaces with large windows. Down drafts on windows are virtually eliminated.

The blinds allow individual adjustment of solar radiation conditions for any sun angle and facade direction. Manipulation improves the daylighting conditions in the interior zones of buildings by regulating daylight intensities at high solar irradiation and by reflecting daylight into the depths of spaces. Glare is eliminated or considerably reduced. The visual connection between inside and outside, however, is more or less diminished depending on the type of sun-shading device.

Because of the favorable thermal and lighting conditions, work areas may be placed directly at the inner facade surface, thus enhancing space utilization. This option is supported by the fact that terminal HVAC components such as radiators or air induction units are rarely located at the windows. The application of air-flow windows reduces the peak heat loss and heat gain compared to windows with double insulating glass and interior venetian blinds. Smaller duct sizes and smaller central HVAC equipment result in vertical and horizontal space savings.

4.2. Building Maintenance Costs

Smaller peak heating and cooling loads also reduce the first costs of HVAC systems and their maintenance costs. Such cost reductions depend very much on the equipment needs for particular buildings.

As mentioned earlier, exterior shading devices are very effective for conventional windows. Such devices must be serviced at considerable cost. Exterior venetian blinds typically have cleaning cycles of six to twelve months. Shading devices in air-flow window cavities have cleaning cycles of between two and five years. In considering operational maintenance, it should be mentioned that blinds in window cavities are not damaged by high winds and do not have to be retracted at high-wind conditions.

First costs of air-flow window facades, on the other hand, are higher than those of conventional, high-quality facades; for example, facades with double glass windows and exterior venetian blinds. Comparable facades have not been built in the United States. European cost data cannot be directly related to U.S. conditions; nevertheless, they give helpful indications.

Comparative evaluations in Europe between two air-flow systems (Protecta-Sol and Koller) and other facade systems show lower combined first and maintenance costs for the air-flow type. These cost comparisons include first costs for the facades, sun shading, HVAC systems, and all maintenance costs, including cleaning of windows and shading devices.

4.3. Energy Consumption

The energy performance of conventional windows is calculated by using the U-value of the glass type, with correction for framing, and by using solar heat gain factors according to solar irradiation exposure. The U-value is, for standard wind conditions, assumed to be a fixed value. The solar heat gain, as a direct gain, varies strongly with cloud cover, window orientation, time of day, and season. Despite these changing conditions, predictions on energy consumption are quite reliable, either achieved through many-year averaging or long-term hourly calculations.

Predicting the energy performance of air-flow windows is more complex. Their thermal properties are largely determined by the heating and cooling capacity of the air moving through the window cavity. A major variable for heating and cooling capacity is the air-flow rate through the window. Unlike conventional windows, air flow windows should be considered a part of the mechanical system.

Two fundamentally different applications of air-flow windows must be considered for predicting energy consumption:

a. Exhaust-air windows which improve the heat loss/heat gain performance of the building envelope; and
b. Return-air windows, which have the same function, but which may feed into an energy-retention system and may act at times as an air-type solar collector. In fact, several HVAC systems of buildings with such air-flow windows have energy-recovery systems (heat-wheel type and heat pumps).

Effective U-values have been established in relation to the air-flow rate. Although they are useful for comparisons with other window types, they do not help very much in calculating energy performance. Performance measurements are important because of the many variables, which are a result of integrating several functions in one component and which mutually influence each other.

5. Case Studies

5.1. The Protecta-Sol System

This system exhausts space air directly to the outside. The air-conditioned space is under slightly positive pressure which causes the exhaust air to enter the window cavity through an aperture in the top frame, flow down through the cavity, and exit to the outside at the bottom. A patented check valve in the lower frame prevents outside air from entering the window cavity in the opposite direction (Figure A5.1.1).

Figures A5.1.2 through A5.1.5 show effective U-values, shading coefficients, inside surface tem-

peratures, and air flow rates according to Protecta-Sol trade literature.

Tests were conducted by the Ingenieurgruppe Keller + Luch to develop performance data for the Protecta-Sol retrofit installation (aluminum windows) in the office building of the Karlsruhe Lebensversicherung Karlsruhe, West Germany (Figures A5.1.6 and 7). This was the first large-scale retrofit installation by Protecta-Sol (1976).

The data summary shows the following performance ranges:

a. Effective U-values at air flow between 15 and 6 cfm per ft of window width (85 to 35 m^3/h m) 0.05 - 0.12 Btu/hr sq ft °F* (0.03 - 0.70 W/m K)*
b. Inside window surface temperatures below space temperatures at a temperature difference of 54°F between outside and inside 5.4 to 9°F.

Figures A5.1.8 through A5.1.10 show the alu-wood window installation in the office building of Foundry Design Company, Rapperswil near Zurich, Switzerland.

5.2. CARDA System

The windows of this system are made with wood frames. The exterior sash is often clad with aluminum. While available as a window system, the fenestration is frequently marketed as part of an HVAC-ceiling-facade package under the trade name COMBIVENT (Figure A5.2.1).

Space air is introduced to the window cavity in a slot in the interior, horizontal, bottom sash. A "manifold" duct collects the air above the top sash and return ducts carry the air to the central equipment (Figure A5.2.2). Space air is returned through the lighting fixtures to extract heat. Depending on the need for heating and/or cooling, the air rate through the air-flow windows and the lighting fixtures is varied. Both constant and variable air-volume systems are used.

A typical installation is the Sparbanken office building in Helsingoer, Sweden. The southeast facade has air-flow windows with venetian blinds in the cavity (Figure A5.2.3). In addition, the southwest facade has sun-reflecting glass (A5.2.4).

A technical report on CARDA air-flow windows mentions that "in order to avoid condensation between the panes during winter, the flow through the window should not be below 5.4 cfm per linear foot of window (30 m^3 per hour) at a glass pane height of 4 ft (1.2m). The flow must be increased as the height of the window is increased."

For effective U-values and shading coefficients see Figures A5.2.5 and A5.2.6.

5.3 SIS-ISAL System

The first ISAL air-flow facade installation was the Suter & Suter architectural office building in Basel, Switzerland (1975). It resulted from team work between three companies: Suter & Suter (architects), Gebrueder Sulzer AG (HVAC engineers and contractors), and ISAL Company (facade and window manufacturers).

This installation consists of an outer, fixed frame with a single sheet of heat-absorbing glass and an inner, sliding frame with regular glass. The frames are of aluminum with neoprene gaskets. The window cavity contains venetian blinds (Figure A5.3.1 and A5.3.2). HVAC is achieved through a conventional dual duct system. A separate supply-and-return air system provides ventilation of the window cavity through a small distribution duct in the window base.

Later installations, such as the recently completed COOP office building in Basel, consist of clear, double pane insulating glass outside, single glass inside, and vertical, white nylon blinds in between. The COOP HVAC system runs with variable air volume and heat pump energy regain.

The functional characteristics of the air-flow windows in the COOP building were thoroughly tested in the ISAL laboratory (Figure A5.3.3). During winter the inside window temperatures were not more than four degrees Fahrenheit below the space temperatures. The effective U-value varied between 0.12 and 0.16, depending on the air-flow rate.

5.4. KOLLER System

The Koller Company near Basel has equipped several large buildings with air-flow window facades. This company is presently installing 20,000 m^2 of air-flow-window curtain wall in the MICROS high-rise office building in Zurich. Previous large projects include two office buildings for the Kloeckner Steel Company in Bremen and Duisburg (Figures A5.4.1 through A5.4.4).

The air-flow windows consist of outer, fixed, lightly heat-reflecting, insulating glass and inner, clear-glass sliding frames. White nylon blinds are located in the window cavity.

At air-flow rates of more than 14 cfm/ft (80 m^3/h m), U-values of 0.14 Btu/hr sq ft °F (0.8 W/m^2 K) or less are achieved. This allows compliance with the rather stringent German Energy Conservation Regulations, even at 100 percent exterior glass facades. Relative humidities of about 45 percent at a temperature difference of 54°F between inside and outside can be maintained in the space without condensation at the inner surface of the insulating glass.

The variable air volume is introduced to the spaces through a floor cavity and floor registers. The air return is either through ceiling luminaires or, in the building peripheral zone, through the window cavity (Figure A5.4.2). Air velocities through the space are low, that is, below four feet per second.

In a life cycle cost analysis of ten facade types, with consideration of first costs, mainten-

* These U-values appear to be too low compared with data from other manufacturers.

ance, operating, and energy costs, this air-flow window showed the lowest total yearly expenditures.

5.5 RIETH System

Rieth and Son has installed various types of air-flow windows during the past three years.

The KWU Office Building in Erlangen, West Germany, has a curtain wall with integrated air-flow windows (Figure A5.5.1). The exterior insulating glass consists of reflecting glass. Space air moves through lighting troffers and then into the window cavity from above. It flows through a sill-panel cavity to a return duct which is located in the suspended ceiling space below. The air flow through the window is about 15 cfm per foot of window, which represents close to the minimum make-up air requirement of the system. Venetian blinds are located in the window cavity.

The largest installation by this company is the Deutsche Texaco Office Building in Hamburg (Figure A5.5.3). The windows have lightly reflecting double pane insulating glass outside and single glass, casement sash inside. Space air enters about four inches above the floor and flows through a sill panel cavity into the window cavity. A return air duct above the window collects the air for transport to the central HVAC equipment. There are no blinds in the cavity space. Fixed, exterior, horizontal metal louvers provide sun shading at a distance of about three feet from the facade. HVAC is achieved by a dual duct system. According to technical information from the window manufacturer, transmission losses in winter are cut by 50 percent and summer by 20 percent.

6. Conclusions

Facades with air-flow windows have proven to be energy conserving in many European buildings. As this type of fenestration is expensive, about 50 to 60 percent more costly than conventional facades, it can generally be justified only in buildings with all-year air conditioning. Careful life cycle cost analysis is necessary. Savings from lower energy consumption and smaller HVAC systems must be compared with higher building costs.

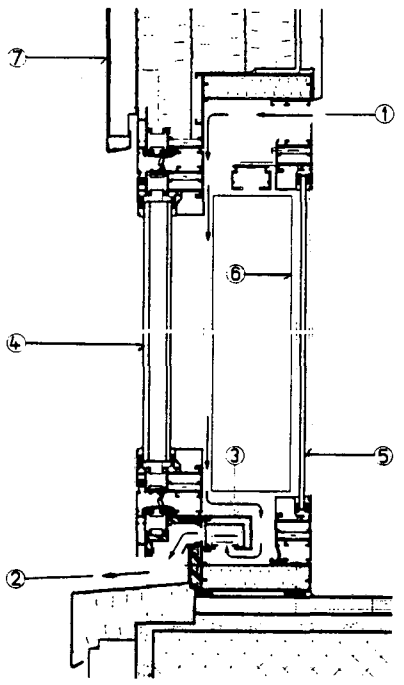
The following criteria and their potential impact should be considered in a comprehensive analysis of a particular building project:

Technical
- Location and type of shading device, including type of glass
- Air flow rate through window cavity
- Integration with HVAC system
- Exhaust air versus return air system
- Maximum relative humidity in spaces
- Energy recovery systems, including use of windows as solar collectors

Economical
- First cost because of more expensive windows
- First cost because of smaller HVAC system and less space need because of smaller air distribution systems
- Operation and maintenance costs
- Savings on energy consumption and costs
- Reduction in electrical costs because of better daylight utilization

Functional
- Mean radiant temperature conditions
- Air-flow velocities through space
- All-year air conditioning
- Daylight utilization
- Improved acoustical protection

The development of facades with air-flow windows is still in progress. Promising is the combination of such windows with solar energy utilization concepts. Figure A6.1 shows a proposal for using the air-flow window concept in combination with an air-type, solar-collector facade.



1 exhaust-air inlet
2 exhaust-air outlet
3 protecta-sol air check valve
4 double glazing
5 single pane
6 vertical louver blinds
7 facade

Figure A5.5.1. Vertical section of typical Protecta-Sol exhaust-air window installation.

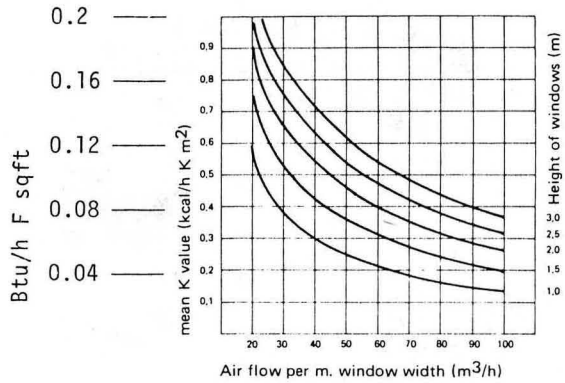


Figure A5.1.2. Effective U-values of Protecta-Sol exhaust-air windows.

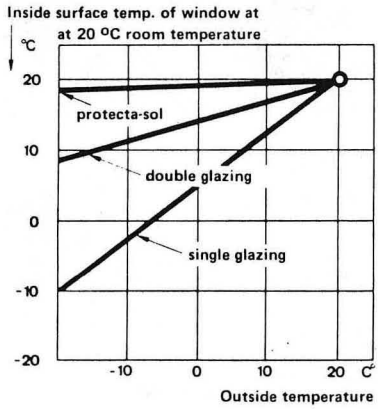
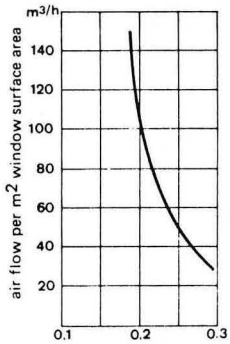
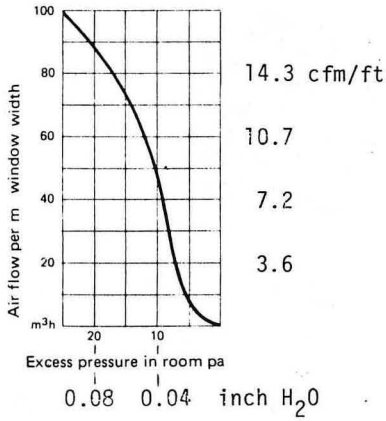


Figure A5.1.3. Inside surface temperatures of conventional and Protecta-Sol exhaust-air windows.





Figures A5.1.4 and A5.1.5. Effective shading coefficients and air-flow/air-pressure relationship of Protecta-Sol exhaust-air windows.

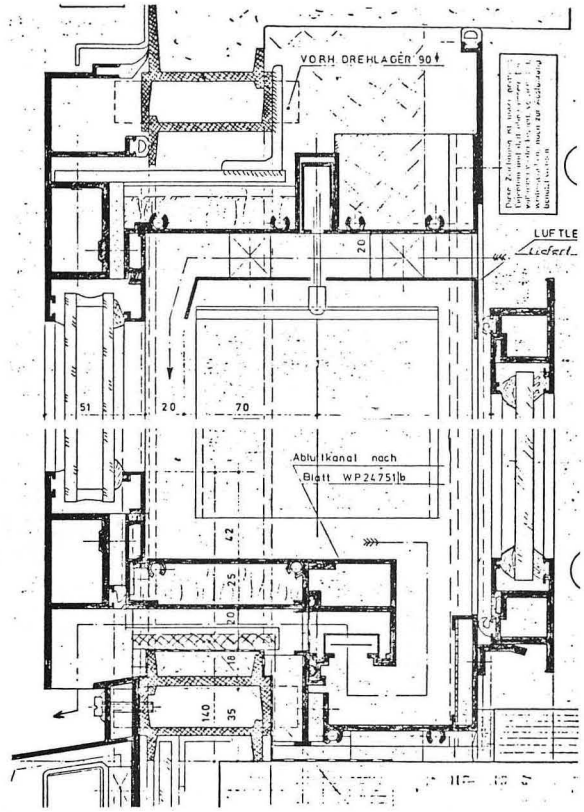


Figure A5.1.6. Vertical section of retrofit Protecta-Sol exhaust-air window installation (Karlsruher Lebensverischerung Building, Karlsruhe).

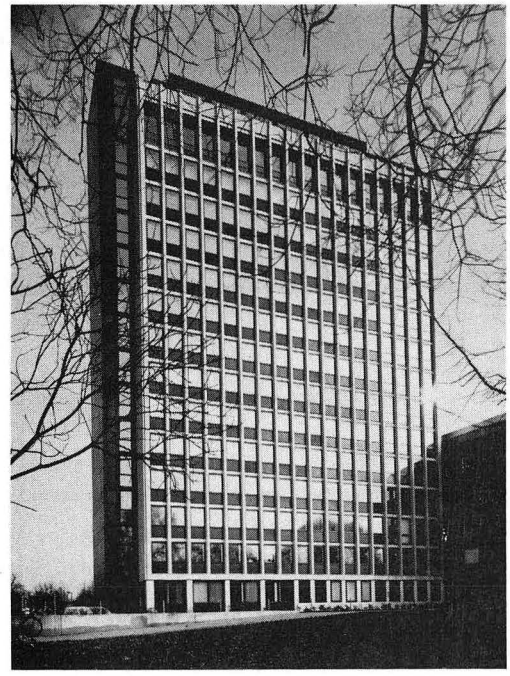
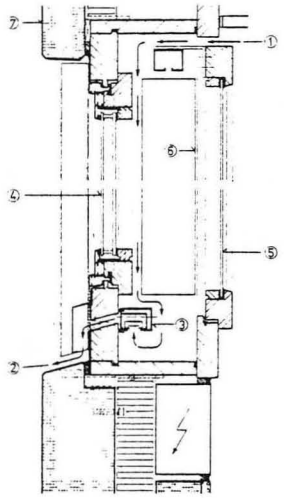


Figure A5.1.7. West facade of Karlsruher Lebensversicherung Building, Karlsruhe. XBB 823-2726



1 exhaust air entry
2 exhaust air exit
3 protecta-sol air check valve
4 insulating glass
5 single glass
6 vertical nylon blinds
7 facade components

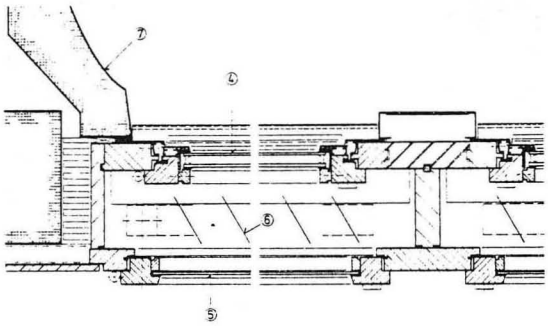
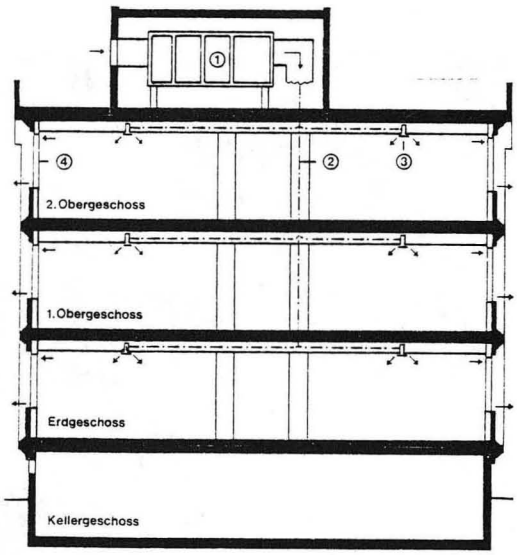


Figure A5.1.8. Vertical and horizontal section of Protecta-Sol exhaust-air window (Foundry Design Corporation Building, Rapperswil, near Zurich).



1 central HVAC equipment
2 supply air
3 supply air register
4 air-flow window

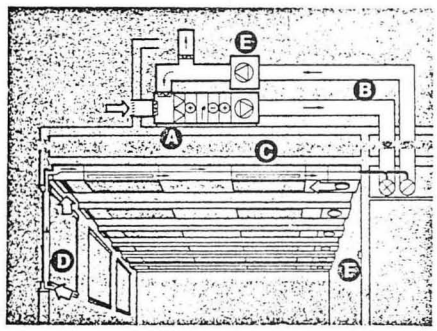
Figure A5.1.9. Section, Foundry Design Corporation Building (Rapperswil, near Zurich).

Figure A5.1.10. Foundry Design Corporation Building (Rapperswil, near Zurich).

XBB 823-2720

COMBIVENT is a system in which air treatment and lighting are fully coordinated. The system is particularly suitable for modular offices, open-plan offices and similar premises where strict demands are made on overall comfort.

In addition to the central unit, ducting, and air supply and exhaust registers, the system also includes ventilated fluorescent light fittings and extract windows in the outer zone.



A. CENTRAL UNIT
B. DUCTING
C. VENTILATED FLUORESCENT LIGHT FITTINGS
D. EXTRACT WINDOWS - IN THE OUTER ZONE
E. EXHAUST AIR FAN
F. ROOM THERMOSTAT

By employing extract windows, the cooling and heating demands in the outer zones of the building are appreciably reduced, and all of the necessary cooling output can therefore be supplied to the premises with the supply air. In addition, the heat emitted by the lighting can be used partially or entirely for direct heating of the premises, which reduces the operating costs of the system. The system is available in a constant flow version or a Variable Air Volume (VAV) version. The supply air is usually at a temperature below that of the premises.

Figure A5.2.1. COMBIVENT System (from COMBIVENT Design Manual, CARDA Division, Stilwell Company).

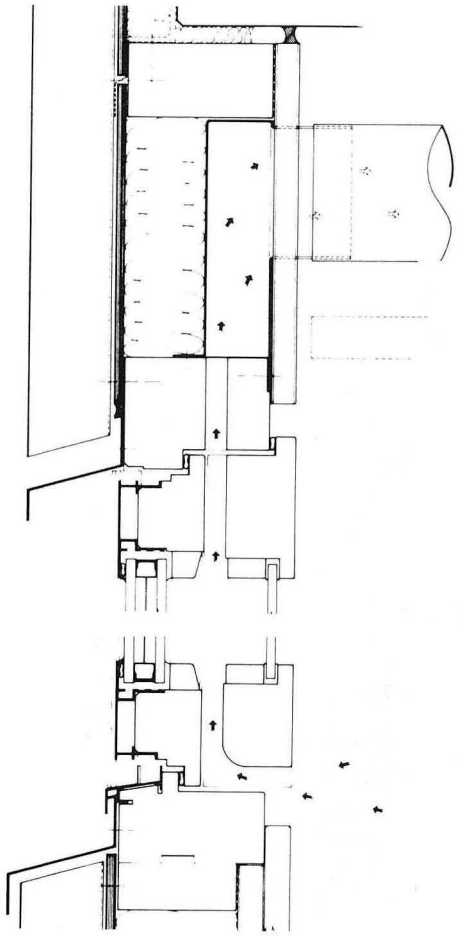


Figure A5.2.2. Vertical section of CARDA return-air window installation (from CARDA trade literature).

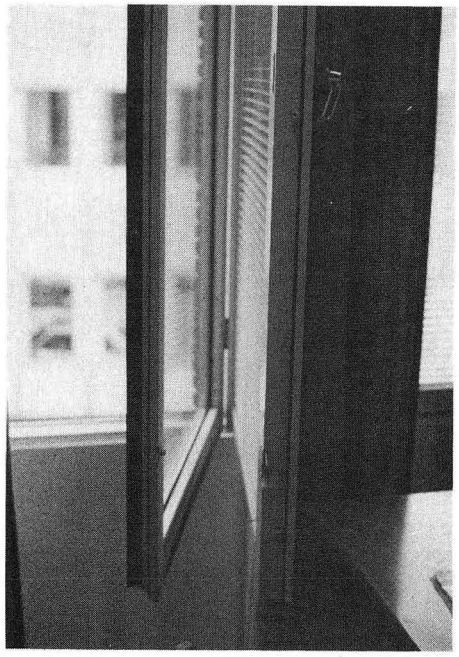
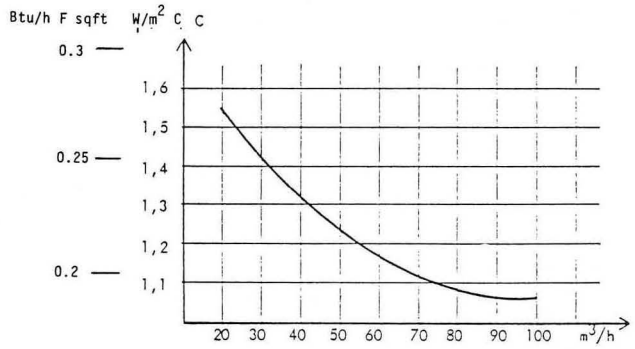


Figure A5.2.3 Sparbanken Office Building, Helsingoer, Sweden

XBB 823-2719

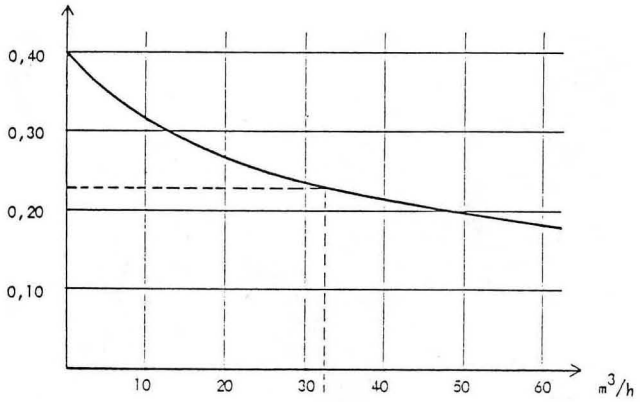
Figure A5.2.4 Sparbanken Office Building, Helsingoer, Sweden

XBB 823-2718



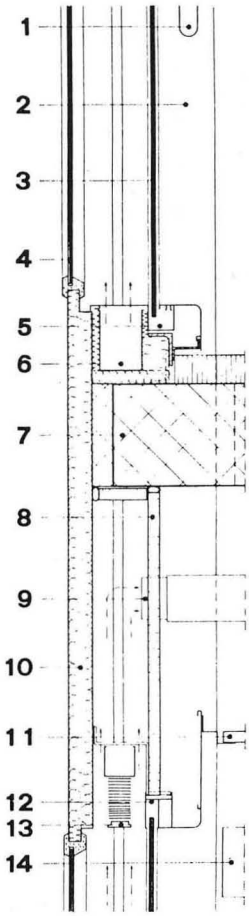
Fictitious coefficient of heat transfer of an extract window as a function of the air flow per linear meter of glass at a window pane height of 1.2 m.

Figure A5.2.5. Effective U-values of Carda return-air windows (from COMBIVENT Design Manual, CARDA Division, Stilwell, Company).



Solar radiation reduction factor of the extract window as a function of the air flow per linear meter of glass at a pane height of 1.2 m. The extract window consists of an insulating pane, venetian blind and a single pane of glass.

Figure A5.2.6. Effective shading coefficients of CARDA return-air windows (from COMBIVENT Design Manual, CARDA Division, Stilwell Company).



1 balustrade
2 mullion
3 sliding sash
4 heat absorbing glass
5 lower guide
6 air supply
7 concrete slab
8 gypsum board
9 return duct
10 sandwich panel
11 suspended ceiling
12 upper guide
13 venetian blind
14 ceiling grid

Figure A5.3.1. Vertical section of SIS-ISAL return-air window installation (Suter + Suter Building, Basel).

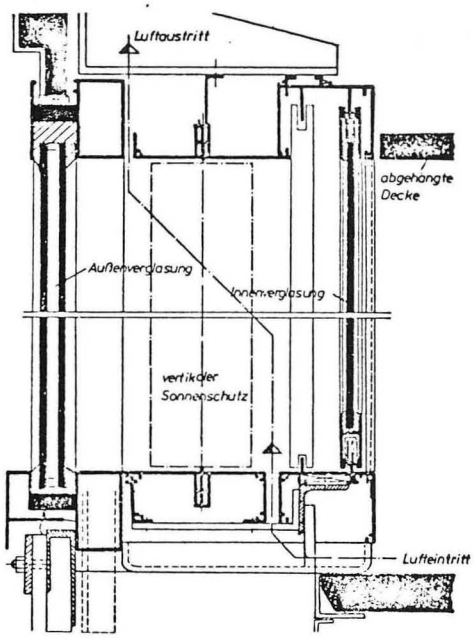
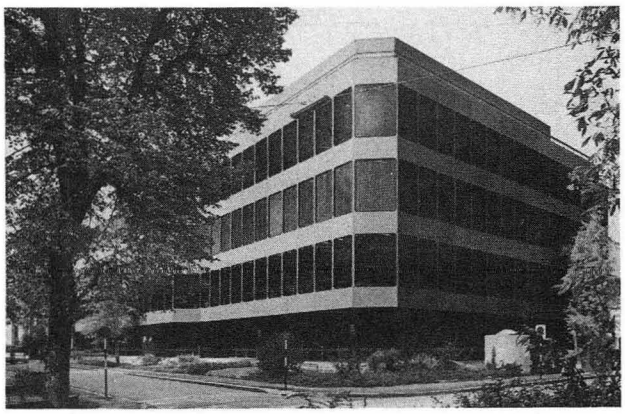


Figure A5.4.1 Vertical section. Koller return-air window system



XBB 823-2724

Figure A5.3.2 SIS-ISAL return-air window installation (Suter + Suter Office Building, Basel)

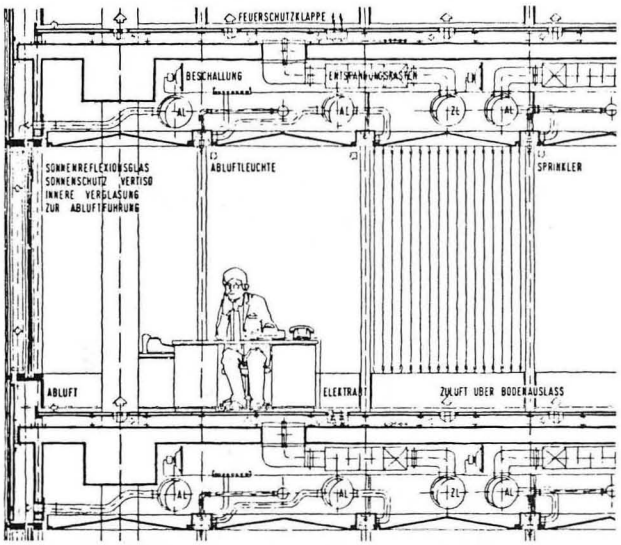
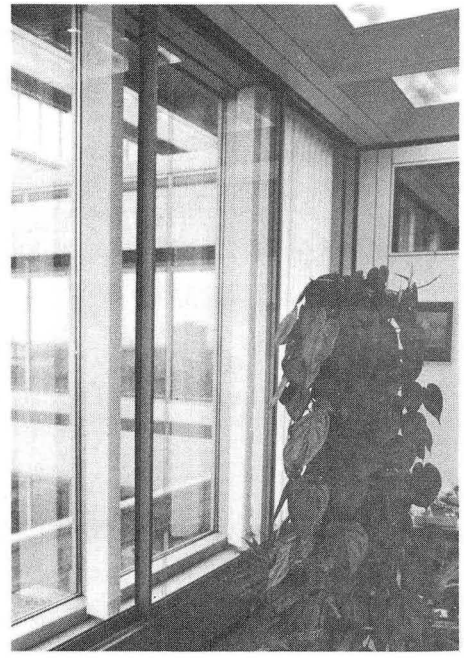


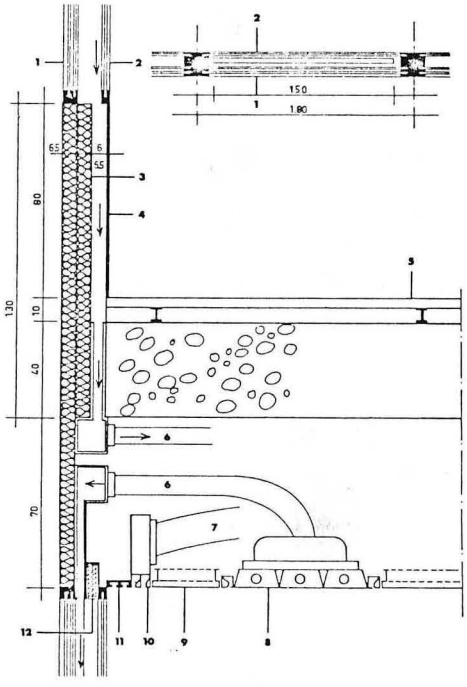
Figure A5.4.2 Systems section. Koller return-air window installations (Kloeckner Office Buildings, Bremen and Duisburg)

XBB 823-2728

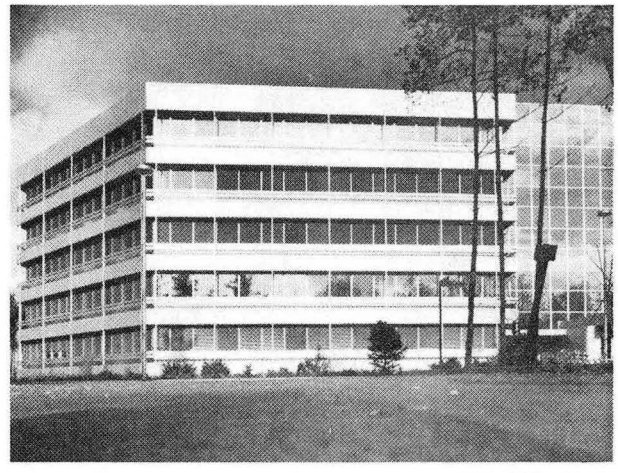


XBB 823-2716

Figures A5.4.3 and A5.4.4 Koller return-air window system (Kloeckner Office Buildings, Bremen and Duisburg)



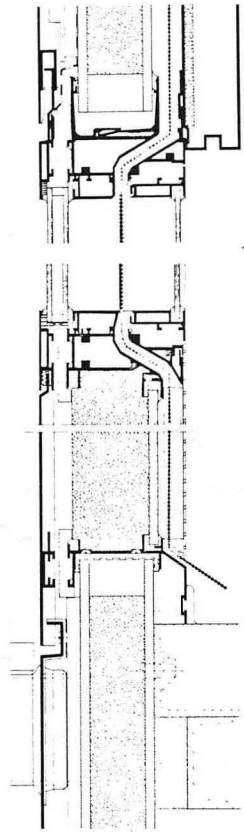
1 Thermoplus insulating glass
2 single glass
3 Isoternit sill panel
4 aluminum panel
5 raised floor
6 return air
7 supply air
8 lighting
9 suspended ceiling
10 supply air register
11 drapery guide
12 venetian blind



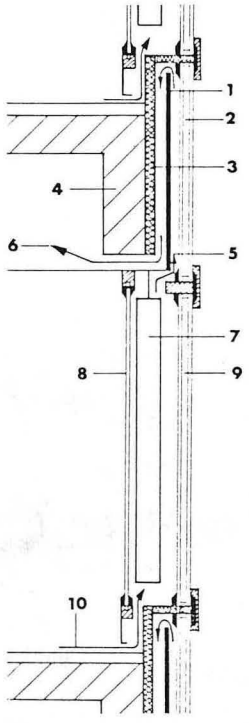
XBB 823-2715

Figures A5.5.1 and A5.5.2 Section and installation of Rieth return-air window system (KWU-Office Building, Erlangen)

YBB 823-2713



Figures A5.5.3 and A5.5.4 Section and installation of Rieth return-air window system (Deutsche Texaco AG Office Building, Hamburg)



1 metal sheet absorber
2 insulating glass for spandrel absorber
3 insulation
4 concrete slab
5 air entry to absorber
6 air exit from absorber
7 solar blinds
8 single glass
9 exterior insulating glass
10 air entry to air-flow window

Figure A6.1. Integrated air-flow window and spandrel components as solar collectors (from Ortmanns G.: "Der Einfluss von Flachglas auf die Energiebilanz eines Gebaudes," Glasforum 6, 1978, p. 23).

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-: "KWU-Bürogebäude in Erlangen. Doppelt verglaste Abluftfassade", Glasforum, No. 6, 1978. pp. 17-20 (Rieth System)

Ortmans G.: "Der Einfluss von Flachglas auf die Energiebilanz eines Gebäudes", Glasforum, No. 6, 1978, pp. 21-24 (general information)

-: "Klöcknerhaus Duisburg", Technik am Bau, No. 9, 1978, pp. 701-718 (Koller System)

Chapman W.F.: "Less Refrigeration. More Glass. A compatable idea?", ASHRAE Journal, Feb. 1979, pp. 31-33 (Protecta-Sol, copy of article attached)

APPENDIX B

Specifications of Test Components

The following specifications were provided by the manufacturers of the test components.

1. Return-Air Window (Wausau Metals Corporation, Wausau, Wisconsin)

1.1. All aluminum air-flow windows and related materials, as specified and shown on the architectural drawings, shall be Wausau Metals Series 2250-T fixed windows with integral venetian blind, as manufactured by the Wausau Metals Corporation.

Combined frames and thermal separator shall form composite frame depth of 7.250 inches and all walls including tubes shall have a minimum thickness of 0.125 inches.

1.2. Air Infiltration: Air Infiltration shall not exceed (0.6) cfm per sq ft of sash under a static pressure drop of 6.24 psf (equivalent to 50 mph wind velocity), when tested in accordance with ASTM 283-73.

Water resistance: During a 15 minute test period under prescribed conditions of water application at a rate of 5.0 gph per sq ft per ASTM E331-70, and a static air pressure differential of 6.24 psf, there shall be no penetration of water into the plane of the innermost face of the window unit.

Thermal: A complete 2250-T Series fixed or operable window containing a thermal break between the interior and exterior frame portion shall when tested in exact accordance with AAMA publication 1502.6-1976 provide a CRF (Condensation Resistance Factor) not less than 55 and a "U" value not to exceed .65 Btu/hr/sq ft/°F based on nominal area and derived from a calorimeter (guarded hot box) constructed in accordance with ASTM standard C236 utilizing CRF data and measuring actual heat loss through the complete test window including air infiltration transfer.

Structural Thermal Barrier: The frame thermal insulator shall be poured in place polyurethane. The polyurethane shall be self-adhering to the adjacent aluminum surfaces. There will be a minimum of 3/8" separation between the exterior and interior metal surfaces after the bridge is removed.

1.3. Window Type and Construction: Fixed. Combined frames and thermal separator shall form composite frame depth of 2.250 inches and all walls including tubes shall have a minimum thickness of .125 inches.

All frames shall be sealed forming a hairline watertight joint. Corners shall be mechanically joined with stainless steel fasteners. Metal to metal joints must be factory sealed. Field applied sealants at horizontal and vertical joints will not be accepted.

Expansion will be provided for in a self-mating mullion system. Provision for expansion in the glazing materials only will not be accepted.

1.4. The interior sash shall be hinged at the jamb to allow access for cleaning, access to the venetian blind, and be equipped with four cam-actuated locks operated by surface mounted cam handles.

All venetian blind access doors shall be mitered and sealed forming a hairline, watertight joint. Corners shall be reinforced with aluminum gusset blocks and chemically welded followed by hydraulic crimping.

Weatherstripping: Provide a double row of replaceable sponge neoprene weatherstripping installed in dovetail grooves.

All hardware shall be compatible with aluminum and shall not bridge the thermal barrier.

1.5. Air Flow: Air flow through unit shall be upward through air space between interior and exterior glazing. Provide continuous 3/4 inch wide air flow slots at interior face of sill and tangential surface of head sections to allow unobstructed air flow through cavity.

1.6. Finish: Anodic Coatings. The exposed surfaces of all aluminum shall be cleaned of all fabricating oils and debris, given a medium matte caustic etch and anodized to an Architectural Class I coating with a minimum coating thickness of .7 mils and a minimum coating weight of 32.0 MG per sq inches.

An electrolytically deposited color of medium bronze shall follow meeting the Aluminum Association Specification AA M10-C22-A44.

1.7. Glazing: 1 inch insulating glass with 2 x 1/4 inch plate and 1/2 inch cavity for exterior frame. 1/4 inch plate for interior operable sash (custom production by Bennett's Glass Corporation, Salt Lake City).

1.8. Venetian Blind: Venetian blind slats shall be spring tempered aluminum 1 inch wide with a baked enamel finish. Color: White. Heat and bottom rail shall be aluminum. The tilting or D-rod mechanism shall be stainless steel centered through nylon guides. Mounting holes in head rails shall have brass cord protectors. Bottom rails shall have molded plastic end caps fitted with hold down pins which engage nylon hold down brackets. Blind slats shall be 0.010 inch aluminum. Tilt control knob (Air-flow window only) shall be designed to snap in place after the final installation is complete and shall be designed to prevent use as a pull handle. Blind shall be equipped with an override to allow friction free movement of control knob when slats are closed in either direction. Pull cord for raising and lowering blinds shall be located between glass lites (Air-flow window only) and be accessible only when access door is open.*

2. Exhaust-Air Window (Protecta-Sol AG, Staefa, Switzerland)

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* Pull cord was made operable for blind positioning from inside through 1/8 inch hole of inside window frame.

2.1. All aluminum Air-flow window as shown in the sectional drawings. Total dimension from outside to inside frame surfaces 8 inches.

2.2. Air Infiltration: Inside profile of exterior frame equipped with patented "Protecta-Sol" air check valve for about 80 percent of window width.

Thermal: The thermal insulator of the exterior frame shall be of poured polyurethane and shall separate the frame by 7/16 inch. The inside profile of the exterior frame and the cavity profile shall be insulated with 3/8 inch to 1/2 inch plastic plates on the outside. The cavity profile shall have a 1 inch thermal insulation behind a perforated aluminum sheet lining all sides of the cavity.

2.3. Window Type and Construction: Fixed. The exterior window frames shall be mechanically joined including sealant.

Operable sash: The hinged interior window frame shall consist of a single profile and be mechanically joined including sealant. It shall provide a 3/4 inch gap at the top allowing the entry of space exhaust air in down-flow direction. The operable sash shall have continuous weather-stripping on the lower and the side frame.

2.4. Finish: All aluminum surfaces shall have natural color anodization.

2.5. Glazing: 1 inch insulating glass with 2 x 1/4 inch plate and 1/2 inch cavity for exterior frame. 1/4 inch plate for interior operable sash.

2.6. Louver Blind: 4 inch vertical opaque plastic louver blinds shall be located in window cavity. Color: White. They shall be operated from inside by mechanism through operable sash. The chain type run-around line shall adjust position and tilt angle of the louver slats.

3. Reference Window (Wausau Metals Corporation, Wausau, Wisconsin)

3.1. All aluminum windows and related materials, as specified and shown on the architectural drawings, shall be Wausau Metals Series 2250-T fixed windows, as manufactured by the Wausau Metals Corporation.

3.2. Air Infiltration: Air Infiltration shall not exceed (0.6) cfm per sq ft of sash under a static pressure drop of 6.24 psf (equivalent to 50 mph wind velocity), when tested in accordance with ASTM 283-73.

Water resistance: During a 15 minute test period under prescribed conditions of water application at a rate of 5.0 gph per sq ft per ASTM E331-70, and a static air pressure differential of 6.24 psf, there shall be no penetration of water into the plane of the innermost face of the window unit.

Thermal: A complete 2250-T Series fixed or operable window containing a thermal break between the interior and exterior frame portion shall when tested in exact accordance with AAMA publication 1502.6-1976 provide a CRF (Condensation Resistance Factor) not less than 55 and a "U" value not to exceed .65 Btu/hr/sq ft/°F based on nominal area and derived from a calorimeter (guarded hot box) constructed in accordance with ASTM standard C236 utilizing CRF data and measuring actual heat loss through the complete test window including air infiltration transfer.

Structural Thermal Barrier: The frame thermal insulator shall be poured in place polyurethane. The polyurethane shall be self-adhering to the adjacent aluminum surfaces. There will be a minimum of 3/8" separation between the exterior and interior metal surfaces after the bridge is removed.

3.3. Window Type and Construction: Fixed. Combined frames and thermal separator shall form composite frame depth of 2.250 inches and all walls including tubes shall have a minimum thickness of .125 inches.

All frames shall be sealed forming a hairline watertight joint. Corners shall be mechanically joined with stainless steel fasteners. Metal to metal joints must be factory sealed. Field applied sealants at horizontal and vertical joints will not be accepted.

Expansion will be provided for in a self-mating mullion system. Provision for expansion in the glazing materials only will not be accepted.

3.4. Finish: Anodic Coatings. The exposed surfaces of all aluminum shall be cleaned of all fabricating oils and debris, given a medium matte caustic etch and anodized to an Architectural Class I coating with a minimum coating thickness of .7 mils and a minimum coating weight of 32.0 MG per sq inches.

An electrolytically deposited color of medium bronze shall follow meeting the Aluminum Association Specification AA M10-C22-A44.

3.5. Glazing: 1 inch insulating glass with 2 x 1/4 inch plate, and 1/2 inch cavity (custom production by Bennett's Glass Corporation, Salt Lake City).

3.6. Venetian Blind: 1 inch slat venetian blind, 47 1/2 inch wide, 84 inch high. Tempered aluminum with baked enamel finish, color: white. Pull cord for raising and lowering blinds. Rod mechanism for tilt adjustment (custom production by Solar Window Company, Salt Lake City).

APPENDIX C

Estimate of Room-side Heat Transfer Coefficient*

Convective Transfer:

Assume: An average temperature for property evaluation is 70°F.
An average atmospheric pressure is 12.5 psi.
The window height is 6 ft.

Correlation will be of the form

$$Nu = c\ (Gr\ Pr)^n, \quad \text{with } Gr = g\beta\Delta T L^3/\nu^2$$

From the assumed,

$$\frac{g\beta}{\nu^2} = 1.72 \times 10^6$$

Assume:

$|\Delta T| = 4F$. Then $Gr = 1.72 \times 10^6(4)(6)^3 = 1.49 \times 10^9$

Then $Gr\ Pr = 1.07 \times 10^9$ is at the break point between laminar and turbulent.

$$\overline{Nu}_L = 0.13\ (Gr_L\ Pr)^{1/3} = 0.13\ (1.07 \times 10^9)^{1/3} = 133$$

$$\overline{h}_c = \frac{k}{L}(133) = \frac{0.0145}{6}(133) = 0.321$$

Thus, for $|\Delta T| > 4$ F,

$$\overline{h}_c = 0.321\ (|\Delta T|/4)^{1/3} = 0.202\ \Delta T^{1/3}$$

For $|\Delta T| < 4F$

$$\overline{Nu}_L = 0.555(Gr_L\ Pr)^{1/4} = 0.555(1.07 \times 10^9)^{1/4} = 100$$

$$\overline{h}_c = \frac{k}{L}(100) = 0.241$$

$$\overline{h}_c = 0.241\ \left(\frac{\Delta T}{4}\right)^{1/4} = 0.17\ |\Delta T|^{1/4}$$

Radiative Transfer:

For radiation between a surface of interest and very large surrounding surface (two body enclosure) is given by

$$q_r = \sigma\ A_w\ \varepsilon_{glass}\ (T_{wi}^4 - T_i^4)$$

or, defining a heat transfer coefficient:

$$\overline{h}_r = \frac{\sigma\ \varepsilon_{glass}\ (T_{wi}^4 - T_i^4)}{T_{wi} - T_i} \approx 4\sigma\ T_{ave}^3\ \varepsilon_w$$

where the last step above is made for $T_{wi} \approx T_i$. Taking the emissivity for glass in the longwwave region to be 0.9, find

$$\overline{h}_r \cong 0.9$$

which varies little over the range of temperatures used in the testing.

Total

The total heat transfer coefficient is found by adding:

$$h_{total} = h_c + h_r$$

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* All equations and properties are taken from J. P. Holman, HEAT TRANSFER, Fourth Edition, McGraw-Hill, 1976.

APPENDIX D

Climatic Data for Salt Lake City

from the National Oceanic and Atmospheric Administration collected over 30 to 40 years at Salt Lake City, Utah.

Temperature	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Highest	61	69	78	85	93	104	107	103	98	89	75	67
Lowest	-22	-30	2	14	25	35	40	37	27	16	-14	-21
Average highest	37	43	51	62	72	81	93	90	80	66	50	39
Average lowest	19	23	28	37	44	61	61	59	49	38	28	22
Average daily	28	33	40	49	58	66	77	75	65	52	39	30
Heating Degree Days												
Average	1147	885	787	474	237	88	0	5	105	402	777	1076
Cooling Degree Days												
Average	0	0	0	0	30	124	363	300	99	11	0	0
Wind												
Average MPH	8	8	9	10	9	9	9	10	9	9	8	8
Sunshine												
Average percentge of possible	48	56	64	67	73	79	84	83	84	73	54	46
Relative Humidity												
Average percentage												
Morning	68	63	51	44	37	31	26	29	34	43	57	70
Afternoon	67	67	44	39	31	25	20	22	27	40	58	71
Solar Radiation*												
Mean Daily Solar Insolation in Langleys**	163	256	354	479	570	621	620	551	446	316	204	146

* from Climatic Atlas of the United States, U. S. Government Printing Office, 1968.
** 1 gram cal. per cm^2 = 1 Langley.

APPENDIX E

Record of Test Days

The following lists show the test days from which data was reduced for establishing of the various thermal performance results in Section 5. The figures give the averages of the daily results and, in parentheses, the test dates. Nighttime testing for U_1 and U_2 typically lasted 8 to 12 hours. Daytime testing for RB, H_1 and H_2 typically lasted 6 to 9 hours. Data was recorded one to three times per hour.

Return Air Window: U_1*

Blind Position	Cavity Air Flow (cfm/ft) 0		3.9		5.4		7.7	
Retracted	.29	(9/4/80)	.24	(9/21/80)	.23	(9/16/80)	.21	(9/9/80)
			.29	(9/31/80)	.26	(9/28/80)	.18	(9/13/80)
0°	---		.20	(9/19/80)	.15	(9/12/80)	.16	(8/31/80)
							.15	(9/10/80)
							.24	(9/18/80)
							.18	(9/29/80)
30°	.29	(9/26/80	.24	(9/17/80)	.23	(9/20/80)	---	
					.24	(9/17/80)		
45°	.25	(9/24/80)	.26	(9/28/80)	.20	(9/25/80)	.14	(9/11/80)
							.13	(9/14/80)
							.27	(9/30/80)

* A great deal of testing and data reduction was also done for April and May 1980. The results which are somewhat lower were not used in Figure 5.1, however, because of an uncertainty in the h_{total} determination.

Exhaust-Air Window: U_1

Blind Position	Cavity Air Flow (cfm/ft) 0		3.9		5.4		7.7	
Retracted, 0° and 60°							.18	(10/26/80)
	.28	(11/17/80)	.14	(10/16/80)	.15	(11/7/80)	.16	(11/25/80)
	.26	(11/26/80)	.17	(1/5/81)	.13	(1/20/81)	.16	(12/15/80)
	.26	(1/8/81)	.16	(1/6/81)	.13	(1/21/81)	.18	(12/5/80)
							.16	(1/9/81)
							.16	(1/10/81)
							.16	(1/11/81)
Closed	.22		---		.12	(10/19/80)	.12	(1/13/81)
	.24						.12	(1/14/81)
	.22						.14	(10/10/80)

Return-Air Window: U_2

Blind Position	Cavity Air Flow (cfm/ft) 0	3.9		5.4		7.7	
Retracted	---	.13	(4/18/80)	.18	(4.16.80)	.22	(5/13/80)
		.12	(5/11/80)	.16	(5/24/80)	.22	(5/16/80)
		.12	(5/12/80)	.19	(5/25/80)	.22	(5/28/80)
		.20	(9/12/80)	.29	(9/16/80)	.28	(9/9/80)
		.17	(9/21/80)	.23	(9/28/80)	.29	(9/13/80)
		.20	(9/31/80)				
0°	---	.13	(4/11/80)	.13	(4/9/80)	.30	(8/13/80)
		.14	(5/14/80)	.15	(4/10/80)	.28	(9/10/80)
		.15	(5/15/80)	.21	(5/22/80)	.28	(9/28/80)
				.24	(9/12/80)	.32	(9/29/80)
30°	---	.20	(8/30/80)	.24	(5/21/80)	.27	(5/21/80)
		.20	(9/17/80)	.20	(5/26/80)		
				.21	(9/20/80)		
45°	---	.17	(4/18/80)	.24	(4/17/80)	.33	(9/1/80)
		.21	(9/28/80)	.24	(9/25/80)	.30	(9/11/80)
						.38	(9/14/80)
						.29	(9/30/80)

Exhaust-Air Window: U_2

Blind Position	Cavity Air Flow (cfm/ft) 0	3.9		5.4		7.7	
Retracted, 0° and 60°	---	.17	(10/16/80)	.23	(10/18/80)	.34	(10/26/80)
		.17	(1/5/81)	.23	(10/17/80)	.33	(11/25/80)
		.15	(1/6/81)	.29	(1/20/81)	.32	(12/15/80)
				.29	(1/21/81)	.33	(1/9/81)
						.32	(1/10/81)
						.33	(1/11/81)
Closed	---	.20	(10/23/80)	.27	(10/21/80)	.35	(1/14/81)
				.27	(11/21/80)	.34	(10/20/80)
				.22	(10/19/80)		

Return-Air Window: H_1

Blind Position	Cavity Air Flow (cfm/ft) 0		3.8		5.4		7.7	
Retracted	.09	(9/7/80)	.09	(5/1/80)	.06	(4/22/80)	0.6	(5/17/80)
			.12	(5/12/80)	.07	(5/10/80)		
			.11	(9/22/80)	.07	(5/11/80)		
					.06	(5/25/80)		
					.07	(9/23/80)		
					.08	(9/25/80)		
0°	.13	(9/4/80)	.12	(4/30/80)	.11	(4/9/80)	.12	(9/18/80)
	.13	(9/6/80)	.08	(5.7.80)	.10	(5/6/80)		
			.11	(5/15/80)	.08	(5/22/80)		
					.12	(5/23/80)		
					.10	(6/4/80)		
					.12	(9/16/80)		
30°	.12	(4/24/80)	.18	(4/23/80)	.09	(4/25/80)	.08	(5/28/80)
			.07	(4/28/80)	.08	(5/21/80)	.07	(6/10/80)
			.09	(4/29/80)	.09	(5/26/80)		
			.17	(5/16/80	.08	(5/27/80)		
			.08	(8/31/80)	.08	(6/5/80)		
			.13	(9/17/80)	.08	(6/9/80)		
					.11	(9/20/80)		
45°	.13	(9/8/80)	.10	(4/19/80)	.11	(4/16/80)	.06	(9/2/80)
	.11	(9/3/80)			.08	(4/17/80)	.08	(9/14/80)
					.09	(9/15/80)		

Exhaust-Air Window: H_1

Blind Position	Cavity Air Flow (cfm/ft) 0		3.9		5.4		7.7	
Retracted	---		.42	(10/15/80)	.30	(10.16.80)	.09	(10/17/80)
							.09	(11/28/80)
0° and 60°	.16	(11/18/80)	.11	(10/22/80)	.11	(10/19/80)	.11	(10/21/80)
					.11	(10/23/80)	.11	(10/24/80)
					.12	(10/30/80)	.11	(11/19/80)
					.10	(10/31/80)	.12	(12/11/80)
					.11	(11/20/80)		
Closed					.08	(10/19/80)		

Return-Air Window: H_2

Blind Position	Cavity Air Flow (cfm/ft) 0	3.9		5.4		7.7	
Retracted	---	.05	(9/21/80)	.06	(4/22/80)	.15	(4/21/80)
		.05	(9/22/80)	.06	(5/10/80)	.12	(5/17/80)
		.07	(9/28/80)	.06	(5/11/80)	.20	(9/27/80)
		.06	(9/31/80)	.06	(9/25/80)		
				.11	(9/29/80)		
0°	---	.06	(4/30/80)	.13	(4/9/80)	.19	(9/18/80)
		.07	(5/7/80)	.13	(5/6/80		
		.11	(5/15/80)	.11	(5/22/80)		
				.14	(5/23/80)		
				.14	(6/4/80)		
				.15	(9/16/80)		
30°	---	.09	(4/23/80)	.14	(4/25/80)	.12	(5/28/80)
		.08	(4/28/80)	.10	(5/21/80)	.12	(6/10/80)
		.06	(4/29/80)	.09	(5/26/80)		
		.07	(5/16/80)	.09	(5/27/80)		
		.09	(8/31/80)	.09	(6/5/80)		
		.12	(9/17/80)	.10	(6/9/80)		
				.14	(9/20/80)		
45°	---	.09	(4/19/80)	.13	(4/16/80)	.15	(9/2/80)
				.10	(4/17/80)	.15	(9/14/80)
				.13	(4/15/80)		

Exhaust-Air Window: H_2

Blind Position	Cavity Air Flow (cfm/ft) 0	3.9		5.4		7.7	
Retracted	---	---		---		.09	(10/17/80)
						.07	(11/28/80)
0° and 60°		0.7	(10/22/80)	.11	(10/19/80)	.15	(10/21/80)
				.12	(10/30/80)	.14	(10/24/80)
				.11	(10/23/80)	.14	(11/19/80)
				.12	(10/31/80)	.16	(12/11/80)
				.11	(11/20/80)		
				.13	(10/19/80)		
Closed				.13	(10/19/80)		

Return-Air Window: RB

Blind Position	Retracted		0°		30°		45°	
	.27	(4/22/80)	.13	(5/30/80)	.08	(4/23/80)	.08	(4/16/80)
					.09	(4/24/80)	.07	(4/18/80)
	.31	(5/8/80)	.14	(5/23/80)	.09	(4/25/80)	.08	(4/19/80)
	.32	(5/10/80)	.14	(5/22/80)			.06	(9/8/80)
	.32	(5/11/80)	.16	(5/15/80)	.09	(4/29/80)	.07	(9/15/80)
	.32	(5/12/80)	.12	(9/6/80)	.09	(5/16/80)	.06	(9/14/80)
	.31	(5/17/80)	.13	(9/18/80)	.10	(5/21/80)	.08	(9/19/80)
	.32	(5/29/80)			.10	(5/26/80)	.08	(9/3/80)
	.31	(9/21/80)			.10	(5/27/80)	.06	(9/2/80)
	.30	(9/23/80)			.10	(5/28/80)		
	.28	(9/31/80			.10	(6/5/80)		
	.27	(9/29/80)			.10	(6/9/80)		
	.31	(9/28/80)			.10	(6/10/80)		
	.31	(9/27/80)			.08	(9/17/80)		
	.32	(9/22/80)			.09	(8/31/80)		
	.31	(9/15/80)						

Exhaust-Air Window: RB

Blind Position:	Retracted		0°		60°	
	0.35	(10/13/81)	0.03	(10/20/81)	0.10	(10/20/81)
	0.36	(10/14/81)	0.14	(10/18/81)	0.08	(10/18/81)
	0.36	(10/15/81)	0.14	(10/21/81)	0.08	(10/21/81)
	0.35	(10/16/81)	0.14	(10/22/81)	0.06	(10/22/81)
	0.36	(11/27/81)	0.16	(10/23/81)	0.07	(10/23/81)
					0.08	(10/29/81)
					0.08	(10/30/81)
					0.09	(11/17/81)
					0.09	(11/18/81)
					0.11	(11/24/81)
					0.09	(12/8/81)
					0.08	(12/9/81)
					0.10	(12/10/81)

Reference Window: U_r

Blind Position:	Open		0°		30°		45°	
	.56	(9/20/80)	.46	(9/11/80)	.56	(9/21/80)	.61	(9/15/80)
	.54	(9/22/80)	.48	(9/13/80)	.50	(9/27/80)	.50	(9/25/80)
	.53	(9/23/80)	.55	(9/19/80)			.47	(9/26/80)
	.53	(9/19/80)	.58	(9/30/80)			.68	(9/28/80)
	.64	(10/1/80)					.58	(9/31/80)
	.61	(9/14/80)						

Reference Window: SC

Blind Position:	Open		0°		30°		45°	
	.48	(9/21/80)	.58	(9/18/80)	.34	(9/17/80)	.43	(9/14/80)
	.57	(9/22/80)	.56	(9/26/80)	.45	(9/20/80)	.42	(9/15/80)
	.53	(9/25/80)	.37	(9/30/80)	.41	(9/28/80)	.38	(9/16/80)
	.59	(9/27/80)	.38	(9/31/80)	.43	(9/29/80)	.41	(9/30/80)
	.49	(9/28/80)						
	.52	(9/29/80)						
	.52	(9/31/80)						

APPENDIX F

Samples of Test Data and Reduction for Thermal Performance

The following samples of test data are representative of the measured recordings during the test days listed in Appendix E. The formulas used for data reduction are described in Section 4 and given here again.

$$U_1 = h_{total} \cdot (T_{wi} - T_i)/(T_o - T_i)$$

where

$$h_{total} = 0.17|T_{wi} - T_i|^{0.25} + 0.09,$$

when $|T_{wi} - T_i| \leq 4.0$

$$0.20\ |T_{wi} - T_i|^{0.33} + 0.9,$$

when $|T_{wi} - T_i| > 4.0$

$$U_2 = \dot{m}_1 \cdot C_p \cdot (T_{fx} - T_{fi})/[(T_o - T_i) \cdot A_w]$$

where

$$\dot{m}_1 \cdot C_p/A_w = 35\ \sqrt{\Delta P}/25.9$$

$$H_1 = [h_{total} \cdot (T_{wi} - T_i) - U_1 \cdot (T_o - T_i)] \cdot A_w/I_o \cdot A_g$$

$$H_2 = ([\dot{m}_1 \cdot C_p \cdot (T_{fx} - T_{fi})] - U_2 \cdot A_w\ (T_o - T_i))/I_o \cdot A_g$$

where

$$A_g = 21.9$$

$$U_r = [\dot{m}_2 \cdot C_p \cdot (T_{rx} - T_{ri}) + U_b \cdot A_b \cdot (T_{box} - T_i)]/[(T_o - T_{bl}) \cdot A_w]$$

where

$$\dot{m}_2 \cdot C_p = 64\ \sqrt{\Delta P},\ U_b \cdot A_b = 2.75,\ A_w = 27.7$$

$$SC = [\dot{m}_2 \cdot C_p\ (T_{rx} - T_{ri}) + U_b \cdot A_b \cdot (T_{box} - T_i) - U_r \cdot A_w\ (T_o - T_{bl})]/(I_o \cdot A_g)$$

where

$$A_g = 23.6$$

Day: 9/21/1980; Cavity Air Flow: 3.9 cfm/ft (ΔP = 0.19); Blind Position: no blinds

Hour	T_i	T_{wi}	T_{fi}	T_{fx}	T_o	U_1	U_2
22	92.0	84.6	93.1	80.3	50.7	.23	.16
0	92.2	84.2	92.9	79.4	50.9	.25	.17
2	91.5	83.7	92.3	78.6	50.4	.25	.17
4	90.8	83.0	91.6	78.2	47.0	.23	.16
6	90.1	82.1	90.9	76.9	48.6	.25	.18
					Average:	.24	.17

Day: 9/10/1980; Cavity Air Flow: 7.7 cfm/ft (ΔP = 0.76); Blind Position: down, 0°

Hour	T_i	T_{wi}	T_{fi}	T_{fx}	T_o	U_1	U_2
22	99.6	94.1	100.4	90.0	63.0	.19	.30
0	97.4	93.8	99.3	90.0	60.3	.11	.26
2	99.1	94.2	100.1	89.5	57.4	.15	.27
4	99.2	93.8	100.3	89.2	58.1	.16	.28
6	99.6	94.3	100.8	89.3	57.7	.16	.29
					Average:	.15	.28

Figure F1. Sample of Return-Air Window Test Data: U_1 and U_2 Values.

Day: 1/5/1981; Cavity Air Flow: 3.9 cfm/ft (ΔP = 0.19); Blind Position: no blinds

Hour	T_i	T_{wi}	T_{fi}	T_{fx}	T_o	U_1	U_2
22	85.3	78.2	88.4	65.4	28.9	.16	.21
0	84.4	77.8	87.8	64.9	29.0	.15	.22
2	84.0	77.2	87.5	63.8	28.4	.16	.22
4	84.2	76.7	87.3	63.2	28.5	.17	.23
6	83.9	76.7	87.0	63.4	28.8	.17	.22
					Average:	.16	.22

Day: 1/1/1981; Cavity Air Flow: 6.5 cfm/ft (ΔP = 0.54); Blind Position: open

Hour	T_i	T_{wi}	T_{fi}	T_{fx}	T_o	U_1	U_2
22	71.5	67.0	74.9	54.5	28.6	.13	.33
0	71.8	67.4	75.4	55.3	28.9	.13	.32
2	72.9	67.8	76.4	55.4	29.0	.13	.32
4	72.3	67.7	75.7	55.2	28.3	.13	.32
6	71.6	67.3	75.1	55.2	28.4	.14	.32
					Average:	.13	.32

Figure F2. Sample of Exhaust-Air Window Test Data: U_1 and U_2 Values.

Day: 4/19/80; Cavity Air Flow: 3.9 cfm/ft (ΔP = 0.19); Blind Position: down, 45°; U_1 = 0.14; U_2 = 0.17

Hour	T_i	T_{wi}	T_{fi}	T_{fx}	T_o	I_{tr}	I_o	H_1	H_1	RB
10	80.0	90.2	86.2	106.7	75.1	12.9	182	.083	.078	.071
11	82.9	94.9	89.2	114.7	75.6	14.3	183	.097	.092	.078
12	82.7	95.5	89.7	114.7	79.9	14.3	196	.092	.081	.073
13	83.4	93.7	88.2	111.0	78.0	12.6	182	.082	.082	.069
14	80.3	90.7	86.6	104.7	78.3	10.1	131	.11	.088	.077
15	81.6	87.2	84.9	97.2	79.6	7.3	90.6	.082	.087	.081
16	80.5	85.0	83.7	90.8	79.8	5.6	42.6	.13	.11	.130
							Average:	.097	.088	.083

Day: 9/14/1980; Cavity Air Flow: 7.7 cfm/ft (ΔP = 0.76); Blind Position: down, 45°; U_1 = 0.10; U_2 = 0.33

Hour	T_i	T_{wi}	T_{fi}	T_{fx}	T_o	I_{tr}	I_o	H_1	H_2	RB
10	83.3	93.2	85.0	106.6	75.0	12.2	209	.070	.14	.058
11	82.2	95.2	83.3	113.5	79.8	15.3	247	.073	.15	.062
12	81.6	95.3	82.6	115.8	82.0	16.6	264	.077	.15	.063
13	81.1	95.6	81.9	113.6	83.5	16.1	252	.064	.15	.064
14	80.3	93.6	81.3	110.0	85.7	14.3	223	.078	.15	.064
15	79.2	90.2	80.4	104.8	84.0	11.8	184	.076	.15	.064
16	77.2	85.3	78.9	95.8	84.6	8.9	132	.068	.15	.068
							Average:	.072	.15	.063

Figure F3. Sample of Return-Air Window Test Data: H_1, H_2 and RB Values.

Day: 10/23/1980; Cavity Air Flow: 5.4 cfm/ft (ΔP = 0.38); U_1 = 0.17; U_2 = 0.24

Hour	Blind	T_i	T_{wi}	T_{fi}	T_{fx}	T_o	I_{tr}	I_o	H_1	H_2	RB
10	0°	79.3	86.0	82.0	94.9	44.6	35.5	209	.071	.14	0.17
11	0°	80.2	94.7	83.4	111.1	48.7	51.8	259	.078	.17	.20
12	0°	84.4	98.4	85.1	111.5	49.6	38.4	276	.088	.17	.14
13	60°	82.2	97.2	86.0	131.7	51.6	18.0	290	.097	.17	.062
14	60°	83.3	98.1	86.8	133.3	54.9	14.4	271	.096	.18	.053
15	60°	83.6	96.7	87.4	127.7	53.7	11.9	237	.11	.20	.050
16	0°	84.9	96.8	88.5	115.6	54.9	28.0	190	.12	.19	.15
								Average:	.094	.17	.17 - 0°
											.055 - 60°

Day: 10/21/1980; Cavity Air Flow: 7.7 cfm/ft (ΔP = 0.76); U_1 = 0.14; U_2 = 0.35

Hour	Blind	T_i	T_{wi}	T_{fi}	T_{fx}	T_o	I_{tr}	I_o	H_1	H_2	RB
10	0°	85.3	94.3	86.6	104.6	52.2	34.4	206	.074	.16	.17
11	60°	86.4	99.7	88.1	123.2	58.0	17.5	250	.089	.21	.070
12	60°	88.2	103.6	90.0	133.9	62.5	22.0	277	.097	.23	.079
13	60°	89.0	106.7	91.6	137.4	67.4	26.3	280	.103	.23	.094
14	60°	90.4	106.9	93.1	135.6	65.2	18.0	256	.017	.24	.070
15	60°	90.8	105.4	93.7	131.7	65.6	14.3	215	.11	.26	.067
16	0°	92.5	104.9	95.0	120.0	66.9	24.7	162	.13	.24	.15
								Average:	.10	.22	.16 - 0°
											.076 - 60°

Figure F4. Sample of Exhaust-Air Window Test Data: H_1, H_2 and RB Values.

Day: 9/18/1980; Box Air Flow: 6.4 cfm/ft (ΔP = 0.15); Blind Position: no blinds

Hour	T_i	T_{bl}	T_o	T_{ri}	T_{rx}	T_{box}	U_r
22	93.6	88.3	79.2	96.1	87.2	87.4	.53
0	96.6	89.4	69.4	99.2	87.1	88.2	.55
2	98.3	89.5	68.3	101.1	86.0	87.7	.50
4	99.6	90.0	64.6	102.5	86.3	88.3	.56
6	99.1	90.1	64.9	103.2	86.0	88.3	.55
						Average:	.54

Day: 9/22/1980; Box Air Flow: 6.4 cfm/ft (ΔP = 0.15); Blind Position: down, 45°

Hour	T_i	T_{bl}	T_o	T_{ri}	T_{rx}	T_{box}	U_r
22	91.2	86.7	60.3	94.6	84.2	86.7	.38
0	92.9	85.4	58.1	96.4	81.8	85.0	.51
2	93.7	84.9	58.2	97.5	81.1	84.6	.59
4	94.0	84.6	53.7	97.8	80.2	84.2	.55
6	93.9	84.4	53.3	97.9	79.7	83.9	.56
						Average:	.52

Figure F5. Sample of Reference Window Test Data: U_r.

Day: 9/15/1980; Box Air Fow = 11.4 cfm/ft (ΔP = 0.48); Blind Position: down, 45°; U_r = 0.55

Hour	T_i	T_{bl}	T_o	T_{ri}	T_{rx}	T_{box}	I_o	SC
10	80.1	114.3	75.1	84.6	109.0	113.2	200	.38
11	79.1	124.9	78.9	83.1	118.5	123.0	233	.44
12	78.7	128.2	80.5	82.6	122.0	126.5	254	.44
13	78.4	129.8	85.3	82.4	124.3	128.8	246	.46
14	78.0	127.4	83.0	82.3	122.4	127.6	224	.51
15	77.7	121.1	84.8	81.9	117.4	122.0	174	.55
16	77.2	110.3	79.0	81.5	108.6	112.4	115	.66
							Average:	.49

Day: 9/20/1980; Box Air Flow = 6/4 cfm/ft (ΔP = 0.15); Blind Position: down, 30°; U_r = 0.55

Hour	T_i	T_{bl}	T_o	T_{ri}	T_{rx}	T_{box}	I_o	SC
10	81.4	120.3	62.6	83.6	114.3	119.4	203	.36
11	80.7	133.9	68.2	81.8	128.2	133.4	240	.40
12	81.3	144.9	71.6	82.4	138.0	144.6	256	.42
13	82.4	148.0	73.6	82.4	140.9	148.8	253	.44
14	81.3	144.9	72.7	82.8	139.7	146.3	225	.48
15	78.8	137.0	75.2	81.1	132.3	139.3	182	.52
16	82.0	124.7	75.2	83.3	121.1	127.2	125	.63
							Average:	.46

Figure F6. Sample of Reference Window Test Data: SC.

APPENDIX G

Temperature Test Data for Calculation of Relative Humidity Limits of Room Air Exhaust-Air Window, Height 7 ft

Air-flow Rate 2.8 cfm/ft of window width
4/13/81 and 4/14/81

Time	T_i	T_o	T_{low}	T_{mid}	T_{up}	T_{ex}	CR
21:45	90.5	50.0	66.9	68.6	71.4	71.6	1.72
23:45	88.7	47.4	64.5	66.4	69.3	69.2	1.72
1:45	87.9	43.9	62.9	64.8	67.9	67.2	1.73
3:45	87.0	44.0	61.5	63.6	66.8	66.0	1.69
5:45	87.2	41.4	60.9	63.1	66.3	65.3	1.74

T_{low} inside surface temperature of insulating glass 6 inches from bottom frame

T_{mid} inside surface temperature of insulating glass at mid height of window

T_{up} inside surface temperature of insulating glass 6 inches from top frame

T_{ex} cavity air temperature at exhaust

$$CR = \frac{T_i - T_o}{T_i - T_{low}}$$

Air Flow Rate 3.9 cfm/ft of window width
3/30/81 and 3/31/81

Time	T_i	T_o	T_{low}	T_{mid}	T_{up}	T_{ex}	CR
21:20	83.7	33.9	58.3	60.9	64.1	63.8	1.96
23:20	83.4	35.1	59.0	61.4	64.5	63.8	1.98
01:20	82.9	34.8	58.7	61.2	64.1	63.5	1.97
03:20	82.4	32.9	56.7	59.3	62.6	61.9	1.93
05:20	81.9	32.2	55.5	58.2	61.5	60.9	1.88

Air-Flow Rate 5.4 cfm/ft of window width
4/1/81 and 4/2/81

Time	T_i	T_o	T_{low}	T_{mid}	T_{up}	T_{ex}	CR
21:10	89.6	53.4	71.6	72.9	75.3	76.1	2.01
23:10	90.7	52.0	71.3	72.6	75.1	76.6	1.99
01:10	89.9	49.9	70.4	71.7	74.3	75.7	2.05
03:10	90.9	47.8	69.9	71.3	74.1	74.7	2.05
05:10	89.4	42.6	68.4	70.0	73.0	74.4	2.23

Air-Flow Rate 6.6 cfm/ft of window width
4/3/81 and 4/4/81

Time	T_i	T_o	T_{low}	T_{mid}	T_{up}	T_{ex}	CR
21:00	90.9	38.3	66.7	68.5	71.8	73.4	2.17
23:00	90.4	39.0	67.0	68.7	71.8	73.3	2.20
01:00	89.0	33.8	64.1	65.5	69.0	71.5	2.22
03:00	89.3	35.6	64.8	66.6	70.1	71.4	2.19
05:00	89.2	34.3	64.1	65.6	69.3	71.2	2.19

Air-Flow Rate 7.7 cfm/ft of window width
4/6/81 and 4/7/81

Time	T_i	T_o	T_{low}	T_{mid}	T_{up}	T_{ex}	CR
21:30	90.1	47.6	72.0	72.7	75.7	78.3	2.34
23:30	89.4	47.1	70.8	71.6	74.4	77.0	2.27
01:30	90.5	44.5	69.6	70.6	73.7	76.1	2.20
03:30	88.7	40.9	67.6	68.4	71.6	74.7	2.27
05:30	90.3	40.0	68.2	69.4	72.9	75.0	2.28

APPENDIX H

Yearly Performance Modeling Program

This program is broken into two sections and is stored in two separate files. The first section handles heat loss/heat gain calculations for windows. The second section takes the results and does further manipulations on the results and does graphic displays of the results.

Control

This program is controlled by a routine called "TOP." TOP asks the user to select an option within the system and branches to that option returning after it is completed to allow the user to select again. This subroutine is typical of the subroutines which control sublevels of the program. It makes use of the subroutine "PARS" which interprets user commands.

Section One

The calculating portion of the program uses output from another program as input. The input functions are "GETHR" and "GETER" which read and sort records of data. The program also uses table stored variables and functions. System variable and function retrieval is handled by: "MONVAR" - monthly variables, "GETFUN," "FUN2" - blind adjustment and sun angle dependent functions, "BLDAJ," "CHKRAD," "AH1ER," "INBAS," "SETVAR" - are support functions. The calculations are controlled by support functions.

The calculations are controlled by "CALTOP" which maintains month, day, hour pointers. The calculations are done within "CALC" which retrieves table stored variables and functions described above, and calls calculation functions "QEAF," "OREFUN," "ORC," "OFR11," "OFR22," which do the final calculations.

Storage

Storage is handled by "SIGMA" on a daily basis, and monthly results are then stored by "MONSUM," with "SUMMER" holding yearly totals. MONSUM uses several subordinate routines "QS1," "QS2," "STUF1," "STUF2," "STUF3," "STUF4." The "STUF" routines are contained in the second section of the program.

Section Two

The graphics portion of the program is controlled by "GRAFIX" which also produces complex functions made from the output of the calculation routine on demand.

"READER," and "DUMPER" do input and output from the calculation storage file made by the first program section, and use subordinate routines "D1," "D2," "R1," "R2."

Graphics uses arrays of functions selected by the user and are limited to four per display. The functions may be output from the first program section, or complex summation functions produced in the second section by "ADDER," "FUNER," "FRSET," "FGET."

The data displayed is selected by using the subroutines "GRAV2," "SLOTR," "GETOR."

Graphing is done in the "GRAF" routine which uses "GRSET," "BOXX," "LAB" to set up the screen and "SCAMBL," "GOUT," "GEPT" to interpret and graph user selections. "GR1" initializes the graphics system.

Note

Some subroutines are included in the program listing which were in the initial phases of developing the project but are no longer used. Also, subroutines developed for system uses prior to the development of this program which are used here are not included in the program listing, such as "ANLIZE," "PARS," "DIS."

The program is not given in flow chart form because it was thought to be to intricate to be readable. Instead the program is documented throughout the listing and these notes were written to help interpret the program.

Section 1

```
AO FOR4,2
BI 3000
LO 2
AC VOUT,226
ST 3000
$LAB= MAIN
C!!!!!!!!!!!!!!!
C  YEARLY ENERGY MODEL
C  WINDOW MODELS
C!!!!!!!!!!!!!!!
      CALL TOP
      STOP
      END
ST 3000
$LAB= TOP
C!!!!!!!!!!!!!!!!!!!!!!
C  MAIN CONTROL ROUTINE
C!!!!!!!!!!!!!!!!!!!!!!
      SUBROUTINE TOP
      INTEGER*2 TOTNUM,ILAB
      INTEGER SYM,POSS(2,5)
C THIS BLOCK CONTAINS POINTERS TO MONTH, CALENDAR DAY AND
C  COUNTING DAY
      COMMON /B2/D91,IMONTH,IDAYS,IBDAY
C  USER CHOICES FOR PROGRAM OPERATION
      DATA POSS/'DO      SU      PO      GRAFIX  EN      '/
C  GRAPHIC SYMBOL FOR USER ASSOCIATION IN INTERACTION WITH PROGRAM
      DATA SYM/'4HE   '/
C
C  THE STRUCTURE OF THIS SUBROUTINE IS TYPICAL OF THE MULTY-WAY
C  BRANCHING SUBROUTINES USED THROUGHOUT THIS PROGRAM
C  THIS IS THE ONLY ONE DOCUMENTED
C
C  INITIALIZE STORAGE ARRAYS (INBAS) AND GRAPHICS (GR1)
      CALL INBAS
      CALL GR1
C  SET YEAR COUNT AND BEGINNING DAY OF THE MODEL YEAR
      IDAYS=365
      IBDAY=244
C  SET TOTAL NUMBER OF USER CHOICES FOR PARS FUNCTION
      TOTNUM=5
    5 CONTINUE
C  'PARS' ASKS USER FOR A SELECTION FROM (POSS) AND RETURNS THE
C  NUMBER OF THE FUNCTION IN THE ARRAY (POSS) THIS IS USED FOR
C  FANNING OUT TO THE ALTERNATIVES
      CALL PARS(ILAB,TOTNUM,POSS,SYM)
C  GOTO THE SELECTED ALTERNATIVE
      GOTO (10,20,30,40,99),ILAB
C
   10 CONTINUE
C  DO YEARLY CALCULATIONS
      CALL CALTOP
      GOTO 5
C
   20 CONTINUE
C  SET SYSTEM VARIABLES AT RUN TIME
      CALL SETVAR
      GOTO 5
C
   30 CONTINUE
C  SET WINDOW POSITION FOR PARTIAL YEAR'S CALCULATIONS
C  NOT RUN TESTED
      CALL POSIT
      GOTO 5
C
   40 CONTINUE
C  DO GRAPHICS,COMPLEX FUNCTIONS, AND DISC ACCESSING FOR RESULTS

      CALL GRAFIX
      GOTO 5
C
   99 CONTINUE
      RETURN
      END
```

```
74 ST 3000
75 $LAB= CALTOP
76 C:::::::::::::::::::::::::::
77 C  DAILY CALCULATION CONTROL
78 C:::::::::::::::::::::::::::
79        SUBROUTINE CALTOP
80        INTEGER M(12)
81        COMMON /B2/D91,IMONTH,IDAYS,IBDAY
82 C  THIS BLOCK: END OF MONTHS IN COUNTING DAYS AND MONTH POINTER

83        COMMON /M2/D96,MONS(13),K
84        DATA (M(I),I=1,12,1)/31,28,31,30,31,30,31,31,30,31,30,31/

85 C
86 C
87 C  INITIALIZE
88        ITOT=0
89        DO 11 I=1,12,1
90        ITOT=ITOT+M(I)
91        MONS(I)=ITOT
92     11 CONTINUE
93        WRITE(1,100) (MONS(I),I=1,12,1)
94    100 FORMAT('MS',/,2(6(I3,1X),/))
95 C  RESET
96        K=1
97 C  SET UP INTERMEDIATE STORAGE BUFFERS
98        CALL INSIG
99 C  SET UP INPUT BUFFERS AND SYSTEM VARIABLES SET BY INPUT DATA (
B2)
100       CALL INGET(RUN,1)
101 C
102 C
103       ICDAY=IBDAY-1
104       IDAY=0
105     2 CONTINUE
106       IDAY=IDAY+1
107       ICDAY=ICDAY+1
108       IF(ICDAY.LE.365) GOTO 4
109 C  ELSE RESET MONTH COUNTER AND CALENDAR DAY
110       K=1
111       ICDAY=1
112     4 CONTINUE
113 C  END CHECK
114       IF(IDAY.GT.IDAYS) GOTO 99
115 C
116 C  GET MONTH
117     5 CONTINUE
118       IF(ICDAY.LE.MONS(K)) GOTO 6
119       K=K+1
120       IF(K.GT.12) K=1
121       GOTO 5
122 C
123     6 CONTINUE
124 C
125 C  DO A DAYS CALCULATIONS
126       CALL CALC(ICDAY)
127 C  CHECK FOR END OF MONTH
128       IF(ICDAY.LT.MONS(K)) GOTO 3
129 C  ELSE OUTPUT MONTHLY TOTAL
130       CALL MONSUM
131 C  SUM YEARLY TOTAL
132       CALL SUMMER
133 C
134     3 GOTO 8
135 C
136 C
137    99 CONTINUE
138       RETURN
139       END
140 ST 3000
141 $LAB= CALC
142 C:::::::::::::::::
143 C  DO CALCULATIONS
144 C:::::::::::::::::
145       SUBROUTINE CALC(ICDAY)
146       EXTERNAL QEAF,QREFUN,QRC,AM1ER,MONVAR,QFR11,QFR22
147       REAL QFR1(4,4),QFR2(4,4),QEA(4),QREF(4),QRCD(4,4)
148       REAL QEAF,QREFUN,QRC,AM1ER,FRS(4)
149       REAL MONVAR,QFR11,QFR22
150 C
151 C  THIS BLOCK: TRANSIENT SYSTEM VARIABLES (HOURLY AND RUN DEP.)
152       COMMON /B4/D94, FR,CFR,UR,HR
153 C  THIS BLOCK: HOUR AND HOUR/FACADE DEPENDANT VARIABLES
154       COMMON /B3/D92,TM,RH,WO,WI,TI,RB,H2,U2,U1,AM1
155 C  THIS BLOCK: RUN DEPENDANT VARIABLES
156       COMMON /B5/D93,ARUT,ARUG,AFUT,AFUG,WW
157       DATA (FRS(K),K=1,4,1)/1.0,0.75,0.5,0.25/
158 C
159 C
160 C     WRITE(1,101) ICDAY
161   101 FORMAT('DOING DAY ',I4)
162 C
163 C  DO ONE DAY
164       DO 20 K=1,24,1
165 C  GET HOURS DATA
166       CALL GETHR
167 C  GET VARIABLES FOR CALCULATIONS
168       TM=MONVAR(ICDAY,1)
169       RH=MONVAR(ICDAY,2)
170       WO=MONVAR(ICDAY,3)
171       WI=MONVAR(ICDAY,4)
172       TI=MONVAR(ICDAY,5)
173 C     WRITE(1,100) TM,RH,WO,WI,TI
174   100 FORMAT('DID TM',F8.3,'RH',F8.3,'WO',F8.3,'WI',F8.3,'TI',F8.3)

175       DO 6 IFAC=1,4,1
176 C  GET FACADE DEPENDANT VARIABLES
177       RB=GETFUN(IFAC,4)
178       H2=GETFUN(IFAC,3)
179       U2=GETFUN(IFAC,2)
180       U1=GETFUN(IFAC,1)
181       AM1=AM1ER(CFR)
182       UR=0.55
183       HR=FUN2(IFAC,2)
184 C  DO CALCULATIONS
185 C     WRITE(1,103) AM1
186       QEA(IFAC)=QEAF(IFAC)
187 C     WRITE(1,103) AM1
188       QREF(IFAC)=QREFUN(IFAC)
189 C     WRITE(1,103) AM1
190 C
191 C
192       DO 10 I=1,4,1
193 C     WRITE(1,103) AM1
194       FR=FRS(I)
195 C     WRITE(1,103) AM1
196 C     WRITE(1,102) FR
197   102 FORMAT('FR ',F8.3)
198 C  DO CALCULATIONS
199       QRCD(IFAC,I)=QRC(IFAC)
200 C     WRITE(1,103) AM1
201   103 FORMAT('AM1',F8.3)
202       QFR1(IFAC,I)=QFR11(IFAC)
203       QFR2(IFAC,I)=QFR22(IFAC)
204    10 CONTINUE
205 C
206 C
207     6 CONTINUE
208 C  SEPERATE POSITIVE FRACTION AND SUM INTO MONTHLY TOTAL
209       CALL SIGMA(QEA,QREF,QRCD,QFR1,QFR2)
210 C
211    20 CONTINUE
212 C
213 C
214       RETURN
215       END
```

```
216 ST 3000
217 $LAB= MONVAR
218 C:::::::::::::
219 C  FUNCTION TO RETRIEVE MONTHLY VARIABLES
220 C:::::::::::::
221       REAL FUNCTION MONVAR(IDAY,IWHO)
222       REAL T(12),RH(12),WO(12),WI(12),TI(12)
223       COMMON /M2/D96,MONS(13),K
224       DATA (T(I),I=1,12,1)/28.0,33.4,39.6,49.2,58.3,68.2,76.7,74.6,

225      ,   64.8,52.4,39.1,30.3/,
226      ,(RH(I),I=1,12,1)/68.0,65.0,53.0,42.0,34.0,29.0,23.0,26.0,
227      ,   31.0,42.0,63.0,71.0/,
228      ,(WO(I),I=1,12,1)/0.003,0.0032,0.0035,0.0039,0.0044,0.005,
229      ,0.0055,0.0056,0.0048,0.0042,0.0039,0.0031/,
230      ,(WI(I),I=1,12,1)/320.0052,730.0075,210.0052/,
231      ,(TI(I),I=1,12,1)/3368.0,7778.0,2368.0/
232 C
233 C     WRITE(1,101) K
234   101 FORMAT('IN MONVAR  K',I3)
235 C  GET MONTH DEPENDANT VARIABLES FROM DATA SET ARRAYS
236       GOTO (10,20,30,40,50,99),IWHO
237    10 CONTINUE
238       MONVAR=T(K)
239       GOTO 99
240    20 CONTINUE
241       MONVAR= RH(K)
242       GOTO 99
243    30 CONTINUE
244       MONVAR= WO(K)
245       GOTO 99
246    40 CONTINUE
247       MONVAR=WI(K)
248       GOTO 99
249    50 CONTINUE
250       MONVAR=TI(K)
251       GOTO 99
252    99 CONTINUE
253       RETURN
254 C
255       RETURN
256       END
257 ST 3000
258 $LAB= GETHR
259 C:::::::::::::::::::::
260 C  RETRIEVE AN HOUR'S DATA
261 C:::::::::::::::::::::
262       SUBROUTINE GETHR
263 C  THIS BLOCK: RAW INPUT DATA PACKET
264       COMMON /B1/D94,T,SINA,TH(4)
265 C
266 C
267 C  GET VARIABLES FROM INPUT BUFFER
268       CALL GETER(T,1)
269       CALL GETER(SINA,1)
270       CALL GETER(TH(1),1)
271       CALL GETER(TH(2),1)
272       CALL GETER(TH(3),1)
273       CALL GETER(TH(4),1)
274 C     WRITE(1,100) T,SINA,TH(1),TH(2),TH(3),TH(4)
275   100 FORMAT('T',F8.3,'SINA',F8.3,'THS',4(F8.3,1X))
276       RETURN
277       END
278 ST 3000
279 $LAB= GETFUN
280 C::::::::::::::::::::
281 C  GET FUNCTION VALUES BASED ON BLIND ADJUSTMENT
282 C  U1,U2,H2,RB IN MODULO 4 DISTRIBUTION
283 C::::::::::::::::::::
284       REAL FUNCTION GETFUN(IFAC,IFUN)
285       INTEGER*2 BAJ
286       COMMON /B1/D94,T,SINA,TH(4)
287       COMMON /B4/D99, FR,CFR,UR,HR
288 C
289 C  GET BLIND ADJUSTMENT
290       CALL BLDAJ(SINA,BAJ)
291 C  SET FOR RADIUS CUTOFFS
292       CALL CHKRAD(IFAC,BAJ)
293 C  SET FOR MODULO 4
294       BAJ=BAJ*4
295 C
296 C
297 C  GET RESULT FROM TABLE
298       EXF=CFR*(-0.056)
299       EXF=EXP(EXF)
300       BAJ=BAJ+IFUN
301       GOTO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16),BAJ
302 C
303     1 GETFUN=0.28*EXF
304       GOTO 99
305     2 GETFUN=0.042*CFR
306       GOTO 99
307     3 GETFUN=0.021*CFR
308       GOTO 99
309     4 GETFUN=0.07
310       GOTO 99
311     5 GETFUN=0.28*EXF
312       GOTO 99
313     6 GETFUN=0.042*CFR
314       GOTO 99
315     7 GETFUN=0.021*CFR
316       GOTO 99
317     8 GETFUN=0.1
318       GOTO 99
319     9 GETFUN=0.28*EXF
320       GOTO 99
321    10 GETFUN=0.042*CFR
322       GOTO 99
323    11 GETFUN=0.021*CFR
324       GOTO 99
325    12 GETFUN=0.14
326       GOTO 99
327    13 GETFUN=0.28*EXF
328       GOTO 99
329    14 GETFUN=0.036*CFR
330       GOTO 99
331    15 GETFUN=0.017*CFR
332       GOTO 99
333    16 GETFUN=0.33
334       GOTO 99
335 C
336    99 CONTINUE
337       RETURN
338       END
339 ST 3000
340 $LAB= BLDAJ
341 C::::::::::::::::
342 C  CALCULATE THE BLIND ADJUSTMENT
343 C::::::::::::::::
344       SUBROUTINE BLDAJ(SINA,BAJ)
345       INTEGER BAJ
346 C
347       BAJ=0
348       IF(SINA.GT.0.5) BAJ=1
349       IF(SINA.GT.7.07) BAJ=2
350 C
351       RETURN
352       END
353 ST 3000
354 $LAB= CHKRAD
355 C::::::::::::::::
356 C  CHECK THE FACADE RADIATION LEVEL
357 C  SET BAJ FOR CUTOFF
358 C::::::::::::::::
359       SUBROUTINE CHKRAD(IFAC,BAJ)
360       INTEGER*2 BAJ
```

```
      COMMON /B1/D94,T,SINA,TH(4)
C
      GOTO (10,20,30,40),IFAC
   10 CONTINUE
      IF(TH(1).LT.50.0) GOTO 88
      GOTO 99
   20 CONTINUE
      IF(TH(2).LT.50.0) GOTO 88
      GOTO 99
   30 CONTINUE
      IF(TH(3).LT.50.0) GOTO 88
      GOTO 99
   40 CONTINUE
      IF(TH(4).LT.50.0) GOTO 88
      GOTO 99
C
   88 CONTINUE
      BAJ=3
C
   99 CONTINUE
      RETURN
      END
ST 3000
$LAB= SETVAR
C:::::::::::::::::
C  SET SYSTEM VARIABLES
C:::::::::::::::::
      SUBROUTINE SETVAR
      INTEGER*2 ILAB,TOTNUM
      INTEGER SYM,POSS(8,9)
C  THIS $LOCK: TRANSIENT HOUR DEPENDANT VARIABLES
      COMMON /B3/D92,TM,RH,WO,WI,RB,H2,U2,U1,AH1
      COMMON /B4/D99, FR,CFM,UR,HR
      DATA POSS /'HU1     HU2     AH1     HR      RB      ',
     ,'FR      CFM     UR      HR      '/
      DATA SYM /4HSU  /
C
C
      TOTNUM=9
C
C  GET VARIABLE CHOICE FROM USER
      CALL PARS(ILAB,TOTNUM,POSS,SYM)
C  GET USER NUMBER
      GOTO (10,20,30,40,50,60,70,80,90),ILAB
C
   10 CONTINUE
      CALL AMLIZE(RES,ER)
      U1=RES
      GOTO 99
   20 CONTINUE
      CALL AMLIZE(RES,ER)
      U2=RES
      GOTO 99
   30 CONTINUE
      CALL AMLIZE(RES,ER)
      AH1=RES
      GOTO 99
   40 CONTINUE
      CALL AMLIZE(RES,ER)
      H2=RES
      GOTO 99
   50 CONTINUE
      CALL AMLIZE(RES,ER)
      RB=RES
      GOTO 99
   60 CONTINUE
      CALL AMLIZE(RES,ER)
      FR=RES
      GOTO 99
   70 CONTINUE
      CALL AMLIZE(RES,ER)
      CFM=RES
      GOTO 99
   80 CONTINUE
      CALL AMLIZE(RES,ER)
      UR=RES
      GOTO 99
   90 CONTINUE
      CALL AMLIZE(RES,ER)
      HR=RES
      GOTO 99
C
   99 CONTINUE
      RETURN
      END
ST 3000
$LAB= AH1ER
C:::::::::::::::::
C  AH1 FUNCTION
C:::::::::::::::::
      REAL FUNCTION AH1ER(CFM)
      AH1ER=CFM*(-0.05)
      AH1ER=0.12*EXP(AH1ER)
      RETURN
      END
ST 3000
$LAB= POSIT
C:::::::::::::::::
C  SET POSITION OF WINDOW ON YEAR
C:::::::::::::::::
      SUBROUTINE POSIT
      COMMON /B2/D91,IMONTH,IDAYS,IBDAY
C
C
      IMONTH=1
      WRITE(1,100)
      CALL AMLIZE(RES,ER)
      IBDAY=RES
C
   10 CONTINUE
      WRITE(1,101)
      CALL AMLIZE(RES,ER)
      IDAYS=RES
C
  100 FORMAT('BEGIN AT WHAT DAY?')
  101 FORMAT('HOW MANY DAYS?')
C
      RETURN
      END
ST 3000
$LAB= QEAF
C:::::::::::::::::
C  QEA FUNCTION
C:::::::::::::::::
      REAL FUNCTION QEAF(IFAC)
      COMMON /B1/D94,T,SINA,TH(4)
      COMMON /B3/D92,TM,RH,WO,WI,TI,RB,H2,U2,U1,AH1
      COMMON /B4/D99, FR,CFM,UR,HR
      COMMON /B5/D93,ARUT,ARUG,AFUT,AFUG,WW
C
C     WRITE(1,100) T,SINA,TH(IFAC),TM,RH,WO,WI,TI,RB
  100 FORMAT(/,'T',F8.4,'SINA',F8.4,'TH',F8.4,'TM',F8.4,'RH',F8
.4,/,
     ,'WO',F8.4,'WI',F8.4,'TI',F8.4,'RB',F8.4)
C     WRITE(1,101) AH1,U1,CFM,AFUT,AFUG,WW
  101 FORMAT('AH1',F8.4,'U1',F8.4,'CFM',F8.4,'AFUT',F8.4,'AFUG'
,F8.4
,/,
     ,'WW',F8.4)
C     WRITE(1,102) UR,HR,U2,H2,FR
  102 FORMAT('UR',F8.3,'HR',F8.3,'U2',F8.3,'H2',F8.3,'FR',F8.3)

      A1=AH1+RB
      QEAF=  TH(IFAC)*A1*ARUG+
     ,   U2*(T-TI)*AFUT
C     ,      CFM*WW*0.92*(T-TI)+
C     ,      CFM*WW*3.84*((1070.0+0.4*TH)*WO-
C     ,          (1070.0+0.4*TI)*WI)
      WRITE(1,103) QEAF
  103 FORMAT('QEAF',F8.2)
C
      RETURN
      END
ST 3000
$LAB= QRC
C:::::::::::::::::
C  QRC FUNCTION
C:::::::::::::::::
      REAL FUNCTION QRC(IFAC)
      COMMON /B1/D94,T,SINA,TH(4)
      COMMON /B3/D92,TM,RH,WO,WI,TI,RB,H2,U2,U1,AH1
      COMMON /B4/D99, FR,CFM,UR,HR
      COMMON /B5/D93,ARUT,ARUG,AFUT,AFUG,WW
C
C     WRITE(1,101) T,SINA,TH(IFAC),TM,RH,WO,WI,TI,RB
  101 FORMAT(9(F8.3,1X))
C     WRITE(1,102) AH1,U1,CFM,AFUT,AFUG,WW
  102 FORMAT(6(F8.3,1X))
C     WRITE(1,103) UR,HR,U2,H2,FR
  103 FORMAT(5(F8.3,1X))
      AK=1.0-FR
      QRC=AK*( U2*(T-TI)*AFUT+ H2*TH(IFAC)*AFUG )
C
C
C     WRITE(1,100) QRC
  100 FORMAT('QRC',F9.2)
      RETURN
      END
ST 3000
$LAB= OUTPUT
C:::::::::::::::::
C  OUTPUT RESULTS
C:::::::::::::::::
      SUBROUTINE OUTPUT
      COMMON /B1/D94,T,SINA,TH(4)
C
C
C     WRITE(1,100)(TH(I),I=1,4,1)
  100 FORMAT('TH$!',/,4(F8.3,2X))
      RETURN
      END
ST 3000
$LAB= GETER
C:::::::::::::::::::::
C  RETRIEVE A DATA PACKET
C:::::::::::::::::::::
      SUBROUTINE GETER(ARAY,IMANY)
      REAL ARAY(100),ARAY2(27)
C
C  LOAD 'KMANY' ELEMENTS INTO 'ARAY'
      DO 10 I=1,IMANY,1
      KOUNT=KOUNT+1
      IF(KOUNT.LE.27) GOTO 20
C  ELSE GET A NEW $TRING
      IRECNO=IRECNO+1
      KOUNT=1
      CALL DIS(IOFIL,IRECNO,ARAY2,108,78)
C     WRITE(1,100)(ARAY2(I),I=1,20,1)
C
C  LOAD AN ELEMENT
   20 CONTINUE
      ARAY(I)=ARAY2(KOUNT)
   10 CONTINUE
C
      RETURN
C
C  INITIALIZE WINDOW TO DATA FILE
      ENTRY INGET
C  INITIALIZE WINDOW TO A RECORD
      IOFIL=9
      CALL DIS(IOFIL,1,ARAY2,108,78)
      ITOP=ARAY2(1)
      IRECNO=IMANY
      KOUNT=0
      CALL DIS(IOFIL,IRECNO,ARAY2,108,78)
C     WRITE(1,100)(ARAY2(I),I=1,20,1)
  100 FORMAT('ARAY',/,2(10(F7.2,1X),/))
      RETURN
      END
ST 3000
$LAB= INBAS
C:::::::::::::
C  DEFAULT INITIALIZE SYSTEM VARIABLES
C:::::::::::::
      SUBROUTINE INBAS
      COMMON /B4/D99, FR,CFM,UR,HR
      COMMON /B5/D93,ARUT,ARUG,AFUT,AFUG,WW
C
C
      AFUT=25.9
      AFUG=21.9
      ARUT=27.7
      ARUG=23.6
      WW=4.0
      FR=0.5
      CFM=4.0
      UR=0.1
      HR=1.0
C
      RETURN
      END
ST 3000
$LAB= QREFUN
C:::::::::::::::::::::::::::
C  QREF FUNCTION
C:::::::::::::::::::::::::::
      REAL FUNCTION QREFUN(IFAC)
      COMMON /B1/D94,T,SINA,TH(4)
      COMMON /B3/D92,TM,RH,WO,WI,TI,RB,H2,U2,U1,AH1
      COMMON /B4/D99, FR,CFM,UR,HR
      COMMON /B5/D93,ARUT,ARUG,AFUT,AFUG,WW
C
C
C
C     WRITE(1,101) AH1
      QREFUN=TH(IFAC)*HR*ARUG+
     ,   UR*(T-TI)*ARUT
C     WRITE(1,101) AH1
  101 FORMAT('AH1 IN QREFUN',F8.3)
C     ,   FR*CFM*WW*0.92*(T-TI)+
C     ,   FR*CFM*WW*3.84*((107%.0+0.4*TH)*WO-
C     ,       (1070.0+0.4*TI)*WI)
C     WRITE(1,100) QREFUN
C 100 FORMAT('QREFUN',F9.2)
C
C
      RETURN
      END
ST 3000
$LAB= FUN2
C:::::::::::::::::::::::::::
C  MORE FUNCTIONS
C  UR,HR  IN MOD 2 DISTRIBUTION
C
C:::::::::::::::::::::::::::
      REAL FUNCTION FUN2(IFAC,IUMO)
      INTEGER*2 BAJ
      COMMON /B1/D94,T,SINA,TH(4)
      COMMON /B4/D99, FR,CFM,UR,HR
C
C  GET BLIND ADJUSTMENT
      CALL BLDAJ(SINA,BAJ)
C  CHECK RADIUS FOR CUTOFF
      CALL CHKRAD(IFAC,BAJ)
```

```
C  SET FOR MODULO 2
      BAJ=BAJ/2
C
C
      BAJ=BAJ+IUNO
C
      GOTO (1,2,3,4,5,6,7,8),BAJ
C
    1 CONTINUE
      FUN2=0.61
      GOTO 99
    2 CONTINUE
      FUN2=0.44
      GOTO 99
    3 CONTINUE
      FUN2=0.59
      GOTO 99
    4 CONTINUE
      FUN2=0.44
      GOTO 99
    5 CONTINUE
      FUN2=0.54
      GOTO 99
    6 CONTINUE
      FUN2=0.44
      GOTO 99
    7 CONTINUE
      FUN2=0.62
      GOTO 99
    8 CONTINUE
      FUN2=0.57
      GOTO 99
C
C
   99 CONTINUE
      RETURN
      END
ST 3000
$LAB= QFR11
C:::::::::::::::::::::::::
C  FRAGMENTARY EQUATION
C:::::::::::::::::::::::::
      REAL FUNCTION QFR11(IFAC)
      COMMON /D1/D94,T,SIMA,TH(4)
      COMMON /D3/D92,TM,RM,WO,WI,TI,RB,H2,U2,U1,AM1
      COMMON /D4/D99, FR,CFM,UR,HR
      COMMON /D5/D93,ARUT,ARUG,AFUT,AFUG,UW
C
C
      QFR11=FR*CFM*UW*0.982*(T-TI)
C     WRITE(1,100) QFR11
  100 FORMAT('QFR11',F9.3)
C
C
      RETURN
      END
ST 3000
$LAB= QFR22
C:::::::::::::::::::::::::
C  SECOND FRESH AIR FUNCTION
C:::::::::::::::::::::::::
      REAL FUNCTION QFR22(IFAC)
C
      COMMON /D1/D94,T,SIMA,TH(4)
      COMMON /D3/D92,TM,RM,WO,WI,TI,RB,H2,U2,U1,AM1
      COMMON /D4/D99, FR,CFM,UR,HR
      COMMON /D5/D93,ARUT,ARUG,AFUT,AFUG,UW
C
C
      QFR22=FR*CFM*UW*3.84*((1070.0+0.45*TR)*WO-
     .     (1070.0+0.45*TI)*WI)
C
C
      WRITE(1,100) QFR22
  100 FORMAT('QFR22',F9.3)
C
      RETURN
      END
ST 3000
$LAB= SIGMA
C::::::::::::::::::::::
C  SUMMATION FUNCTION
C  ADD HOURLY VALUES INTO HOLDING ARRAYS
C::::::::::::::::::::
      SUBROUTINE SIGMA(QEA,QREF,QRCD,QFR1,QFR2)
      REAL QEA(4),QREF(4),QRCD(4,4),QFR1(4,4),QFR2(4,4)
C  THIS BLOCK: MONTHLY HOLDING ARRAYS
      COMMON /SUM/D97,QEAFS1(4),QEAFS2(4),QREF1(4),QREF2(4),
     .   QRC1(4,4),QRC2(4,4),QFR111(4,4),QFR222(4,4),QFR112(4,4
),
     .   QFR221(4,4)
C
C
C
C
      WRITE(1,100) QEAFS2(1)
  100 FORMAT('ENTERING SIGMA',E9.4)
      DO 10 I=1,4,1
C
C
C  SUM POSITIVE VALUES INTO '1'  ARRAYS
C  SUMM ALL VALUES INTO '2'  ARRAYS
      IF(QEA(I).GT.0.0) QEAFS1(I)=QEAFS1(I)+QEA(I)
      QEAFS2(I)=QEAFS2(I)+QEA(I)
      IF(QREF(I).GT.0.0) QREF1(I)=QREF1(I)+QREF(I)
      QREF2(I)=QREF2(I)+QREF(I)
C
      DO 20 J=1,4,1
      IF(QRCD(I,J).GT.0.0) QRC1(I,J)=QRC1(I,J)+QRCD(I,J)
      QRC2(I,J)=QRC2(I,J)+QRCD(I,J)
      IF(QFR1(I,J).GT.0.0) QFR111(I,J)=QFR111(I,J)+QFR1(I,J)
      QFR112(I,J)=QFR112(I,J)+QFR1(I,J)
      IF(QFR2(I,J).GT.0.0) QFR221(I,J)=QFR221(I,J)+QFR2(I,J)
      QFR222(I,J)=QFR222(I,J)+QFR2(I,J)
   20 CONTINUE
C
   10 CONTINUE
      RETURN
C
C
      RETURN
      END
ST 3000
$LAB= INSIG
C:::::::::::::::::::::::::
C  INITIALIZE STORAGE ARRAYS
C:::::::::::::::::::::::::
      SUBROUTINE INSIG
      COMMON /SUM/D97,QEAFS1(4),QEAFS2(4),QREF1(4),QREF2(4),
     .   QRC1(4,4),QRC2(4,4),QFR111(4,4),QFR222(4,4),QFR112(4,4)
     .   QFR221(4,4)
C
C
      DO 30 I=1,4,1
      QEAFS1(I)=0.0
      QEAFS2(I)=0.0
      QREF1(I)=0.0
      QREF2(I)=0.0
      DO 40 J=1,4,1
      QRC1(I,J)=0.0
      QRC2(I,J)=0.0
      QFR111(I,J)=0.0
      QFR222(I,J)=0.0
      QFR112(I,J)=0.0
      QFR221(I,J)=0.0
   40 CONTINUE
   30 CONTINUE
C
C
C
      RETURN
      END
ST 3000
$LAB= QS1
C::::::::::::::::::::
C  SUBTRACTION FUNCTION
C::::::::::::::::::::
      SUBROUTINE QS1(YTOT,YPLUS,SUBS)
      REAL YTOT(4),YPLUS(4),SUBS(4)
C
      DO 10 I=1,4,1
      SUBS(I)=YTOT(I)-YPLUS(I)
   10 CONTINUE
C
      RETURN
      END
ST 3000
$LAB= QS2
C::::::::::::::::::::
C  SUBTRACTION FUNCTION
C::::::::::::::::::::
      SUBROUTINE QS2(YTOT,YPLUS,SUBS,I)
      REAL YTOT(4,4),YPLUS(4,4),SUBS(4)
C
      DO 10 J=1,4,1
      SUBS(J)=YTOT(I,J)-YPLUS(I,J)
   10 CONTINUE
C
      RETURN
      END
ST 3000
$LAB= SUMMER
C::::::::::::::::::::::
C  MAKE YEARLY SUM
C  SUM YEARLY TOTAL
C  THESE RESULTS HAVE NOT BEEN MADE USE OF
C  ALSO ZERO MONTHLY COLLECTION ARRAYS TO COLLECT THE NEXT MONT
H
C::::::::::::::::::::::C
      SUBROUTINE SUMMER
      COMMON /SUM/D97,QEAFS1(4),QEAFS2(4),QREF1(4),QREF2(4),
     .   QRC1(4,4),QRC2(4,4),QFR111(4,4),QFR222(4,4),QFR112(4,4
),
     .   QFR221(4,4)
C  THIS BLOCK: YEARLY TOTAL ARRAYS
      COMMON /SUM2/D98,D96,FS1(4),FS2(4),RF1(4),RF2(4),
     .RC1(4,4),RC2(4,4),FR1A1(4,4),FR1A2(4,4),
     .FR2A1(4,4),FR2A2(4,4)
C
C
C  MAKE YEARLY SUM
      DO 10 I=1,4,1
      FS1(I)=QEAFS1(I)
      FS2(I)=QEAFS2(I)
      RF1(I)=QREF1(I)
      RF2(I)=QREF2(I)
C  ZERO ARRAYS
      QEAFS1(I)=0.0
      QEAFS2(I)=0.0
      QREF1(I)=0.0
      QREF2(I)=0.0
      DO 20 J=1,4,1
      RC1(I,J)=QRC1(I,J)
      RC2(I,J)=QRC2(I,J)
      FR1A1(I,J)=QFR111(I,J)
      FR1A2(I,J)=QFR112(I,J)
      FR2A1(I,J)=QFR221(I,J)
      FR2A2(I,J)=QFR222(I,J)
C  ZERO ARRAYS
      QRC1(I,J)=0.0
      QRC2(I,J)=0.0
      QFR111(I,J)=0.0
      QFR112(I,J)=0.0
      QFR221(I,J)=0.0
      QFR222(I,J)=0.0
   20 CONTINUE
   10 CONTINUE
C
C
      RETURN
      END
ST 3000
$LAB= MONSUM
C::::::::::::::::::::
C  OUTPUT MONTHLY SUMS
C::::::::::::::::::::
      SUBROUTINE MONSUM
      INTEGER FACS(4)
      REAL SUBS1(4),SUBS2(4),SUBS3(4),SUBS4(4),SUBS5(4)
      COMMON /M2/D96,MONS(13),K
      COMMON /SUM/D97,QEAFS1(4),QEAFS2(4),QREF1(4),QREF2(4),
     .   QRC1(4,4),QRC2(4,4),QFR111(4,4),QFR222(4,4),QFR112(4,4),
     .   QFR221(4,4)
      DATA FACS/4HSO. ,4HEAST,4HWEST,4HNO. /
C
C
      WRITE(1,107)
  107 FORMAT(//////////,'ENTERING MONSUM')
C  'QS1' AND 'QS2' FUNCTIONS ARE USED TO SEPERATE THE NEGATIVE
C  COMPONENT FROM THE STORED TOTAL MONTHLY VALUES
      CALL QS1(QREF2,QREF1,SUBS1)
      CALL QS1(QEAFS2,QEAFS1,SUBS2)
C  'STUF1' IS THE LINK TO THE GRAPHICS PORTION OF THE PROGRAM
C  MONTHLY VALUES ARE STORED HERE FOR GRAPHING AND DISC STORAGE
      CALL STUF1(1,1,QEAFS1,K)
      CALL STUF1(2,1,SUBS2,K)
      CALL STUF1(3,1,QREF1,K)
      CALL STUF1(4,1,SUBS1,K)
C
      DO 20 I=1,4,1
      CALL QS2(QRC2,QRC1,SUBS3,I)
      CALL QS2(QFR112,QFR111,SUBS4,I)
      CALL QS2(QFR222,QFR221,SUBS5,I)
C  OUTPUT MONTHLY SUMS
      WRITE(8,114) FACS(I)
      WRITE(8,103) QREF1(I),SUBS1(I),QEAFS1(I),SUBS2(I)
      WRITE(8,105)
      WRITE(8,108)
      WRITE(8,106) (QRC1(I,J),J=1,4,1)
      WRITE(8,109)
      WRITE(8,106) (SUBS3(J),J=1,4,1)
      WRITE(8,110)
      WRITE(8,106) (QFR111(I,J),J=1,4,1)
      WRITE(8,111)
      WRITE(8,106) (SUBS4(J),J=1,4,1)
      WRITE(8,112)
      WRITE(8,106) (QFR221(I,J),J=1,4,1)
      WRITE(8,113)
      WRITE(8,106) (SUBS5(J),J=1,4,1)
      CALL STUF1(5,I,QRC1,K)
      CALL STUF1(6,I,SUBS3,K)
      CALL STUF1(7,I,QFR111,K)
      CALL STUF1(8,I,SUBS4,K)
      CALL STUF1(9,I,QFR221,K)
      CALL STUF1(10,I,SUBS5,K)
   20 CONTINUE
C
  103 FORMAT('QREF+',/,E10.3,/,'QREF-',/,E10.3,/,'QEAF+',/,E10.3,/,

     .'QEAF-',/,E10.3)
  105 FORMAT('FR1',5X,'1.0',8X,'.75',8X,'.50',8X,'.25')
  106 FORMAT(4(E10.3,1X))
  108 FORMAT('QRC +')
  109 FORMAT('QRC -')
  110 FORMAT('QFRESAM1 +')
  111 FORMAT('QFRESAM1 -')
  112 FORMAT('QFRESH2 +')
  113 FORMAT('QFRESH2 -')
  114 FORMAT(//,A4,/)
C
C
      RETURN
      END
TR
)
```

Section 2

```
 1 AC FOR4,8
 2 DI 3000
 3 LO 8
 4 AC YOUT2.BDS
 5 ST 3000
 6 $LAB= MAIN
 7 C!!!!!!!!!!!
 8 C  MAIN TEST ROUTINE
 9 C!!!!!!!!!!!
10        CALL TESTR
11        STOP
12        END
13 ST 3000
14 $LAB= TESTR
15 C!!!!!!!!!!
16 C  TEST THIS PROGRAM FILE
17 C!!!!!!!!!!
18        SUBROUTINE TESTR
19        REAL FF(4,4),GG(4)
20        COMMON /ST1/A(4,12),B(4,12),C(4,12),D(4,12),E(4,4,12),
21       ,F(4,4,12),G(4,4,12),H(4,4,12),HI(4,4,12),HJ(4,4,12),FS(4,4)
22 C
23        CALL GR1
24        DO 10 I=1,4,1
25        DO 10 J=1,12,1
26        A(I,J)=J*50
27        B(I,J)=J*25
28        C(I,J)=0.0
29        D(I,J)=0.0
30        DO 10 K=1,4,1
31        E(I,K,J)=J*30
32        F(I,K,J)=J*20
33        G(I,K,J)=J*20
34        H(I,K,J)=J*20
35        HI(I,K,J)=J*20
36        HJ(I,K,J)=J*33
37     10 CONTINUE
38 C
39 C
40        DO 20 I=1,4,1
41        GG(I)=I
42        DO 20 J=1,4,1
43        FF(I,J)=J+I
44     20 CONTINUE
45 C
46        A(2,7)=0.0
47        B(3,7)=0.0
48        E(3,3,5)=0.0
49        E(4,3,3)=0.0
50 C
51        CALL STUF1(2,1,GG,1)
52        WRITE(1,101)
53    101 FORMAT('DID FIRST ONE')
54        CALL STUF1(3,1,FF,1)
55        WRITE(1,101)
56        CALL STUF1(5,1,FF,2)
57 C
58        DO 30 I=1,4,1
59        WRITE(1,100) (B(I,J),J=1,4,1)
60     30 CONTINUE
61        WRITE(1,102)
62 C
63 C
64        WRITE(1,100) (GG(J),J=1,4,1)
65        WRITE(1,102)
66 C
67        DO 40 I=1,4,1
68        WRITE(1,100) (FF(I,J),J=1,4,1)
69     40 CONTINUE
70        WRITE(1,102)
71        DO 50 I=1,4,1
72        WRITE(1,100) (C(I,J),J=1,4,1)
73     50 CONTINUE
74 C
75        WRITE(1,102)
76        WRITE(1,102)
77        DO 70 I=1,4,1
78        DO 60 J=1,4,1
79        WRITE(1,100) (E(J,K,I),K=1,4,1)
80     60 CONTINUE
81        WRITE(1,102)
82     70 CONTINUE
83 C
84 C
85    100 FORMAT(4(F8.2))
86    102 FORMAT(/)
87 C
88 C  TEST GRAFIX
89        CALL GRAFIX
90 C
91        RETURN
92        END
93 ST 3000
94 $LAB= STUF1
95 C!!!!!!!!!!!!!!!!!!!!!!!!!!!
96 C  LOAD MONTHLY SUM TABLES
97 C  SUBSCRIPTS: ORIENTATION,(FRESH AIR FRACTION),MONTH
98 C  PARAMETERS:  IUND1-ARRAY POINTER
99 C                    IN1  -ORIENTATION POINTER
100 C                    STFERS-ARRAY INPUT
101 C                    KMONTH-MONTH INPUT
102 C!!!!!!!!!!!!!!!!!!!!!!!!!!!
103       SUBROUTINE STUF1(IUND1,IN1,STFERS,KMONTH)
104       REAL STFERS(4,4)
105 C  THIS BLOCK: MONTHLY SUM ARRAYS
106       COMMON /ST1/A(4,12),B(4,12),C(4,12),D(4,12),E(4,4,12),
107      ,F(4,4,12),G(4,4,12),H(4,4,12),HI(4,4,12),HJ(4,4,12),FS(4,
12)
108 C
109 C  STUFF UND ?
110       GOTO (10,20,30,40,50,60,70,80,90,110),IUND1
111    10 CONTINUE
112       CALL STUF3(A,STFERS,KMONTH)
113       GOTO 99
114    20 CONTINUE
115       CALL STUF3(B,STFERS,KMONTH)
116       GOTO 99
117    30 CONTINUE
118       CALL STUF3(C,STFERS,KMONTH)
119       GOTO 99
120    40 CONTINUE
121       CALL STUF3(D,STFERS,KMONTH)
122       GOTO 99
123    50 CONTINUE
124       CALL STUF2(E,IN1,STFERS,KMONTH)
125       GOTO 99
126    60 CONTINUE
127       CALL STUF4(F,IN1,STFERS,KMONTH)
128       GOTO 99
129    70 CONTINUE
130       CALL STUF2(G,IN1,STFERS,KMONTH)
131       GOTO 99
132    80 CONTINUE
133       CALL STUF4(H,IN1,STFERS,KMONTH)
134       GOTO 99
135    90 CONTINUE
136       CALL STUF2(HI,IN1,STFERS,KMONTH)
137       GOTO 99
138   110 CONTINUE
139       CALL STUF4(HJ,IN1,STFERS,KMONTH)
140       GOTO 99
141 C
142    99 CONTINUE
143       RETURN
144       END
145 ST 3000
146 $LAB= STUF2
147 C!!!!!!!!!!!!!!!!!!!!
148 C  LOAD PARTICULAR NUMBERS
149 C  LOAD 2D INTO 3D ARRAYS
150 C!!!!!!!!!!!!!!!!!!!!!!!
151       SUBROUTINE STUF2(XRAY,IN1,STFERS,KMONTH)
152       REAL XRAY(4,4,12),STFERS(4,4)
153 C
154       DO 10 I=1,4,1
155       XRAY(IN1,I,KMONTH)=STFERS(IN1,I)
156 C     WRITE(1,100) STFERS(IN1,I)
157    10 CONTINUE
158 C
159   100 FORMAT('XRAY ',E9.3)
160       RETURN
161       END
162 ST 3000
163 $LAB= STUF3
164 C!!!!!!!!!!!!!!!!!
165 C  ANOTHER LOAD ROUTINE
166 C  LOAD 1D INTO 2D ARRAYS
167 C!!!!!!!!!!!!!!!!!!
168       SUBROUTINE STUF3(XRAY,STFERS,KMONTH)
169       REAL XRAY(4,12),STFERS(4,4)
170 C
171       DO 10 I=1,4,1
172       XRAY(I,KMONTH)=STFERS(I,1)
173 C     WRITE(1,100) STFERS(I,1)
174   100 FORMAT('ZRAY ',E9.3)
175    10 CONTINUE
176 C
177       RETURN
178       END
179 ST 3000
180 $LAB= STUF4
181 C!!!!!!!!!!!!!!!
182 C  LOAD 1D INTO 3D ARRAYS
183 C!!!!!!!!!!!!!!!!
184       SUBROUTINE STUF4(XRAY,IN1,STFERS,KMONTH)
185       REAL XRAY(4,4,12),STFERS(4,4)
186 C
187       DO 10 I=1,4,1
188       XRAY(IN1,I,KMONTH)=STFERS(I,1)
189 C     WRITE(1,100) STFERS(I,1)
190   100 FORMAT('YRAY',E9.3)
191    10 CONTINUE
192 C
193       RETURN
194       END
195 ST 3000
196 $LAB= GRAFIX
197 C!!!!!!!!!!!!!!!!!!!!!
198 C  GRAFIX CONTROL FUNCTION
199 C!!!!!!!!!!!!!!!!!!!!!
200       SUBROUTINE GRAFIX
201       INTEGER POSS(2,8),SYM
202       INTEGER*2 TOTNUM,ILAB
203       DATA POSS /'FUN    SLOT    GETOR   GRAF    DUMP    ',
204      ,'READ    AD      STOP    '/
205       DATA SYM /4HGFX /
206 C
207 C
208       TOTNUM=8
209 C
210 C  ZERO GRAF LIST
211       CALL ZERGRF
212 C
213     5 CONTINUE
214       CALL PARS(ILAB,TOTNUM,POSS,SYM)
215       GOTO (10,20,30,40,50,60,70,99),ILAB
216 C
217    10 CONTINUE
218 C  SET FUNCTION
219       CALL GRAV2
220       GOTO 5
221    20 CONTINUE
222 C  SET SLOT
223       CALL SLOTR
224       GOTO 5
225    30 CONTINUE
226 C  GET ORIENTATION
227       CALL GETOR
228       GOTO 5
229    40 CONTINUE
230 C  GRAPH
231       CALL GRAF
232       GOTO 5
233    50 CONTINUE
234 C WRITE OUT
235       CALL DUMPER
236       GOTO 5
237    60 CONTINUE
238 C  READ IN
239       CALL READER
240       GOTO 5
241    70 CONTINUE
242 C  AD FUNCTIONS
243       CALL ADDER
244       GOTO 5
245 C
246 C
247    99 CONTINUE
248       RETURN
249       END
250 ST 3000
251 $LAB= ZERGRF
252 C!!!!!!!!!!!!!!!!!!!!!!!!
253 C  ZERO GRAF LIST
254 C!!!!!!!!!!!!!!!!!!!!!!!
255       SUBROUTINE ZERGRF
256       INTEGER BLANK
257 C  THIS BLOCK: LABELS FOR FUNCTION SLOTS
258       COMMON /GB/IFNER(8,4)
259 C  THIS BLOCK: LIST OF FUNCTIONS TO BE GRAPHED
260 C  AND POINTERS
261       COMMON /GRB/IGRFS(4,8),KNUM,KSLOT
262       DATA BLANK /'    '/
263 C
264       KSLOT=1
265       DO 10 I=1,4,1
266       DO 10 J=1,8,1
267       IGRFS(I,J)=0
268       IFNER(J,I)=BLANK
269    10 CONTINUE
270 C
271       RETURN
272       END
273 ST 3000
274 $LAB= GRAV2
275 C!!!!!!!!!!!!!!!!!!
276 C  SET FUNCTION VARIABLES IN FUNCTION LIST
277 C!!!!!!!!!!!!!!!!!!
278       SUBROUTINE GRAV2
279       COMMON /GRB/IGRFS(4,8),KNUM,KSLOT
280 C
281 C
282       WRITE(1,100)
283 C
284     5 CONTINUE
285 C  'ANLIZE' READS UNFORMATTED NUMBERS FROM USER
286       CALL ANLIZE(RES,ER)
287       NUM=RES
288       IF(NUM.LT.0.OR.NUM.GT.32) GOTO 5
289 C  ELSE NUMBER IS OK
290       WRITE(1,101) NUM
291       IGRFS(KSLOT,1)=NUM
292 C
293   100 FORMAT('   SELECT THE IDENTIFYING NUMBER OF THE FUNCTION
```

```
294        ,'QEAF+ (1)',/,
295        ,'QEAF- (2)',/,
296        ,'QREF+ (3)',/,
297        ,'QREF- (4)',/,
298        ,'     FRESH AIR FRACTIONS',/,
299        ,'     1.00 0.75 0.50 0.25',/,
300        ,'QRC+ (5), (6), (7), (8)', /,
301        ,'QRC- (9), (10),(11),(12)', /,
302        ,'FR1+ (13),(14),(15),(16)',/,
303        ,'FR1- (17),(18),(19),(20)',/,
304        ,'FR2+ (21),(22),(23),(24)',/,
305        ,'FR2- (25),(26),(27),(28)',/,
306        ,/,'    SIGMA FUNCTIONS',/,
307        ,'       1    2    3    4',/,
308        ,'    (29) (30) (31) (32)')
309    101 FORMAT('FUNCTION ',I2)
310 C
311 C
312        RETURN
313        END
314 ST 3000
315 $LAB= $LOTR
316 C:::::::::::::::::::
317 C  GET SLOT VARIABLE
318 C:::::::::::::::::::
319        SUBROUTINE SLOTR
320        COMMON /GRB/IGRFS(4,2),KNUM,KSLOT
321 C
322      $ CONTINUE
323        WRITE(1,100)
324        CALL ANLIZE(RES,ER)
325        KSLOT=RES
326        IF(KSLOT.GT.4.OR.KSLOT.LT.1) GOTO $
327 C  ELSE OK SLOT
328        WRITE(1,101) KSLOT
329 C
330    100 FORMAT('WHICH SLOT ?  1-4')
331    101 FORMAT(' SLOT SELECTED: ',I4)
332 C
333 C
334        RETURN
335        END
336 ST 3000
337 $LAB= GRAF
338 C:::::::::::::::::::
339 C  GRAPH FUNCTIONS IN IGRFS ON SCREEN
340 C:::::::::::::::::::
341        SUBROUTINE GRAF
342        INTEGER IGRAF(3)
343        COMMON /GRB/IGRFS(4,2),KNUM,KSLOT
344 C
345 C  DUMP INFO
346        WRITE(1,100) (IGRFS(I,1),I=1,4,1)
347        WRITE(1,100) (IGRFS(I,2),I=1,4,1)
348        WRITE(1,101) KSLOT
349 C
350    100 FORMAT('GRAFS',/,4(I4,2X))
351    101 FORMAT('KSLOT',I4)
352 C  GET A SCALE FOR THE GRAPH
353        WRITE(1,103)
354        CALL ANLIZE(SCAL,ER)
355    103 FORMAT('WHAT IS THE SCALE ?')
356 C  SET UP THE GRAPH
357        CALL GRSET
358        DO 10 I=1,4,1
359        IF(IGRFS(I,1).EQ.0) GOTO 10
360 C  TRANSLATE USER SELECTIONS INTO POINTERS TO STORAGE ARRAYS
361        CALL SCARBL(I,IGRAF)
362 C  GRAPH OUT AN ARRAY
363        CALL GOUT(I,IGRAF,SCAL)
364 C  LABEL THE GRAPH FOR THIS FUNCTION
365        CALL LAB(IGRAF,I)
366     10 CONTINUE
367 C
368        RETURN
369        END
370 ST 3000
371 $LAB= GETOR
372 C:::::::::::::::::::
373 C  SET ORIENATION OF FUNCTION
374 C  TO BE GRAPHED
375 C:::::::::::::::::::
376        SUBROUTINE GETOR
377        COMMON /GRB/IGRFS(4,2),KNUM,KSLOT
378 C
379        WRITE(1,100)
380 C
381      $ CONTINUE
382        CALL ANLIZE(RES,ER)
383        IGRFS(KSLOT,2)=RES
384        IF(IGRFS(KSLOT,2).LT.1.OR.IGRFS(KSLOT,2).GT.4) GOTO $
385 C  ELSE ORIENTATION OK
386        WRITE(1,101) IGRFS(KSLOT,2)
387    100 FORMAT('SELECT ORIENTATION  S,E,W,N  1-4')
388    101 FORMAT('ORIENTATION SELECTED ',I4)
389 C
390        RETURN
391        END
392 ST 3000
393 $LAB= SCARBL
394 C:::::::::::::::::
395 C  UNSCRAMBLE USER CHOICES OF FUNCTIONS AND GRAPH
396 C  IGRAF:  FUNCTION,FRESH AIR FRACTION,ORIENTATION
397 C:::::::::::::::::
398        SUBROUTINE SCARBL(I,IGRAF)
399        INTEGER IGRAF(3)
400        COMMON /GRB/IGRFS(4,2),KNUM,KSLOT
401        COMMON /ST1/A(4,12),B(4,12),C(4,12),D(4,12),E(4,4,12),
402       ,F(4,4,12),G(4,4,12),H(4,4,12),HI(4,4,12),HJ(4,4,12),FS(4,4,12)
403 C
404        IGRAF(2)=1
405        IGRAF(1)=IGRFS(I,1)
406        IGRAF(3)=IGRFS(I,2)
407 C  CHECK FOR FUNCTION WHICH NEEDN'T BE UNSCRAMBLED
408        IF(IGRFS(I,1).LT.5) GOTO 99
409 C  CHECK FOR A SIGMA FUNCTION
410        IF(IGRFS(I,1).GT.28) GOTO 88
411 C  ELSE UNSCRAMBLE FUNCTION
412 C
413        IGRAF(2)=MOD(IGRFS(I,1),4)
414        IF(IGRAF(2).EQ.0) IGRAF(2)=4
415        IGRAF(1)=( IGRFS(I,1)-IGRAF(2) )/4 +4
416        GOTO 99
417 C
418     88 CONTINUE
419 C  SET FOR SIGMA FUNCTION
420        IGRAF(1)=11
421        IGRAF(2)=IGRFS(I,1)-28
422 C
423     99 CONTINUE
424        CALL ANMODE
425 C      WRITE(1,100) (IGRAF(J),J=1,3,1)
426    100 FORMAT('IGRAFS ',3(I4,1X))
427 C
428        RETURN
429        END
430 ST 3000
431 $LAB= GOUT
432 C:::::::::::::::::::
433 C  GRAPHIT
434 C:::::::::::::::::::
435        SUBROUTINE GOUT(I,IGRAF,SCAL)
436        EXTERNAL GEPT
437        REAL GEPT
438        INTEGER IGRAF(3)
439 C
440 C
441 C
442 C  FIRST PT.
443        IX=30
444        IY=450.0+SCAL*GEPT(1,IGRAF)
445        IOLDY=IY
446        CALL MOVABS(IX,IY)
447 C
448        DO 10 K=1,12,1
449        IY=SCAL*GEPT(K,IGRAF)+450.0
450        KZ=IY-IOLDY
451         CALL DSMREL(74,KZ,I)
452 C      WRITE(1,102) IY,IGRAF(1),IGRAF(2),IGRAF(3)
453    102 FORMAT('IY',I4,'IGRAFS',3(I3,1X))
454        IOLDY=IY
455     10 CONTINUE
456 C
457 C  SETUP
458 C      WRITE(1,100)
459    100 FORMAT('GOUT')
460        RETURN
461        END
462 ST 3000
463 $LAB= GRSET
464 C:::::::::::::::::::
465 C  SETUP FOR GRAPHICS
466 C:::::::::::::::::::
467        SUBROUTINE GRSET
468        COMMON /G2/IFNER(2,4)
469 C
470        CALL NEWPAG
471 C
472 C  DRAW BORDERS
473        CALL MOVABS(30,10)
474        CALL BOXX(200,80)
475        CALL MOVABS(30,100)
476        CALL BOXX(900,700)
477        CALL MOVABS(250,10)
478        CALL BOXX(200,80)
479 C
480 C  DRAW VERTICLE SCALE
481        CALL MOVABS(55,100)
482        DO 10 I=1,28,1
483        CALL MOVREL(-25,25)
484        CALL DRWREL(25,0)
485     10 CONTINUE
486 C
487 C  DRAW HORIZONTAL SCALE
488        CALL MOVABS(30,400)
489        DO 20 I=1,12,1
490        CALL MOVREL(0,-10)
491        CALL DRWREL(75,0)
492        CALL DRWREL(0,10)
493     20 CONTINUE
494 C
495 C
496        CALL MOVABS(1,90)
497        CALL ANMODE
498        WRITE(1,100)
499        WRITE(1,101) ((IFNER(I,J),I=1,2,1),J=1,4,1)
500    100 FORMAT('    FUNCT.  AIR %  ORIENT. ',5X,'SIGMA FUNCTIONS'
)
501    101 FORMAT(4(37X,2A4,/))
502 C
503        RETURN
504        END
505 ST 3000
506 $LAB= BOXX
507 C:::::::::::
508 C  DRAW A RELATIVE BOX
509 C:::::::::::
510        SUBROUTINE BOXX(IXDIR,IYDIR)
511        CALL DRWREL(0,IYDIR)
512        CALL DRWREL(IXDIR,0)
513        KY=(-1)*IYDIR
514        KX=(-1)*IXDIR
515        CALL DRWREL(0,KY)
516        CALL DRWREL(KX,0)
517        RETURN
518        END
519 ST 3000
520 $LAB= GR1
521 C:::::::::
522 C  GRAPHICS INIT
523 C:::::::::
524        SUBROUTINE GR1
525        CALL INITT(30)
526        CALL CHRSIZ(3)
527        CALL TERM(1,1024)
528        CALL ANMODE
529        RETURN
530        END
531 ST 3000
532 $LAB= GEPT
533 C:::::::::::::::::
534 C  RETRIEVE POINT FROM A FUNCTION
535 C:::::::::::::::::
536        REAL FUNCTION GEPT(IPT,IGRAF)
537        INTEGER IGRAF(3)
538        COMMON /ST1/A(4,12),B(4,12),C(4,12),D(4,12),E(4,4,12),
539       ,F(4,4,12),G(4,4,12),H(4,4,12),HI(4,4,12),HJ(4,4,12),FS(4,4,12)
540 C
541 C
542        ILAB=IGRAF(1)
543        GOTO (10,20,30,40,50,60,70,80,90,11,22),ILAB
544 C
545     10 CONTINUE
546        K1=IGRAF(3)
547        GEPT=A(K1,IPT)
548        GOTO 99
549     20 CONTINUE
550        K1=IGRAF(3)
551        GEPT=B(K1,IPT)
552        GOTO 99
553     30 CONTINUE
554        K1=IGRAF(3)
555        GEPT=C(K1,IPT)
556        GOTO 99
557     40 CONTINUE
558        K1=IGRAF(3)
559        GEPT=D(K1,IPT)
560        GOTO 99
561     50 CONTINUE
562        K1=IGRAF(3)
563        K2=IGRAF(2)
564        GEPT=E(K1,K2,IPT)
565        GOTO 99
566     60 CONTINUE
567        K1=IGRAF(3)
568        K2=IGRAF(2)
569        GEPT=F(K1,K2,IPT)
570        GOTO 99
571     70 CONTINUE
572        K1=IGRAF(3)
573        K2=IGRAF(2)
574        GEPT=G(K1,K2,IPT)
575        GOTO 99
576     80 CONTINUE
577        K1=IGRAF(3)
578        K2=IGRAF(2)
579        GEPT=H(K1,K2,IPT)
580        GOTO 99
581     90 CONTINUE
582        K1=IGRAF(3)
583        K2=IGRAF(2)
584        GEPT=HI(K1,K2,IPT)
585        GOTO 99
586     11 CONTINUE
587        K1=IGRAF(3)
588        K2=IGRAF(2)
589        GEPT=HJ(K1,K2,IPT)
590        GOTO 99
591     22 CONTINUE
592        K=IGRAF(2)
593        GEPT=FS(K,IPT)
594        GOTO 99
```

```
595 C
596    99 CONTINUE
597       RETURN
598       END
599 ST 3000
600 $LAB= LAB
601 C:::::::::::::::::
602 C  LABEL FUNCTIONS
603 C:::::::::::::::::
604       SUBROUTINE LAB(IGRAF,I)
605       INTEGER IGRAF(3),L(2,10),M(2,4),N(4)
606       DATA L /'QEAF+   QEAF-   QREF+   QREF-   QRC+    ',
607      ,'QRC-    QFR1+   QFR1-   QFR2+   QFR2-   '/
608       DATA M /'SOUTH   EAST    WEST    NORTH   '/
609       DATA N /'1.000.750.500.25'/
610 C
611 C
612       K1=IGRAF(1)
613       K2=IGRAF(2)
614       K3=IGRAF(3)
615 C
616 C  POSITION FOR FUNCTION LABEL
617       CALL MOVABS(1,90)
618       CALL AMMODE
619       DO 10 K=1,I,1
620       WRITE(1,101)
621    10 CONTINUE
622 C
623       IF(IGRAF(1).LT.5) GOTO 2
624       IF(IGRAF(1).GT.10) GOTO 3
625 C  ELSE FUNCTION USES FRESH AIR FRACTION
626 C
627       WRITE(1,100) L(1,K1),L(2,K1),M(K2),M(1,K3),M(2,K3)
628       RETURN
629 C
630     2 CONTINUE
631       WRITE(1,102) L(1,K1),L(2,K1),M(1,K3),M(2,K3)
632       RETURN
633 C
634     3 CONTINUE
635       WRITE(1,103) IGRAF(2)
636       RETURN
637 C
638 C
639 C
640   100 FORMAT(4X,2A4,1X,A4,1X,2A4)
641   101 FORMAT(' ')
642   102 FORMAT(4X,2A4,6X,2A4)
643   103 FORMAT(4X,'SIGMA FUNCTION NO. ',I2)
644 C
645 C
646       RETURN
647       END
648 ST 3000
649 $LAB= DUMPER
650 C:::::::::::::::
651 C  WRITE OUT MONTHLY SUMS
652 C:::::::::::::::
653       SUBROUTINE DUMPER
654       COMMON /ST1/A(4,12),B(4,12),C(4,12),D(4,12),E(4,4,12),
655      ,F(4,4,12),G(4,4,12),H(4,4,12),HI(4,4,12),HJ(4,4,12),FS(4,4,12)
656 C
657 C  GET LOGICAL UNIT
658       WRITE(1,100)
659       CALL AMLIZE(RES,ER)
660       IO=RES
661 C
662 C
663       REWIND IO
664       CALL D1(A,IO)
665       CALL D1(B,IO)
666       IO=RES
667       CALL D1(C,IO)
668       CALL D1(D,IO)
669       IO=RES
670       CALL D2(E,IO)
671       CALL D2(F,IO)
672       CALL D2(G,IO)
673       CALL D2(H,IO)
674       CALL D2(HI,IO)
675       CALL D2(HJ,IO)
676   100 FORMAT('WHAT LOGICAL UNIT ?')
677       RETURN
678       END
679 ST 3000
680 $LAB= READER
681 C:::::::::::::::
682 C  READ IN MONTHLY SUMS
683 C:::::::::::::::
684       SUBROUTINE READER
685       COMMON /ST1/A(4,12),B(4,12),C(4,12),D(4,12),E(4,4,12),
686      ,F(4,4,12),G(4,4,12),H(4,4,12),HI(4,4,12),HJ(4,4,12),FS(4,4,12)
687 C
688 C  GET LOGICAL UNIT
689       WRITE(1,100)
690       CALL AMLIZE(RES,ER)
691       IO=RES
692 C
693 C
694       REWIND IO
695       CALL R1(A,IO)
696       CALL R1(B,IO)
697       CALL R1(C,IO)
698       CALL R1(D,IO)
699       CALL R2(E,IO)
700       CALL R2(F,IO)
701       CALL R2(G,IO)
702       CALL R2(H,IO)
703       CALL R2(HI,IO)
704       CALL R2(HJ,IO)
705   100 FORMAT('WHAT LOGICAL UNIT?')
706 C
707 C
708       RETURN
709       END
710 ST 3000
711 $LAB= D1
712 C:::::::::::::::
713 C  WRITE OUT SMALL ARRAYS
714 C:::::::::::::::
715       SUBROUTINE D1(ARRAY,IO)
716       REAL ARRAY(4,12)
717 C  OUTPUT ARRAY
718       WRITE(1,102)
719       WRITE(IO,101) ((ARRAY(I,J),I=1,4,1),J=1,12,1)
720   101 FORMAT(6(BE10.3,/))
721   102 FORMAT('D1ING')
722       RETURN
723       END
724 ST 3000
725 $LAB= D2
726 C:::::::::::::::
727 C  OUTPUT LARGE ARRAYS
728 C:::::::::::::::
729       SUBROUTINE D2(ARRAY,IO)
730       REAL ARRAY(4,4,12)
731       WRITE(1,103)
732   103 FORMAT('D2ING')
733       WRITE(IO,102) (((ARRAY(I,J,K),I=1,4,1),J=1,4,1),K=1,12,1)
734   102 FORMAT(12(2(BE10.3,/)))
735       RETURN
736       END
737 ST 3000
738 $LAB= R1
739 C:::::::::::::::::
740 C  READ IN SMALL ARRAYS
741 C:::::::::::::::::
742       SUBROUTINE R1(ARRAY,IO)
743       REAL ARRAY(4,12)
744       WRITE(1,102)
745   102 FORMAT('R1ING')
746       READ(IO,101)  ((ARRAY(I,J),I=1,4,1),J=1,12,1)
747   101 FORMAT(6(BE10.3,/))
748       RETURN
749       END
750 ST 3000
751 $LAB= R2
752 C:::::::::::::::
753 C  READ LARGE ARRAYS
754 C:::::::::::::::
755       SUBROUTINE R2(ARRAY,IO)
756       REAL ARRAY(4,4,12)
757       WRITE(1,101)
758   101 FORMAT('R2ING')
759       READ(IO,102) (((ARRAY(I,J,K),I=1,4,1),J=1,4,1),K=1,12,1)
760   102 FORMAT(12(2(BE10.3,/)))
761       RETURN
762       END
763 ST 3000
764 $LAB= ADDER
765 C:::::::::::::::::::::::
766 C MAKE COMPLEX FUNCTIONS FROM RAW FUNCTION ARRAYS
767 C:::::::::::::::::::::::
768       SUBROUTINE ADDER
769       INTEGER PS(2,6),SYM
770       INTEGER*2 TOTNUM,ILAB
771       DATA PS/'PAUSE   FACADE  SLOT    FUNCTIONFRESH   DONE
772       DATA SYM /4HAD  /
773 C
774 C
775       TOTNUM=6
776 C
777     5 CONTINUE
778       CALL PARS(ILAB,TOTNUM,PS,SYM)
779       GOTO (6,10,20,30,40,99),ILAB
780 C
781     6 CONTINUE
782       PAUSE
783       GOTO 5
784    10 CONTINUE
785 C  SET FACADE
786       WRITE(1,100)
787   100 FORMAT('WHICH FACADE  S,E,W,N ?')
788       CALL AMLIZE(RES,ER)
789       KFAC=RES
790       GOTO 5
791    20 CONTINUE
792 C  DO FUNCTION
793 C  SET SLOT
794       WRITE(1,101)
795   101 FORMAT('WHICH SLOT 1-4 ?')
796       CALL AMLIZE(RES,ER)
797       ISLOT=RES
798       GOTO 5
799    30 CONTINUE
800 C  DO FUNCTION
801       CALL FGET(IFUN,ISLOT)
802       CALL FRSET(IFR,FR)
803       DO 35 I=1,12,1
804       CALL FUNER(IFUN,I,KFAC,ISLOT,IFR,FR)
805    35 CONTINUE
806       GOTO 5
807    40 CONTINUE
808 C  SET FRESH AIR FRACTION
809       WRITE(1,102)
810   102 FORMAT('SELECT FRESH AIR FRACTION',/,
811      ,'   1.00  0.75  0.50  0.25',/,
812      ,'    1     2     3     4')
813       CALL AMLIZE(RES,ER)
814       IFR=RES
815       GOTO 5
816 C
817 C
818    99 CONTINUE
819       RETURN
820       END
821 ST 3000
822 $LAB= FUNER
823 C:::::::::::::::::::
824 C  ADDITION FUNCTON
825 C:::::::::::::::::::
826       SUBROUTINE FUNER(IFUN,IPT,IFAC,ISLOT,IFR,FR)
827       COMMON /ST1/A(4,12),B(4,12),C(4,12),D(4,12),E(4,4,12),
828      ,F(4,4,12),G(4,4,12),H(4,4,12),HI(4,4,12),HJ(4,4,12),FS(4,4,12)
829 C
830 C
831       GOTO (10,20,30,40,50,60),IFUN
832 C
833 C
834    10 CONTINUE
835 C  $QEA+
836       FS(ISLOT,IPT)=A(IFAC,IPT)+G(IFAC,IFR,IPT)+HI(IFAC,IFR,IPT
)
837       GOTO 99
838    20 CONTINUE
839 C  $QEAF-
840       FS(ISLOT,IPT)=B(IFAC,IPT)+H(IFAC,IFR,IPT)+HI(IFAC,IFR,IPT
)
841       GOTO 99
842    30 CONTINUE
843 C  $QRA+
844       FS(ISLOT,IPT)=A(IFAC,IPT)+E(IFAC,IFR,IPT)+FR2
845      ,(G(IFAC,IFR,IPT)+HI(IFAC,IFR,IPT))
846       GOTO 99
847    40 CONTINUE
848 C  $QRA-
849       FS(ISLOT,IPT)=B(IFAC,IPT)+F(IFAC,IFR,IPT)+FR2
850      ,(H(IFAC,IFR,IPT)+HJ(IFAC,IFR,IPT))
851       GOTO 99
852    50 CONTINUE
853 C  $QREF+
854       FS(ISLOT,IPT)=C(IFAC,IPT)+FR2
855      ,(G(IFAC,IFR,IPT)+HI(IFAC,IFR,IPT))
856       GOTO 99
857    60 CONTINUE
858 C  $QREF-
859       FS(ISLOT,IPT)=D(IFAC,IPT)+FR2
860      ,(H(IFAC,IFR,IPT)+HJ(IFAC,IFR,IPT))
861       GOTO 99
862 C
863 C
864    99 CONTINUE
865       RETURN
866       END
867 ST 3000
868 $LAB= FRSET
869 C:::::::::::::::::
870 C  SET FRESH AIR FRACTION MINUS ONE
871 C:::::::::::::::::
872       SUBROUTINE FRSET(IFR,FR)
873 C
874 C
875       GOTO (10,20,30,40),IFR
876    10 FR=1.0
877       GOTO 99
878    20 FR=0.75
879       GOTO 99
880    30 FR=0.50
881       GOTO 99
882    40 FR=0.25
883       GOTO 99
884 C
885       FR=1.0-FR
886    99 CONTINUE
887       RETURN
888       END
889 ST 3000
890 $LAB= FGET
891 C:::::::::::::::::
892 C  SET FUNCTION
```

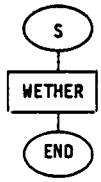
```
893 C:::::::::::::::::
894       SUBROUTINE FGET(IFUN,ISLOT)
895       INTEGER FNS(2,6)
896       COMMON /GB/IFNER(2,4)
897       DATA FNS /'SQEA+   SQEA-   SQRA+   SQRA-   SQREF+  SQREF-  '/

898 C
899     5 CONTINUE
900       WRITE(1,100)
901   100 FORMAT('WHICH FUNCTION 1-6 ?',/,
902      ,'SQEA+,SQEA-,SQRA+,SQRA-,SQREF+,SQREF-')
903       CALL ANLIZE(RES,ER)
904       IFUN=RES
905       IF(IFUN.LT.1.OR.IFUN.GT.6) GOTO 5
906 C
907       IFNER(1,ISLOT)=FNS(1,IFUN)
908       IFNER(2,ISLOT)=FNS(2,IFUN)
909 C
910       RETURN
911       END
912 TR
)
```

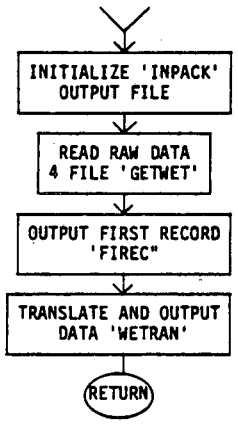
APPENDIX I

Climatic Data Manipulation Program for Input to Yearly Performance Modeling Program

MAIN

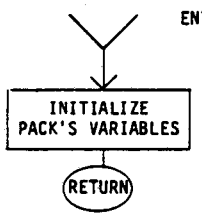


WETHER

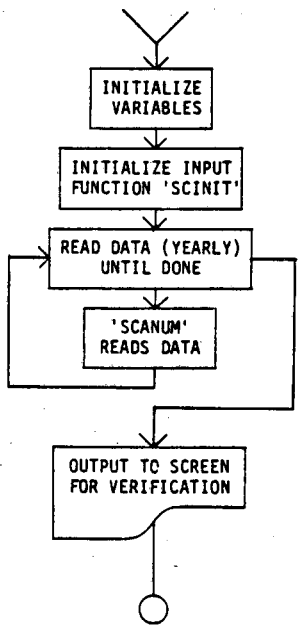


INPACK

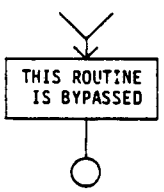
ENTRY INTO 'PACK'



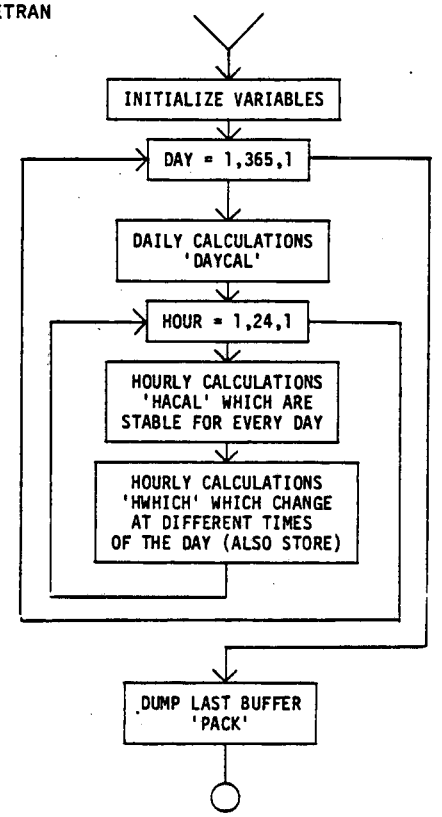
GETWET



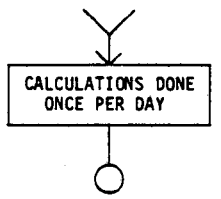
FIREC



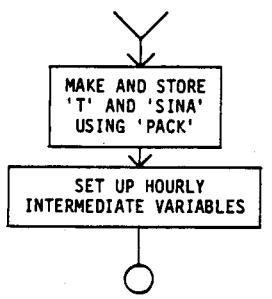
WETRAN



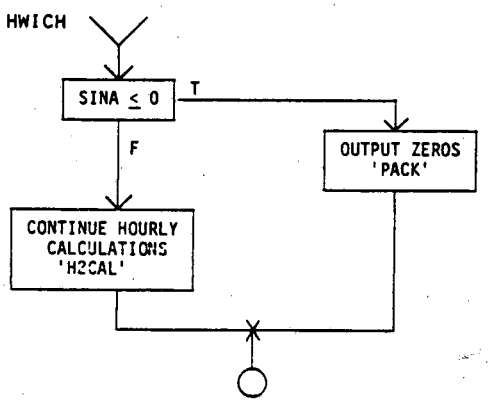
DAYCAL



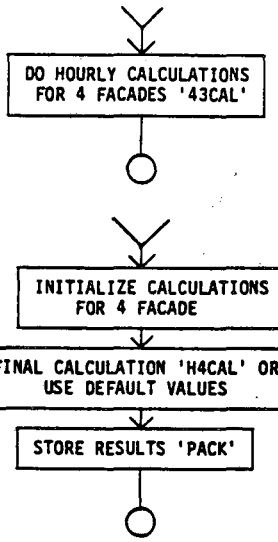
HCAL



HWICH

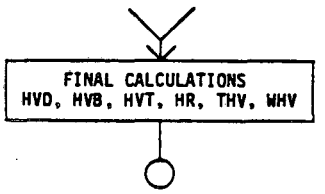


H2CAL

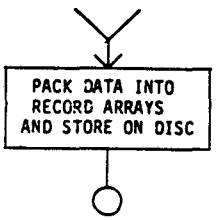


H3CAL

H4CAL



PACK




```
1 AC FOR4.B
2 ST 3000
3 LO B
4 AC WETOUT.EDG
5 ST 3000
6 $LAB= MAIN
7       CALL WETHER
8       STOP
9       END
10 ST 3000
11 $LAB= WETHER
12 C-----------------------------------------
13 C  DO WEATHER CONVERSION FOR ENERGY MODELING PROG
14 C-----------------------------------------
15      SUBROUTINE WETHER
16      A=ARCSIN(0.35)
17      WRITE(1,100) A
18  100 FORMAT('ARCSIN(0.35)',E9.3)
19      CALL INPACK(1.0)
20 C  GET FROM RAW DATA FILE
21      CALL GETWET
22 C  OUTPUT FIRST RECORD
23      CALL FIREC
24 C  TRANSLATE AND STORE/OUTPUT
25      CALL WETRAN
26      RETURN
27      END
28 ST 3000
29 $LAB= GETWET
30 C-----------------------------------------
31 C  GET WEATHER DATA FROM RAW DATA FILE
32 C-----------------------------------------
33      SUBROUTINE GETWET
34      REAL MTHNDS(12)
35      COMMON /B1/BLAT,RRT,OSF,BIT(365),BTH(365),BTL(365)
36      COMMON /B3/ARTHNO(12),CALDAY,HOUR,IDAY,ICDAY
37 C
38      WRITE(1,101)
39      INFIL=8
40      IOFIL=8
41  101 FORMAT('ENTERING GETWET')
42      CALL SCINIT(ARTHNO,12,INFIL)
43      WRITE(1,103)
44  103 FORMAT('JUST INITIALIZED')
45 C
46 C  BEGINNING DAY OF YEAR
47      CALL SCANUM(CALDAY,1,INFIL)
48      ICDAY=CALDAY
49 C
50 C  GET MONTHLY DAY COUNTS
51      CALL SCANUM(ARTHNO,12,INFIL)
52 C  GET OUT A YEAR OF WEATHER DATA
53      ITOT=0
54 C
55      DO 10 I=1,12,1
56      J1=ARTHNO(I)
57 C  GET LANGLEYS
58      DO 11 K=1,J1,1
59      L=ITOT+K
60   11 CALL SCANUM(BIT(L),1,INFIL)
61 C  GET DAILY MAX TEMP
62      DO 12 K=1,J1,1
63      L=ITOT+K
64   12 CALL SCANUM(BTH(L),1,INFIL)
65 C  GET DAILY MIN TEMP
66      DO 13 K=1,J1,1
67      L=ITOT+K
68   13 CALL SCANUM(BTL(L),1,INFIL)
69 C  DEGREE DAYS ARE NOT USED
70      DO 14 K=1,J1,1
71   14 CALL SCANUM(DUMMY,1,INFIL)
72      ITOT=ITOT+J1
73      WRITE(1,102)
74  102 FORMAT('LOOPING IN GETWET')
75   10 CONTINUE
76 C
77      WRITE(1,104) ICDAY,ARTHNO(1),BIT(1),BTH(1),BTL(1)
78  104 FORMAT('JUST READ:',I3,1X,I3,1X,3(F8.3,2X))
79      WRITE(1,105) (BIT(K),K=1,30,1)
80  105 FORMAT(/,3(10(F7.3,1X),/))
81      WRITE(1,105) (BTH(K),K=1,30,1)
82      WRITE(1,106) (BTL(K),K=1,30,1)
83      RETURN
84      END
85 ST 3000
86 $LAB= WETRAN
87 C-----------------------------------------
88 C  WEATHER TRANSLATION ROUTINES
89 C  JOHN EVANS  SEPT. 1980
90 C-----------------------------------------
91      SUBROUTINE WETRAN
92      COMMON /B1/BLAT,RRT,OSF,BIT(365),BTH(365),BTL(365)
93      COMMON /B3/ARTHNO(12),CALDAY,HOUR,IDAY,ICDAY
94      COMMON /B5/HVD,HVB,HVT,HR,THV,WHV
95 C
96      RRT=0.2
97      OSF=0.0
98      BLAT=0.7156
99 C  LOOP THROUGH DAY CALCULATIONS AND HOUR CALCULATIONS
100      DO 10 IDAY=1,365,1
101      CALDAY=ICDAY
102      WRITE(1,100) ICDAY
103  100 FORMAT('DAY ',I4)
104      CALL DAYCAL
105      DO 20 J=1,24,1
106      HOUR=J
107 C  DO STATIC HOURLY CALCULATIONS
108      CALL HCAL
109 C    WRITE(1,104) HVD,HVB,HVT,HR,THV,WHV
110  104 FORMAT('HVD',F8.3,'HVB',F8.3,'HVT',F8.3,'HR',F8.3,/,
111     , 'THV',F8.3,'WHV',F8.3)
112 C    WRITE(1,105) BIT(IDAY),BTH(IDAY),BTL(IDAY)
113  105 FORMAT('BIT',F8.3,'BTH',F8.3,'BTL',F8.3)
114 C  DO HOURLY CALCULATIONS WHICH VARY
115      CALL MWHICH
116   20 CONTINUE
117      ICDAY=ICDAY+1
118      IF(ICDAY.GT.365) ICDAY=1
119   10 CONTINUE
120 C
121 C  MAKE SURE LAST BUFFER IS DUMPED TO FILE
122      DO 30 I=1,27,1
123      CALL PACK(0.0)
124   30 CONTINUE
125 C
126      RETURN
127      END
128 ST 3000
129 $LAB= DAYCAL
130 C-----------------------------------------
131 C  DAILY CALCULATIONS
132 C-----------------------------------------
133      SUBROUTINE DAYCAL
134      COMMON /B1/BLAT,RRT,OSF,BIT(365),BTH(365),BTL(365)
135      COMMON /B3/ARTHNO(12),CALDAY,HOUR,IDAY,ICDAY
136      COMMON /B4/SINA,COSI,DCL,DLEW,AIO,RDT,HH,HHD,HHB,DDO,AZ
137 C
138 C  DAILY SETUP
139 C
140 C  DCL
141      A=4.89+0.0172*CALDAY
142      DCL=0.41*SIN(A)
143 C
144 C  DLEW
145      A=TAN(DCL)*TAN(BLAT)*(-1.0)
146      DLEW=2.0*ARCOS(A)
147 C
148 C  IO
149      A=0.0172*CALDAY
150      B=DLEW*0.5
151      AIO= 889.0*(1.0+0.033*COS(A))*
152     ,  (COS(BLAT)*COS(DCL)*SIN(B)+B*
153     ,  SIN(BLAT)*SIN(DCL))
154 C
155 C  RDT
156      A=BIT(IDAY)/AIO
157 C    WRITE(1,101) A
158  101 FORMAT('A @ RDT ',F8.3)
159      CALL PACK(A)
160      RDT=0.97
161      IF(A.GT.0.1) RDT=0.97+0.1*A-3.7*A**2+2.0*A**3
162 C    WRITE(1,100) DCL,DLEW,AIO,RDT
163  100 FORMAT('DCL',F8.3,'DLEW',F8.3,'AIO',F8.3,'RDT',F8.3)
164 C
165      RETURN
166      END
167 ST 3000
168 $LAB= HCAL
169 C-----!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
170 C  DO HOURLY CALCULATIONS
171 C!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
172      SUBROUTINE HCAL
173      COMMON /B1/BLAT,RRT,OSF,BIT(365),BTH(365),BTL(365)
174      COMMON /B3/ARTHNO(12),CALDAY,HOUR,IDAY,ICDAY
175      COMMON /B4/SINA,COSI,DCL,DLEW,AIO,RDT,HH,HHD,HHB,DDO,AZ
176      COMMON /B5/HVD,HVB,HVT,HR,THV,WHV
177 C
178 C  TEMPERATURE CALCULATIONS
179 C  NOTE: OUTPUT LAST HOURS VALUES
180 C
181 C  TAVE
182      TAVE=(BTH(IDAY)+BTL(IDAY)) / 2.0
183      A=0.26*HOUR-(3.1415D+0.0182*DLEW)
184      T=TAVE+0.5*(BTH(IDAY)-BTL(IDAY))*COS(A)
185 C  STORE T
186      CALL PACK(T)
187 C
188 C  SIN OF ALT. ANGLE
189 C
190 C  SINA
191 C    A=0.26*HOUR-3.1415D
192      SINA=SIN(BLAT)*SIN(DCL)+COS(BLAT)*COS(DCL)*(COS(A))
193 C  STORE SINA
194 C    CALL PACK(SINA)
195 C    WRITE(1,101) TAVE,T,SINA
196  101 FORMAT('TAVE',F8.3,'T',F8.3,/,'SINA',F8.3)
197 C
198 C  V VALUE
199      Y=ABS(0.5E4*(HOUR-12.0)/DLEW)
200      IF (Y.LT.0.01) GOTO 10
201 C    IF(Y.GT.1.0) WRITE(1,103) Y
202  103 FORMAT('XXXXXXXX',/,'Y IS GREATER THAN 1',F8.3)
203 C  ELSE COMPLETE CALCULATIONS
204      DLEW2=DLEW/0.26
205      HH=BIT(IDAY)/DLEW2*(1.81-1.63*Y+
206     , 5.00*Y**2-15.2*Y**3+13.9*Y**4-3.8*Y**5)
207 C    WRITE(1,998) HH
208 998  FORMAT('0','HH',F8.3)
209      HHD=BIT(IDAY)*RDT/DLEW2*
210     , (1.7-2.34*Y+12.8*Y**2-34.8*Y**3+38.5*Y**4-15.0*Y**5)
211      GOTO 20
212 C  SIMPLIFIED CALCULATIONS FOR Y00
```

```
   10 CONTINUE
C
C  HH
      HH=BIT(IDAY)/BLEV**1.81
C  HHD
      HHD=BIT(IDAY)*RDT/BLEV**1.7
   20 CONTINUE
      IF(HH.LT.4.0) HH=4.0
      IF(HHD.LT.4.0) HHD=4.0
      IF(HH.LT.HHD) HH=HHD
C
C  HHD
C
      HHD=HH-HHD
      IF(HHD.LT.0.0) WRITE(1,105) HHD
  105 FORMAT('HHD IS LESS THAN ZERO ',F8.3,//)
C
C  DDO
      DDO=HHD*20.5*(1.35-0.35*(HHD/HH)**2)
      WRITE(1,100) DDO,HHD,HH
  100 FORMAT('DDO',F8.3,'HHD',F8.3,'HH',F8.3)
C
      H3=HH/0.271
      IF(SINA.LE.0.0) H3=0.0
      CALL PACK(H3)
C
      RETURN
      END
ST 3000
$LAB= H2CAL
C::::::::::::::::::::::::::::::::::::::::
C  DO FACADE CALCULATIONS
C::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE H2CAL
      COMMON /B1/BLAT,RRT,OBF,BIT(365),BTH(365),BTL(365)
      COMMON /B3/ARTHNO(12),CALDAY,HOUR,IDAY,ICDAY
      COMMON /B4/SINA,COSI,DCL,DLEV,AIO,RDT,HH,HHD,HHB,DDO,AZ
C
C  DO EACH FACADE AND STORE
C  SOUTH AZ
      AZCON=0.0175*DEG
      AZ=AZCON
      CALL H3CAL
C  EAST AZ
      AZ=AZCON+1.57
      CALL H3CAL
C  WEST AZ
      AZ=AZCON-1.57
      CALL H3CAL
C  NORTH AZ
      AZ=AZCON+3.1415D
      CALL H3CAL
C
      RETURN
      END
ST 3000
$LAB= H3CAL
C::::::::::::::::::::::::::::::::::::::::
C  THIRD LEVEL HOURLY CALCULATIONS
C
C::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE H3CAL
      COMMON /B1/BLAT,RRT,OBF,BIT(365),BTH(365),BTL(365)
      COMMON /B3/ARTHNO(12),CALDAY,HOUR,IDAY,ICDAY
      COMMON /B4/SINA,COSI,DCL,DLEV,AIO,RDT,HH,HHD,HHB,DDO,AZ
      COMMON /B5/HUD,HUB,HUT,HR,THU,UHU
C
C  SET DEFAULT VALUES
      THU=DDO
      UHU=DDO
      HUD=0.0
      HUB=0.0
      HUT=0.0
      HR=0.0
C  COSI
      A=0.26*HOUR-3.1415D
      COSDCL=COS(DCL)
      COSAZ=COS(AZ)
      COSI=COSDCL*SIN(BLAT)*COSAZ*COS(A)+
     ,  COSDCL*SIN(AZ)*SIN(A)-
     ,  SIN(DCL)*COS(BLAT)*COSAZ
C
C
      WRITE(1,100) COSI
  100 FORMAT('COSI',F8.3)
C  CHECK FOR AND CALCULATE DIRECT SUN COMPONENTS
      IF(COSI.GT.0.0) CALL H4CAL
C  ELSE OUTPUT DEFAULT VALUES
C  CONVERT LANGLEYS
      THU=THU/0.271
      UHU=UHU/0.271
C  OUTPUT TO FILE
      CALL PACK(THU)
      CALL PACK(UHU)
C     WRITE(1,101) THU,UHU
  101 FORMAT('THU',F8.3,'UHU',F8.3)
C
      RETURN
      END
ST 3000
$LAB= H4CAL
C::::::::::::::::::::::::::::::::::::::::
C  FOURTH LEVEL CALCULATIONS
C::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE H4CAL
      COMMON /B1/BLAT,RRT,OBF,BIT(365),BTH(365),BTL(365)
      COMMON /B4/SINA,COSI,DCL,DLEV,AIO,RDT,HH,HHD,HHB,DDO,AZ
      COMMON /B5/HUD,HUB,HUT,HR,THU,UHU
C
C
C  HUB
      A=(HHB/HH)**2
      B=1.57-ARCSIN(SINA)
      HUB=HH*20.5*(1.35-0.35*A)*(1.0+(1.0-A)*COSI**2
     ,  SIN(B)**3)
C
C  HUB
      HUB=HHB*COSI/SINA
C
C
C  HUT
      HUT=0.5*HH*COSI**1.5/SINA
C
C  HR
      HR=HH*RRT
C
C  THU
      THU=(HUD+HUB)*(1.0+RRT)
C
C  UHU
      UHU=(HUD+HUT)*(1.0+RRT)
C
C     WRITE(1,990) THU,UHU
990   FORMAT('0','THU',F8.3,'UHU',F8.3)
      RETURN
      END
ST 3000
$LAB= FIREC
C::::::::::::::::
C  OUTPUT MONTHNOS ETC. TO FILE
C::::::::::::::::
      SUBROUTINE FIREC
      COMMON /B3/ARTHNO(12),CALDAY,HOUR,IDAY,ICDAY
      REAL RS2(27)
C
C
      GOTO 11
C     WRITE(1,100)
  100 FORMAT('ENTERING FIREC')
      DO 10 I=1,12,1
      CALL PACK(ARTHNO(I))
   10 CONTINUE
      CALL PACK(CALDAY)
   11 CONTINUE
C
      RETURN
      END
ST 3000
$LAB= PACK
C::::::::::::::::::::::
C  PACK DATA AND SENDOFF
C::::::::::::::::::::::
      SUBROUTINE PACK(UND)
      REAL ARRY(27)
      INTEGER*2 KOUNT,IRECNO,IOFIL
C
C  STUFF INTO ARRY
      KOUNT=KOUNT+1
      ARRY(KOUNT)=UND
C
      IF(KOUNT.LT.27) GOTO 99
C  ELSE SEND OUT
      CALL DIS(IOFIL,IRECNO,ARRY,108,44)
      KOUNT=0
      IRECNO=IRECNO+1
C
   99 CONTINUE
      RETURN
C
C  INITIALIZE
      ENTRY INPACK
      IRECNO=1
      IOFIL=8
      KOUNT=0
      RETURN
      END
ST 3000
$LAB= HUMICH
C::::::::::::::::::::
C  DO HOURLY CALCULATIONS WHICH VARY
C  AND STORE ON DISC
C::::::::::::::::::::
      SUBROUTINE HUMICH
      COMMON /B4/SINA,COSI,DCL,DLEV,AIO,RDT,HH,HHD,HHB,DDO,AZ
C
C
      IF(SINA.LE.0.0) GOTO 11
C  DO CALCULATIONS
      CALL H2CAL
      RETURN
C
   11 CONTINUE
C  ELSE ZERO ALL OUTPUT
C     WRITE(1,100)
  100 FORMAT('PACKING FOUR ZEROS')
      CALL PACK(0.0)
      CALL PACK(0.0)
      CALL PACK(0.0)
      CALL PACK(0.0)
      CALL PACK(0.0)
      CALL PACK(0.0)
      CALL PACK(0.0)
      CALL PACK(0.0)
C
C
      RETURN
      END
TR
$LAB= PUTWET
C-----------------------------------
C  STORE WEATHER DATA
C-----------------------------------
      SUBROUTINE PUTWET
      COMMON /B8/BLDAJ,HINW,HIVW,HIVB,HIBW,HIVE,HIEW,HIVW,HIWW
C
      IOFIL=7
C     WRITE(IOFIL,1)BLDAJ,HIVB,HIBW,HIVE,HIEW,HIVW,HIWW,HIVW,HIWW
    1 FORMAT(8(F8.2,1X),F8.2)
      RETURN
      END
ST 3000
C::::::::::::::::
C  OUTPUT MONTHNOS ETC. TO FLE
C::::::::::::::::
      SUBROUTINE FIREC
      COMMON /B3/ARTHNO(12),CALDAY,HOUR,IDAY,ICDAY
      COMMON /B8/IOFIL,IRECNO,KOUNT
      REAL RS2(27)
C
C
      IRECNO=1
C     WRITE(1,100)
  100 FORMAT('ENTERING FIREC')
      DO 10 I=1,12,1
      RS2(I)=ARTHNO(I)
   10 CONTINUE
      RS2(13)=CALDAY
      DO 20 I=14,27,1
      RS2(I)=0.0
   20 CONTINUE
C
C  SEND
      IRECNO=1
      CALL DIS(IOFIL,IRECNO,KOUNT,RS2,108,44)
C     WRITE(1,101) (RS2(KK),KK=1,13,1)
  101 FORMAT( 13(F5.2,1X))
C
      RETURN
      END
TR
```

APPENDIX K

Climatic Data of Reference Year, Salt Lake City

This is the data file of weather data used for interpolating hourly weather data of the modeling programs. The first number is the beginning day of the data. The next twelve numbers are the number of days per month for the months sequentially from September through August. For each month data is grouped as follows: (1) horizontal insolation for each day, (2) maximum temperature for each day, (3) minimum temperature for each day, (4) degree days for each day (this is not used for the programs). The first number in each line is the line number and not data. The program scans the numbers and bypasses standard Fortran formatted input for numbers. It ignores text and spacing of the numbers.

```
1 C BEGINNING DAY OF DATA
2 243
3 C  NUMBER OF DAYS IN EACH MONTH
4 30 31 30 31 31 28
5 31 30 31 30 31 31
6 C  SEPT
7 C  LANGLEYS
8 579 477 567 628 281 140 518
9 636 580 639 506 591 601 560
10 438 145 193 536 478 587 180
11 414 517 491 616 440 476 106
12 189 506
13 C  MAX TEMP
14 82 84 85 77 77 64 76
15 72 72 80 84 88 83 73
16 74 55 43 54 56 60 57
17 72 71 72 78 83 82 54
18 56 65
19 C  MIN TEMP
20 42 54 54 43 57 50 49
21 50 44 47 55 52 47 47
22 53 39 31 27 35 30 38
23 47 40 40 43 50 49 40
24 40 32
25 C  DEGREE DAYS (NOT USED IN PROGRAM)
26 2 0 0 5 0 0 2
27 4 7 1 0 0 0 5
28 1 18 28 24 19 20 17
29 5 0 9 4 0 0 18
30 17 16
31 C  OCT
32 491 482 471 486 460 474 482
33 465 447 438 430 432 374 428
34 73 230 352 423 377 396 396
35 366 364 358 366 355 357 346
36 352 352 346
37 71 76 80 81 78 71 74
38 78 83 83 76 74 73 79
39 67 59 47 49 65 63 66 66 68 70 68
40 70 69 71 70 72 70
41 38 41 41 43 45 39 37
42 43 45 44 40 39 42 40
43 41 41 36 33 38 34 33
44 34 35 34 32 33 33 35
45 37 37 30
46 10 6 4 3 3 10 0
47 4 1 1 7 8 7 5
48 11 15 18 10 13 16 16
49 15 13 13 16 13 14 18
50 11 10 16
51 C  NOV
52 318 324 387 281 301 231
53 310
54 267 291 274 118 52 220 94
55 128 80 60 137 100 223 273
56 273 141
57 159 69 249 184 287
58 166 218
59 70 73 71 70 68 70 70
60 67 61 59 52 60 58 58
61 66 66 52 60 64 66 62
62 58 61 60 43 48 41 41
63 40 40
64 31 38 40 40 37 40 40
65 34 30 36 38 40 40 46
66 41 38 44 46 38 37 38
67 32 43 42 30 28 26 28
68 20 16
69 14 11 19 10 12 10 10
70 14 19 18 21 20 16 13
71 16 18 17 12 10 10 23
72 21 13 14 28 30 32 33
73 35 37
74 C  DEC
75 214 195 228 176 170 68 35
76 41 111 36 189 139 111 200
77 211 155 146 209 216 123 95
78 46 187 273 89 216 157 71
79 41 92 207
80 40 43 49 45 41 32 28
81 31 46 42 49 49 38 39
82 35 32 30 32 33 27 25
83 30 30 38 43 35 35 53
84 49 44 41
85 20 20 18 23 22 23 23
86 28 29 33 31 29 28 28
87 23 21 20 17 15 13 14
88 23 0 10 22 10 12 28
89 41
90 31 28
91 35 33 31 31 33 37 39
92 36 27 27 25 26 32 32
93 36 38 40 40 41 45 46
94 38 45 41 32 42 41 24
95 20 27 30
96 C  JAN
97 239 260 178 164 210 108 57
98 279 154 168 55 257 260 242
99 249 201 156 83 49 41 37
100 206 176 38 214 208 208 80
101 163 163 163
102 32 34 42 48 51 52 48
103 30 32 35 33 36 37 41
104 40 38 30 30 31 20 30
105 33 44 47 31 33 38 38
106 50 48 52
107 16 15 31 35 39 48 17
108 11 12 25 30 20 18 23
109 21 20 18 24 26 28 16
110 3 18 24 20 19 27 32
111 35 40 27
112 41 40 28 23 20 18 32
113 44 43 35 33 37 37 33
114 34 36 41 38 36 37 48
115 47 34 29 39 39 32 30
116 22 21 25
117 C FEB
118 337 337 337 337 337 337 337
119 296 216 334 398 234 198 280
120 419 339 337 359 395 418 417
121 301 438 423 487 401 90 488
122 39 46 52 59 54 40 38
123 38 35 28 27 31 31 36
124 33 35 41 47 61 65 58
125 64 49 57 65 60 66 44
126 22 22 25 28 37 30 21
127 19 83 13 23 27 28 30
128 89 83 88 84 87 30 83
129 54 31 86 81 10 30 38
130 36 36 44 47 44 48 36
131 46 40 32 30 28 23 81
132 84 34 29 86 21 82 31
133 C MARCH
134 381 475 477 468 476 851 344
135 491 839 497 496 187 279 568
136 639 449 182 648 568 271 568
137 115 378 384 385 864 804 604
138 584 583 582
139 37 37 39 46 61 58 58
140 54 60 48 61 44 48 52
141 56 59 40 31 35 43 60
142 52 48 38 39 53 51 52
143 62 67 74
144 19 15 17 18 20 28 27
145 24 25 20 19 26 31 31
146 28 23 23 12 10 17 30
147 31 24 18 14 26 34 30
148 22 28 43
149 37 39 37 33 29 23 23
150 26 27 31 38 30 25 23
151 23 24 33 43 42 35 20
152 23 29 37 38 25 22 24
153 20 12 6
154 C APRIL
155 507 414 574 296 492 439 398
156 373 315 181 327 411 605 556
157 607 567 494 518 475 497 547
158 692 153 585 686 748 747 724
159 661 458
160 71 56 61 61 54 58 53
161 58 51 45 46 53 53 58
162 66 71 60 64 73 77 76
163 77 53 66 67 65 66 71
164 79 80
165 42 39 31 33 37 41 40
166 40 34 33 32 28 33 34
167 34 44 36 42 46 48 47
168 45 43 38 43 36 33 39
169 52 50
170 8 17 19 18 19 15 18
171 16 22 28 26 24 22 19
172 16 7 17 12 5 2 3
173 4 17 13 10 14 16 10
174 0 0
175 CMAY
176 662 747 748 205 112 814 283
177 352 614 782 774 768 338 518
178 776 778 739 719 562 670 413
179 681 628 421 561 709 819
180 809 806 659 690
181 75 60 64 68 55 46 47
182 61 57 65 70 74 67 69
183 71 82 70 76 77 68 76
184 76 65 61 65 62 67 76
185 88 86 78
186 47 38 31 41 29 25 27
187 35 37 38 37 39 48 50
188 43 46 60 48 46 50 60
189 62 41 43 48 41 37 40
190 45 62 48
191 4 16 17 10 23 29 28
192 22 18 13 11 8 7 5
193 8 1 5 6 4 6 8
194 1 18 13 11 13 13 7
195 1 0 8
196 C JUNE
197 534 662 790 803 798 787 784
198 628 381 570 707 406 810 689
199 394 658 608 843 806 815 800
200 781 733 220 386 225 738 800
201 798 836
202 73 79 80 79 80 85 86
203 84 77 77 82 86 73 76
204 77 71 75 88 83 85 90
205 92 91 69 76 65 70 78
206 84 93
207 43 43 42 47 44 50 56
208 57 55 54 57 56 50 52
209 44 49 46 47 44 50 53
210 57 56 54 52 46 50 43
211 46 49
212 7 4 4 2 3 0 0
213 0 0 0 0 0 3 1
214 4 5 4 1 1 0 0
215 0 0 3 1 9 5 4
216 0 0
217 C JULY
218 817 810 824 780 835 761 539
219 694 791 521 682 799 793 696
220 520 506 516 567 635 749 778
221 583 642 552 547 754 733 767
222 652 360 466
223 85 83 89 93 88 90 90
224 94 98 94 92 85 91 97
225 96 94 90 87 85 87 92
226 85 90 90 80 90 92 98
227 97 80 85
228 59 52 51 58 53 51 62
229 59 68 72 69 54 50 55
230 65 63 58 62 61 58 56
231 67 62 59 61 62 59 64
232 65 66 60
233 0 0 0 0 0 0 0
234 0 0 0 0 0 0 0
235 0 0 0 0 0 0 0
236 0 0 0 0 0 0 0
237 0 0 0
238 C AUGUST
239 371 636 586 693 716 628 618
240 631 534 650 657 608 633 633
241 674 587 310 257 364 465 458
242 440 593 673 657 649 673 620
243 653 670 667
244 79 87 90 87 89 91 97
245 97 97 96 95 94 86 88
246 87 89 83 70 74 83 74
247 80 80 85 87 83 80 87
248 77 73 77
249 64 61 61 55 54 60 56
250 65 66 61 62 64 60 60
251 63 59 66 57 54 53 51
252 51 53 54 66 60 68 58
253 50 43 37
254 0 0 0 0 0 0 0
255 0 0 0 0 0 0 0
```

APPENDIX L

Monthly Mean Temperatures, Relative Humidities and Related Humidity Ratios for Salt Lake City.

	TM	TI*	Relative Humidity	WO	WI (RH = 30%)
January	28	68	68	0.003	0.0052
February	33.4	68	65	0.0032	0.0052
March	39.6	68	53	0.0035	0.0052
April	49.2	78	42	0.0039	0.0075
May	58.3	78	34	0.0044	0.0075
June	66.2	78	29	0.005	0.0075
July	76.7	78	23	0.0055	0.0075
August	74.6	78	26	0.0056	0.0075
September	64.8	78	31	0.0048	0.0075
October	52.4	78	42	0.0042	0.0075
November	39.1	68	63	0.0038	0.0052
December	30.3	68	71	0.0031	0.0052

* The inside temperature, TI, is assumed steady state, for winter 68°F, for summer 78°F.

APPENDIX M

Hourly Temperature and Vertical Insolation Subroutine

Using weather data for total daily horizontal insolation, this subroutine calculates total hourly insolation for vertical facades of any orientation. Hourly temperatures are also calculated from daily high and low temperatures. These three pieces of information are readily found for numerous locations from U. S. Weather Service data. The radiation prediction draws heavily on the technique of Liu and Jordan,[1] while the temperature prediction is an approximate method developed here. Both were used extensively in developing performance information for active solar systems.[2] Some parts of this have been reported in a Master of Science thesis.[3]

The daily weather data should represent an average year. Averaging of insolation data can be achieved by normalizing a particular year's daily data according to monthly insolations averaged over several years. Or:

$$H_a = H_d \left[J \cdot H_m / \sum_{i=1}^{J} H_{di}\right]$$

where H_a = average daily solar radiation

H_d = daily solar radiation (specific weather year)

J = number of days in the month

H_m = average daily solar radiation for the month.

The temperatures can be normalized using compiled values for degree days averaged for each month. Our model used instead a year with reasonably average monthly insolation and degree days.

For each day, the day number, total insolation, and high and low temperatures are read in. The daily calculations include declination, δ,[1]

$$\delta = 23.45 \sin \left(360 \frac{284 + n}{365}\right)$$

where n = day of the year. The sunset hour angle ω_s is

$$\cos \omega_s = -\tan \delta \tan \phi$$

where ϕ is the latitude.

The declination and day length are then used to calculate H_o, the total daily extra-terrestrial insolation on a horizontal surface at that latitude.[1]

$$H_o = \frac{24 \times 3600\, G_{sc}}{\pi} \left[1 + 0.033 \cos \left(\frac{360n}{365}\right)\right] \cdot$$

$$\left[\cos \phi \cos \delta \sin \omega_s + \frac{2\pi\omega_s}{360} \sin \phi \sin \delta\right]$$

where G_{sc} = solar constant.

The ratio of terrestrial (weather data) horizontal to extra-terrestrial daily insolation is then used in an empirical equation which determines the ratio of diffuse to total radiation.[3]

$$DOH = 0.9733 + 0.1767\, KT - 3.783\, KT^2 + 2.833\, KT^3$$

where

DOH = ratio of daily diffuse to total radiation

KT = ratio of daily total to extra-terrestrial radiation.

After the daily-varying parameters are set, the hourly varying parameters are calculated. The ambient temperature, T_o is taken to vary sinusoidally between the maximum and minimum temperatures of the day. A slight shift relative to solar noon is inserted.[3]

$$T_o = \frac{T_{max} + T_{min}}{2} + \left[\frac{(T_{max} - T_{min})}{2}\right] \cdot$$

$$\cos (0.262\, t - 0.0436\, t_d)$$

where t = time of day

t_d = day length.

The sine of the altitude angle (SINA) is next calculated to determine when to start the daytime calculations and for use in the conversion from horizontal to vertical insolation.[4]

$$SINA = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega$$

where ω is the hour angle. If SINA is less than zero, all of the radiation variables are set to zero. As soon as SINA is greater than zero, the insolation components are calculated.

The horizontal total hourly insolation and horizontal diffuse hourly insolation are distributed differently over the day.[3] The daily diffuse component is found using the ratio of diffuse to total from the daily calculation, as indicated above. The hourly total and diffuse insolations are found using empirical relations which vary approximately sinusoidally with day fraction from solar noon.[3] The hourly total radiation to the daily total radiation, R_T, was curve fit from the classical work of Liu and Jordan.[3]

$$R_T = [a_1 + b_1 (2g/t_d) + c_1 (2g/t_d)^2 + d_1 (2g/t_d)^3 + e_1 (2g/t_d)^4 + f_1 (2g/t_d)^5]/t_d$$

1. J. Duffie and W. Beckman, SOLAR ENGINEERING OF THERMAL PROCESSES, Wiley-Interscience, 1980.

2. R. Boehm and S. Swanson, SOLAR SYSTEM DESIGN HANDBOOK FOR UTAH, Utah Engineering Experiment Station, 1978.

3. T. Newell, PARAMETRIC STUDIES OF ACTIVE RESIDENTIAL SOLAR HEATING SYSTEMS, MS Thesis, University of Utah, 1980.

4. F. Kreith and J. Kreider, PRINCIPLES OF SOLAR ENGINEERING, McGraw-Hill, 1979.

where g = hour from solar noon

a_1 =	1.8128184	d_1 =	- 15.232471
b_1 =	- 1.6258314	e_1 =	13.931593
c_1 =	5.0047414	f_1 =	- 3.852214

A similar method of least squares fit was developed for the hourly diffuse radiation to daily diffuse radiation, R_D.

$$R_D = [a_2 + b_2 (2g/t_d) + c_2 (2g/t_d)^2 + d_2 (2g/t_d)^3 + e_2 (2g/t_d)^4 + f_2 (2g/t_d)^5]/t_d$$

where

a_2 =	1.7009221	d_2 =	- 34.836388
b_2 =	- 2.3402858	e_2 =	38.541068
c_2 =	11.961985	f_2 =	- 15.046364

From the hourly total radiation and the hourly diffuse radiation, the hourly beam radiation can be calculated.

$$I_b(t) = (R_T - R_D) \cdot H_a$$

Now that the horizontal beam and diffuse components have been found, the insolation for a particular facade can be calculated. The angle of incidence is the angle between the perpendicular to a surface and the sun's rays on the surface. The amount of insolation intercepted by a surface is a function of the cosine of the incidence angle (COSI). For a horizontal surface COSI = 1/SINA. Therefore, the direct beam insolation on a surface facing the sun can be found by dividing the hourly total horizontal insolation by SINA.

The model has a ground reflectance incorporated to account for this type of solar interaction. This is used with the beam component always, and the diffuse component also when a facade intercepts the beam component (see more on this below). It is assumed in the model that the diffuse radiation is uniformly distributed over the sky. For that reason, the view factor for the diffuse component is simply 0.5.

When a facade is not in the direct sunlight (COSI less than zero), the insolation is assumed totally diffuse with no ground reflected component. This is a simplification to an equation proposed by Klucher.[5] When COSI is greater than zero, the vertical beam and diffuse components are calculated separately, added together, and multiplied by one plus the ground reflectance to determine the total hourly vertical insolation.[5]

---

5. T. M. Klucher, "Evaluation of Models to Predict Insolation of Tilted Surfaces," SOLAR ENERGY, Vol. 23, No. 2, pp. 111-114, 1979.

APPENDIX N

Air-Flow Window Application: Questions and Answers

The following questions and answers cover areas not directly related to the main scope of work of the project (testing and performance modeling). They are helpful, however, in the discussion on the applicability of air-flow windows and as a basis for the demonstration project outline in Section 8.

The questions and answers were developed from numerous site visits in buildings with air-flow windows in Europe and from interviews with architects and engineers who have designed and operated such buildings. The format was chosen as many advantages and disadvantages of building components cannot be fully described with measurable parameters but are, nevertheless, of tangible value. Where applicable, answers are based on the test and modeling results as shown in previous sections of the report.

1. For which building types are AF windows most suitable?

AF windows are most suitable for buildings which are designed with large window to opaque wall ratio, for example, in buildings for which large daylight contributions are desired. While air-flow windows have been used in many building types, their major application has been in office buildings.

The small temperature difference of AF windows between inside window surface and room air, 5 to 7°F at t outside to inside of 50°F, results in very favorable mean radiant temperature conditions, compared with other glazing types (20°F for double insulating and 12.5°F for triple insulating glass at the same t). This favors their application in buildings where down-drafts close to windows or asymmetrical radiant conditions related to windows must be minimized, for example, in clinics and hospitals.

In buildings with large fresh-air rates, that is, larger or the same as the AF window cavity flow rates, exhaust-air windows will perform favorably, if energy recovery systems are not used for exhaust air. With energy recovery systems, return-air windows may perform better; especially during the winter season, as the performance modeling results show (see Section 7 of main report).

2. Which types of HVAC systems have been used in buildings with AF windows?

AF windows reduce the impact of climate and weather conditions on the interior environment by means of a facade-integrated air stream. Generally, shading devices are also located in this transition zone and interact thermally with the air stream. Therefore, the heating and cooling loads of the exterior zones of buildings with AF windows are considerably lower, which may result in smaller HVAC distribution and central systems than for conventional buildings. The sizing of the HVAC distribution system will be governed by occupant air change requirements and not, as often the case, by heat gain/heat loss conditions.

AF windows influence mainly the HVAC systems for the exterior zones of buildings which are typically assumed to have a depth of 20 to 30 feet. Because of the smaller temperature difference between room air and inside window surface as compared with conventional window systems, the air supply outlets need not be located close to the window wall.

For exhaust-air windows pressurization of the building is necessary to overcome the resistance of the window and its air check valve which protects against outside wind pressures. Protecta-Sol gives excess pressures in the room for good functioning of its exhaust-air windows as shown in Figure A5.1.5.

The simplest HVAC system with exhaust-air windows is the supply duct air distribution as shown in Figure A5.1.9. Depending on building zoning, internal heat gains, needs for individual room control, etc., such a system may use a single or dual duct system with or without the air supply volume to the exterior building zone being subject to low limit control required for pressurization.

With return-air windows, all-air or water-air systems are chosen mainly with respect to the general building functions and loads. The air-flow windows may be considered as the terminal parts of the return duct systems in the exterior zones of the building. Conventional dual duct systems with or without variable volume control have been used.

A minimum air flow through the windows is provided for either constant volume or variable volume application. The remainder of the room air is returned through grilles or lighting fixtures. The Swedish Combivent System shows an arrangement of a dual duct system which allows constant or variable volume operation (Figure A.5.2.1).

3. Do AF windows, considering their all-year performance, yield advantages only in areas with strong daily and seasonal climate fluctuations or are they helpful also in mild climates?

AF windows are especially useful in climates with strong seasonal climate fluctuations and high solar radiation impact on buildings. The peak loads are reduced, particularly for cooling, as the air flow combined with the adjustable shading devices allows direct transport of radiation energy to the outside.

In mild climates, the relatively small energy savings achieved by AF windows generally will not balance their rather high additional first cost.*

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* Typical exhaust-air window systems including outer 1 inch double pane insulating glass, inner single pane glass and white vertical louver blinds are 40 to 50 percent more expensive than conventional 1 inch double pane insulating glass with the same louver blinds (information on recent projects by P. Wiedmer, Protecta-Sol, February 1981). Preliminary cost estimates for return-air windows with outer 1 inch double pane insulating glass, inner single pane glass and white venetian blinds have been estimated at about $12 above 1 inch double insulating glass windows with the same blinds on the room side (Steve Fronek, Wausau Metals Corporation, May 1981).

HVAC systems in mild climates can run during large portions of the year on economizer cycles for which AF windows are not advantageous compared with conventional systems.

4. What has to be considered in life-cycle costing of AF windows versus conventional window systems?

As mentioned above, first costs of AF windows are 40 to 50 percent higher than conventional window systems, such as double-pane insulating glass with venetian blinds inside. In the case of the return-air window, first costs for return air connections must be added. They are subject to a wide variety of design configurations but are small or negligible if the integration of the connections occurs during the design stage of the project.

Against these first costs, the following major advantages of AF windows must be considered:

1) Reduction in first costs of the HVAC equipment and distribution system (in case of an exhaust-air window, possibly the omission of the return-air system);

2) Reduction of space requirements because of a smaller HVAC system;

3) Decrease in yearly energy consumption for heating, cooling and electrical lighting;

4) Reduction in peak load conditions and related peak energy demand ratings;

5) Lower costs to achieve improved thermal and visual comfort conditions.

5. How does the ratio of perimeter versus core area of a building influence the applicability of AF windows?

The larger the exterior zone compared with total floor area, the stronger is the influence of the outside environment on the energy performance of a building. This influence can be advantageous, or it may present problems depending on the way the building skin is functioning in response to the exterior environment.

If full advantage is taken of daylight while using AF windows, a considerable reduction in artificial lighting consumption is the result. With proper shading, which AF windows can provide, a strong reduction of external and artificial lighting heat gains is achievable.

Internal zones of buildings are normally not influenced by AF window applications. In open spaces - for example in office landscaping where exterior and interior zones are not separated - part or all of the return air from the interior zone may also be used for window cavity air supply. In buildings with large interior zones and where physical separations exist, such zones obviously must have their own return system.

One of the most favorable situations exists when the requirement for circulated air in the exterior zone matches a high enough air-flow rate for successful AF window operation.

6. What are the advantages of AF windows in projects with daylighting being of prime consideration?

The AF window assembly with blinds in the cavity is highly adjustable to the nature and interdependence of solar radiation and daylight levels. With light-colored venetian blinds especially, the daylight factor sequence into space depth can be achieved as a much flatter curve than at open window light (Figures N1 through N3) and, in addition, glare is reduced.

The blinds can be completely retracted at times of low outside light levels, thus allowing maximum utilization of the available daylight. When sun shading is needed, light-colored venetian blinds provide deep penetration of daylight into the space while effectively keeping out direct sunlight. With the exception of exterior venetian blinds, no other shading device can achieve such results.

Dark-colored blinds do not have the advantage of providing substantial daylight penetration. Where solar heat gains are desired the higher absorptivity of dark blinds will support the collector properties of the AF windows.

7. How does the application of energy recovery equipment influence the energy efficiency of AF windows?

Energy recovery systems can save 30 - 60 percent of the heating and 20 - 40 percent of the cooling energy from the exhaust air stream of a building. Sensible and latent heat may be recovered.

With exhaust-air windows this function does not come into play as, typically, most or all of the exterior building zone air is discarded directly through the windows. Actually the exhaust-air window may be considered a type of energy-recovery system as it reduces room heating and cooling loads by use of exhaust air. If the minimum cavity air flow is less or about the same as the fresh air rate of this zone, then the exhaust air window is highly efficient as there is little or no return air flow through the conventional return air system. In special cases this system may even be omitted.

The larger the minimum cavity air flow compared with the fresh-air rate of the exterior zone, the more efficient is the return-air window (see Section 7 of main report).

The portion of air which is not discarded is treated in the central HVAC system before recycling. Energy recovery can be applied to the discarded portion. If this portion is small, energy recovery may not be economically feasible unless it is large in actual cfm. Obviously the larger the overall exhaust-air portion of the total building air flow, the more favorable the application of energy recovery.

In cases where heating and cooling loads often occur simultaneously, recovery may be used for energy savings through "load shifting" from one part of the building to another. Under favorable solar radiation conditions, return-air windows may func-

tion as a solar collector system and provide useful and rather easily transported solar gain for heating elsewhere, with or without intermediate energy storage.

Whether an energy recovery system together with AF windows should be applied or not can only be decided within the context of a particular building situation and after a computerized yearly energy consumption analysis has been performed.

8. Do high internal heat gains from people, production processes and artificial illumination favor the application of AF windows?

High internal heat gains require large amounts of circulating air for transporting this energy to the outside. An alternative is the cooling of the air locally by means of elaborate water-air systems such as induction units. For buildings with such heat gains, thermal balance points between the outside and inside below 40° or even lower are quite common.

For example, the largest office building in Salt Lake City has, during occupancy, a balance point of 24°F at no solar influence and a balance point of 17°F at solar influence. The mean monthly outside temperatures for Salt Lake City from November through March fluctuate from 39.1° to 28.0° to 39.6°F. The building is in a cooling mode nearly all the time, even through the coldest winter months.

Under such conditions, and if large exterior building zones are present as they are in the example, AF windows would perform very well. During most of the year, the building could be run on an economizer cycle in conjunction with AF windows. Such windows would be especially helpful in reducing solar impact which would allow longer use of the economizer cycle at the beginning and end of summer.

Large exterior zones and window surfaces with considerable fresh air needs will favor the application of exhaust-air windows. Energy recovery equipment will not help during most of the heating season, as large amounts of excess heat will be available. Whether it would be economical in consideration of the cooling season is rather doubtful and would have to be analyzed carefully.

9. How do major facade orientations, for example east-west versus north-south, affect the choice for or against AF windows?

Buildings with the same facade in all orientations have been notoriously energy-inefficient with respect to heat gains and daylighting unless exterior adjustable blinds are used. Such blinds have not been popular in the United States. The AF window concept provides a situation similar to the customary application of (inside) blinds in this country with somewhat similar effects of exterior blinds.

In buildings for which the same facades are desired in all directions fixed shading devices do not provide adequate solar protection and at the same time allow favorable daylight utilization. AF windows with integrated blinds can provide the necessary dynamic response. However, they must be adjusted periodically to provide full shading. Because of the small solar altitude changes from day to day at southern orientations, venetian blind slat angles must be adjusted only in long-term increments, say monthly. Vertical blinds must be adjusted several times in the course of a day. At east and west orientations one or two adjustments are required per morning and afternoon respectively.

Such adjustments can be done by the occupants, which is also customary for inside blinds. Automatic adjustment by mini-motor is also available with radiation sensors and appropriate controls.

Facade orientations evolve mainly from restrictions of particular sites and from functional building requirements. Because of the favorable responsiveness of AF windows to high solar impact, they lend themselves very well to installations where extensive east/west fenestrations are unavoidable.

10. How are the comfort conditions in buildings influenced by AF windows?

During winter the inside window surfaces are generally colder than the air temperature in the room. This temperature difference creates air currents and possible drafts within short distances from the window. These lower temperatures also create asymmetric radiant conditions for thermal comfort even at considerable distances from windows.

At an inside temperature of 70°F and an outside temperature of 32°F, conventional double-pane insulating glass has a temperature difference from room to surface of 15°F and triple-pane glass a difference of 9°F. AF windows at a typical cavity air flow of 4 cfm per foot of window width yield a difference of only 4°F. At such a small difference level, resulting air currents are too small to be perceived as draft (see Section 5.5 of main report).

Also, comfort conditions often are impaired by high heat gains under solar radiation impact. Interior venetian blinds, although shading against direct solar exposure, cannot prevent the greenhouse effect and reradiate part of the absorbed energy to the room. With blinds in the AF window cavity the reradiation impact is reduced. Most of the absorbed energy is transported away by the cavity air stream.

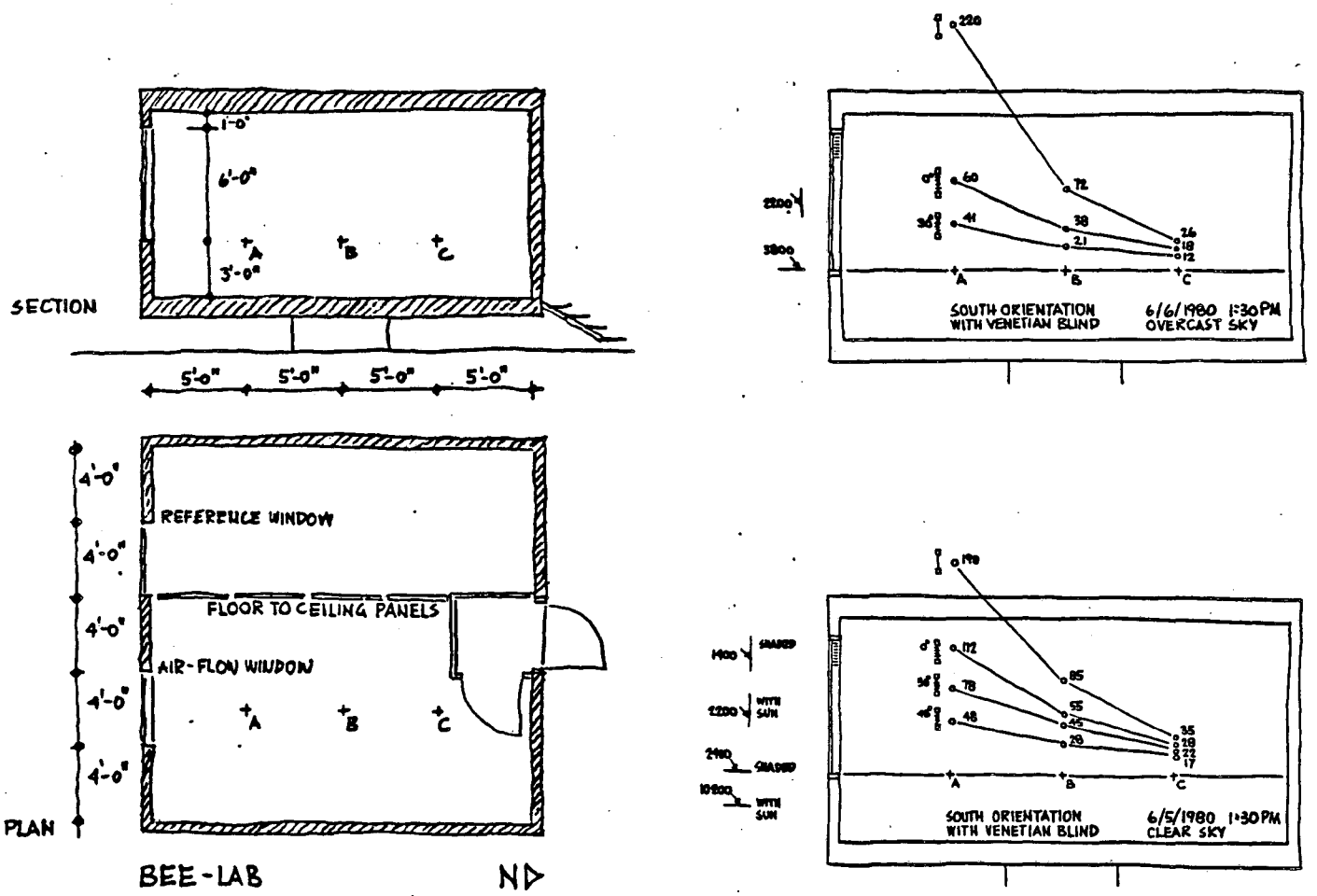
11. Do the energy savings from lower space heating/cooling loads over a year's period considerably outweigh the energy lost or gained in the window cavity, and if applicable, in the exhaust air?

This is one of the most difficult questions to answer in a general way with regard to the performance of AF windows, but it is one of the most important. In addition, the fresh air requirements of a particular project must be considered.

In comparing the performance data for the reference window, which relates to space heating-cooling loads only, and the data for the AF windows, which relates to both space loads and loads absorbed in the window cavity, one will conclude that AF window applications bring large energy savings. The

main reason is the fact that the attack against impact on the internal environment is fought in the envelope after the cavity air has been used for space heating or cooling. The energy gained or lost in the window cavity does not affect the internal environment and, as generally most of the cavity air will be discarded for fresh air replacement, does not add substantially to the HVAC load, if at all.

The advantage of utilizing some or all of the exhaust air and its energy content for a tempering effect is clearly established in the performance data given in Section 5 and in the performance modeling results in Section 7 of the main report. It is necessary, however, that fresh air rates, which allow favorable operation of an AF window system, be available. The answers to questions numbers 1 and 8 must be considered in this context. Computerized yearly energy consumption analysis is indispensable because of the many variables and the bulk of data involved.



Figures N1 through N3. Daylight measurements in Building Environment and Energy Laboratory, University of Utah.

NOMENCLATURE

$a_1, b_1 \ldots f_1$	constants for curve fit
$a_2, b_2, \ldots f_2$	constants for curve fit
A_b	reference window test box area (ft^2)
A_g	glass area (ft^2)
A_w	gross area of window (ft^2)
CFM	cubic feet per minute per ft of window width
C_p	specific heat of air (Btu/lb F)
COSI	cosine of incidence angle
DOH	ratio of diffuse to total horizontal radiation
f	functional relationship
FR	outside air fraction
g	hour from solar noon or gravitational acceleration
G_r	Grasoff number
G_{sc}	solar constant (Btu/sec ft^2)
h_c	convective heat transfer coefficient (Btu/hr ft^2 F)
h_r	radiative heat transfer coefficient (Btu/hr ft^2 F)
h_{total}	total heat transfer coefficient (Btu/hr ft^2 F)
H_a	average daily solar radiation (Btu/ft^2)
H_d	daily solar radiation (specific year) (Btu/ft^2)
H_m	average daily solar radiation for the month (Btu/ft^2)
H_o	total daily extraterrestrial insolation, horizontal (Btu/ft^2)
H_1	fraction of long wave radiative transmission
H_2	fraction of solar energy absorbed in window cavity air stream
I_b	hourly beam radiation (Btu/hr ft^2)
I_o	outside solar irradiation of the vertical window plane (Btu/hr ft^2)
I_{tr}	directly transmitted solar radiation in the vertical window plane (Btu/hr ft^2)
J	number of days in the month
K	thermal conductivity (Btu/hr ft F)
L	height of window (ft)
KT	ratio of daily total to extraterrestrial radiation
$\dot{m}_1$	mass flow of air through window cavity (lb/hr)
$\dot{m}_2$	mass flow of air through reference window test box (lb/hr)
Nu	Nusselt number
n	day of the year

P_{atm}	atmospheric pressure (psi)
Pr	Prandtl number
QEAF	energy balance of air-flow in exhaust-air window (Btu/hr) or (Btu/month)
Q_{FR1} = QFRESH 1	sensible heat content of fresh make-up air (Btu/hr) or (Btu/month)
Q_{FR2} = QFRESH 2	latent heat content of fresh make-up air (Btu/hr) or (Btu/month)
QI	QS less the directly transmitted solar energy (Btu/hr) or (Btu/month)
QRA	energy balance of air-flow in return-air window (Btu/hr) or (Btu/month)
QRC	energy needed for treating recycled air (Btu/hr) or (Btu/month)
QREF	energy balance of reference window (Btu/hr) or (Btu/month)
QRT	heat loss or gain of returned cavity air (Btu/hr) or (Btu/month)
QS	energy balance of window, that is, transfer at inner window surface neglecting energy in cavity air flow, if present (Btu/hr)
RB	radiation ratio (transmissivity)
R_D	ratio of hourly diffuse radiation to daily diffuse radiation
R_T	ratio of hourly total radiation to daily total radiation
SC	shading coefficient
SHGF	solar heat gain factor
SINA	sine of the altitude angle
SQEAF	net energy balance of exhaust-air window (Btu/month)
SQRA	net energy balance of return-air window (Btu/month)
SQREF	net energy balance of reference window (Btu/month)
t	time of day
t_d	day length (hr)
T_{ave}	temperature for fluid property evaluation or average of T_{wi} and T_i (F)
T_{bl}	temperature directly behind (room side) venetian blind of reference window, (F)
T_{box}	inner surface temperature inside test bos of reference window (F)
T_{fi}	inlet temperature of air to air-flow window (F)
T_{fx}	exit temperature of air from air-flow window (F)
T_i	inside room temperature (F)
TM	monthly mean outside temperature (F)
T_{max}	maximum temperature (F)
T_{min}	minimum temperature (F)
T_o	outside temperature (F)
T_{ri}	inlet temperature of air to reference window test box (F)
T_{rx}	exit temperature of air from reference window test box (F)

T_{wi}	inside temperature of window glass surface (F)
U_b	U of test box of reference window (Btu/hr ft^2 F)
U_r	transmission coefficient of reference window (Btu/hr ft^2 F)
U	overall heat transfer coefficient (Btu/hr ft^2 F)
U_1	effective heat transfer coefficient (Btu/hr ft^2 F)
U_2	pseudo heat transfer coefficient (Btu/hr ft^2 F)
WI	inside humidity ratio (lb H_2O/lb dry air)
WO	outside humidity ratio (lb H_2O/lb dry air)
WW	window width (ft)
β	coefficient of thermal expansion (1/R)
ε_{glass}	long wave length emissivity
ω	hour angle
ω_s	sunset hour angle
δ	declination
ϕ	latitude

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