NATURAL VENTILATION GENERATES BUILDING FORM

by

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Bachelor of Architecture
University of Southern California
May 1994

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ARCHITECTURE STUDIES
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 1996

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Abstract

Natural ventilation is an efficient design strategy for thermal comfort in hot and humid climates. The building forms can generate different pressures and temperatures to induce natural ventilation. This thesis develops a methodology that uses a computational fluid dynamics (CFD) program. The purpose of the CFD program is to assist architects to design optimum building form for natural ventilation. The design of a cottage in Miami, Florida demonstrates the application of this methodology.

The first phase of this methodology is to create an input file for the CFD program. The input file uses wind velocity, wind direction, and air temperature of the site to simulate the weather. Different weather conditions can be generated through modification of the first input file.

The second phase of this methodology is to develop building forms. The CFD programs can simulate airflow in different building forms by changing the building geometry in the input files. The program calculates the airflow pattern, velocity, and temperature for different forms. The printouts of the simulations allow architects to understand the airflow behavior in spaces with different forms.

This thesis also uses the CFD program to study variance between the proposed and the actual results of a design. As demonstrated in a sports museum in Washington, DC, this case study clearly displays a difference between the intentions of the architect and the results of CFD calculation.

Some problems appear in developing CFD models. However, when the input files are correctly defined, and the calculations converge, very few computational problems appear in developing building forms. Therefore, architects can easily use the CFD programs to develop building form after the input files are correctly defined.

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1 Introduction

Thermal comfort is one of the most essential design aspects in architecture. A building can maintain thermal comfort through many passive design strategies. Among these strategies, natural ventilation is most efficient in achieving thermal comfort in hot and humid climates. Ventilation may remove heat from the human body by evaporation and convection and reduce indoor air humidity by exchanging air (Olgyay 1963, 17).

Ventilation may achieve human comfort only when air is moving in the proper velocity and pattern. People are extremely sensitive to airflow velocity. A certain air velocity will achieve human comfort while higher air velocity is considered drafty, and lower air velocity generates complaint about stagnant conditions. On the other hand, airflow can achieve human comfort only when it passes over human skin; therefore, air needs to flow through the area of human activities (Egan 1975, 12).

Indoor airflow is generated by different air pressures caused by wind or different temperatures between spaces. When wind blows against a building, the air generates a positive pressure on the windward side and a negative pressure on the leeward side of the building. The different pressure will induce airflow through the building if the windows are located on both the windward and leeward sides. Also, the warmer indoor air is lighter and tends to rise to the ceiling, and the heavier cooler outdoor air tends to enter the building from lower openings. If the outlet windows are located higher than the inlet windows, a stack effect will generate airflow between these windows (Konya 1980, 52-3).

The location of windows, the shape and location of partitions and the building envelope may change the indoor airflow pattern and velocity. If the space is designed thoughtfully, the building form may induce the proper airflow pattern and velocity throughout the building.

In order to design a building form that may generate the proper airflow velocity and pattern, it is important to use proper tools to predict the airflow behavior. Airflow behavior has been described by the theory of fluid mechanics which involves some complicated mathematical equations. Taking the advantage of the computer as a powerful calculation tool, several computational fluid dynamics (CFD) programs have been developed to solve these complicate mathematics and make the prediction of airflow accessible for application.

Among these CFD programs, the Parabolic, Hyperbolic, or Elliptic Numerical Integration Code Series (PHOENICS) is suitable for the purpose of predicting airflow pattern. PHOENICS can provide the user with the airflow velocity, pattern, and temperature through space in a combined study of indoor and outdoor airflow (CHAM 1991, 1.1). The graphical output displays the comfortable area in a room and can be easily interpreted and used to create building form.

Development of a methodology of using the CFD tools to develop optimal building form for natural ventilation is the topic of this research. The first phase is to establish the CFD models to simulate the climate condition. The second phase is to utilize these CFD models to design building forms. PHOENICS plots the airflow pattern, velocity, and temperature which allow the architects to adjust the building form for better airflow. The purpose of developing this methodology is to assist architects in designing optimal building form for natural ventilation. This allows architects to model and control airflow behavior and to generate proper natural ventilation within the building. Design of a beach cottage in Miami, Florida is developed in this thesis to illustrate the application of the methodology.

2 Thermal Comfort

2.1 Theory of Thermal Comfort

Human Body Temperature

The human body naturally maintains a constant internal temperature of 37°C (98.6°F). In order to maintain this temperature, the human body releases superfluous heat generated by metabolic activities to the environment. The release of heat is accomplished by circulating blood near the skin. The blood carries heat from deep within the body to just below the skin surface and releases it to the environment. A physiological process controls the blood migration and therefore controls this heat transfer to the environment.

When the ambient temperature is low, the vessels near the skin constrict to reduce the blood circulation while the vessels deep in the body dilate to maintain a large portion of blood circulating among the vital organs. This process reduces heat loss to the environment and keep the deep body's internal temperature at 37°C. When the ambient temperature is too low, too much heat flow from the body to the environment. The internal body temperature can no longer be maintained in 37°C, and shivering occurs to produce extra internal heat and prevent further drop of body temperature.

When the ambient temperature is above comfortable condition, the human body needs to expend extra heat to the environment. The vessels near the skin dilate to increase the amount of blood circulation. Blood circulation increases the skin temperature and increases heat loss through skin by convection and radiation. When the skin temperature reaches 37 °C throughout the body, no more heat loss occurs by convection or radiation. This causes the human body to sweat. Sweating brings extra heat to the environment and also take latent heat to the environment by evaporation (Moore 1993, 31).

Theory of Heat Transfer

Human body releases heat to the environment through conduction, radiation, convection, and evaporation (Bradshaw 1993, 14). The four mechanisms of heat transfer occurs in different environmental conditions. These four theories are explained as follows:

Conduction heat transfer happens when skin directly contacts cold objects such as cloth and floor. The equation for conductive heat loss is:

$$Q_{cond} = U \times A_{sk} \times \Delta T \qquad (2.1)$$

where Q_{cond} is the conductive heat loss (kcal/hr).
U is thermal conductivity of the object (kcal/m^2 hr °C).
A_{sk} is the skin area which has contact with the object (m^2).
ΔT is the temperature between skin and the object (°C).

The human body is mostly covered with clothing which is generally made of good thermal resistance material. The thermal conductivity for cloth is very small. This makes the conductive heat loss through cloth very little even though the area between body and clothing is large. Some area of skin has direct contact with the cold surface such as a hand to the table and a foot to the floor. Even though the temperature and thermal conductivity for these materials are relatively large, the area of direct contact is small, so the conductive heat loss is small. The conductive heat loss is so small that it is usually neglected.

Radiant heat transfer occurs when the human surfaces (e.g. bare skin and clothing) have a temperature difference to the temperature of the surrounding surfaces such as windows and walls. The surrounding surfaces do not have direct contact with the human surfaces when radiation occurs. The equation for radiation is:

$$Q_{rad} = A_{cl} \times \varepsilon \times \sigma \ (T_{cl}^4 - T_{mrt}^4) \qquad (2.2)$$

where Q_{rad} is the radiation heat loss (kcal/hr).

A_{cl} is the outer area of clothed body (m^2).

ε is the emittance of the outer surface of the clothed body.

σ is the Stefan-Boltzmann constant (4.96×10^{-8} Kcal/m^2 hr $^oK^4$).

T_{cl} is the absolute temperature of the cloth surface (^{o}K).

T_{mrt} is the absolute mean radiant temperature (^{o}K).

The magnitude of radiant heat loss depends on the temperature difference, the absorption of the surface, and the distance between the surfaces. Mean radiant temperature (MRT) is the combined measure of the surface temperature and the surface exposure angle. The larger the difference between the surface temperature of human skin and clothing and the MRT of the walls and windows in a room, the greater the radiant heat loss. Radiation accounts for about 40 percent of total human body heat loss (Egan 1975, xiii).

Convection heat transfer primarily occurs when air flows passing skin surface. When air is passing the skin, it absorbs heat from skin if the skin temperature is higher than the air. The equation for convection is:

$$Q_{conv} = A \times f_{cl} \times h_c \times \Delta T \qquad (2.3)$$

where Q_{conv} is the convection heat loss (kcal/hr).

A is the surface area of the nude body (m^2).

f_{cl} is the ratio of the surface area of the clothed body to the surface area of the nude body.

h_c is the convective heat transfer coefficient (kcal/$m^2 \cdot$hr$\cdot$ ^{o}C).

ΔT is the temperature difference between air and skin (^{o}C).

In the case of buoyancy-driven convection with air velocity less than 0.1 m/s, the convective heat transfer coefficient is calculated as:

$$h_c = 2.05\ \Delta T^{0.25} \qquad (2.4)$$

In this case, the conductive heat transfer coefficient is a function of the temperature difference between air and the skin. For a given person wearing the same clothes, the area of nude body (A) and the ratio of the surface area of the clothed body to the surface area of the nude body (f_{cl}) are constant. When the ambient temperature is low, the temperature difference increase. Both the conductive heat transfer coefficient and the heat loss by convection increase (Fanger 1970, 35-7)

In the case of wind-driven convection with air velocity higher than 0.1 m/s, the convective heat transfer coefficient is calculated as:

$$h_c = 10.4\ (V)^{0.5} \qquad (2.5)$$

where V is the air velocity (m/s).

In the case of wind-driven convection, the convective heat transfer coefficient is a function of air velocity. For a given temperature difference, more heat is removed by convection when the air flow rate increases. Convective heat loss accounts for about 40 percent of total heat loss of human body.

Evaporative heat loss happens in both "sweating" and "no sweating" conditions. When humans sweat, the sweat carries heat from the body directly to the environment. When the water evaporates, some latent heat is taken from the body. The equation of evaporative heat loss by sweating is:

$$Q_{sw} = m \times \lambda \qquad (2.6)$$

where Q_{sw} is the evaporative heat loss by sweating (kcal/hr).
m is the rate of sweat (kg/hr).
λ is the latent heat of water (575 kcal/kg).

Since the latent heat of water is constant, evaporative heat loss is simply a factor of sweating rate. When the body is not sweating, some evaporative heat is taken by skin diffusion. The equation for skin diffusion is:

$$Q_{dif} = \lambda \times c \times A\ (p_s - p_a) \qquad (2.7)$$

where Q_{dif} is the evaporative heat loss by diffusion (kcal/hr).
λ is the latent heat of water (575 kcal/kg).
c is the permeance coefficient of the skin (kg/hr·m^2·mmHg).
A is the skin area (m^2).
p_s is the saturated vapor pressure at skin temperature (mmHg).
p_a is the vapor pressure in ambient air (mmHg).

The evaporative heat loss by diffusion is proportional to the pressure difference between the air and the skin surface. The vapor pressure on skin surface is assumed to be the saturated water vapor pressure. Since the pressure difference is proportional to the humidity ratio, the evaporation heat loss by diffusion is a factor of relative humidity. When the relative humidity of air is low, the pressure difference between air and skin surface is high, and the evaporation rate is high. Evaporation heat loss accounts for about 20 percent of total heat loss.

Environmental Factors in Thermal Comfort

The theory of heat transfer explains the impact of environmental factors on thermal comfort. Four environmental factors have the most direct effect on thermal comfort:

relative humidity, air temperature, mean radiant temperature, and air velocity (Lechner 1991, 28).

Relative humidity primarily affects evaporative heat loss by diffusion. When the relative humidity is high, the water vapor in the air is close to its saturation point. Therefore, the air can remove less water from skin, and the evaporation rate will be low. The heat loss through evaporation will therefore be low. Desirable thermal comfort exists when the relative humidity is above 20% all year, below 60% in the summer and below 80% in winter (Lechner 1991, 28).

Air temperature primarily affects convective heat loss. When the temperature difference between air and skin is large, the heat loss through convection is large. MRT affects the radiant heat loss. When the MRT is low, the radiation heat loss is low. In terms of temperature, thermal comfort is influenced by the combined effect of the air temperature and MRT. The effective temperature can be described as:

$$t_{eff} = (t_{air} + t_{mrt}) / 2 \qquad (2.8)$$

where t_{eff} is the effective temperature (°C).
t_{air} is the air temperature (°C).
t_{mrt} is the mean radiant temperature (°C).

Thermal comfort exists when the effective temperature is between 20 °C and 26 °C (ASHRAE 1993, 8.13).

Air velocity affects both convective and evaporative heat loss. When air velocity is high, more air is passing the skin, and more heat is carried away by the air. Air movement can also increase evaporation rate because the moving air may carry the water vapor away from the skin. The influence of air velocity on thermal comfort is expressed in the following chart:

Air Velocity	Typical Occupant Reaction
Up to 0.05 m/s	Complain about stagnation.
0.05 to 0.25 m/s	General favorable.
0.25 to 0.51 m/s	Awareness of air motion, but may be comfortable.
0.51 to 1.02 m/s	Constant awareness of air motion, but may be acceptable.
1.02 to 1.52 m/s	From slight drafty to annoyingly drafty (Olgyay 1962, 20).
1.52 to 2.03 m/s	Good air velocity for natural ventilation in hot and humid area.
2.03 to 4.60 m/s	Considered a "gentle breeze" when felt outdoors (Lechner 1991, 196).

Since these environmental factors directly affects thermal comfort, it is important to express these factors in a sufficient way in which the thermal condition can be studied and used efficiently.

2.2 Bioclimatic Chart

The Bioclimatic Chart

In Victor Olgyay's book, *Design with Climate: A Bioclimatic Approach to Architectural Regionalism*, the author introduces a bioclimatic chart to study thermal comfort. The bioclimatic chart describes the air temperature and relative humidity and their relation to thermal comfort. A typical bioclimatic chart is depicted below:

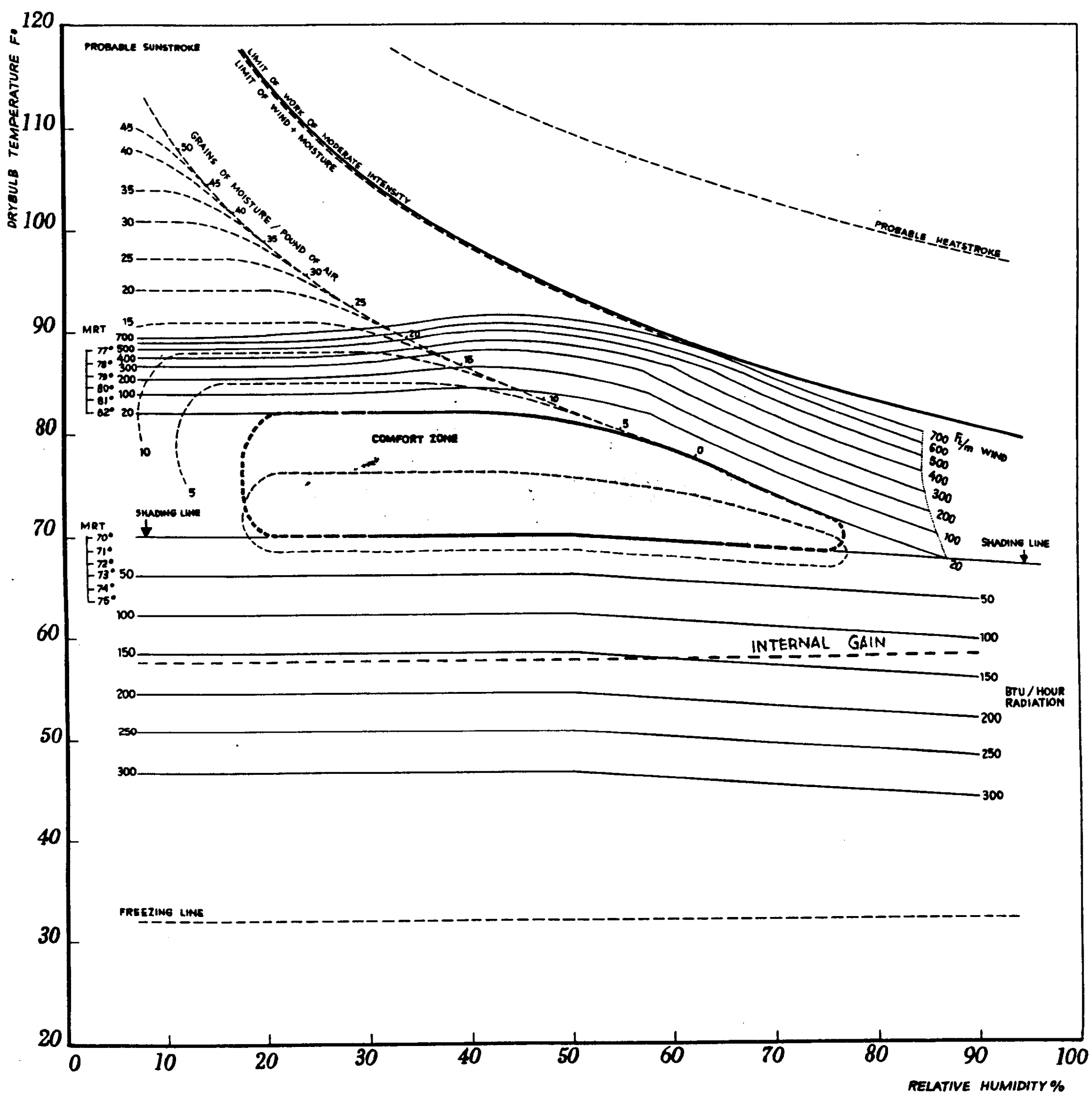


Figure. 2.1 Bioclimatic chart
(Modified from Olgyay 1963, 22)

In this bioclimatic chart, the air (dry-bulb) temperature is the ordinate and the relative humidity is the abscissa. The temperature range is from the temperature of probable sunstroke, 49°C (120°F), to the temperature of possible frostbite of finger and toes, -2°C (28°F). The temperature of sunstroke is considered the highest limit temperature for human activities, and the temperature of frostbite is consider the lowest limit temperature for human activities. The temperature range may extend due to actual highest and lowest air temperature in different locations. The humidity is in the range from 0% (no water vapor in the air) to 100% (saturated air). Any weather condition which is represented in terms of temperature and relative humidity can be plotted in such a chart.

Comfort Zone

Thermal comfort is highly dependent on individual characteristics such as clothing, activity, gender, age, etc. It is also dependent on geographic location because people in different climates have different thermal comfort preferences. Therefore, there is no single point of boundary for thermal comfort zone. The typical way to define the thermal comfort zone is by mean vote. The comfort zone plotted in Olgyay's bioclimatic chart is applicable to moderate climate zone in the United States at elevations not exceeding 1,000 feet above sea level for individuals wearing indoor clothing and doing light work (Olgyay 1963, 22).

The comfort zone is plotted in the center of the bioclimatic chart. The summer comfort zone (the shaded area) is slightly higher in temperature than the winter comfort zone. Because people generally wear more or heavier clothes in winter, they feel more comfortable at a lower temperature. If the weather fall within the comfort zone, it is generally comfortable for most people. If the weather is plotted on the right side of the comfort zone , it is too humid for most people. If the weather is plotted above the comfort zone, it is too hot. If the weather is plotted on the left side of the comfort zone, it is generally is too dry. Any weather plotted below the comfort zone is too cold. For such weather conditions plotted outside the comfort zone, some environmental factor may correct these uncomfortable conditions.

Internal heat gain and radiation may shift the comfort zone to lower temperatures. Occupants and appliances generate heat and increase the indoor air temperature. When the outdoor temperature is lower than the comfortable temperature, some heat generated by occupants and appliances may release to the outdoor by conduction and convection and keep the indoor temperature higher than the outdoor. If the outdoor temperature is not too low, the indoor temperature will be in comfortable zone.

In cold climate, the air temperature and MRT are low. A lot of heat is lost by convection and radiation to the cold objects around human body. It is important to reduce the air change in a room in order to reduce heat loss by convection. It is also important to use good insulation material for exterior walls to maintain higher indoor surface temperature. A high indoor surface temperature may reduce radiant heat loss between human body and the walls. Radiation heat gain from hot material such as sun, fire, and heaters are necessary to increase thermal comfort.

Evaporation can contribute to thermal comfort in a hot and dry climate. In such a condition, both air temperature and MRT are high. It is important to avoid heat gain and increase heat loss. Because there is very little water vapor in the air, radiation heat gain from the sun is intense. Both human skin and surrounding objects receive a lot of heat from the sun. Because of the high surface temperature of the surrounding objects, radiation heat gain from hot objects to human body is also high. It is important to avoid all these radiation heat gains. Since the air temperature is high, convective heat loss is very little. In some cases when the air temperature is higher than skin temperature, wind may cause even more heat gain to human body by convection.

In a hot and dry climate, heat can be removed from the environment by evaporating water. Water receives its latent heat from the air when it evaporates. This process simultaneously reduces air temperature and increases humidity and hence creates a comfortable thermal condition.

Wind may create thermal comfort when both the temperature and the humidity are too high. In a hot and humid climate, water vapor reduces radiant heat gain from the sun and the MRT is not as high as in a hot and dry climate. However, if human skin is exposed to the sun, some radiation heat gain might occur. Shading may be used as one strategy to avoid radiation heat gain from the sun. On the other hand, the air temperature is high, and the temperature difference between air and skin is very small. Convection heat loss due to the temperature difference is very small. The only way to increase convective heat loss is to increase air velocity. Because the humidity is high, evaporation heat loss can only be achieved by increase air velocity. As a result, convection and evaporation via high air velocity is the best strategy to improve thermal comfort.

An example of designing a cottage in Miami, Florida considering thermal comfort will be developed in the following chapters. To do so, it is first necessary to study the climate of Miami in order to evaluate a suitable design strategy to attain thermal comfort. A study of the weather in Miami based on the bioclimatic chart is the subject of the next chapter.

3 Design Parameters of Miami, Florida

3.1 Weather of Miami

Climate Regions

Donald Watson divides the climate of the United States into 6 regions in the book, *Climatic Building Design: Energy-efficient Building Principles and Practice*. Among the 6 climate regions, Miami Florida, located in the southeastern corner of the United States, is defined as a typical hot-and-humid climate. The city is surrounded by ocean in three sides and its latitude is as low as 26° north. Yearly ocean wind increases convective and evaporative heat loss and brings significant comfort to this city (Lechner 1991, 76). The location of Miami and the 6 climate regions are expressed in the following map:

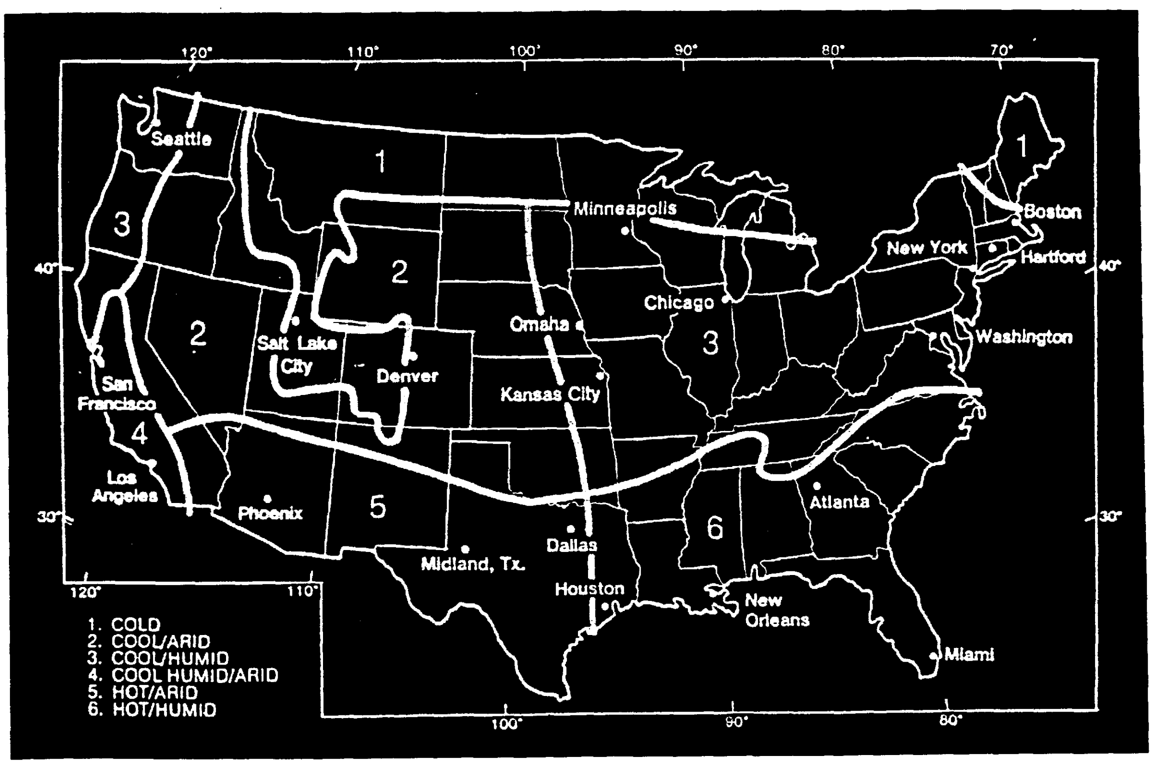


Figure 3.1 Climate regions in the United States.
(Cited from Watson 1983, 7)

Bioclimatic Chart

The air temperature and humidity of Miami is plotted in the following bioclimatic chart:

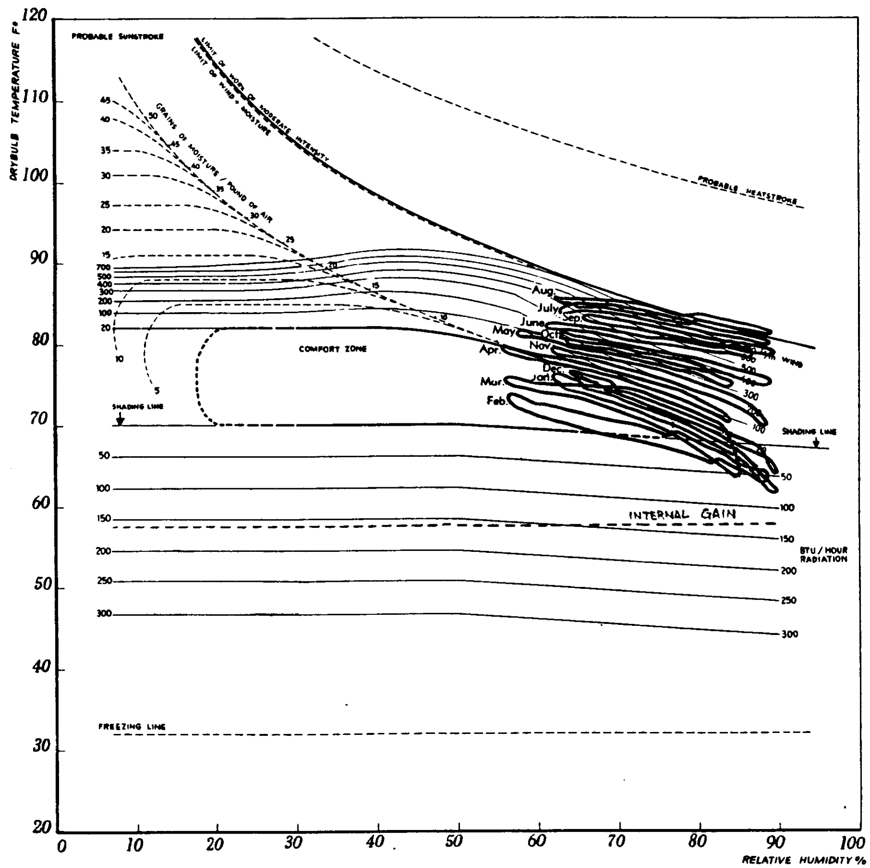


Figure. 3.2 Bioclimatic registration of climate data in Miami, Florida.
(Modified from Olgyay 1963, 30)

In this bioclimatic chart, the distribution of Miami's climate is in the region of comfort, too hot, or too humid. The distribution of the climate from December to March is generally inside the comfort zone. Only in some evenings, the air temperature is too low and the humidity is too high; however, the air temperature is still in the range where the internal heat gain can correct thermal comfort. With the internal heat gain, the indoor temperature is comfortable without any additional thermal devices.

The air temperature in summer is in the range of 24°C to 32°C (75°F to 90°F). Even though the air temperature in Miami is never extremely high, the high humidity makes this city's summer very uncomfortable. The relative humidity of Miami is between 76% and 92%, much higher than the comfortable humidity range of 20% to 60%.

The temperature in spring and fall are slightly too warm and humid. In April, May, October, and November, the temperature is in the range of 19°C to 29°C (66°F to 85°F), and the relative humidity is in the range of 52% to 88%. Generally, the weather from April to November is correctable with air movement. The following table shows the required wind velocity to correct Miami's weather from April to November when the weather is too hot and humid.

Month	Corrective Air Velocity
April	0.1 to 0.76 m/s
May	0.25 to 2.5 m/s
June	1.02 to 3.56 m/s
July	1.78 to above 3.56 m/s
August	2.03 to above 3.56 m/s
September	1.78 to above 3.56 m/s
October	0.76 to 2.54 m/s
November	0.25 to 1.27 m/s

From the table of typical reaction of occupants to wind velocity, wind of velocity 0.05 m/s to 2.03 m/s are desirable to thermal comfort in a hot and humid climate. Any wind with a velocity below 0.05 m/s or above 2.03 m/s is not desirable for indoor activities. Therefore, because the temperature from June to September is so high it requires wind velocity higher than 3.56 m/s to be comfortable, it is impossible to correct the weather simply by ventilation. Some mechanical device of reducing temperature and humidity is necessary. On the other hand, for the climate of April, May, October, November, ventilation is the best solution to achieve thermal comfort. As the result, a design involving the strategy of natural ventilation for passive cooling in these four months is desirable in Miami.

Wind in Miami

Since the thermal comfort may be achieved by natural ventilation in April, May, October, and November, it is essential to understand the wind speed and direction in these months in order to introduce wind into design. The Bulletin of American Institute of Architects has a table of wind roses for Miami.

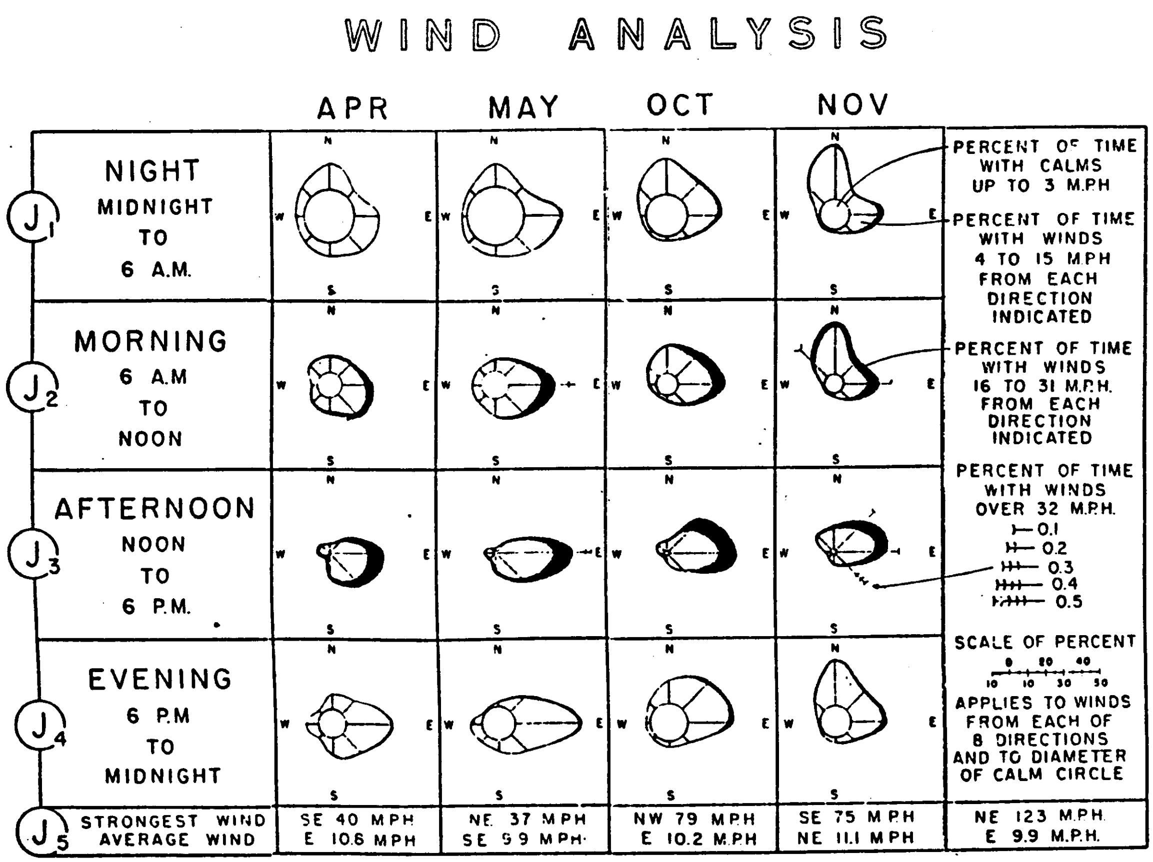


Figure. 3.3 Wind roses for Miami, Florida
(Reproduced from Bulletin of the A.I.A. 1952, 44-5)

The average wind velocity and direction for these four months are converted to SI units in the following table.

Month	Velocity	Direction
April	4.83 m/s	East
May	4.43 m/s	Southeast
October	4.56 m/s	East
November	4.96 m/s	Northeast

The average wind for these four months are 4.7 m/s (925 ft/m) from the east, 4.96 m/s (976 ft/m) from the northeast, and 4.43 m/s (872 ft/m) from the southeast. In order to use natural ventilation for cooling in all these four months, The building form should be able to receive moving air in all three wind directions.

3.2 Computational Representation of Miami's Coastal Area

The q1 file

PHOENICS requires an input file "q1" for calculation. The q1 file assigns temperature, wind velocity, geometry of the building and the properties of air such as density and viscosity. Only after the q1 file is correctly developed can the PHOENICS program accurately simulate the airflow.

In the present design case, a q1 file which simulates the weather of Miami in April, May, October, and November, is first developed. Because the wind in these four months are from northeast, east and southeast, three separate q1 files are developed. After the establishment of the first q1 file, other parameter modifications can be made. All models assume a coastal site with no surrounding buildings.

The following sections describes a q1 file developed for east wind. The input parameters are representative of the average weather conditions in Miami during April and October:

Input Parameters	
Wind direction	East
Wind velocity	4.7 m/s
Temperature	24 °C (75.4°F)
Building dimensions	3 m × 5 m × 3 m (10 ft × 16.5 ft × 10 ft)

The building geometry contains a wall and a table with a 225 °C (437 °F) stove on the top.

The Title

The q1 file organizes information by groups. The first group assigns the title of the model in parentheses as:

```
TALK=F;RUN( 1, 1);VDU=X11-TERM
    GROUP 1. Run title and other preliminaries
       A title up to 40 characters can be used.
TEXT(MIAMI: EAST WIND)
       The airflow pattern with east wind in Miami.
TITLE
       This basic model represents the east wind in Miami.  It
       will be used for further development of building form.
```

The Grid

The next step is to define the grid for calculation. In this model, a three dimensional Cartesian coordinate system defines the grid. X-coordinates are defined from west to east, Y-coordinates are from south to north, and Z-coordinates are from low to high. The grid and its coordinates are:

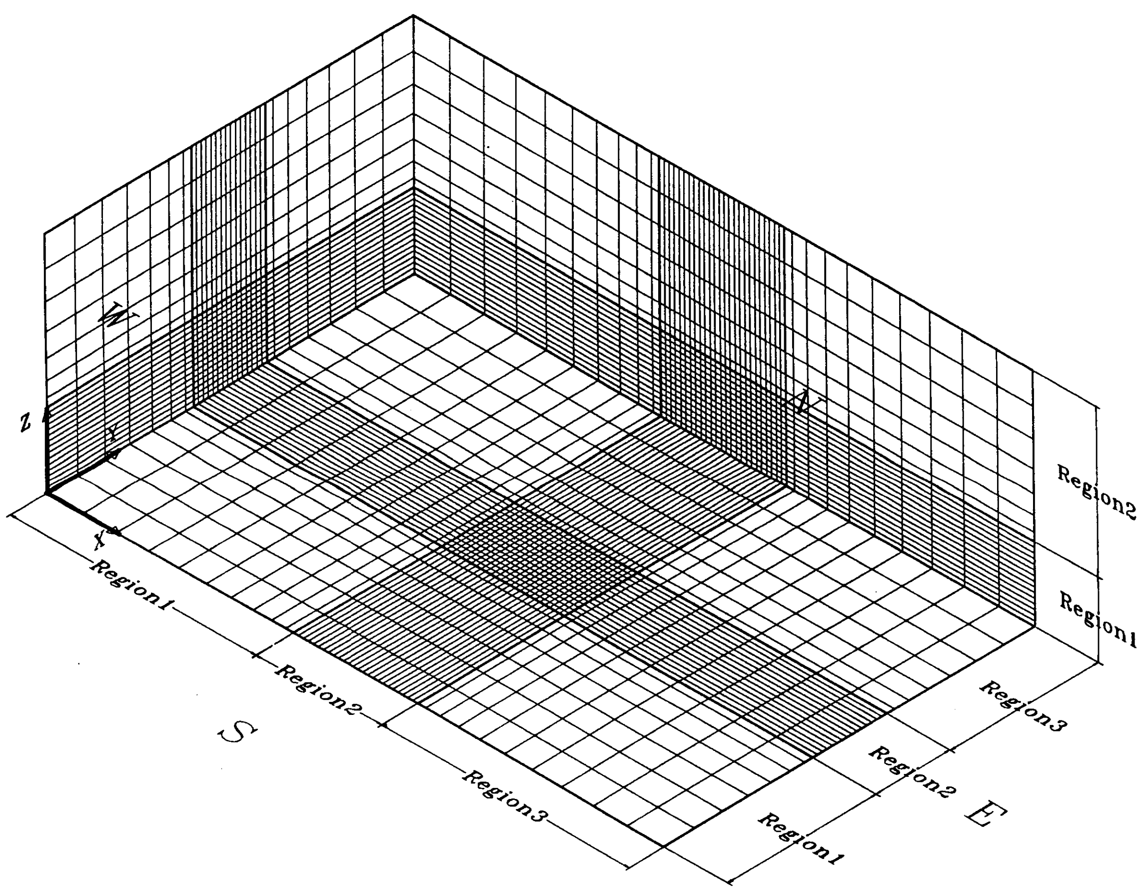


Figure 3.3 The grid of basic model

The dimension of the house is 3 m from south to north, 5 m from east to west, and 3 m in height. In this model, the outdoor space and indoor space are calculated simultaneously. In order to have an accurate result, it is necessary to define the outdoor boundary large enough that the airflow close to the boundary is not affected by the building. The distance is usually defined as twice as long as the building dimensions. In this case, the distance from the building to the boundary will be 10 m (33 ft) in both east and west sides, 6 m (20 ft) in both south and north sides, and 6 m (20 ft) above the building.

```
REAL(XLENGTH,YLENGTH,ZLENGTH,TKEIN,EPSIN)
       Assign values to the variables declared.
       The length, width and height of outdoor space are 25 m
       (82.5 ft), 15 m (50 ft), 9 m (30 ft) respectively.
XLENGTH=25;YLENGTH=15;ZLENGTH=9
NX=45;NY=29;NZ=22
```

The grid in the X-direction is divided into 3 regions. The first region is on the west side of the building. The second region is for the building itself. The third region one region is on the east side of the building. The dimensions of the cells in the building site is defined as the thickness of walls. The regions and grids in the X-direction is defined as:

```
    GROUP 2. Transience; time-step specification
    GROUP 3. X-direction grid specification
       Total region number in the X-direction is 3.
       10 cells are in the first region.
       25 cells are in the second region.
       10 cells are in the third region.
       The dimension in x direction is 10 m (33 ft), 5 m (16.5 ft),
       and 10 m (33 ft) in three regions.
       The cells are evenly divided in the second region.
       The dimensions of the cells become bigger when they are away
       from the building area.
NREGX=3
IREGX=1;GRDPWR(X,10,10,-1.5)
IREGX=2;GRDPWR(X,25,5,1)
IREGX=3;GRDPWR(X,10,10,1.5)
```

The last argument in the command GRDPWR is the exponent in the power law which defines the distribution of intervals. When the number is positive, the equation is:

$$X_i = (i/n)^e \times L \qquad (3.1)$$

where X_i is the coordinate of cell i in x direction.

i is the number of the cell.

n is the total number of cells in the region.

L is the length of the region. (m)

When the exponent of the power-law is negative the equation is:

$$X_i = [\,1 - (i/n)^e\,] \times L \qquad (3.2)$$

The resulting coordinates of the cells in x direction are :

Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.
1	1.462	9	9.685	17	11.400	25	13.000	33	14.600	41	19.648
2	2.845	10	10.000	18	11.600	26	13.200	34	14.800	42	20.858
3	4.143	11	10.200	19	11.800	27	13.400	35	15.000	43	22.155
4	5.353	12	10.400	20	12.000	28	13.600	36	15.315	44	23.538
5	6.465	13	10.600	21	12.200	29	13.800	37	15.895	45	2.500
6	7.470	14	10.800	22	12.400	30	14.000	38	16.643		
7	8.358	15	11.000	23	12.600	31	14.200	39	17.530		
8	9.105	16	11.200	24	12.800	32	14.400	40	18.535		

The grid in Y-direction is divided in a similar way as in the X-direction. The first region is on the south side of the building. The second region is for the building itself. The third region is on the north side of the building. The regions and grids in Y-direction are defined as:

```
GROUP 4. Y-direction grid specification
    Total region number in the Y-direction is 3.
    7 cells are in the first region.
    15 cells are in the second region.
    7 cells are in the third region.
    The dimension in y direction is 6 m (20 ft), 3 m (10 ft) ,
    and  6 m (20 ft) in three regions.
    The cells are evenly divided in the second region.
    The dimensions of the cells become wider when they are away
    from the building area.
```

```
NREGY=3
IREGY=1;GRDPWR(Y,7,6,-1.5)
IREGY=2;GRDPWR(Y,15,3,1)
IREGY=3;GRDPWR(Y,7,6,1.5)
```

The coordinates of the cells in the Y-direction are:

Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.
1	1.239	6	5.676	11	6.800	16	7.800	21	8.801	26	11.592
2	2.378	7	6.000	12	7.001	17	8.000	22	9.000	27	12.623
3	3.408	8	6.200	13	7.200	18	8.201	23	9.324	28	13.761
4	4.317	9	6.401	14	7.400	19	8.400	24	9.917	29	15.000
5	5.084	10	6.600	15	7.601	20	8.600	25	10.683		

The grid in the Z-direction is divided into 2 regions. The first region is for the building, and the second region is for the sky above the building. The regions and grids in Z-direction are defined as:

```
    GROUP 5. Z-direction grid specification
       Total region number in the Z-direction is 2.
       15 cells are in the first region.
        7 cells are in the second region.
       The dimension in z direction is 3 m (10 ft) and 6 m (20 ft)
       in the two regions.
       The cells are evenly divided in the first region.
       The dimensions of the cells become wider when they are away
       from the building area.
NREGZ=2
IREGZ=1;GRDPWR(Z,15,3,1)
IREGZ=2;GRDPWR(Z,7,6,1.5)
    GROUP 6. Body-fitted coordinates or grid distortion
```

The coordinates of the cells in Z direction are:

Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.	Cell #	Coordi.
1	0.200	5	1.000	9	1.800	13	2.600	17	3.916	21	7.762
2	0.400	6	1.200	10	2.000	14	2.800	18	4.684	22	9.000
3	0.600	7	1.400	11	2.200	15	3.000	19	5.592		
4	0.800	8	1.600	12	2.400	16	3.324	20	6.622		

Variables, Properties, and Media

PHOENICS solves pressure, velocity, and temperature for calculating airflow according to the model. Wind velocity is calculated as three components U1, V1, and W1 in X, Y, and Z directions.

```
GROUP 7. Variables stored, solved & named
       Solve the following variables:
       P1 - The first phase pressure.
       U1 - The first phase velocity in X-direction.
       V1 - The first phase velocity in Y-direction.
       W1 - The first phase velocity in Z-direction.
       TEM1 - The first phase temperature.
SOLVE(P1,U1,V1,W1,TEM1)
```

In the scale of simulating ventilation in buildings involving outdoor wind flow, the flow type is mostly turbulent. For turbulent flow, PHOENICS solves the kinetic energy (KE), and the rate of dissipation of kinetic energy (EP). The command required for turbulence flow is:

```
TURMOD(KEMODL)
```

The next step is to define the properties of air.

```
    GROUP 8. Terms (in differential equations) & devices
    GROUP 9. Properties of the medium (or media)
       Set the laminar kinetic viscosity of air as 1.5E-5.
       Set the density of air as 1.2.
       Set the turbulent Prandtl number of air as 0.9.
       Set the laminar Prandtl number of air as 0.7.
ENUL=1.5E-5
RHO1=1.2
PRT(TEM1)=0.9
PRNDTL(TEM1)=0.7
```

The next step is to define the initial air velocity, air temperature, KE, and EP. The initial air velocity in X direction (U1) is defined as the highest velocity of the inlet air and used for the calculation of KE. The initial value of U1 will be explained later in the Boundary

Condition section. The initial value of air temperature is defined as the average temperature of Miami in the two months under consideration. The initial air velocity, air temperature, KE, and EP are defined as:

```
        GROUP 10. Inter-phase-transfer processes and properties
        GROUP 11. Initialization of variable or porosity fields
           Set initial air velocity 4.34 m/s (854 f/m).
           Set initial air temperature 24 C (75.4 F).
    FIINIT(U1)=-4.34
    FIINIT(TEM1)=24.
    PRESS0=1.0E5
    TEMP0=273.15
      ** Calculation of KE
    TKEIN=0.018*0.25*4.34*4.34
      ** Calculation of EP
    EPSIN=TKEIN**1.5*0.1643/3.429E-3
    FIINIT(KE)=TKEIN
    FIINIT(EP)=EPSIN
```

Building Geometry

This section defines the building geometry on the site. For this basic model, a 1 m wall in the east side of the site and a table with a stove on top are considered. This model allows the further development of more building attributes by simply adding more CONPOR commands.

```
      ** East wall
    CONPOR(EWALL,0.0,cell,-35,-35,-8,-22,-1,-5)
      ** Table
    CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
```

The CONPOR command defines the patches of blockage. A patch is one cell or a group of cells defined with same property. The second argument in this command specifies the rate of penetration. A value of 0.0 means complete blockage and a value of 1.0 means no blockage. The third argument specifies the sides of the patch, which should be assigned as NORTH, SOUTH, EAST, WEST, LOW, or HIGH for the six sides of the patch. An assignment of CELL for the third argument means all 6 sides of the patch are defined.

The low wall and the table in the background grid is:

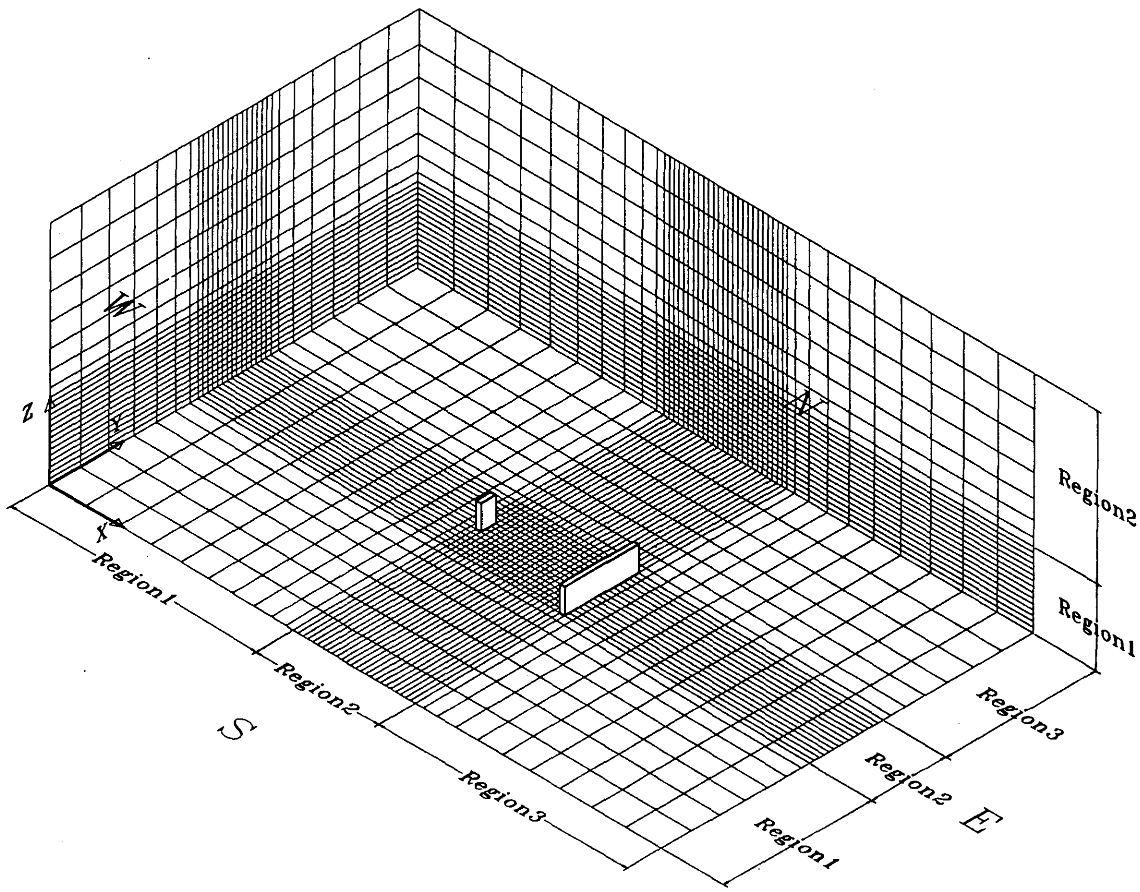


Figure. 3.4 The geometry of the basic model

Gravity and Temperature

The next step is to define the gravity and temperature. In this model, since the Z axis is defined as the vertical direction, the gravity should be assigned in BOUYC. The average temperature of 24°C is used as the reference temperature.

```
GROUP 12. Patchwise adjustment of terms
GROUP 13. Boundary conditions and special sources
      Use Boussinesq approximation
      BUOYA - gravity in X-direction.
      BUOYB - gravity in Y-direction.
      BUOYC - gravity in Z-direction.
```

```
       BUOYD - air expansion coefficient (=1/T in Kelvin).
       BUOYE - BUOYD * Reference temperature (in Celsius).
  ** Thermal buoyancy
BUOYC=-9.8; BUOYD=-1./300; BUOYE=-BUOYD*24.
       Define the space and time the boundary condition to be
       applied
PATCH(BUOY,PHASEM,1,NX,1,NY,1,NZ,1,LSTEP)
       Apply the Buossinesq approximation (GRND3).
COVAL(BUOY,W1,FIXFLU,GRND3)
```

Boundaries

This section defines the six boundaries of the calculation area. In this model, the west boundary is defined as one opening for the outlet of air. North, south, and upper boundaries are defined as three non-friction walls. The ground is defined as one hard surface with no air movement right above it.

On the east boundary, the inlet of air, boundary layer flow is applied consistent with the beach site condition. The boundary layer flow defines air velocity from zero up to the thickness of the boundary, the gradient height (Zg). Above the gradient height, the wind velocity remain constant. The boundary layer flow is shown in the following figure:

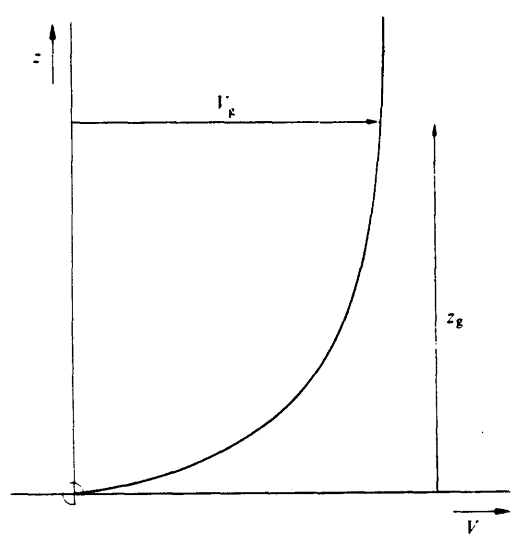


Figure 3.5 Boundary layer flow
(Cited from Houghton 1976, 30)

Because there are 22 cells in Z direction, 22 patches are defined. Each patch will be assigned with the wind velocity corresponding to the height. The geometry of the boundaries is shown in Figure 3.6. For the 22 patches on the east boundary, the wind velocity should be calculated according to the boundary condition. The equation of the wind velocity at height Z is:

$$V / V_g = (Z / Z_g)^{\alpha} \qquad (3.3)$$

where V is the wind velocity. (m/s)

V_g is the gradient wind velocity. (m/s)

Z is the height. (m)

Z_g is the gradient height. (215 m in coastal areas)

α is the power-law coefficient. (0.1 in coastal areas) (Simiu 1978, 48)

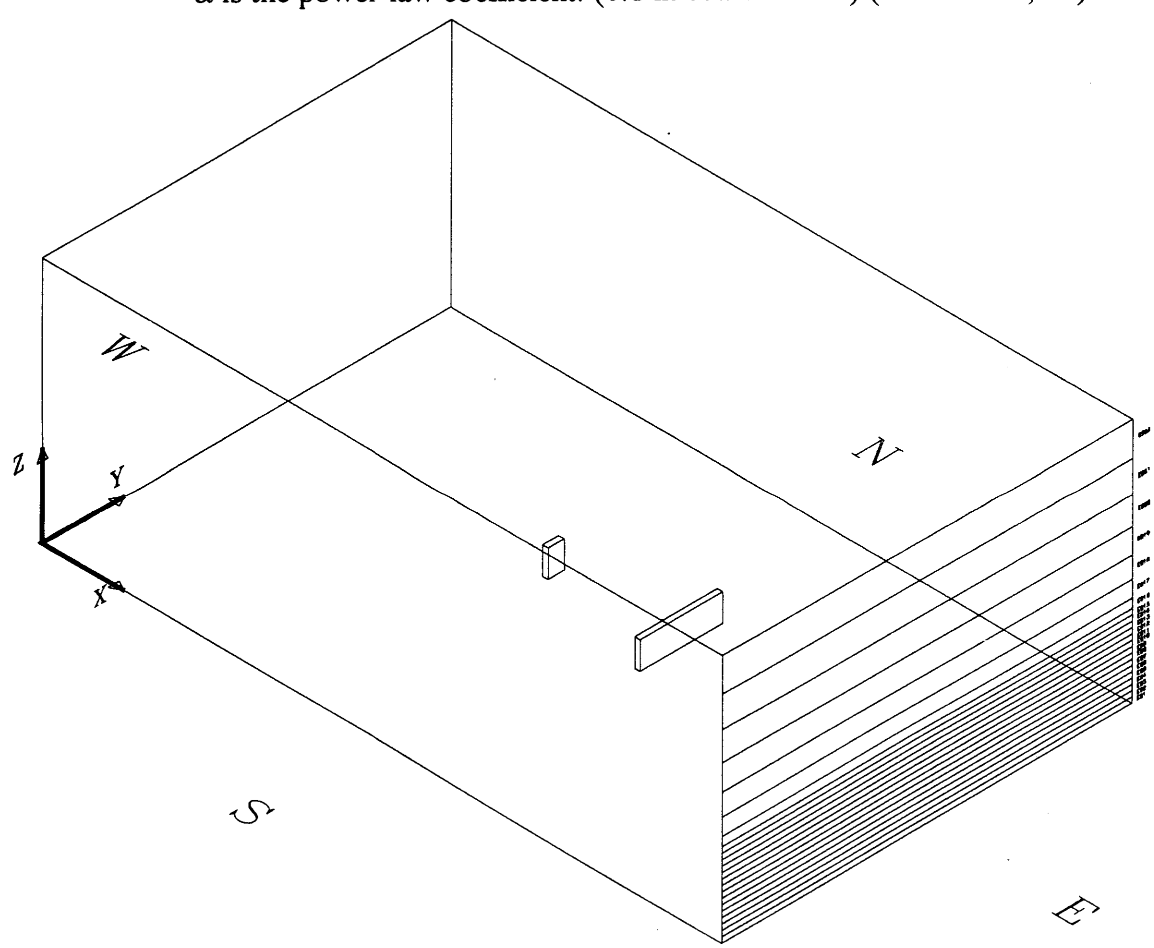


Figure 3.6 Geometry of patches for east wind

The average east wind velocity in Miami is 4.7 m/s, which is measured 20 m (66 ft) above ground. From the above equation, the gradient wind velocity is calculated as 6.0 m/s. The coordinate of the center of each cell in the east boundary, and the air velocity which corresponds to the coordinate is calculated as:

Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)
1	0.100	2.79	7	1.300	3.60	13	2.500	3.84	19	5.138	4.13
2	0.300	3.11	8	1.500	3.65	14	2.700	3.87	20	6.107	4.20
3	0.500	3.27	9	1.700	3.70	15	2.900	3.90	21	7.192	4.27
4	0.700	3.38	10	1.900	3.74	16	3.162	3.93	22	8.381	4.34
5	0.900	3.47	11	2.100	3.78	17	3.620	3.99			
6	1.100	3.54	12	2.300	3.81	18	4.300	4.06			

The value of wind velocity (V) should be plugged into the commands of the inlet boundary as U1. The wind velocity of the highest cell (cell # 22) should be used for the initial air velocity and calculation of KE in group 11 and the maximum velocity in group 17.

```
  ** East boundary
        Define the space and time the boundary condition to be
        applied
PATCH(EB1,EAST,NX,NX,1,NY,1,1,1,1)
        Use non-slip boundary condition for U1 and V1.
        Set wind velocity as 2.79 m/s.
        Set mass of airflow as 2.79 m/s * RHO1.
COVAL(EB1,P1,FIXFLU,2.79*RHO1)
COVAL(EB1,U1,ONLYMS,-2.79)
COVAL(EB1,KE,ONLYMS,TKEIN)
COVAL(EB1,EP,ONLYMS,EPSIN)
        Set air temperature to 24 C (75.4 F).
COVAL(EB1,TEM1,ONLYMS,24.)
        Set coastal boundary condition by changing U1 and mass of
        airflow according to height.
PATCH(EB2,EAST,NX,NX,1,NY,2,2,1,1)
COVAL(EB2,P1,FIXFLU,3.11*RHO1)
COVAL(EB2,U1,ONLYMS,-3.11)
COVAL(EB2,KE,ONLYMS,TKEIN)
COVAL(EB2,EP,ONLYMS,EPSIN)
COVAL(EB2,TEM1,ONLYMS,24.)
PATCH(EB3,EAST,NX,NX,1,NY,3,3,1,1)
COVAL(EB3,P1,FIXFLU,3.27*RHO1)
COVAL(EB3,U1,ONLYMS,-3.27)
COVAL(EB3,KE,ONLYMS,TKEIN)
COVAL(EB3,EP,ONLYMS,EPSIN)
COVAL(EB3,TEM1,ONLYMS,24.)
```

```
PATCH(EB4,EAST,NX,NX,1,NY,4,4,1,1)
COVAL(EB4,P1,FIXFLU,3.38*RHO1)
COVAL(EB4,U1,ONLYMS,-3.38)
COVAL(EB4,KE,ONLYMS,TKEIN)
COVAL(EB4,EP,ONLYMS,EPSIN)
COVAL(EB4,TEM1,ONLYMS,24.)
PATCH(EB5,EAST,NX,NX,1,NY,5,5,1,1)
COVAL(EB5,P1,FIXFLU,3.47*RHO1)
COVAL(EB5,U1,ONLYMS,-3.47)
COVAL(EB5,KE,ONLYMS,TKEIN)
COVAL(EB5,EP,ONLYMS,EPSIN)
COVAL(EB5,TEM1,ONLYMS,24.)
PATCH(EB6,EAST,NX,NX,1,NY,6,6,1,1)
COVAL(EB6,P1,FIXFLU,3.54*RHO1)
COVAL(EB6,U1,ONLYMS,-3.54)
COVAL(EB6,KE,ONLYMS,TKEIN)
COVAL(EB6,EP,ONLYMS,EPSIN)
COVAL(EB6,TEM1,ONLYMS,24.)
PATCH(EB7,EAST,NX,NX,1,NY,7,7,1,1)
COVAL(EB7,P1,FIXFLU,3.6*RHO1)
COVAL(EB7,U1,ONLYMS,-3.6)
COVAL(EB7,KE,ONLYMS,TKEIN)
COVAL(EB7,EP,ONLYMS,EPSIN)
COVAL(EB7,TEM1,ONLYMS,24.)
PATCH(EB8,EAST,NX,NX,1,NY,8,8,1,1)
COVAL(EB8,P1,FIXFLU,3.65*RHO1)
COVAL(EB8,U1,ONLYMS,-3.65)
COVAL(EB8,KE,ONLYMS,TKEIN)
COVAL(EB8,EP,ONLYMS,EPSIN)
COVAL(EB8,TEM1,ONLYMS,24.)
PATCH(EB9,EAST,NX,NX,1,NY,9,9,1,1)
COVAL(EB9,P1,FIXFLU,3.7*RHO1)
COVAL(EB9,U1,ONLYMS,-3.7)
COVAL(EB9,KE,ONLYMS,TKEIN)
COVAL(EB9,EP,ONLYMS,EPSIN)
COVAL(EB9,TEM1,ONLYMS,24.)
PATCH(EB10,EAST,NX,NX,1,NY,10,10,1,1)
COVAL(EB10,P1,FIXFLU,3.74*RHO1)
COVAL(EB10,U1,ONLYMS,-3.74)
COVAL(EB10,KE,ONLYMS,TKEIN)
COVAL(EB10,EP,ONLYMS,EPSIN)
COVAL(EB10,TEM1,ONLYMS,24.)
PATCH(EB11,EAST,NX,NX,1,NY,11,11,1,1)
COVAL(EB11,P1,FIXFLU,3.78*RHO1)
COVAL(EB11,U1,ONLYMS,-3.78)
COVAL(EB11,KE,ONLYMS,TKEIN)
COVAL(EB11,EP,ONLYMS,EPSIN)
COVAL(EB11,TEM1,ONLYMS,24.)
PATCH(EB12,EAST,NX,NX,1,NY,12,12,1,1)
COVAL(EB12,P1,FIXFLU,3.81*RHO1)
COVAL(EB12,U1,ONLYMS,-3.81)
COVAL(EB12,KE,ONLYMS,TKEIN)
COVAL(EB12,EP,ONLYMS,EPSIN)
COVAL(EB12,TEM1,ONLYMS,24.)
PATCH(EB13,EAST,NX,NX,1,NY,13,13,1,1)
```

```
COVAL(EB13,P1,FIXFLU,3.84*RHO1)
COVAL(EB13,U1,ONLYMS,-3.84)
COVAL(EB13,KE,ONLYMS,TKEIN)
COVAL(EB13,EP,ONLYMS,EPSIN)
COVAL(EB13,TEM1,ONLYMS,24.)
PATCH(EB14,EAST,NX,NX,1,NY,14,14,1,1)
COVAL(EB14,P1,FIXFLU,3.87*RHO1)
COVAL(EB14,U1,ONLYMS,-3.87)
COVAL(EB14,KE,ONLYMS,TKEIN)
COVAL(EB14,EP,ONLYMS,EPSIN)
COVAL(EB14,TEM1,ONLYMS,24.)
PATCH(EB15,EAST,NX,NX,1,NY,15,15,1,1)
COVAL(EB15,P1,FIXFLU,3.9*RHO1)
COVAL(EB15,U1,ONLYMS,-3.9)
COVAL(EB15,KE,ONLYMS,TKEIN)
COVAL(EB15,EP,ONLYMS,EPSIN)
COVAL(EB15,TEM1,ONLYMS,24.)
PATCH(EB16,EAST,NX,NX,1,NY,16,16,1,1)
COVAL(EB16,P1,FIXFLU,3.93*RHO1)
COVAL(EB16,U1,ONLYMS,-3.93)
COVAL(EB16,KE,ONLYMS,TKEIN)
COVAL(EB16,EP,ONLYMS,EPSIN)
COVAL(EB16,TEM1,ONLYMS,24.)
PATCH(EB17,EAST,NX,NX,1,NY,17,17,1,1)
COVAL(EB17,P1,FIXFLU,3.99*RHO1)
COVAL(EB17,U1,ONLYMS,-3.99)
COVAL(EB17,KE,ONLYMS,TKEIN)
COVAL(EB17,EP,ONLYMS,EPSIN)
COVAL(EB17,TEM1,ONLYMS,24.)
PATCH(EB18,EAST,NX,NX,1,NY,18,18,1,1)
COVAL(EB18,P1,FIXFLU,4.06*RHO1)
COVAL(EB18,U1,ONLYMS,-4.06)
COVAL(EB18,KE,ONLYMS,TKEIN)
COVAL(EB18,EP,ONLYMS,EPSIN)
COVAL(EB18,TEM1,ONLYMS,24.)
PATCH(EB19,EAST,NX,NX,1,NY,19,19,1,1)
COVAL(EB19,P1,FIXFLU,4.13*RHO1)
COVAL(EB19,U1,ONLYMS,-4.13)
COVAL(EB19,KE,ONLYMS,TKEIN)
COVAL(EB19,EP,ONLYMS,EPSIN)
COVAL(EB19,TEM1,ONLYMS,24.)
PATCH(EB20,EAST,NX,NX,1,NY,20,20,1,1)
COVAL(EB20,P1,FIXFLU,4.2*RHO1)
COVAL(EB20,U1,ONLYMS,-4.2)
COVAL(EB20,KE,ONLYMS,TKEIN)
COVAL(EB20,EP,ONLYMS,EPSIN)
COVAL(EB20,TEM1,ONLYMS,24.)
PATCH(EB21,EAST,NX,NX,1,NY,21,21,1,1)
COVAL(EB21,P1,FIXFLU,4.27*RHO1)
COVAL(EB21,U1,ONLYMS,-4.27)
COVAL(EB21,KE,ONLYMS,TKEIN)
COVAL(EB21,EP,ONLYMS,EPSIN)
COVAL(EB21,TEM1,ONLYMS,24.)
PATCH(EB22,EAST,NX,NX,1,NY,22,22,1,1)
COVAL(EB22,P1,FIXFLU,4.34*RHO1)
```

```
COVAL(EB22,U1,ONLYMS,-4.34)
COVAL(EB22,KE,ONLYMS,TKEIN)
COVAL(EB22,EP,ONLYMS,EPSIN)
COVAL(EB22,TEM1,ONLYMS,24.)
```

The west boundary is the outlet side. The definition of the outlet is:

```
  ** West boundary
PATCH(WB,WEST,1,1,1,NY,1,NZ,1,1)
COVAL(WB,P1,FIXP,0.0)
COVAL(WB,TEM1,0.0,24.)
COVAL(WB,KE,0.0,1.E-5)
COVAL(WB,EP,0.0,1.E-5)
```

The south, north, and upper boundaries are considered as non-friction walls. The definition of these boundaries are:

```
  ** South boundary
PATCH(SB,SOUTH,1,NX,1,1,1,NZ,1,1)
COVAL(SB,TEM1,0.0,24.)
  ** North boundary
PATCH(NB,NORTH,1,NX,NY,NY,1,NZ,1,1)
COVAL(NB,TEM1,0.0,24.)
  ** Upper boundary
PATCH(UPPER,HIGH,1,NX,1,NY,NZ,NZ,1,1)
COVAL(UPPER,TEM1,0.0,24.)
```

The ground is a solid surface. It should be defined as a surface without wind velocity in either X or Y directions:

```
  ** Ground
PATCH(GROUND,LWALL,1,NX,1,NY,1,1,1,1)
COVAL(GROUND,U1,GRND2,0.0)
COVAL(GROUND,V1,GRND2,0.0)
COVAL(GROUND,TEM1,GRND2,24.)
COVAL(GROUND,KE,GRND2,GRND2)
COVAL(GROUND,EP,GRND2,GRND2)
```

Heat Source

A stove is assigned in this model as a heat source. The purpose of assigning a heat source is to study the air temperature distribution. The heat source is defined in the following manner:

```
** Stove
      Set the temperature of stove as 200 C above air temperature.
PATCH(STOVE,LOW,12,12,14,16,6,6,1,1)
COVAL(STOVE,TEM1,FIXFLU,4.*200.)
```

In this case a patch is defined right above the table. The surface in the low side of the patch is the surface of heat flux.

Number of Calculation

The number of calculations is originally defined as 3000 in this model. It may be reduced if the calculation converges before the defined number, or it may be increased if the calculation cannot converge until this number of calculation. The convergence can be observed in the result file. A detailed explanation of the convergence will be discussed in a later chapter.

```
    GROUP 14. Downstream pressure for PARAB=.TRUE.
    GROUP 15. Termination of sweeps
       Total iteration number
LSWEEP=3000
       Print the iteration number during runsat
LSWEEP
    GROUP 16. Termination of iterations
```

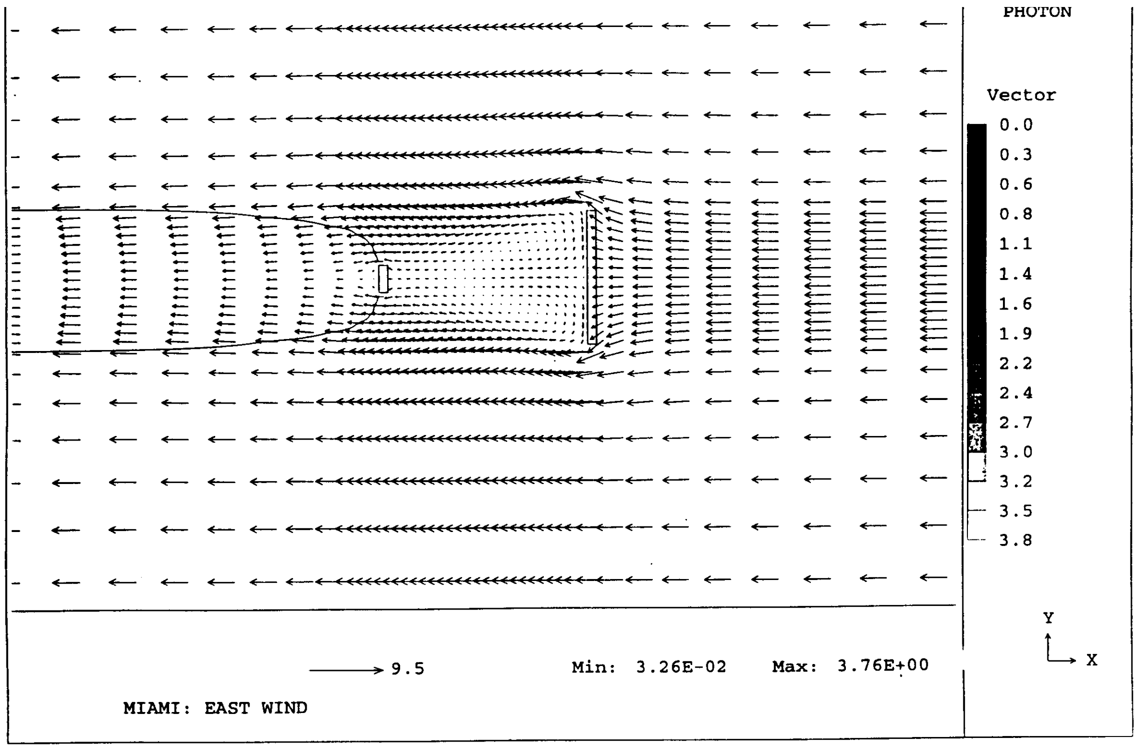
Relaxation and Print Out

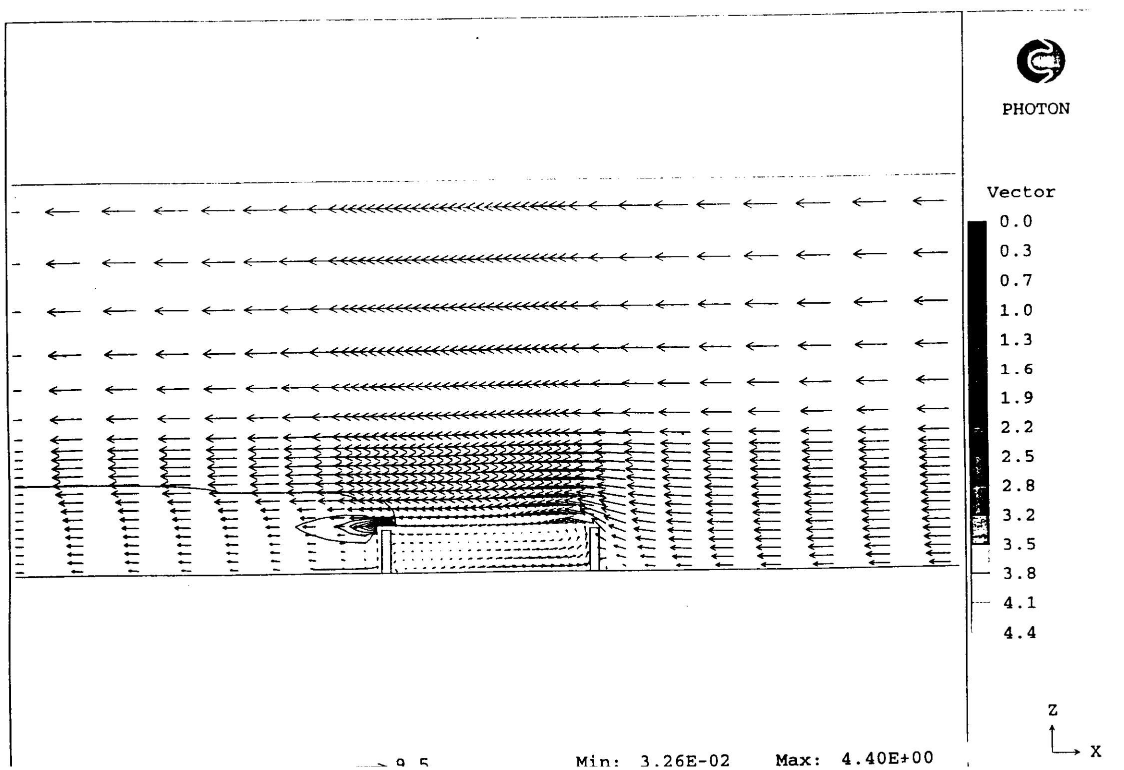
The last section of the file defines relaxation. The under-relaxation factor for pressure is set equal to 0.8 for fluid-flow computations (Patankar 1980, 128). DTF is the size of false time step for U1, V1, W1, TEM1, KE, and EP. The minimum dimension of the cell and the maximum velocity are used to decide the initial DTF value. If the calculation does not converge, the number of DTF may be increased or decreased until the calculation converges.

```
    GROUP 17. Under-relaxation devices
       Determine false-time-step
REAL(DTF, MINCELL, MAXV)
MINCELL=0.2
MAXV=4.34
DTF=1.*MINCELL/MAXV
DTF
       Under-relaxation factor for P1 is 0.8
RELAX(P1,LINRLX,0.8)
RELAX(U1,FALSDT,DTF)
RELAX(V1,FALSDT,DTF)
RELAX(W1,FALSDT,DTF)
RELAX(TEM1,FALSDT,DTF)
RELAX(KE,FALSDT,DTF)
RELAX(EP,FALSDT,DTF)
    GROUP 18. Limits on variables or increments to them
    GROUP 19. Data communicated by satellite to GROUND
    GROUP 20. Preliminary print-out
       Echo printout of the q1 file in the result file.
ECHO=T
    GROUP 21. Print-out of variables
    GROUP 22. Spot-value print-out
IXMON=NX/2;IYMON=NY/2;IZMON=NZ
    GROUP 23. Field print-out and plot control
       Set print out of the residual in every 20 sweeps.
TSTSWP=LSWEEP/20
STOP
```

Result

The graphical output presents the air velocity and temperature. The vectors show the air direction, the length of which is in proportion to the magnitude. A vector in the bottom of the graphics gives the scale of the vectors (in SI units). The contours shows the air temperature, where each contour represents 0.1°C (0.18°F). Two outputs are selected here. The first one is a plan view at 0.8 m (2.64 ft) above ground. The second one is a sectional view cut from the center of the wall in east-west direction and looking to the north. The graphical outputs of the basic model after the calculation are complete is:


PHOTON
Vector
0.0
0.3
0.6
0.8
1.1
1.4
1.6
1.9
2.2
2.4
2.7
3.0
3.2
3.5
3.8
Y
X
9.5
Min: 3.26E-02
Max: 3.76E+00
MIAMI: EAST WIND


PHOTON
Vector
0.0
0.3
0.7
1.0
1.3
1.6
1.9
2.2
2.5
2.8
3.2
3.5
3.8
4.1
4.4
Z
X
9.5
Min: 3.26E-02
Max: 4.40E+00

3.3 Modification of the q1 file

Northeast wind

As previously mentioned, the case of Miami considers three wind directions (east, northeast, and southeast). In this chapter, two q1 files of northeast wind and southeast wind will be developed by modifying the q1 file of east wind. Boundaries are the only portions to modify. For example, in the case of northeast wind, both north and east boundaries are inlets. The geometry of the inlets in east and north boundaries is depicted below:

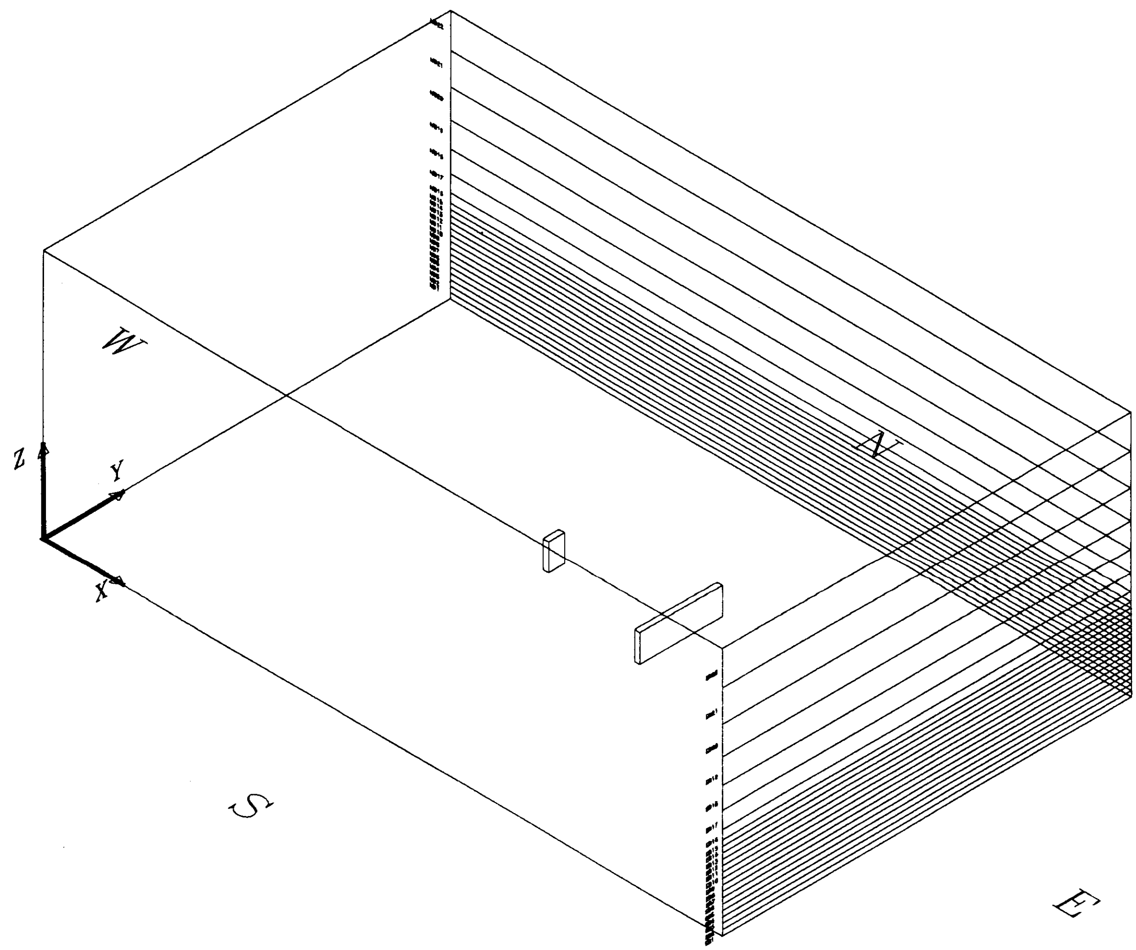


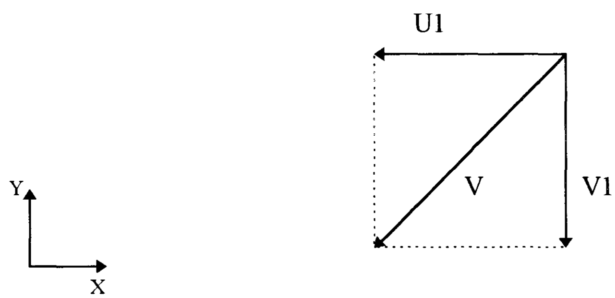
Figure 3.8 Geometry of boundaries for northeast wind.

The wind velocity for patches in east and north boundaries are:

V = 4.96 m/s
Z = 20 m
Z_g = 215 m
α = 0.1
V_g = 6.3 m/s

Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)
1	0.100	2.92	7	1.300	3.77	13	2.500	4.03	19	5.138	4.33
2	0.300	3.26	8	1.500	3.83	14	2.700	4.06	20	6.107	4.41
3	0.500	3.43	9	1.700	3.88	15	2.900	4.09	21	7.192	4.48
4	0.700	3.55	10	1.900	3.92	16	3.162	4.12	22	8.381	4.55
5	0.900	3.64	11	2.100	3.96	17	3.620	4.18			
6	1.100	3.71	12	2.300	4.00	18	4.300	4.25			

PHOENICS defines velocity as vectors in the X and Y directions. U1 is the vector in x direction, and V1 is the vector in y direction.



All velocity value in the above table should be calculated by Pythagorean theorem to obtain the U1 and the V1. In this case, since the wind is from northeast, the two vectors V1 and U1 should have the same velocity. The resulted velocities for both V1 and U1 are:

U1 = 3.51 m/s
Z = 20 m
Z_g = 215 m
α = 0.1
U_g = 4.4 m/s

Cell #	Z (m)	U1(m/s)	Cell #	Z (m)	U1(m/s)	Cell #	Z (m)	U1(m/s)	Cell #	Z (m)	U1(m/s)
1	0.100	2.06	7	1.300	2.67	13	2.500	2.85	19	5.138	3.06
2	0.300	2.30	8	1.500	2.71	14	2.700	2.87	20	6.107	3.11
3	0.500	2.43	9	1.700	2.74	15	2.900	2.89	21	7.192	3.17
4	0.700	2.51	10	1.900	2.77	16	3.162	2.92	22	8.381	3.22
5	0.900	2.57	11	2.100	2.80	17	3.620	2.96			
6	1.100	2.62	12	2.300	2.83	18	4.300	3.01			

Again, we should input the U1 and V1 to the boundaries. In this case, both east boundary and north boundary are inlets, and both U1 and V1 should be defined in these patches. The mass of air uses the velocity (V) to multiply the density of air (RHO1).

```
  ** East boundary
       Define the space and time the boundary condition to be applied
PATCH(EB1,EAST,NX,NX,1,NY,1,1,1,1)
       Use non-slip boundary condition for U1 and V1.
       Set wind velocity as 2.07 m/s in x and y directions.
       Set mass of airflow as 2.92 m/s * RHO1.
COVAL(EB1,P1,FIXFLU,2.92*RHO1)
COVAL(EB1,U1,ONLYMS,-2.07)
COVAL(EB1,V1,ONLYMS,-2.07)
COVAL(EB1,KE,ONLYMS,TKEIN)
COVAL(EB1,EP,ONLYMS,EPSIN)
       Set air temperature to 24 C (75.4 F).
COVAL(EB1,TEM1,ONLYMS,24.)
       Set coastal boundary condition by changing U1
PATCH(EB2,EAST,NX,NX,1,NY,2,2,1,1)
COVAL(EB2,P1,FIXFLU,3.26*RHO1)
COVAL(EB2,U1,ONLYMS,-2.31)
COVAL(EB2,V1,ONLYMS,-2.31)
COVAL(EB2,KE,ONLYMS,TKEIN)
COVAL(EB2,EP,ONLYMS,EPSIN)
COVAL(EB2,TEM1,ONLYMS,24.)
PATCH(EB3,EAST,NX,NX,1,NY,3,3,1,1)
COVAL(EB3,P1,FIXFLU,3.43*RHO1)
COVAL(EB3,U1,ONLYMS,-2.43)
COVAL(EB3,V1,ONLYMS,-2.43)
COVAL(EB3,KE,ONLYMS,TKEIN)
COVAL(EB3,EP,ONLYMS,EPSIN)
COVAL(EB3,TEM1,ONLYMS,24.)
PATCH(EB4,EAST,NX,NX,1,NY,4,4,1,1)
COVAL(EB4,P1,FIXFLU,3.55*RHO1)
COVAL(EB4,U1,ONLYMS,-2.51)
COVAL(EB4,V1,ONLYMS,-2.51)
COVAL(EB4,KE,ONLYMS,TKEIN)
COVAL(EB4,EP,ONLYMS,EPSIN)
COVAL(EB4,TEM1,ONLYMS,24.)
PATCH(EB5,EAST,NX,NX,1,NY,5,5,1,1)
```

```
COVAL(EB5,P1,FIXFLU,3.64*RHO1)
COVAL(EB5,U1,ONLYMS,-2.57)
COVAL(EB5,V1,ONLYMS,-2.57)
COVAL(EB5,KE,ONLYMS,TKEIN)
COVAL(EB5,EP,ONLYMS,EPSIN)
COVAL(EB5,TEM1,ONLYMS,24.)
PATCH(EB6,EAST,NX,NX,1,NY,6,6,1,1)
COVAL(EB6,P1,FIXFLU,3.71*RHO1)
COVAL(EB6,U1,ONLYMS,-2.63)
COVAL(EB6,V1,ONLYMS,-2.63)
COVAL(EB6,KE,ONLYMS,TKEIN)
COVAL(EB6,EP,ONLYMS,EPSIN)
COVAL(EB6,TEM1,ONLYMS,24.)
PATCH(EB7,EAST,NX,NX,1,NY,7,7,1,1)
COVAL(EB7,P1,FIXFLU,3.77*RHO1)
COVAL(EB7,U1,ONLYMS,-2.67)
COVAL(EB7,V1,ONLYMS,-2.67)
COVAL(EB7,KE,ONLYMS,TKEIN)
COVAL(EB7,EP,ONLYMS,EPSIN)
COVAL(EB7,TEM1,ONLYMS,24.)
PATCH(EB8,EAST,NX,NX,1,NY,8,8,1,1)
COVAL(EB8,P1,FIXFLU,3.83*RHO1)
COVAL(EB8,U1,ONLYMS,-2.71)
COVAL(EB8,V1,ONLYMS,-2.71)
COVAL(EB8,KE,ONLYMS,TKEIN)
COVAL(EB8,EP,ONLYMS,EPSIN)
COVAL(EB8,TEM1,ONLYMS,24.)
PATCH(EB9,EAST,NX,NX,1,NY,9,9,1,1)
COVAL(EB9,P1,FIXFLU,3.88*RHO1)
COVAL(EB9,U1,ONLYMS,-2.74)
COVAL(EB9,V1,ONLYMS,-2.74)
COVAL(EB9,KE,ONLYMS,TKEIN)
COVAL(EB9,EP,ONLYMS,EPSIN)
COVAL(EB9,TEM1,ONLYMS,24.)
PATCH(EB10,EAST,NX,NX,1,NY,10,10,1,1)
COVAL(EB10,P1,FIXFLU,3.92*RHO1)
COVAL(EB10,U1,ONLYMS,-2.77)
COVAL(EB10,V1,ONLYMS,-2.77)
COVAL(EB10,KE,ONLYMS,TKEIN)
COVAL(EB10,EP,ONLYMS,EPSIN)
COVAL(EB10,TEM1,ONLYMS,24.)
PATCH(EB11,EAST,NX,NX,1,NY,11,11,1,1)
COVAL(EB11,P1,FIXFLU,3.96*RHO1)
COVAL(EB11,U1,ONLYMS,-2.8)
COVAL(EB11,V1,ONLYMS,-2.8)
COVAL(EB11,KE,ONLYMS,TKEIN)
COVAL(EB11,EP,ONLYMS,EPSIN)
COVAL(EB11,TEM1,ONLYMS,24.)
PATCH(EB12,EAST,NX,NX,1,NY,12,12,1,1)
COVAL(EB12,P1,FIXFLU,4.0*RHO1)
COVAL(EB12,U1,ONLYMS,-2.83)
COVAL(EB12,V1,ONLYMS,-2.83)
COVAL(EB12,KE,ONLYMS,TKEIN)
COVAL(EB12,EP,ONLYMS,EPSIN)
COVAL(EB12,TEM1,ONLYMS,24.)
```

```
PATCH(EB13,EAST,NX,NX,1,NY,13,13,1,1)
COVAL(EB13,P1,FIXFLU,4.03*RHO1)
COVAL(EB13,U1,ONLYMS,-2.85)
COVAL(EB13,V1,ONLYMS,-2.85)
COVAL(EB13,KE,ONLYMS,TKEIN)
COVAL(EB13,EP,ONLYMS,EPSIN)
COVAL(EB13,TEM1,ONLYMS,24.)
PATCH(EB14,EAST,NX,NX,1,NY,14,14,1,1)
COVAL(EB14,P1,FIXFLU,4.06*RHO1)
COVAL(EB14,U1,ONLYMS,-2.87)
COVAL(EB14,V1,ONLYMS,-2.87)
COVAL(EB14,KE,ONLYMS,TKEIN)
COVAL(EB14,EP,ONLYMS,EPSIN)
COVAL(EB14,TEM1,ONLYMS,24.)
PATCH(EB15,EAST,NX,NX,1,NY,15,15,1,1)
COVAL(EB15,P1,FIXFLU,4.09*RHO1)
COVAL(EB15,U1,ONLYMS,-2.89)
COVAL(EB15,V1,ONLYMS,-2.89)
COVAL(EB15,KE,ONLYMS,TKEIN)
COVAL(EB15,EP,ONLYMS,EPSIN)
COVAL(EB15,TEM1,ONLYMS,24.)
PATCH(EB16,EAST,NX,NX,1,NY,16,16,1,1)
COVAL(EB16,P1,FIXFLU,4.12*RHO1)
COVAL(EB16,U1,ONLYMS,-2.92)
COVAL(EB16,V1,ONLYMS,-2.92)
COVAL(EB16,KE,ONLYMS,TKEIN)
COVAL(EB16,EP,ONLYMS,EPSIN)
COVAL(EB16,TEM1,ONLYMS,24.)
PATCH(EB17,EAST,NX,NX,1,NY,17,17,1,1)
COVAL(EB17,P1,FIXFLU,4.18*RHO1)
COVAL(EB17,U1,ONLYMS,-2.96)
COVAL(EB17,V1,ONLYMS,-2.96)
COVAL(EB17,KE,ONLYMS,TKEIN)
COVAL(EB17,EP,ONLYMS,EPSIN)
COVAL(EB17,TEM1,ONLYMS,24.)
PATCH(EB18,EAST,NX,NX,1,NY,18,18,1,1)
COVAL(EB18,P1,FIXFLU,4.25*RHO1)
COVAL(EB18,U1,ONLYMS,-3.01)
COVAL(EB18,V1,ONLYMS,-3.01)
COVAL(EB18,KE,ONLYMS,TKEIN)
COVAL(EB18,EP,ONLYMS,EPSIN)
COVAL(EB18,TEM1,ONLYMS,24.)
PATCH(EB19,EAST,NX,NX,1,NY,19,19,1,1)
COVAL(EB19,P1,FIXFLU,4.33*RHO1)
COVAL(EB19,U1,ONLYMS,-3.06)
COVAL(EB19,V1,ONLYMS,-3.06)
COVAL(EB19,KE,ONLYMS,TKEIN)
COVAL(EB19,EP,ONLYMS,EPSIN)
COVAL(EB19,TEM1,ONLYMS,24.)
PATCH(EB20,EAST,NX,NX,1,NY,20,20,1,1)
COVAL(EB20,P1,FIXFLU,4.41*RHO1)
COVAL(EB20,U1,ONLYMS,-3.12)
COVAL(EB20,V1,ONLYMS,-3.12)
COVAL(EB20,KE,ONLYMS,TKEIN)
COVAL(EB20,EP,ONLYMS,EPSIN)
```

```
COVAL(EB20,TEM1,ONLYMS,24.)
PATCH(EB21,EAST,NX,NX,1,NY,21,21,1,1)
COVAL(EB21,P1,FIXFLU,4.48*RHO1)
COVAL(EB21,U1,ONLYMS,-3.17)
COVAL(EB21,V1,ONLYMS,-3.17)
COVAL(EB21,KE,ONLYMS,TKEIN)
COVAL(EB21,EP,ONLYMS,EPSIN)
COVAL(EB21,TEM1,ONLYMS,24.)
PATCH(EB22,EAST,NX,NX,1,NY,22,22,1,1)
COVAL(EB22,P1,FIXFLU,4.55*RHO1)
COVAL(EB22,U1,ONLYMS,-3.22)
COVAL(EB22,V1,ONLYMS,-3.22)
COVAL(EB22,KE,ONLYMS,TKEIN)
COVAL(EB22,EP,ONLYMS,EPSIN)
COVAL(EB22,TEM1,ONLYMS,24.)
  ** North boundary
PATCH(NB1,NORTH,1,NX,NY,NY,1,1,1,1)
COVAL(NB1,P1,FIXFLU,2.92*RHO1)
COVAL(NB1,U1,ONLYMS,-2.07)
COVAL(NB1,V1,ONLYMS,-2.07)
COVAL(NB1,KE,ONLYMS,TKEIN)
COVAL(NB1,EP,ONLYMS,EPSIN)
COVAL(NB1,TEM1,ONLYMS,24.)
PATCH(NB2,NORTH,1,NX,NY,NY,2,2,1,1)
COVAL(NB2,P1,FIXFLU,3.26*RHO1)
COVAL(NB2,U1,ONLYMS,-2.31)
COVAL(NB2,V1,ONLYMS,-2.31)
COVAL(NB2,KE,ONLYMS,TKEIN)
COVAL(NB2,EP,ONLYMS,EPSIN)
COVAL(NB2,TEM1,ONLYMS,24.)
PATCH(NB3,NORTH,1,NX,NY,NY,3,3,1,1)
COVAL(NB3,P1,FIXFLU,3.43*RHO1)
COVAL(NB3,U1,ONLYMS,-2.43)
COVAL(NB3,V1,ONLYMS,-2.43)
COVAL(NB3,KE,ONLYMS,TKEIN)
COVAL(NB3,EP,ONLYMS,EPSIN)
COVAL(NB3,TEM1,ONLYMS,24.)
PATCH(NB4,NORTH,1,NX,NY,NY,4,4,1,1)
COVAL(NB4,P1,FIXFLU,3.55*RHO1)
COVAL(NB4,U1,ONLYMS,-2.51)
COVAL(NB4,V1,ONLYMS,-2.51)
COVAL(NB4,KE,ONLYMS,TKEIN)
COVAL(NB4,EP,ONLYMS,EPSIN)
COVAL(NB4,TEM1,ONLYMS,24.)
PATCH(NB5,NORTH,1,NX,NY,NY,5,5,1,1)
COVAL(NB5,P1,FIXFLU,3.64*RHO1)
COVAL(NB5,U1,ONLYMS,-2.57)
COVAL(NB5,V1,ONLYMS,-2.57)
COVAL(NB5,KE,ONLYMS,TKEIN)
COVAL(NB5,EP,ONLYMS,EPSIN)
COVAL(NB5,TEM1,ONLYMS,24.)
PATCH(NB6,NORTH,1,NX,NY,NY,6,6,1,1)
COVAL(NB6,P1,FIXFLU,3.71*RHO1)
COVAL(NB6,U1,ONLYMS,-2.63)
COVAL(NB6,V1,ONLYMS,-2.63)
```

```
COVAL(NB6,KE,ONLYMS,TKEIN)
COVAL(NB6,EP,ONLYMS,EPSIN)
COVAL(NB6,TEM1,ONLYMS,24.)
PATCH(NB7,NORTH,1,NX,NY,NY,7,7,1,1)
COVAL(NB7,P1,FIXFLU,3.77*RHO1)
COVAL(NB7,U1,ONLYMS,-2.67)
COVAL(NB7,V1,ONLYMS,-2.67)
COVAL(NB7,KE,ONLYMS,TKEIN)
COVAL(NB7,EP,ONLYMS,EPSIN)
COVAL(NB7,TEM1,ONLYMS,24.)
PATCH(NB8,NORTH,1,NX,NY,NY,8,8,1,1)
COVAL(NB8,P1,FIXFLU,3.83*RHO1)
COVAL(NB8,U1,ONLYMS,-2.71)
COVAL(NB8,V1,ONLYMS,-2.71)
COVAL(NB8,KE,ONLYMS,TKEIN)
COVAL(NB8,EP,ONLYMS,EPSIN)
COVAL(NB8,TEM1,ONLYMS,24.)
PATCH(NB9,NORTH,1,NX,NY,NY,9,9,1,1)
COVAL(NB9,P1,FIXFLU,3.88*RHO1)
COVAL(NB9,U1,ONLYMS,-2.74)
COVAL(NB9,V1,ONLYMS,-2.74)
COVAL(NB9,KE,ONLYMS,TKEIN)
COVAL(NB9,EP,ONLYMS,EPSIN)
COVAL(NB9,TEM1,ONLYMS,24.)
PATCH(NB10,NORTH,1,NX,NY,NY,10,10,1,1)
COVAL(NB10,P1,FIXFLU,3.92*RHO1)
COVAL(NB10,U1,ONLYMS,-2.77)
COVAL(NB10,V1,ONLYMS,-2.77)
COVAL(NB10,KE,ONLYMS,TKEIN)
COVAL(NB10,EP,ONLYMS,EPSIN)
COVAL(NB10,TEM1,ONLYMS,24.)
PATCH(NB11,NORTH,1,NX,NY,NY,11,11,1,1)
COVAL(NB11,P1,FIXFLU,3.96*RHO1)
COVAL(NB11,U1,ONLYMS,-2.8)
COVAL(NB11,V1,ONLYMS,-2.8)
COVAL(NB11,KE,ONLYMS,TKEIN)
COVAL(NB11,EP,ONLYMS,EPSIN)
COVAL(NB11,TEM1,ONLYMS,24.)
PATCH(NB12,NORTH,1,NX,NY,NY,12,12,1,1)
COVAL(NB12,P1,FIXFLU,4.0*RHO1)
COVAL(NB12,U1,ONLYMS,-2.83)
COVAL(NB12,V1,ONLYMS,-2.83)
COVAL(NB12,KE,ONLYMS,TKEIN)
COVAL(NB12,EP,ONLYMS,EPSIN)
COVAL(NB12,TEM1,ONLYMS,24.)
PATCH(NB13,NORTH,1,NX,NY,NY,13,13,1,1)
COVAL(NB13,P1,FIXFLU,4.03*RHO1)
COVAL(NB13,U1,ONLYMS,-2.85)
COVAL(NB13,V1,ONLYMS,-2.85)
COVAL(NB13,KE,ONLYMS,TKEIN)
COVAL(NB13,EP,ONLYMS,EPSIN)
COVAL(NB13,TEM1,ONLYMS,24.)
PATCH(NB14,NORTH,1,NX,NY,NY,14,14,1,1)
COVAL(NB14,P1,FIXFLU,4.06*RHO1)
COVAL(NB14,U1,ONLYMS,-2.87)
```

```
COVAL(NB14,V1,ONLYMS,-2.87)
COVAL(NB14,KE,ONLYMS,TKEIN)
COVAL(NB14,EP,ONLYMS,EPSIN)
COVAL(NB14,TEM1,ONLYMS,24.)
PATCH(NB15,NORTH,1,NX,NY,NY,15,15,1,1)
COVAL(NB15,P1,FIXFLU,4.09*RHO1)
COVAL(NB15,U1,ONLYMS,-2.89)
COVAL(NB15,V1,ONLYMS,-2.89)
COVAL(NB15,KE,ONLYMS,TKEIN)
COVAL(NB15,EP,ONLYMS,EPSIN)
COVAL(NB15,TEM1,ONLYMS,24.)
PATCH(NB16,NORTH,1,NX,NY,NY,16,16,1,1)
COVAL(NB16,P1,FIXFLU,4.12*RHO1)
COVAL(NB16,U1,ONLYMS,-2.92)
COVAL(NB16,V1,ONLYMS,-2.92)
COVAL(NB16,KE,ONLYMS,TKEIN)
COVAL(NB16,EP,ONLYMS,EPSIN)
COVAL(NB16,TEM1,ONLYMS,24.)
PATCH(NB17,NORTH,1,NX,NY,NY,17,17,1,1)
COVAL(NB17,P1,FIXFLU,4.18*RHO1)
COVAL(NB17,U1,ONLYMS,-2.96)
COVAL(NB17,V1,ONLYMS,-2.96)
COVAL(NB17,KE,ONLYMS,TKEIN)
COVAL(NB17,EP,ONLYMS,EPSIN)
COVAL(NB17,TEM1,ONLYMS,24.)
PATCH(NB18,NORTH,1,NX,NY,NY,18,18,1,1)
COVAL(NB18,P1,FIXFLU,4.25*RHO1)
COVAL(NB18,U1,ONLYMS,-3.01)
COVAL(NB18,V1,ONLYMS,-3.01)
COVAL(NB18,KE,ONLYMS,TKEIN)
COVAL(NB18,EP,ONLYMS,EPSIN)
COVAL(NB18,TEM1,ONLYMS,24.)
PATCH(NB19,NORTH,1,NX,NY,NY,19,19,1,1)
COVAL(NB19,P1,FIXFLU,4.33*RHO1)
COVAL(NB19,U1,ONLYMS,-3.06)
COVAL(NB19,V1,ONLYMS,-3.06)
COVAL(NB19,KE,ONLYMS,TKEIN)
COVAL(NB19,EP,ONLYMS,EPSIN)
COVAL(NB19,TEM1,ONLYMS,24.)
PATCH(NB20,NORTH,1,NX,NY,NY,20,20,1,1)
COVAL(NB20,P1,FIXFLU,4.41*RHO1)
COVAL(NB20,U1,ONLYMS,-3.12)
COVAL(NB20,V1,ONLYMS,-3.12)
COVAL(NB20,KE,ONLYMS,TKEIN)
COVAL(NB20,EP,ONLYMS,EPSIN)
COVAL(NB20,TEM1,ONLYMS,24.)
PATCH(NB21,NORTH,1,NX,NY,NY,21,21,1,1)
COVAL(NB21,P1,FIXFLU,4.48*RHO1)
COVAL(NB21,U1,ONLYMS,-3.17)
COVAL(NB21,V1,ONLYMS,-3.17)
COVAL(NB21,KE,ONLYMS,TKEIN)
COVAL(NB21,EP,ONLYMS,EPSIN)
COVAL(NB21,TEM1,ONLYMS,24.)
PATCH(NB22,NORTH,1,NX,NY,NY,22,22,1,1)
COVAL(NB22,P1,FIXFLU,4.55*RHO1)
```

```
COVAL(NB22,U1,ONLYMS,-3.22)
COVAL(NB22,V1,ONLYMS,-3.22)
COVAL(NB22,KE,ONLYMS,TKEIN)
COVAL(NB22,EP,ONLYMS,EPSIN)
COVAL(NB22,TEM1,ONLYMS,24.)
```

Both south and west boundaries are considered as outlets. They should be defined in the same way as the west boundary in the east wind case.

```
  ** South boundary
PATCH(SB,SOUTH,1,NX,1,1,1,NZ,1,1)
COVAL(SB,P1,FIXP,0.0)
COVAL(SB,TEM1,0.0,24.)
COVAL(SB,KE,0.0,1.E-5)
COVAL(SB,EP,0.0,1.E-5)
  ** West boundary
PATCH(WB,WEST,1,1,1,NY,1,NZ,1,1)
COVAL(WB,P1,FIXP,0.0)
COVAL(WB,TEM1,0.0,24.)
COVAL(WB,KE,0.0,1.E-5)
COVAL(WB,EP,0.0,1.E-5)
```

The upper boundary and the ground remain the same as in the east wind case.

```
  ** Upper boundary
PATCH(UPPER,HIGH,1,NX,1,NY,NZ,NZ,1,1)
COVAL(UPPER,TEM1,0.0,24.)
  ** Ground
PATCH(GROUND,LWALL,1,NX,1,NY,1,1,1,1)
COVAL(GROUND,U1,GRND2,0.0)
COVAL(GROUND,V1,GRND2,0.0)
COVAL(GROUND,TEM1,GRND2,24.)
COVAL(GROUND,KE,GRND2,GRND2)
COVAL(GROUND,EP,GRND2,GRND2)
```

In group 11, the U1 of cell # 22 should be used for the initial air velocity, and the air velocity V of cell # 22 should be used to calculate KE.

```
GROUP 11. Initialization of variable or porosity fields
       Set initial air velocity 3.22 m/s (634 ft/m).
       Set initial air temperature 24 C (75.4 F).
FIINIT(U1)=-3.22
FIINIT(V1)=-3.22
FIINIT(TEM1)=24.
PRESS0=1.0E5
TEMP0=273.15
```

```
  ** Calculation of KE
TKEIN=0.018*0.25*4.55*4.55
  ** Calculation of EP
EPSIN=TKEIN**1.5*0.1643/3.429E-3
FIINIT(KE)=TKEIN
FIINIT(EP)=EPSIN
```

In group 17, the maximum velocity (MAXV) should also be changed to the value of U1 of cell # 22:

```
    GROUP 17. Under-relaxation devices
       Determine false-time-step
REAL(DTF, MINCELL, MAXV)
MINCELL=0.2
MAXV=3.22
DTF=.1*MINCELL/MAXV
DTF
```

The complete q1 file for northeast wind is reported in Appendix B. The graphic outputs of the northeast wind models are:

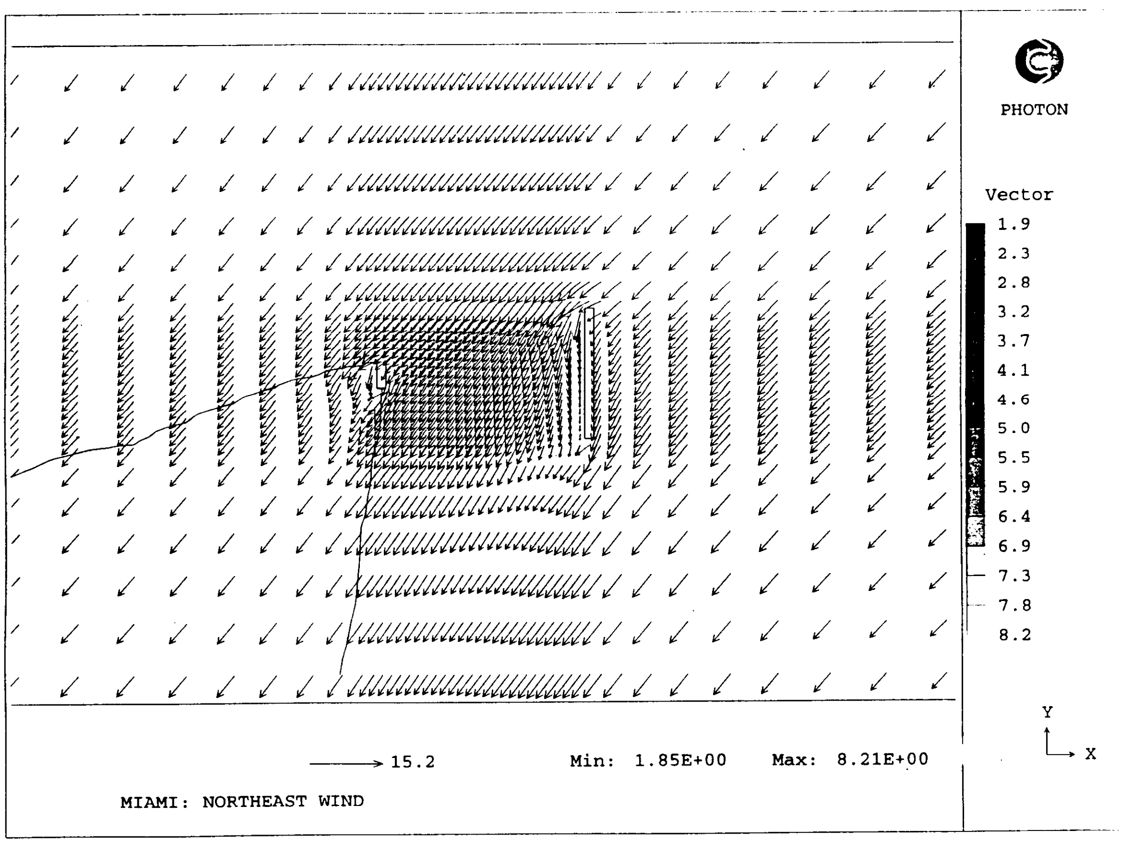


Figure 3.9 Plan view of airflow simulation in northeast wind model

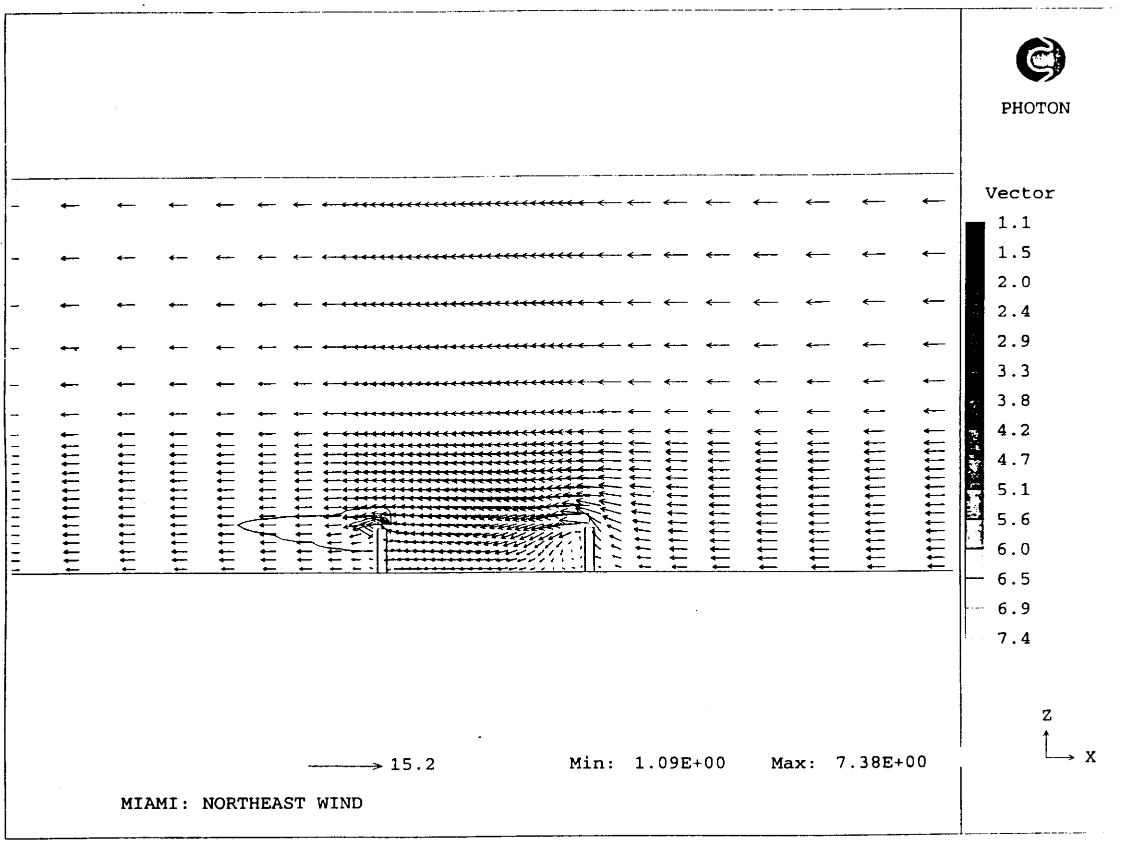


Figure 3.10 Section view of airflow simulation in northeast wind model

Southeast wind

The q1 file for the southeast wind should be modified in a similar way as the northeast wind. In this case, both east and south boundaries are then inlets and north and west boundaries are outlets. The geometry of the inlet patches in east and south boundaries is depicted in the following figure:

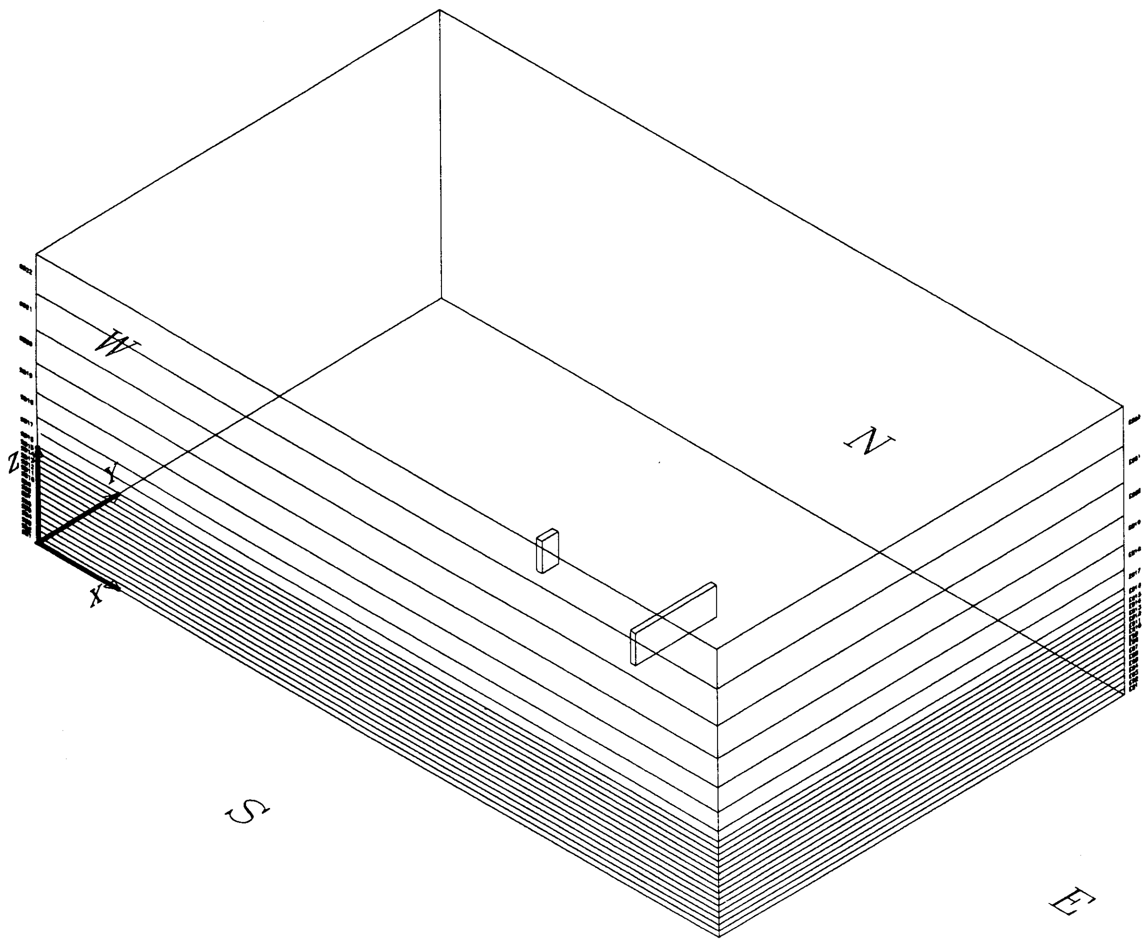


Figure 3.11 Geometry of boundaries for southeast wind

Again, the first step is to calculate the wind velocity according to the boundary condition:

V = 4.43 m/s
Z = 20 m
Z_g = 215 m
α = 0.1 m
V_g = 5.6 m/s

Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)	Cell #	Z (m)	V (m/s)
1	0.100	2.61	7	1.300	3.37	13	2.500	3.60	19	5.138	3.87
2	0.300	2.91	8	1.500	3.42	14	2.700	3.63	20	6.107	3.93
3	0.500	3.06	9	1.700	3.46	15	2.900	3.65	21	7.192	4.00
4	0.700	3.17	10	1.900	3.50	16	3.162	3.68	22	8.381	4.06
5	0.900	3.25	11	2.100	3.54	17	3.620	3.73			
6	1.100	3.31	12	2.300	3.57	18	4.300	3.80			

The U1 and V1 is calculated as:

U = 3.13 m/s
Z = 20 m
Z_g = 215 m
α = 0.1 m
U_g = 4.0 m/s

Cell #	Z (m)	V1(m/s)	Cell #	Z (m)	V1(m/s)	Cell #	Z (m)	V1(m/s)	Cell #	Z (m)	V1(m/s)
1	0.100	1.84	7	1.300	2.38	13	2.500	2.54	19	5.138	2.73
2	0.300	2.06	8	1.500	2.42	14	2.700	2.56	20	6.107	2.78
3	0.500	2.17	9	1.700	2.45	15	2.900	2.58	21	7.192	2.83
4	0.700	2.24	10	1.900	2.48	16	3.162	2.60	22	8.381	2.87
5	0.900	2.30	11	2.100	2.50	17	3.620	2.64			
6	1.100	2.34	12	2.300	2.52	18	4.300	2.69			

The next step is to assign V1 and U1 to the east and south boundaries.

```
** East boundary
      Define the space and time the boundary condition to be applied
PATCH(EB1,EAST,NX,NX,1,NY,1,1,1,1)
      Use non-slip boundary condition for U1 and V1.
COVAL(EB1,P1,FIXFLU,2.61*RHO1)
COVAL(EB1,U1,ONLYMS,-1.84)
COVAL(EB1,V1,ONLYMS,1.84)
COVAL(EB1,KE,ONLYMS,TKEIN)
COVAL(EB1,EP,ONLYMS,EPSIN)
      Set air temperature to 24 C (75.4 F).
COVAL(EB1,TEM1,ONLYMS,24.)
      Set coastal boundary condition by changing U1
PATCH(EB2,EAST,NX,NX,1,NY,2,2,1,1)
COVAL(EB2,P1,FIXFLU,2.91*RHO1)
COVAL(EB2,U1,ONLYMS,-2.06)
COVAL(EB2,V1,ONLYMS,2.06)
COVAL(EB2,KE,ONLYMS,TKEIN)
COVAL(EB2,EP,ONLYMS,EPSIN)
COVAL(EB2,TEM1,ONLYMS,24.)
```

```
PATCH(EB3,EAST,NX,NX,1,NY,3,3,1,1)
COVAL(EB3,P1,FIXFLU,3.06*RHO1)
COVAL(EB3,U1,ONLYMS,-2.17)
COVAL(EB3,V1,ONLYMS,2.17)
COVAL(EB3,KE,ONLYMS,TKEIN)
COVAL(EB3,EP,ONLYMS,EPSIN)
COVAL(EB3,TEM1,ONLYMS,24.)
PATCH(EB4,EAST,NX,NX,1,NY,4,4,1,1)
COVAL(EB4,P1,FIXFLU,3.17*RHO1)
COVAL(EB4,U1,ONLYMS,-2.24)
COVAL(EB4,V1,ONLYMS,2.24)
COVAL(EB4,KE,ONLYMS,TKEIN)
COVAL(EB4,EP,ONLYMS,EPSIN)
COVAL(EB4,TEM1,ONLYMS,24.)
PATCH(EB5,EAST,NX,NX,1,NY,5,5,1,1)
COVAL(EB5,P1,FIXFLU,3.25*RHO1)
COVAL(EB5,U1,ONLYMS,-2.30)
COVAL(EB5,V1,ONLYMS,2.30)
COVAL(EB5,KE,ONLYMS,TKEIN)
COVAL(EB5,EP,ONLYMS,EPSIN)
COVAL(EB5,TEM1,ONLYMS,24.)
PATCH(EB6,EAST,NX,NX,1,NY,6,6,1,1)
COVAL(EB6,P1,FIXFLU,3.31*RHO1)
COVAL(EB6,U1,ONLYMS,-2.34)
COVAL(EB6,V1,ONLYMS,2.34)
COVAL(EB6,KE,ONLYMS,TKEIN)
COVAL(EB6,EP,ONLYMS,EPSIN)
COVAL(EB6,TEM1,ONLYMS,24.)
PATCH(EB7,EAST,NX,NX,1,NY,7,7,1,1)
COVAL(EB7,P1,FIXFLU,3.37*RHO1)
COVAL(EB7,U1,ONLYMS,-2.38)
COVAL(EB7,V1,ONLYMS,2.38)
COVAL(EB7,KE,ONLYMS,TKEIN)
COVAL(EB7,EP,ONLYMS,EPSIN)
COVAL(EB7,TEM1,ONLYMS,24.)
PATCH(EB8,EAST,NX,NX,1,NY,8,8,1,1)
COVAL(EB8,P1,FIXFLU,3.42*RHO1)
COVAL(EB8,U1,ONLYMS,-2.42)
COVAL(EB8,V1,ONLYMS,2.42)
COVAL(EB8,KE,ONLYMS,TKEIN)
COVAL(EB8,EP,ONLYMS,EPSIN)
COVAL(EB8,TEM1,ONLYMS,24.)
PATCH(EB9,EAST,NX,NX,1,NY,9,9,1,1)
COVAL(EB9,P1,FIXFLU,3.46*RHO1)
COVAL(EB9,U1,ONLYMS,-2.45)
COVAL(EB9,V1,ONLYMS,2.45)
COVAL(EB9,KE,ONLYMS,TKEIN)
COVAL(EB9,EP,ONLYMS,EPSIN)
COVAL(EB9,TEM1,ONLYMS,24.)
PATCH(EB10,EAST,NX,NX,1,NY,10,10,1,1)
COVAL(EB10,P1,FIXFLU,3.50*RHO1)
COVAL(EB10,U1,ONLYMS,-2.48)
COVAL(EB10,V1,ONLYMS,2.48)
COVAL(EB10,KE,ONLYMS,TKEIN)
COVAL(EB10,EP,ONLYMS,EPSIN)
```

```
COVAL(EB10,TEM1,ONLYMS,24.)
PATCH(EB11,EAST,NX,NX,1,NY,11,11,1,1)
COVAL(EB11,P1,FIXFLU,3.54*RHO1)
COVAL(EB11,U1,ONLYMS,-2.5)
COVAL(EB11,V1,ONLYMS,2.5)
COVAL(EB11,KE,ONLYMS,TKEIN)
COVAL(EB11,EP,ONLYMS,EPSIN)
COVAL(EB11,TEM1,ONLYMS,24.)
PATCH(EB12,EAST,NX,NX,1,NY,12,12,1,1)
COVAL(EB12,P1,FIXFLU,3.57*RHO1)
COVAL(EB12,U1,ONLYMS,-2.52)
COVAL(EB12,V1,ONLYMS,2.52)
COVAL(EB12,KE,ONLYMS,TKEIN)
COVAL(EB12,EP,ONLYMS,EPSIN)
COVAL(EB12,TEM1,ONLYMS,24.)
PATCH(EB13,EAST,NX,NX,1,NY,13,13,1,1)
COVAL(EB13,P1,FIXFLU,3.60*RHO1)
COVAL(EB13,U1,ONLYMS,-2.54)
COVAL(EB13,V1,ONLYMS,2.54)
COVAL(EB13,KE,ONLYMS,TKEIN)
COVAL(EB13,EP,ONLYMS,EPSIN)
COVAL(EB13,TEM1,ONLYMS,24.)
PATCH(EB14,EAST,NX,NX,1,NY,14,14,1,1)
COVAL(EB14,P1,FIXFLU,3.63*RHO1)
COVAL(EB14,U1,ONLYMS,-2.56)
COVAL(EB14,V1,ONLYMS,2.56)
COVAL(EB14,KE,ONLYMS,TKEIN)
COVAL(EB14,EP,ONLYMS,EPSIN)
COVAL(EB14,TEM1,ONLYMS,24.)
PATCH(EB15,EAST,NX,NX,1,NY,15,15,1,1)
COVAL(EB15,P1,FIXFLU,3.65*RHO1)
COVAL(EB15,U1,ONLYMS,-2.58)
COVAL(EB15,V1,ONLYMS,2.58)
COVAL(EB15,KE,ONLYMS,TKEIN)
COVAL(EB15,EP,ONLYMS,EPSIN)
COVAL(EB15,TEM1,ONLYMS,24.)
PATCH(EB16,EAST,NX,NX,1,NY,16,16,1,1)
COVAL(EB16,P1,FIXFLU,3.68*RHO1)
COVAL(EB16,U1,ONLYMS,-2.60)
COVAL(EB16,V1,ONLYMS,2.60)
COVAL(EB16,KE,ONLYMS,TKEIN)
COVAL(EB16,EP,ONLYMS,EPSIN)
COVAL(EB16,TEM1,ONLYMS,24.)
PATCH(EB17,EAST,NX,NX,1,NY,17,17,1,1)
COVAL(EB17,P1,FIXFLU,3.73*RHO1)
COVAL(EB17,U1,ONLYMS,-2.64)
COVAL(EB17,V1,ONLYMS,2.64)
COVAL(EB17,KE,ONLYMS,TKEIN)
COVAL(EB17,EP,ONLYMS,EPSIN)
COVAL(EB17,TEM1,ONLYMS,24.)
PATCH(EB18,EAST,NX,NX,1,NY,18,18,1,1)
COVAL(EB18,P1,FIXFLU,3.80*RHO1)
COVAL(EB18,U1,ONLYMS,-2.69)
COVAL(EB18,V1,ONLYMS,2.69)
COVAL(EB18,KE,ONLYMS,TKEIN)
```

```
COVAL(EB18,EP,ONLYMS,EPSIN)
COVAL(EB18,TEM1,ONLYMS,24.)
PATCH(EB19,EAST,NX,NX,1,NY,19,19,1,1)
COVAL(EB19,P1,FIXFLU,3.87*RHO1)
COVAL(EB19,U1,ONLYMS,-2.73)
COVAL(EB19,V1,ONLYMS,2.73)
COVAL(EB19,KE,ONLYMS,TKEIN)
COVAL(EB19,EP,ONLYMS,EPSIN)
COVAL(EB19,TEM1,ONLYMS,24.)
PATCH(EB20,EAST,NX,NX,1,NY,20,20,1,1)
COVAL(EB20,P1,FIXFLU,3.93*RHO1)
COVAL(EB20,U1,ONLYMS,-2.78)
COVAL(EB20,V1,ONLYMS,2.78)
COVAL(EB20,KE,ONLYMS,TKEIN)
COVAL(EB20,EP,ONLYMS,EPSIN)
COVAL(EB20,TEM1,ONLYMS,24.)
PATCH(EB21,EAST,NX,NX,1,NY,21,21,1,1)
COVAL(EB21,P1,FIXFLU,4.00*RHO1)
COVAL(EB21,U1,ONLYMS,-2.83)
COVAL(EB21,V1,ONLYMS,2.83)
COVAL(EB21,KE,ONLYMS,TKEIN)
COVAL(EB21,EP,ONLYMS,EPSIN)
COVAL(EB21,TEM1,ONLYMS,24.)
PATCH(EB22,EAST,NX,NX,1,NY,22,22,1,1)
COVAL(EB22,P1,FIXFLU,4.06*RHO1)
COVAL(EB22,U1,ONLYMS,-2.87)
COVAL(EB22,V1,ONLYMS,2.87)
COVAL(EB22,KE,ONLYMS,TKEIN)
COVAL(EB22,EP,ONLYMS,EPSIN)
COVAL(EB22,TEM1,ONLYMS,24.)
  ** South boundary
PATCH(SB1,SOUTH,1,NX,1,1,1,1,1,1)
COVAL(SB1,P1,FIXFLU,2.61*RHO1)
COVAL(SB1,U1,ONLYMS,-1.84)
COVAL(SB1,V1,ONLYMS,1.84)
COVAL(SB1,KE,ONLYMS,TKEIN)
COVAL(SB1,EP,ONLYMS,EPSIN)
COVAL(SB1,TEM1,ONLYMS,24.)
PATCH(SB2,SOUTH,1,NX,1,1,2,2,1,1)
COVAL(SB2,P1,FIXFLU,2.91*RHO1)
COVAL(SB2,U1,ONLYMS,-2.06)
COVAL(SB2,V1,ONLYMS,2.06)
COVAL(SB2,KE,ONLYMS,TKEIN)
COVAL(SB2,EP,ONLYMS,EPSIN)
COVAL(SB2,TEM1,ONLYMS,24.)
PATCH(SB3,SOUTH,1,NX,1,1,3,3,1,1)
COVAL(SB3,P1,FIXFLU,3.06*RHO1)
COVAL(SB3,U1,ONLYMS,-2.17)
COVAL(SB3,V1,ONLYMS,2.17)
COVAL(SB3,KE,ONLYMS,TKEIN)
COVAL(SB3,EP,ONLYMS,EPSIN)
COVAL(SB3,TEM1,ONLYMS,24.)
PATCH(SB4,SOUTH,1,NX,1,1,4,4,1,1)
COVAL(SB4,P1,FIXFLU,3.17*RHO1)
COVAL(SB4,U1,ONLYMS,-2.24)
```

```
COVAL(SB4,V1,ONLYMS,2.24)
COVAL(SB4,KE,ONLYMS,TKEIN)
COVAL(SB4,EP,ONLYMS,EPSIN)
COVAL(SB4,TEM1,ONLYMS,24.)
PATCH(SB5,SOUTH,1,NX,1,1,5,5,1,1)
COVAL(SB5,P1,FIXFLU,3.25*RHO1)
COVAL(SB5,U1,ONLYMS,-2.30)
COVAL(SB5,V1,ONLYMS,2.30)
COVAL(SB5,KE,ONLYMS,TKEIN)
COVAL(SB5,EP,ONLYMS,EPSIN)
COVAL(SB5,TEM1,ONLYMS,24.)
PATCH(SB6,SOUTH,1,NX,1,1,6,6,1,1)
COVAL(SB6,P1,FIXFLU,3.31*RHO1)
COVAL(SB6,U1,ONLYMS,-2.34)
COVAL(SB6,V1,ONLYMS,2.34)
COVAL(SB6,KE,ONLYMS,TKEIN)
COVAL(SB6,EP,ONLYMS,EPSIN)
COVAL(SB6,TEM1,ONLYMS,24.)
PATCH(SB7,SOUTH,1,NX,1,1,7,7,1,1)
COVAL(SB7,P1,FIXFLU,3.37*RHO1)
COVAL(SB7,U1,ONLYMS,-2.38)
COVAL(SB7,V1,ONLYMS,2.38)
COVAL(SB7,KE,ONLYMS,TKEIN)
COVAL(SB7,EP,ONLYMS,EPSIN)
COVAL(SB7,TEM1,ONLYMS,24.)
PATCH(SB8,SOUTH,1,NX,1,1,8,8,1,1)
COVAL(SB8,P1,FIXFLU,3.42*RHO1)
COVAL(SB8,U1,ONLYMS,-2.42)
COVAL(SB8,V1,ONLYMS,2.42)
COVAL(SB8,KE,ONLYMS,TKEIN)
COVAL(SB8,EP,ONLYMS,EPSIN)
COVAL(SB8,TEM1,ONLYMS,24.)
PATCH(SB9,SOUTH,1,NX,1,1,9,9,1,1)
COVAL(SB9,P1,FIXFLU,3.46*RHO1)
COVAL(SB9,U1,ONLYMS,-2.45)
COVAL(SB9,V1,ONLYMS,2.45)
COVAL(SB9,KE,ONLYMS,TKEIN)
COVAL(SB9,EP,ONLYMS,EPSIN)
COVAL(SB9,TEM1,ONLYMS,24.)
PATCH(SB10,SOUTH,1,NX,1,1,10,10,1,1)
COVAL(SB10,P1,FIXFLU,3.50*RHO1)
COVAL(SB10,U1,ONLYMS,-2.48)
COVAL(SB10,V1,ONLYMS,2.48)
COVAL(SB10,KE,ONLYMS,TKEIN)
COVAL(SB10,EP,ONLYMS,EPSIN)
COVAL(SB10,TEM1,ONLYMS,24.)
PATCH(SB11,SOUTH,1,NX,1,1,11,11,1,1)
COVAL(SB11,P1,FIXFLU,3.54*RHO1)
COVAL(SB11,U1,ONLYMS,-2.5)
COVAL(SB11,V1,ONLYMS,2.5)
COVAL(SB11,KE,ONLYMS,TKEIN)
COVAL(SB11,EP,ONLYMS,EPSIN)
COVAL(SB11,TEM1,ONLYMS,24.)
PATCH(SB12,SOUTH,1,NX,1,1,12,12,1,1)
COVAL(SB12,P1,FIXFLU,3.57*RHO1)
```

```
COVAL(SB12,U1,ONLYMS,-2.52)
COVAL(SB12,V1,ONLYMS,2.52)
COVAL(SB12,KE,ONLYMS,TKEIN)
COVAL(SB12,EP,ONLYMS,EPSIN)
COVAL(SB12,TEM1,ONLYMS,24.)
PATCH(SB13,SOUTH,1,NX,1,1,13,13,1,1)
COVAL(SB13,P1,FIXFLU,3.60*RHO1)
COVAL(SB13,U1,ONLYMS,-2.54)
COVAL(SB13,V1,ONLYMS,2.54)
COVAL(SB13,KE,ONLYMS,TKEIN)
COVAL(SB13,EP,ONLYMS,EPSIN)
COVAL(SB13,TEM1,ONLYMS,24.)
PATCH(SB14,SOUTH,1,NX,1,1,14,14,1,1)
COVAL(SB14,P1,FIXFLU,3.63*RHO1)
COVAL(SB14,U1,ONLYMS,-2.56)
COVAL(SB14,V1,ONLYMS,2.56)
COVAL(SB14,KE,ONLYMS,TKEIN)
COVAL(SB14,EP,ONLYMS,EPSIN)
COVAL(SB14,TEM1,ONLYMS,24.)
PATCH(SB15,SOUTH,1,NX,1,1,15,15,1,1)
COVAL(SB15,P1,FIXFLU,3.65*RHO1)
COVAL(SB15,U1,ONLYMS,-2.58)
COVAL(SB15,V1,ONLYMS,2.58)
COVAL(SB15,KE,ONLYMS,TKEIN)
COVAL(SB15,EP,ONLYMS,EPSIN)
COVAL(SB15,TEM1,ONLYMS,24.)
PATCH(SB16,SOUTH,1,NX,1,1,16,16,1,1)
COVAL(SB16,P1,FIXFLU,3.68*RHO1)
COVAL(SB16,U1,ONLYMS,-2.60)
COVAL(SB16,V1,ONLYMS,2.60)
COVAL(SB16,KE,ONLYMS,TKEIN)
COVAL(SB16,EP,ONLYMS,EPSIN)
COVAL(SB16,TEM1,ONLYMS,24.)
PATCH(SB17,SOUTH,1,NX,1,1,17,17,1,1)
COVAL(SB17,P1,FIXFLU,3.73*RHO1)
COVAL(SB17,U1,ONLYMS,-2.64)
COVAL(SB17,V1,ONLYMS,2.64)
COVAL(SB17,KE,ONLYMS,TKEIN)
COVAL(SB17,EP,ONLYMS,EPSIN)
COVAL(SB17,TEM1,ONLYMS,24.)
PATCH(SB18,SOUTH,1,NX,1,1,18,18,1,1)
COVAL(SB18,P1,FIXFLU,3.80*RHO1)
COVAL(SB18,U1,ONLYMS,-2.69)
COVAL(SB18,V1,ONLYMS,2.69)
COVAL(SB18,KE,ONLYMS,TKEIN)
COVAL(SB18,EP,ONLYMS,EPSIN)
COVAL(SB18,TEM1,ONLYMS,24.)
PATCH(SB19,SOUTH,1,NX,1,1,19,19,1,1)
COVAL(SB19,P1,FIXFLU,3.87*RHO1)
COVAL(SB19,U1,ONLYMS,-2.73)
COVAL(SB19,V1,ONLYMS,2.73)
COVAL(SB19,KE,ONLYMS,TKEIN)
COVAL(SB19,EP,ONLYMS,EPSIN)
COVAL(SB19,TEM1,ONLYMS,24.)
PATCH(SB20,SOUTH,1,NX,1,1,20,20,1,1)
```

```
COVAL(SB20,P1,FIXFLU,3.93*RHO1)
COVAL(SB20,U1,ONLYMS,-2.78)
COVAL(SB20,V1,ONLYMS,2.78)
COVAL(SB20,KE,ONLYMS,TKEIN)
COVAL(SB20,EP,ONLYMS,EPSIN)
COVAL(SB20,TEM1,ONLYMS,24.)
PATCH(SB21,SOUTH,1,NX,1,1,21,21,1,1)
COVAL(SB21,P1,FIXFLU,4.00*RHO1)
COVAL(SB21,U1,ONLYMS,-2.83)
COVAL(SB21,V1,ONLYMS,2.83)
COVAL(SB21,KE,ONLYMS,TKEIN)
COVAL(SB21,EP,ONLYMS,EPSIN)
COVAL(SB21,TEM1,ONLYMS,24.)
PATCH(SB22,SOUTH,1,NX,1,1,22,22,1,1)
COVAL(SB22,P1,FIXFLU,4.06*RHO1)
COVAL(SB22,U1,ONLYMS,-2.87)
COVAL(SB22,V1,ONLYMS,2.87)
COVAL(SB22,KE,ONLYMS,TKEIN)
COVAL(SB22,EP,ONLYMS,EPSIN)
COVAL(SB22,TEM1,ONLYMS,24.)
```

North and west boundaries are outlets:

```
  ** North boundary
PATCH(NB,NORTH,1,NX,NY,NY,1,NZ,1,1)
COVAL(NB,P1,FIXP,0.0)
COVAL(NB,TEM1,0.0,24.)
COVAL(NB,KE,0.0,1.E-5)
COVAL(NB,EP,0.0,1.E-5)
  ** West boundary
PATCH(WB,WEST,1,1,1,NY,1,NZ,1,1)
COVAL(WB,P1,FIXP,0.0)
COVAL(WB,TEM1,0.0,24.)
COVAL(WB,KE,0.0,1.E-5)
COVAL(WB,EP,0.0,1.E-5)
```

Upper boundary and ground remain the same.

```
  ** Upper boundary
PATCH(UPPER,HIGH,1,NX,1,NY,NZ,NZ,1,1)
COVAL(UPPER,TEM1,0.0,24.)
  ** Ground
PATCH(GROUND,LWALL,1,NX,1,NY,1,1,1,1)
COVAL(GROUND,U1,GRND2,0.0)
COVAL(GROUND,V1,GRND2,0.0)
COVAL(GROUND,TEM1,GRND2,24.)
COVAL(GROUND,KE,GRND2,GRND2)
COVAL(GROUND,EP,GRND2,GRND2)
```

The initial velocity and calculation of KE in group 11 and the maximum velocity in group 17 also need to be changed.

```
GROUP 11. Initialization of variable or porosity fields
      Set initial air velocity 2.87 m/s (854 f/m).
      Set initial air temperature 24 C (75.4 F).
FIINIT(U1)=-2.87
FIINIT(V1)=-2.87
FIINIT(TEM1)=24.
PRESS0=1.0E5
TEMP0=273.15
  ** Calculation of KE
TKEIN=0.018*0.25*4.06*4.06
  ** Calculation of EP
EPSIN=TKEIN**1.5*0.1643/3.429E-3
FIINIT(KE)=TKEIN
FIINIT(EP)=EPSIN


    GROUP 17. Under-relaxation devices
        Determine false-time-step
REAL(DTF, MINCELL, MAXV)
MINCELL=0.2
MAXV=2.87
DTF=1.*MINCELL/MAXV
DTF
```

The complete q1 file for southeast wind is reported in Appendix C. The graphical outputs of the southeast wind simulation are:

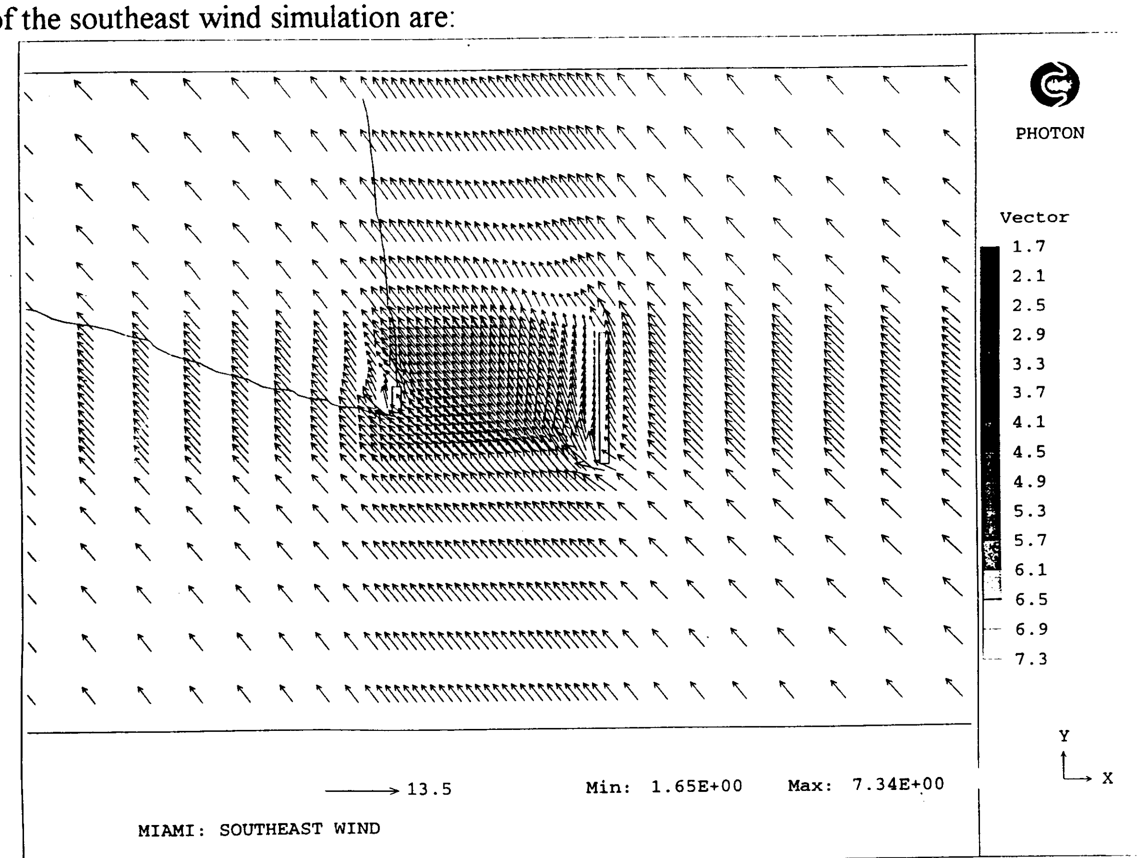


Figure 3.12 Plan view of airflow simulation in southeast wind model

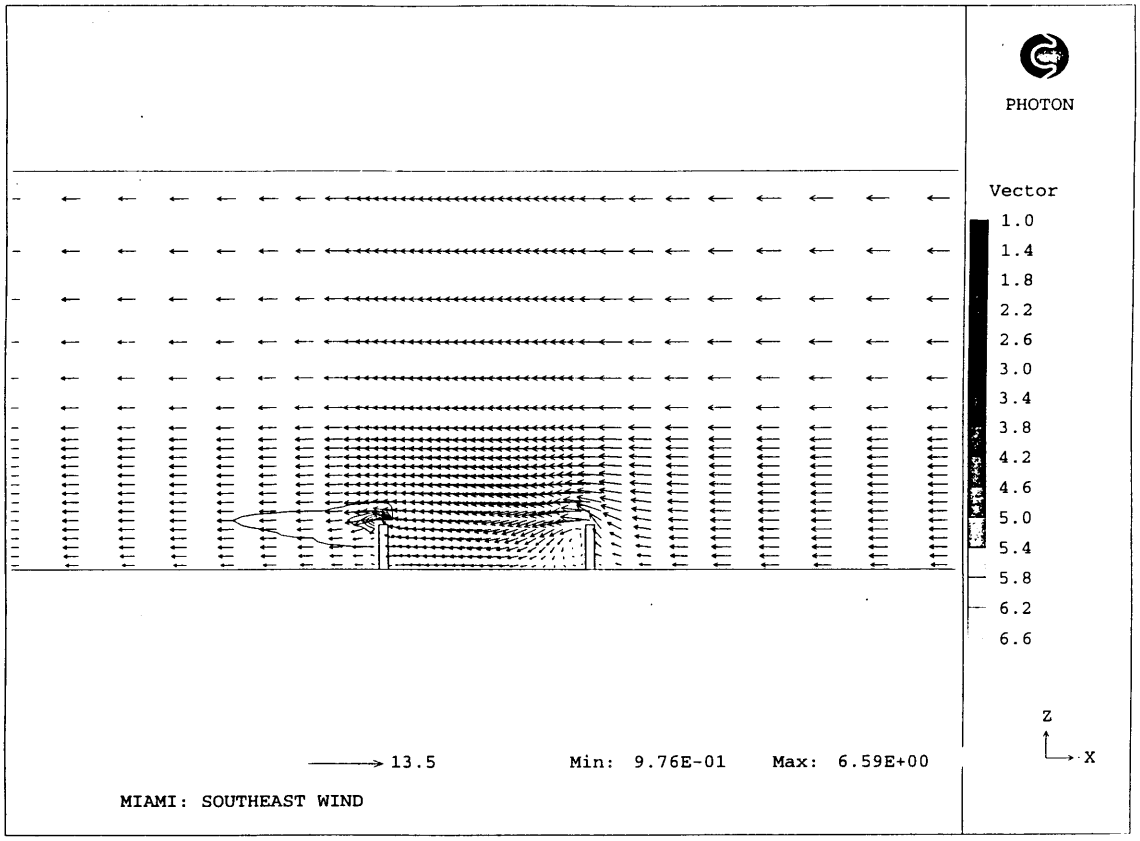


Figure 3.13 Section view of airflow simulation in southeast wind model

In the next chapter , the three q1 files developed here will be used to develop building form. In the case of developing building form, the portion to be changed is the commands of CONPOR.

4 Development of Building Form

4.1 A Beach Cottage in Miami, Florida

Program

In order to test the possibility of developing a building form by using the CFD model, this chapter discusses the design of a cottage in the Miami coastal area. The function of the cottage is for weekend leisure on the beach. The site is located on the beach with no adjacent buildings.

The footprint of the cottage is 15 m^2 (161.5 ft^2). The cottage contains only a living room and a kitchen. The living room is a 9 m^2 (96.9 ft^2) room for eating, sleeping, and other private activities. The kitchen is 6 m^2 (64.6 ft^2). There is a stove in the kitchen. Large windows are desired for both ocean view and natural ventilation. The first design scheme will be started with the optimum proportion developed by Victor Olgyay.

Olgyay's Optimum Proportion

Olgyay developed an optimum building proportion for solar energy in his book, *Design With Climate*. The criteria of the optimum building proportion are to minimize heat loss in winter and accept least solar heat gain in summer. The building is assumed to be a single family residential type with insulation material whose thermal conductivity is 5.37×10^{-4} cal/s·cm·°C (0.13 Btu/hr·ft·°F). Forty percent of the openings are on the south facing wall, and 20% of the openings are on each of the other three walls.

Using the weather data of different cities, Olgyay calculated the winter heat loss and summer heat gain in the house with different proportional plans. By comparing the annual heat loss and heat gain in different proportional plans, he concluded with the optimum proportion, which has the minimum heat loss in winter and least heat gain in summer. The optimum building proportion in plan is:

Climate Region	Reference City	Optimal Proportion
Cold	Minneapolis, MN	1:1.1
Cool/humid	New York, NY	1:1.6
Hot/arid	Phoenix, AZ	1:1.3
Hot/humid	Miami, FL	1:1.7

The optimum proportion is the ratio of north-south dimension to the east-west dimension. In all the four areas the east-west dimensions are longer than the north-south dimensions. For the city of Miami, the optimum proportion is 1:1.7.

This optimum proportion is used in the plan of the beach cottage in this thesis. Since Olgyay does not consider the situation of wind in his study, the design in this thesis will take Olgyay's model and improve it by developing the location of openings and partition walls for best natural ventilation.

In this case, the footprint of the cottage is 3 m by 5 m. The total area of south facing opening is 3.4 m^2 (36.6 ft^2). The area of openings on each of the other walls is 1.8 m^2 (19 ft^2).

4.2 Development of Form

First Design Scheme

In the first scheme, the building was developed by the program and the rule of Olgyay's optimal proportion. A partition wall divides the plan into two rooms. The room in the east side is the living room and the room in the west side is the kitchen. The plan and elevation of the house are shown in Figure 4.1.

The background grids in Figure 4.1 represent the cells defined in the q1 files developed in last chapter. The axes corresponds to the X, Y, and Z axes in the q1 files. The building geometry is constructed in the q1 files as the following CONPOR commands:

```
** East wall
      20% of opening on the east wall area
CONPOR(EUPPER,0.0,cell,-35,-35,-8,-22,-11,-15)
CONPOR(ELOWER,0.0,cell,-35,-35,-8,-22,-1,-5)
CONPOR(ELEFT,0.0,cell,-35,-35,-8,-10,-6,-10)
CONPOR(ERIGHT,0.0,cell,-35,-35,-20,-22,-6,-10)
  ** South wall
      40% of opening on the south wall area
CONPOR(SUPPER,0.0,cell,-12,-34,-8,-8,-11,-15)
CONPOR(SLOWER,0.0,cell,-12,-34,-8,-8,-1,-5)
CONPOR(SLEFT,0.0,cell,-12,-14,-8,-8,-6,-10)
CONPOR(SRIGHT,0.0,cell,-32,-34,-8,-8,-6,-10)
  ** West wall
      20% of opening on the west wall area
CONPOR(WUPPER,0.0,cell,-11,-11,-8,-22,-11,-15)
CONPOR(WLOWER,0.0,cell,-11,-11,-8,-22,-1,-5)
CONPOR(WLEFT,0.0,cell,-11,-11,-8,-10,-6,-10)
CONPOR(WRIGHT,0.0,cell,-11,-11,-20,-22,-6,-10)
  ** North wall
      20% of opening on the north wall area
CONPOR(NUPPER,0.0,cell,-12,-34,-22,-22,-11,-15)
CONPOR(NLOWER,0.0,cell,-12,-34,-22,-22,-1,-5)
CONPOR(NLEFT,0.0,cell,-12,-14,-22,-22,-6,-10)
CONPOR(NCENTER,0.0,cell,-18,-25,-22,-22,-6,-10)
CONPOR(NRIGHT,0.0,cell,-32,-34,-22,-22,-6,-10)
  ** Roof
CONPOR(ROOF,0.0,cell,-12,-34,-9,-21,-15,-15)
  ** Partition
CONPOR(PARTI,0.0,cell,-21,-21,-13,-21,-1,-14)
  ** Table
CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
```

These commands should replace the portion of building geometry in the three q1 files. PHOENICS simulates the airflow patterns in the first scheme with all three wind directions. The graphical printouts of the first scheme are shown in plans and sections in Figure 4.2 ~ 4.4.

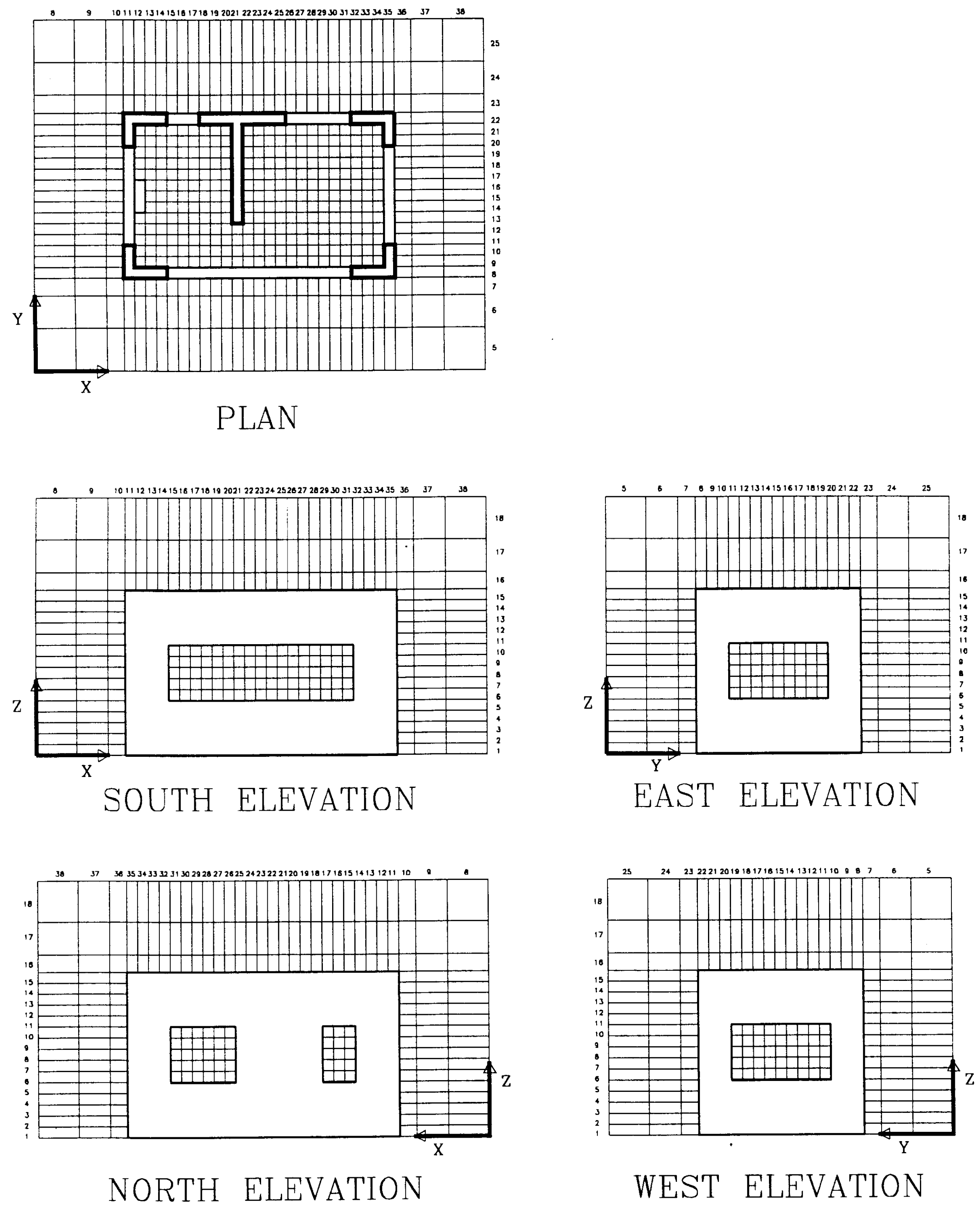
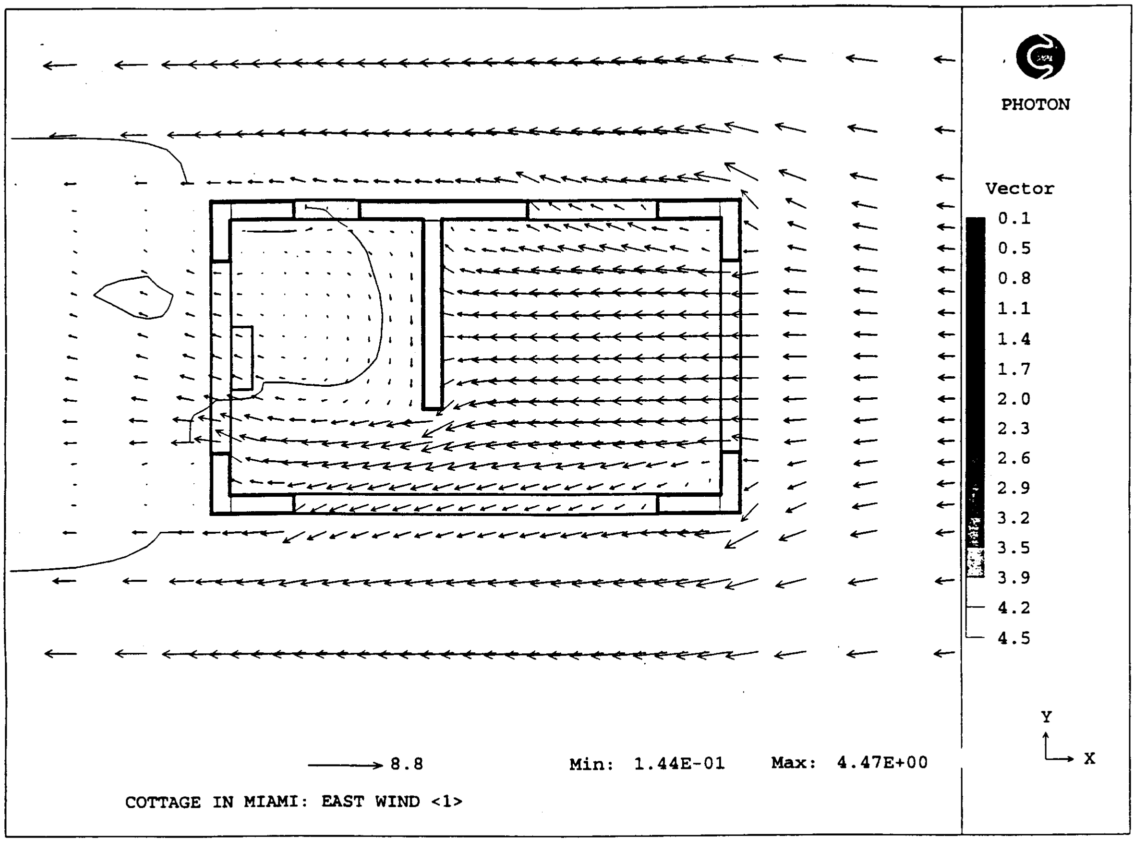


Figure 4.1 Plan and elevations of the first scheme



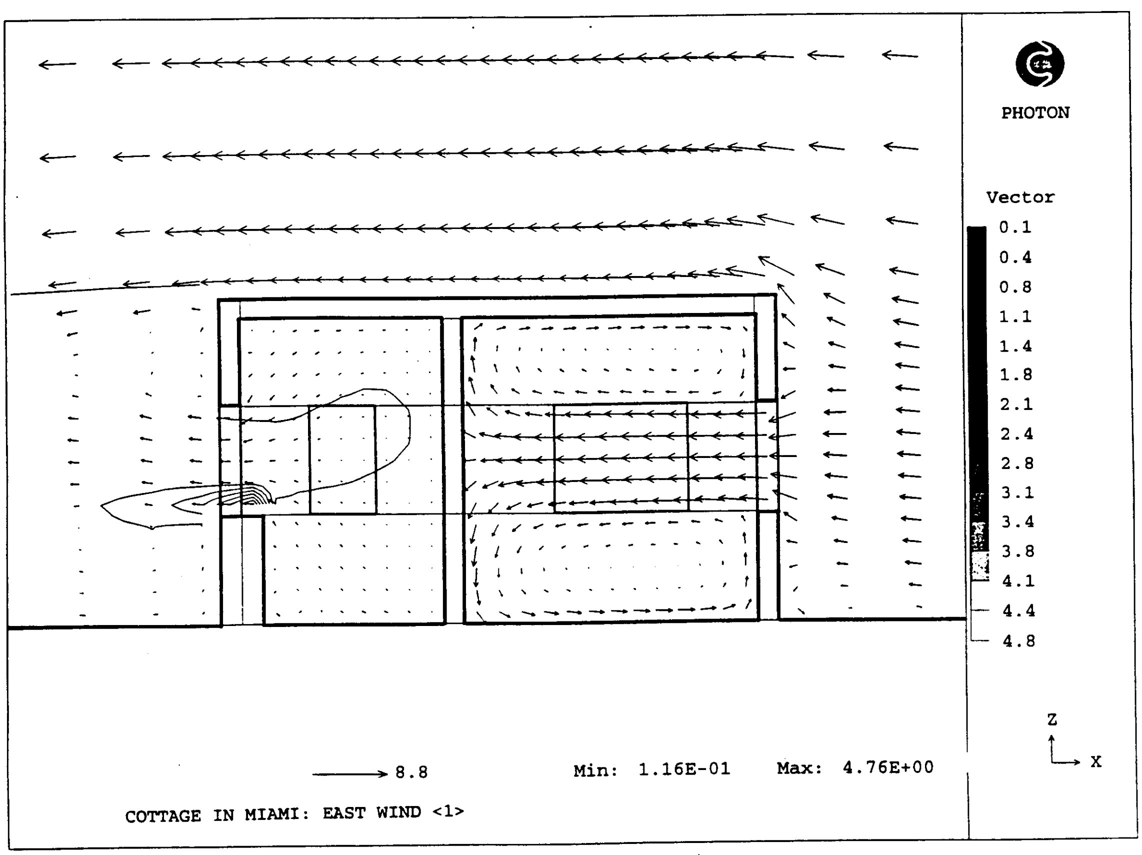
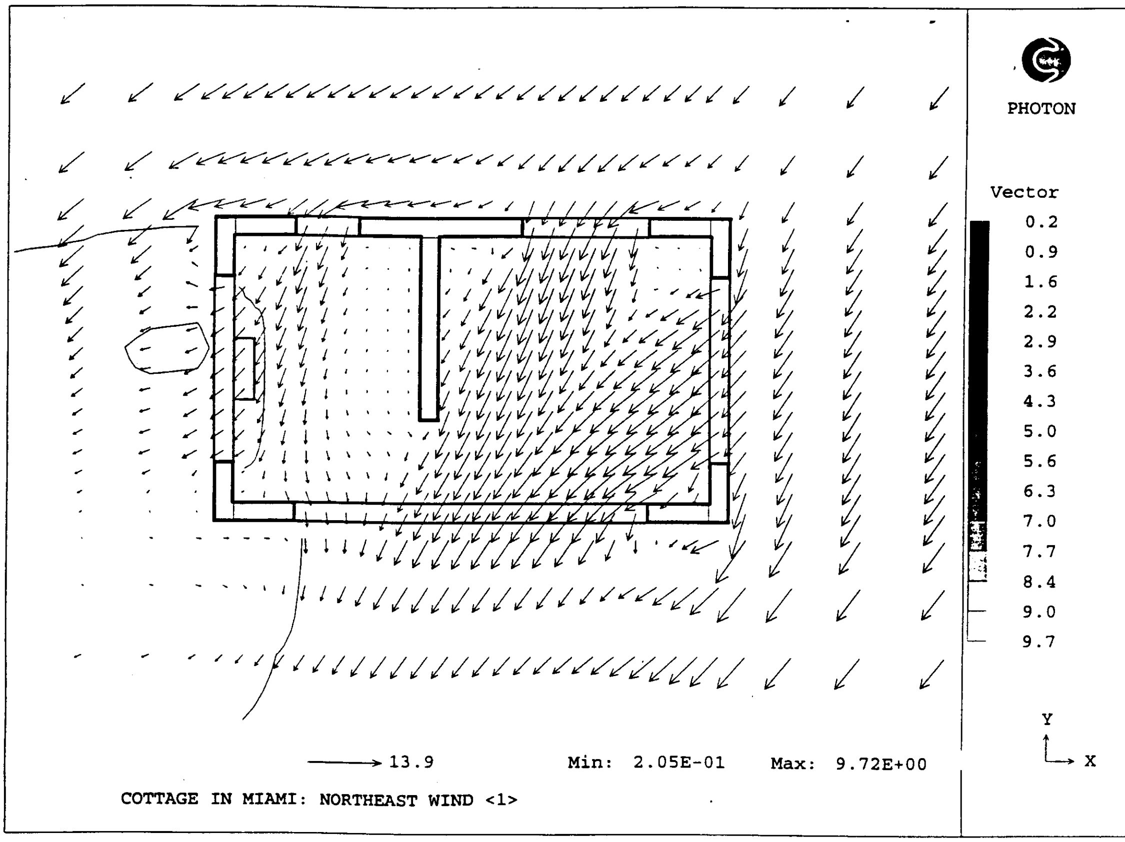


Figure 4.2 Airflow simulation of east wind for the first scheme



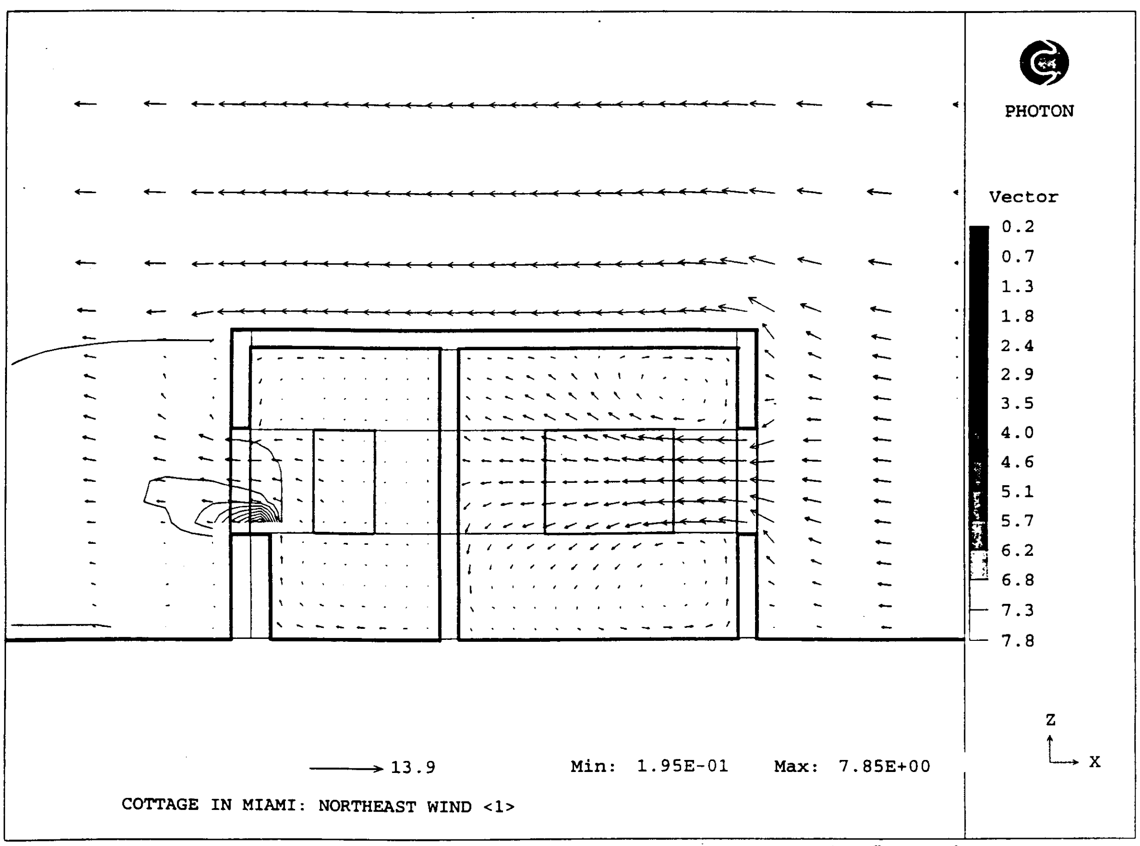


Figure 4.3 Airflow simulation of northeast wind for the first scheme

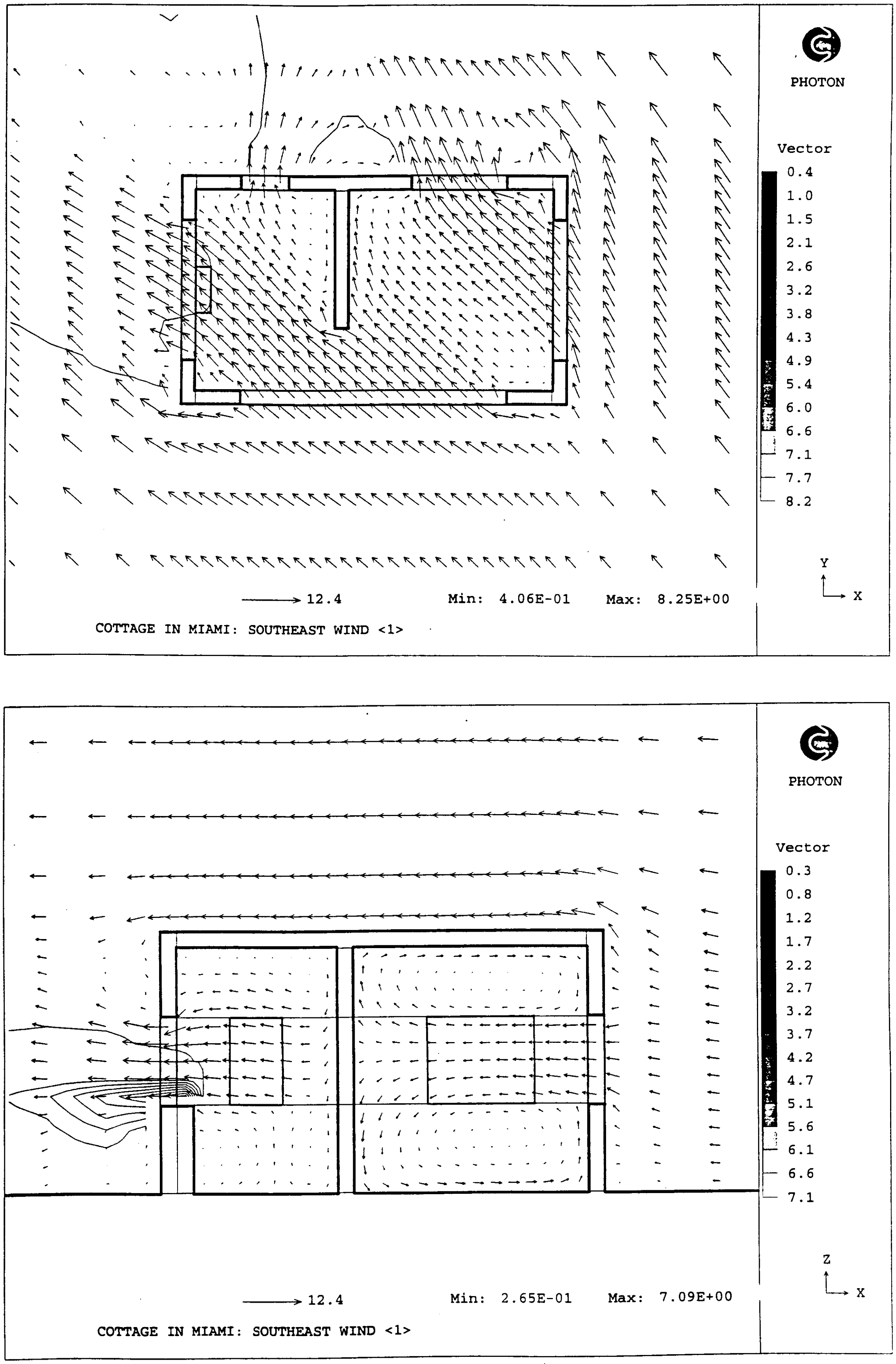


Figure 4.4 Airflow simulation of southeast wind for the first scheme

The simulation in the plan is taken from the horizontal surface of 1.6 m (5.26 ft) above ground. The sectional view is taken from the vertical surface in the east-west direction in the center of the house looking toward the north. All the other simulation printouts in this chapter will be taken from the same horizontal and vertical surfaces for plan and sections.

The graphical outputs of the first scheme show a serious problem in the kitchen when wind comes from the east. There is almost no air movement in the kitchen. Since there is no wind to remove the heat generated by the stove, the air temperature in the kitchen is 0.1°C higher than the living room. The contour in the northwest part of the kitchen's plan shows the area of higher temperature. The sectional view also shows a region of higher air temperature right in the height of standing people. Even though the temperature is not much higher in the kitchen, it is desirable to blow all internal heat to outdoors in such a climate.

Under northeast wind, the east part of the kitchen has very little air movement, too. The air velocities are below the comfort level of 0.05 m/s in these two situations. On the other hand, very few problems appear when wind comes from the southeast. Because of the large opening in the south facing wall, wind can flow through most of the room.

The wind velocities in the living room are too strong in all three situations. However, these velocities are acceptable because windows can control them. When the wind is too strong, adjusting the opening of the windows can reduce the wind velocity.

Second Design Scheme

The simulation shows that the partition wall blocks the path of east wind from entering the kitchen. In order to increase wind velocity in the kitchen, the design changes the shape of the partition wall. In the second scheme, the first solution is to divide the long partition wall into two narrow ones and have a 1 m (3.3 ft) doorway in the center. Because the new south partition wall touches the south facing window, the window needs to be divided into two parts. The one in the living room is 2.6 m^2 (8.6 ft^2), and the one in kitchen is 0.8 m^2 (1.3 ft^2). The north facing window in the kitchen is moved to the east by 0.4 m (1.3 ft) in order to introduce northeast wind to the east part of kitchen. The resulting building geometry is constructed in the three q1 files as the following commands:

```
** East wall
      20% of opening on the east wall area
CONPOR(EUPPER,0.0,cell,-35,-35,-8,-22,-11,-15)
CONPOR(ELOWER,0.0,cell,-35,-35,-8,-22,-1,-5)
CONPOR(ELEFT,0.0,cell,-35,-35,-8,-10,-6,-10)
CONPOR(ERIGHT,0.0,cell,-35,-35,-20,-22,-6,-10)
  ** South wall
      40% of opening on the south wall area
CONPOR(SUPPER,0.0,cell,-12,-34,-8,-8,-11,-15)
CONPOR(SLOWER,0.0,cell,-12,-34,-8,-8,-1,-5)
CONPOR(SLEFT,0.0,cell,-12,-14,-8,-8,-6,-10)
CONPOR(SCENTER,0.0,cell,-19,-21,-8,-8,-6,-10)
  ** West wall
      20% of opening on the west wall area
CONPOR(WUPPER,0.0,cell,-11,-11,-8,-22,-11,-15)
CONPOR(WLOWER,0.0,cell,-11,-11,-8,-22,-1,-5)
CONPOR(WLEFT,0.0,cell,-11,-11,-8,-10,-6,-10)
CONPOR(WRIGHT,0.0,cell,-11,-11,-20,-22,-6,-10)
  ** North wall
      20% of opening on the north wall area
CONPOR(NUPPER,0.0,cell,-12,-34,-22,-22,-11,-15)
CONPOR(NLOWER,0.0,cell,-12,-34,-22,-22,-1,-5)
CONPOR(NLEFT,0.0,cell,-12,-16,-22,-22,-6,-10)
CONPOR(NCENTER,0.0,cell,-20,-25,-22,-22,-6,-10)
CONPOR(NRIGHT,0.0,cell,-32,-34,-22,-22,-6,-10)
  ** Roof
CONPOR(ROOF,0.0,cell,-12,-34,-9,-21,-15,-15)
  ** Partition
CONPOR(PARTI1,0.0,cell,-21,-21,-9,-12,-1,-14)
CONPOR(PARTI2,0.0,cell,-21,-21,-18,-21,-1,-14)
  ** Table
CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
```

The plan and elevations of the second scheme are shown in Figure 4.5, and the outputs of the simulation in all three wind directions are shown in Figure 4.6 ~ 4.8.

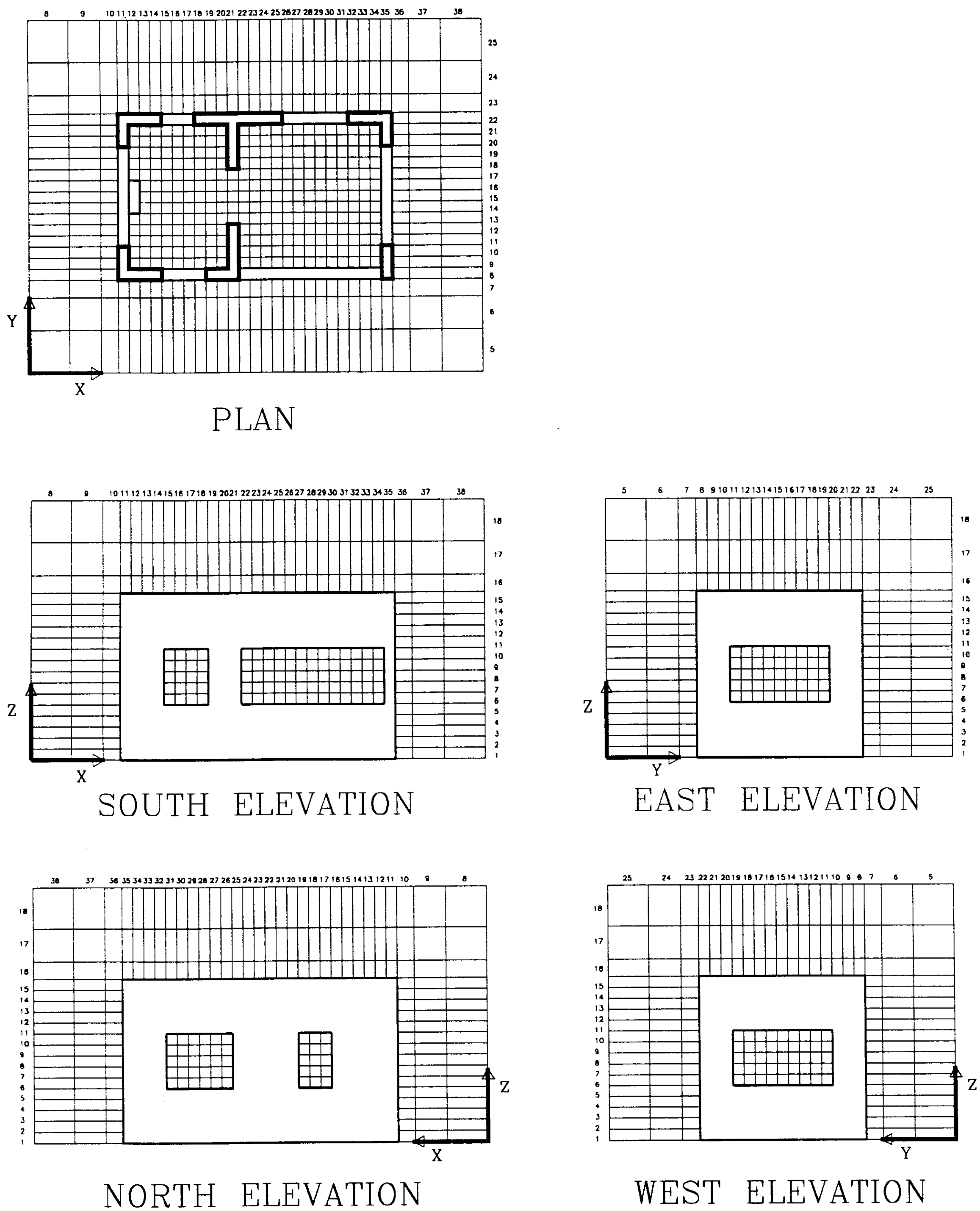
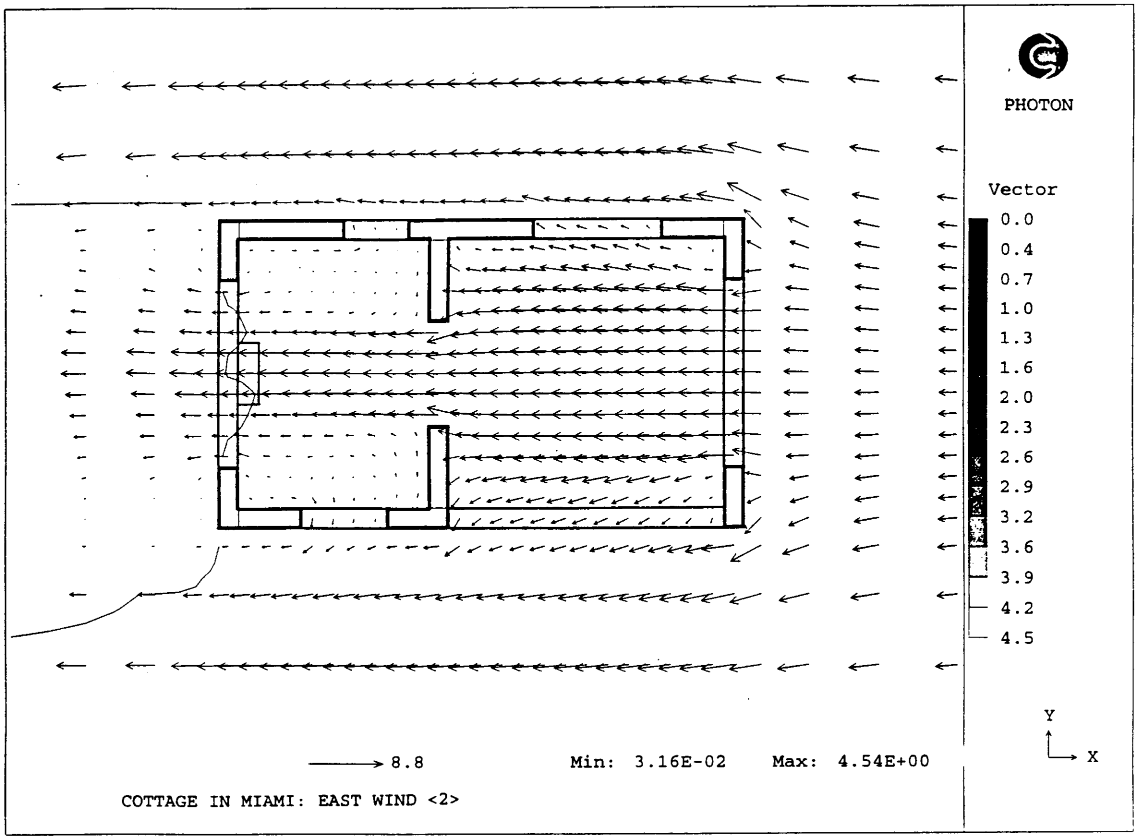


Figure 4.5 Plan and elevations of the second scheme



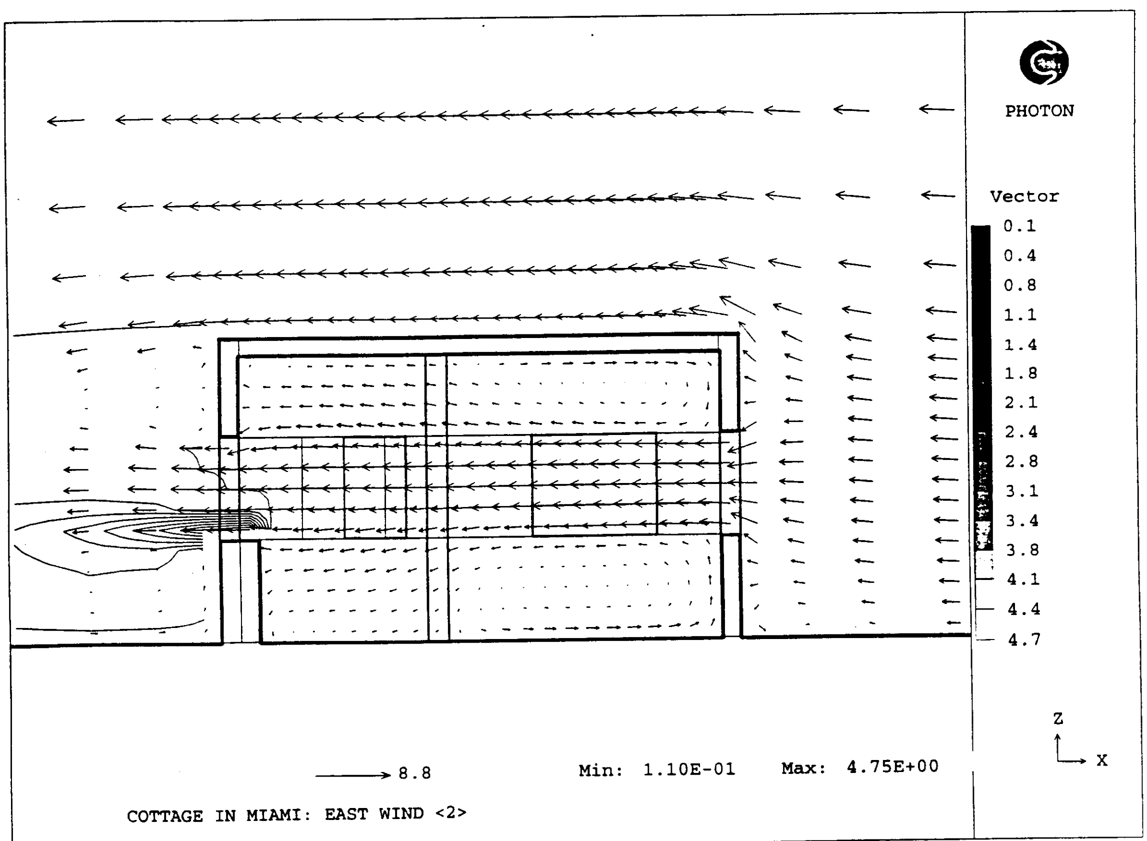


Figure 4.6 Airflow simulation of east wind for the second scheme

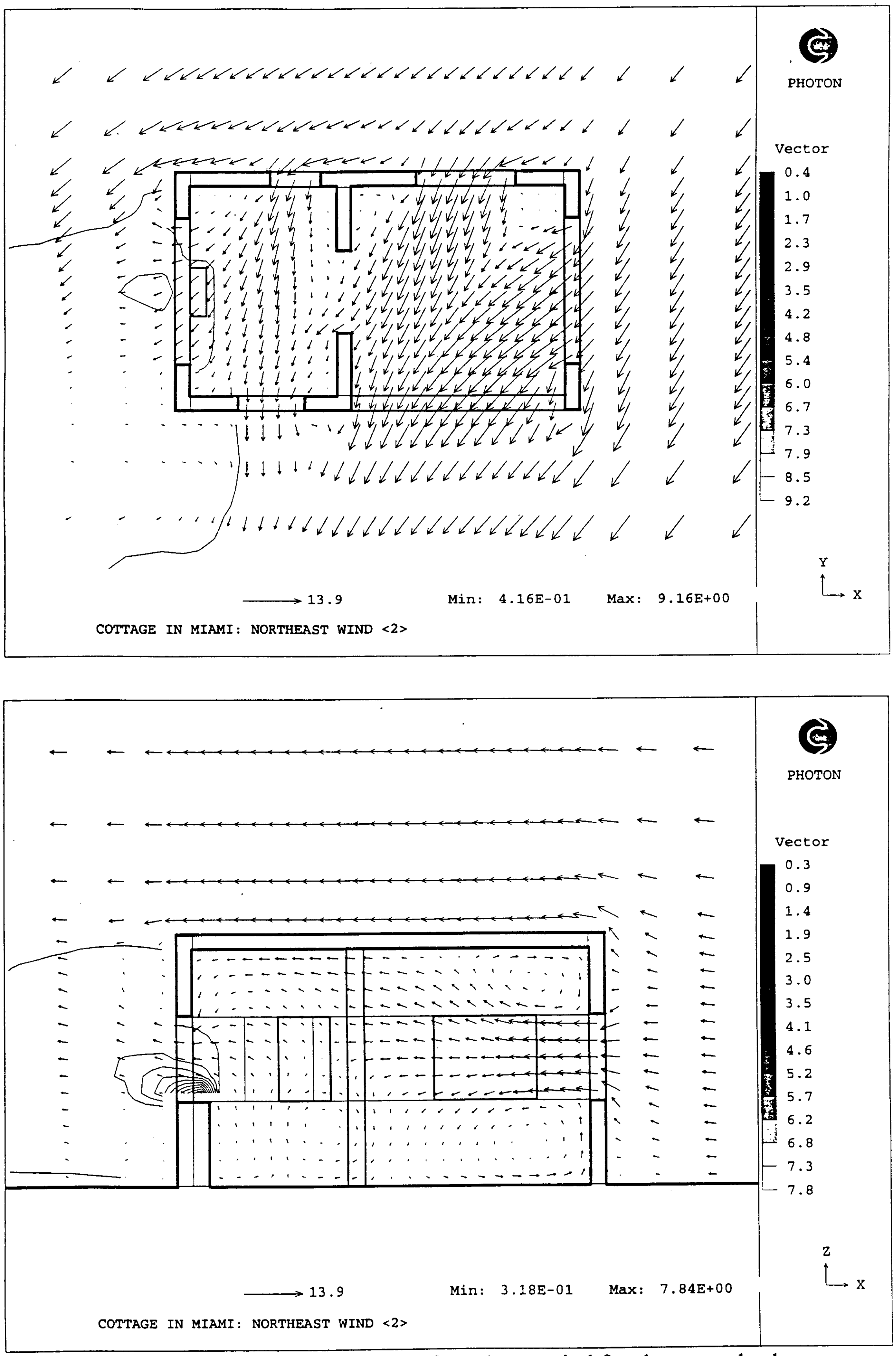


Figure 4.7 Airflow simulation of northeast wind for the second scheme

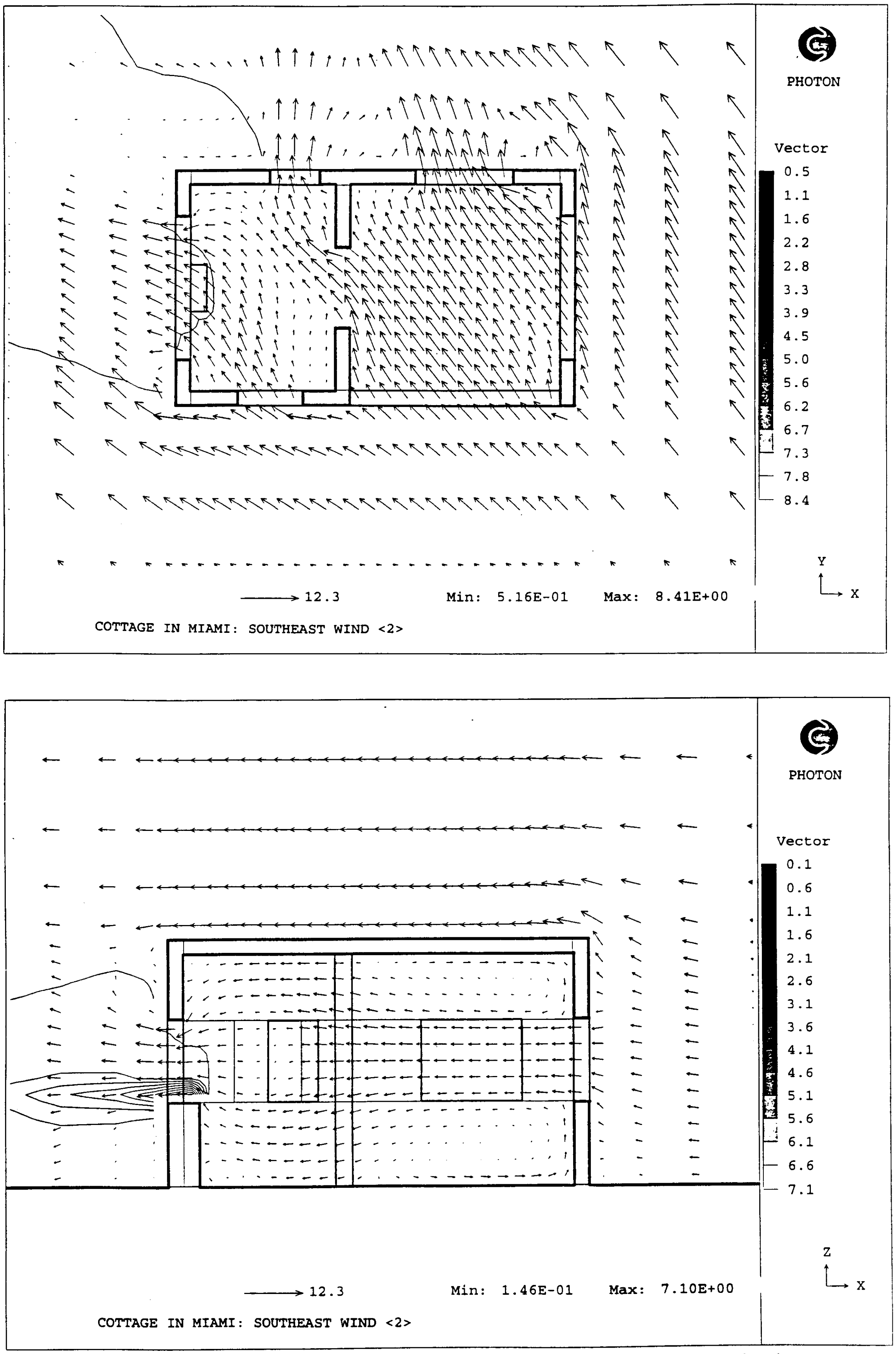


Figure 4.8 Airflow simulation of southeast wind for the second scheme

The graphical printouts of the second scheme show some improvement as well as some new problems in the kitchen. The most significant improvement is the decrease in air temperature in the kitchen when wind comes from the east. The air temperature in the kitchen is the same as in the living room now. All heat generated by the stove is blown to the outdoor space on the west side of the cottage.

East wind enters the kitchen through the center doorway and increases the air velocity. However, wind passes through only the middle portion of the kitchen. Air velocities in both the north and south parts of the kitchen are still too low to be comfortable. In the situation when wind comes from the northeast, the airflow pattern is more evenly distributed. Only the air velocities in the four corners are too low.

Some problems exist in the section. Air velocity in the space below the lower sill of the window is too low. Since people sit in this area most of the time, it is necessary to solve this problem in the next scheme.

Third Design Scheme

This scheme shifts the two partition walls to allow more air moving through the doorway and entering the kitchen. The north partition wall moves to the west by 0.4 m, and the south partition wall moves to the east by 0.4 m. The north and south facing windows also move to the west and east by the same distance corresponding to the new location of the partition walls.

Two overhangs are added to the east and north windows in the living room. Slots between the overhangs and the windows are designed to generate downward pressure of the inlet air in order to guide air to the lower portion of the house. The representation of the geometry in CONPOR commands is:

```
** East wall
      20% of opening on the east wall area
CONPOR(EUPPER,0.0,cell,-35,-35,-8,-22,-11,-15)
CONPOR(ELOWER,0.0,cell,-35,-35,-8,-22,-1,-5)
CONPOR(ELEFT,0.0,cell,-35,-35,-8,-10,-6,-10)
CONPOR(ERIGHT,0.0,cell,-35,-35,-20,-22,-6,-10)
CONPOR(ESHADE,0.0,cell,-37,-37,-11,-19,-11,-11)
  ** South wall
      40% of opening on the south wall area
CONPOR(SUPPER,0.0,cell,-12,-34,-8,-8,-11,-15)
CONPOR(SLOWER,0.0,cell,-12,-34,-8,-8,-1,-5)
CONPOR(SLEFT,0.0,cell,-12,-14,-8,-8,-6,-10)
CONPOR(SCENTER,0.0,cell,-21,-23,-8,-8,-6,-10)
  ** West wall
      20% of opening on the west wall area
CONPOR(WUPPER,0.0,cell,-11,-11,-8,-22,-11,-15)
CONPOR(WLOWER,0.0,cell,-11,-11,-8,-22,-1,-5)
CONPOR(WLEFT,0.0,cell,-11,-11,-8,-10,-6,-10)
CONPOR(WRIGHT,0.0,cell,-11,-11,-20,-22,-6,-10)
  ** North wall
      20% of opening on the north wall area
CONPOR(NUPPER,0.0,cell,-12,-34,-22,-22,-11,-15)
CONPOR(NLOWER,0.0,cell,-12,-34,-22,-22,-1,-5)
CONPOR(NLEFT,0.0,cell,-12,-14,-22,-22,-6,-10)
CONPOR(NCENTER,0.0,cell,-18,-24,-22,-22,-6,-10)
CONPOR(NRIGHT,0.0,cell,-31,-34,-22,-22,-6,-10)
CONPOR(NSHADE,0.0,cell,-25,-30,-24,-24,-11,-11)
  ** Roof
CONPOR(ROOF,0.0,cell,-12,-34,-9,-21,-15,-15)
  ** Partition
CONPOR(PARTI1,0.0,cell,-23,-23,-9,-12,-1,-14)
CONPOR(PARTI2,0.0,cell,-19,-19,-18,-21,-1,-14)
  ** Table
CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
```

The plan and elevations of this scheme are shown in Figure 4.9, and the printouts of the simulation are shown in Figure 4.10 ~ 4.12.

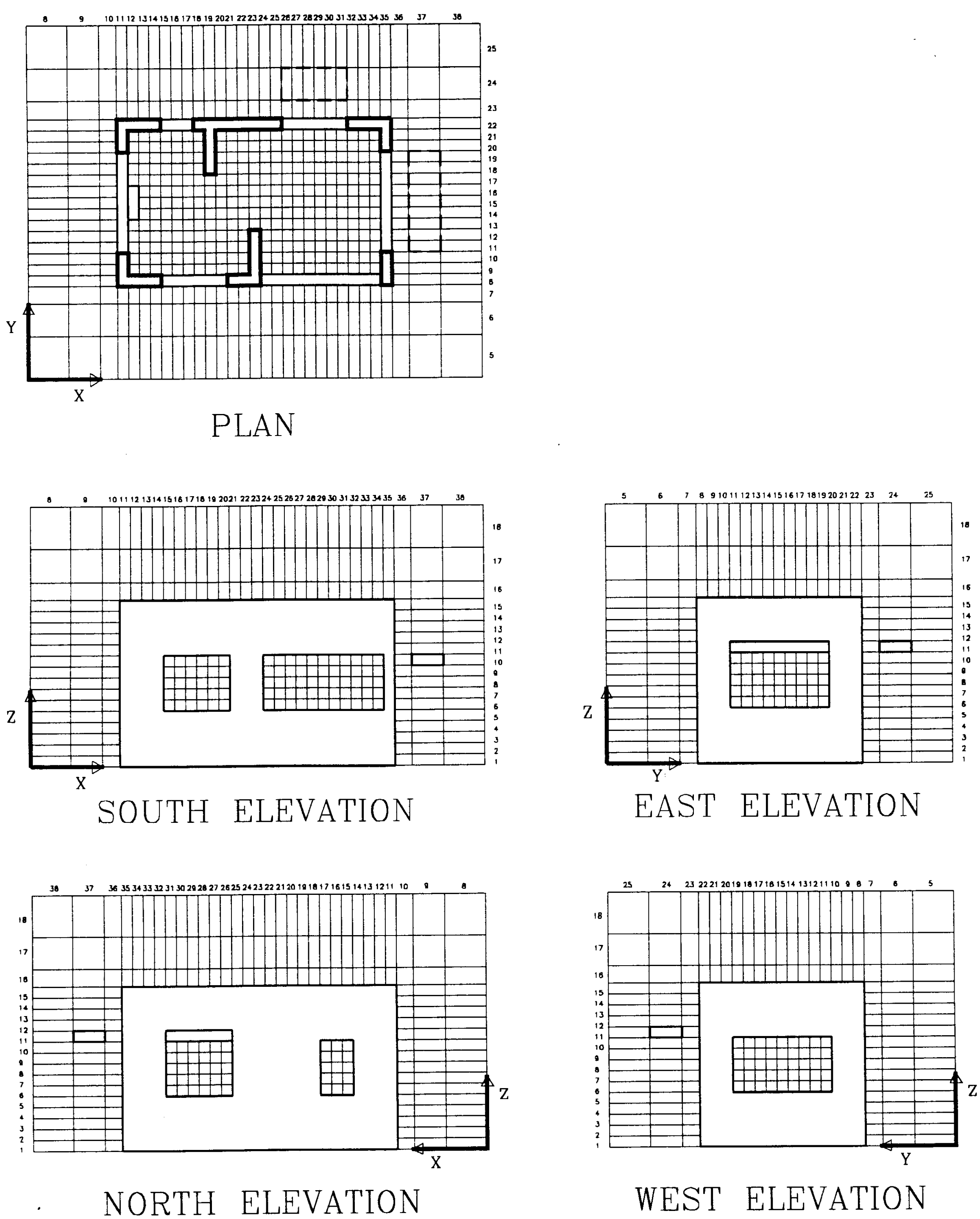
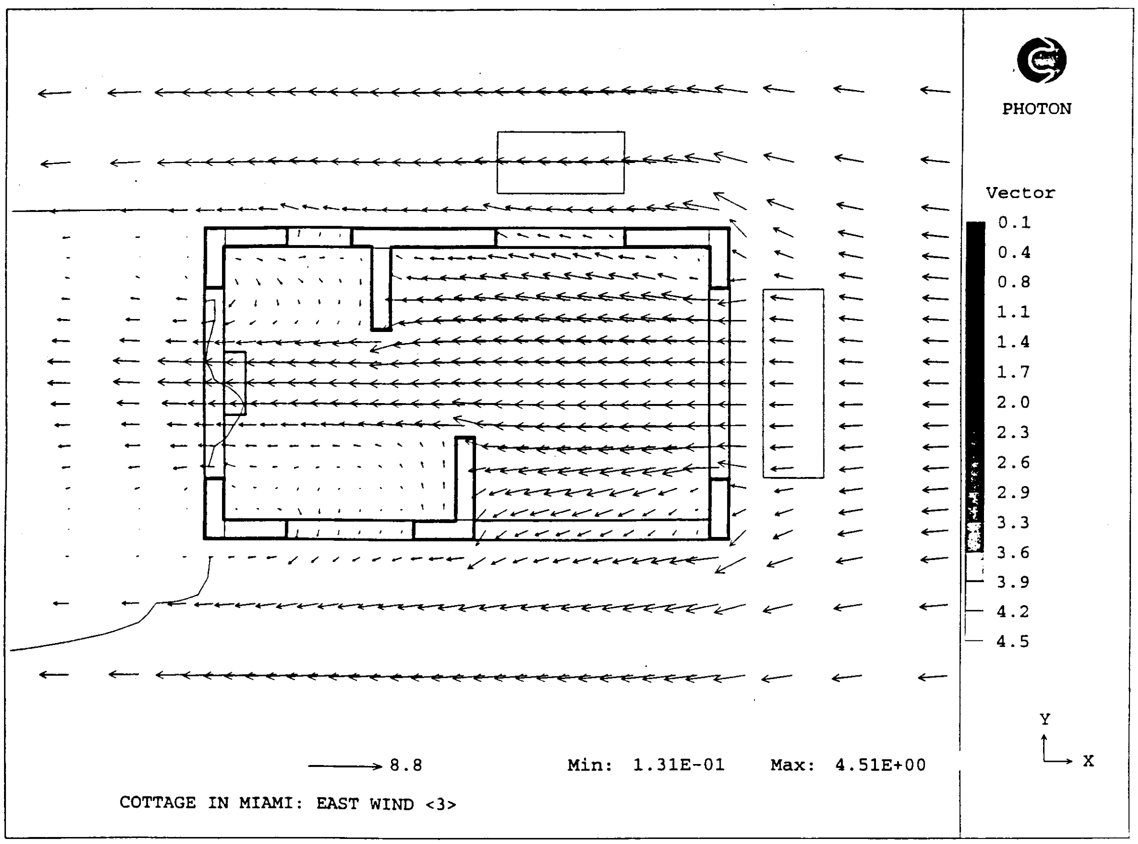


Figure 4.9 Plan and elevations of the third scheme



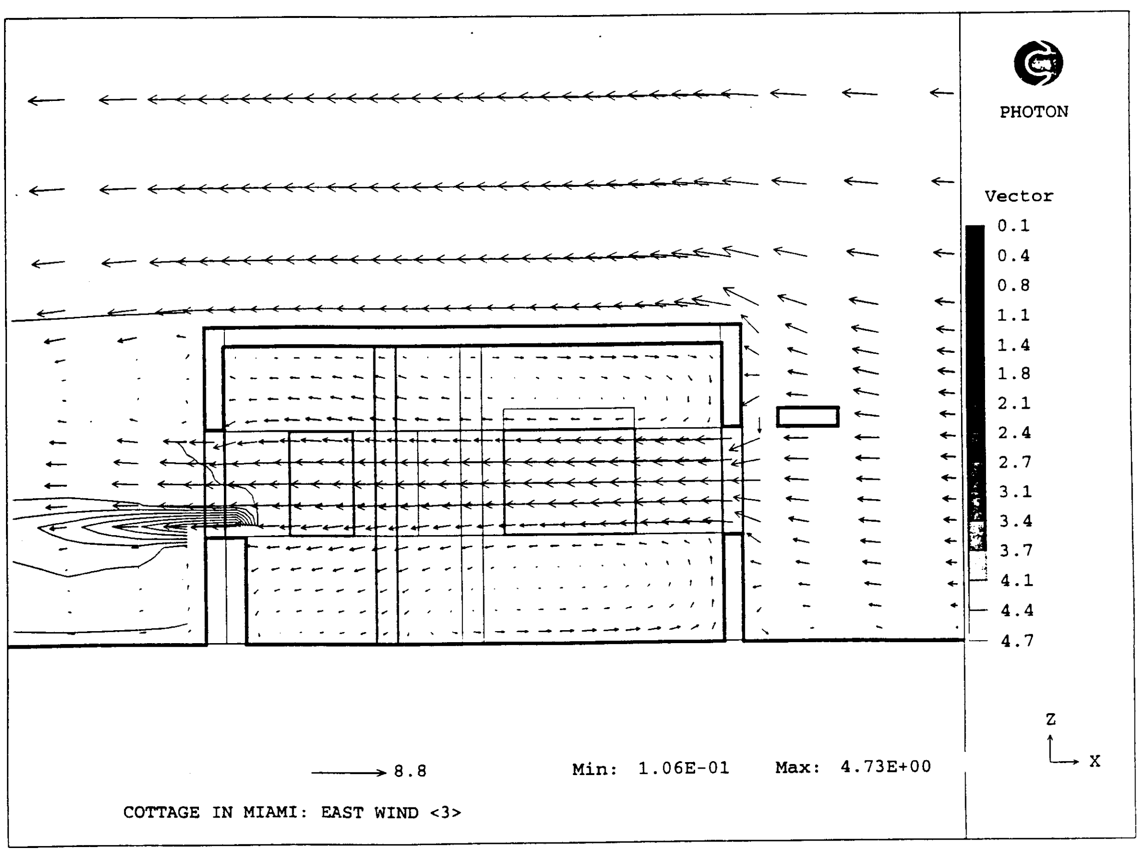
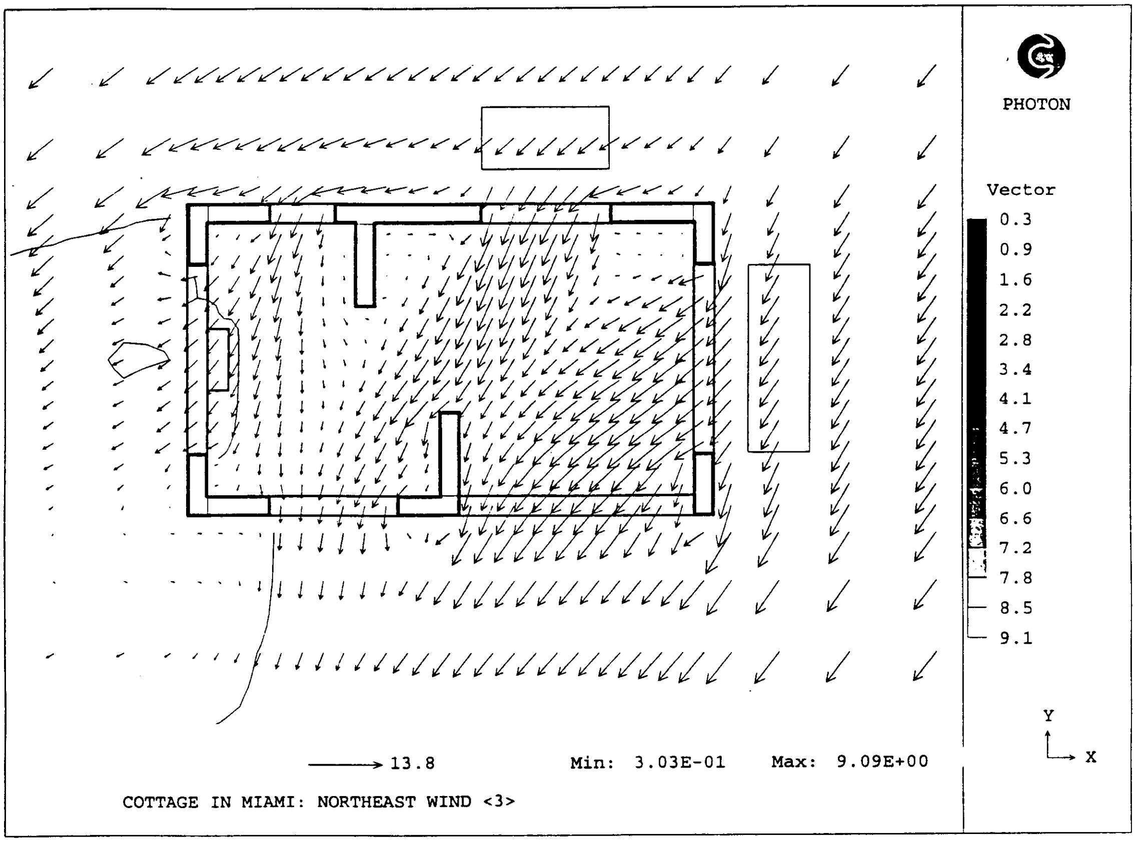


Figure 4.10 Airflow simulation of east wind for the third scheme



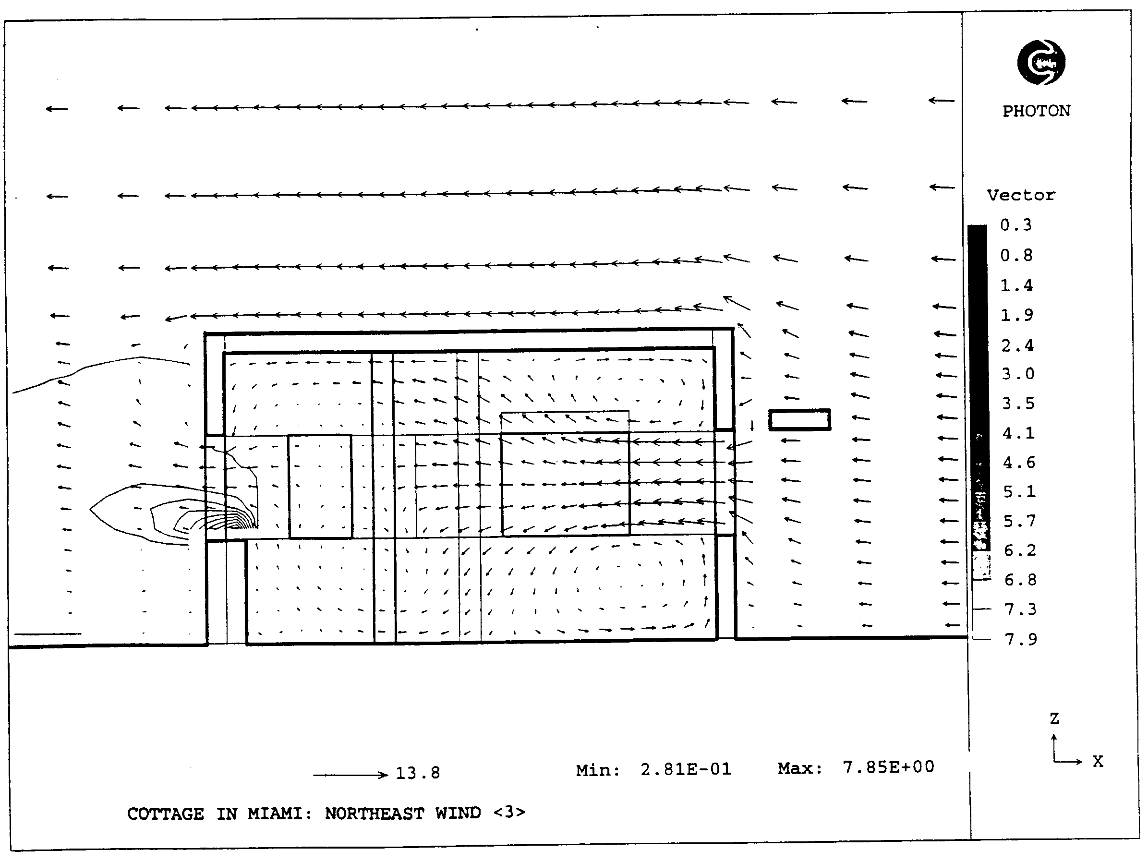
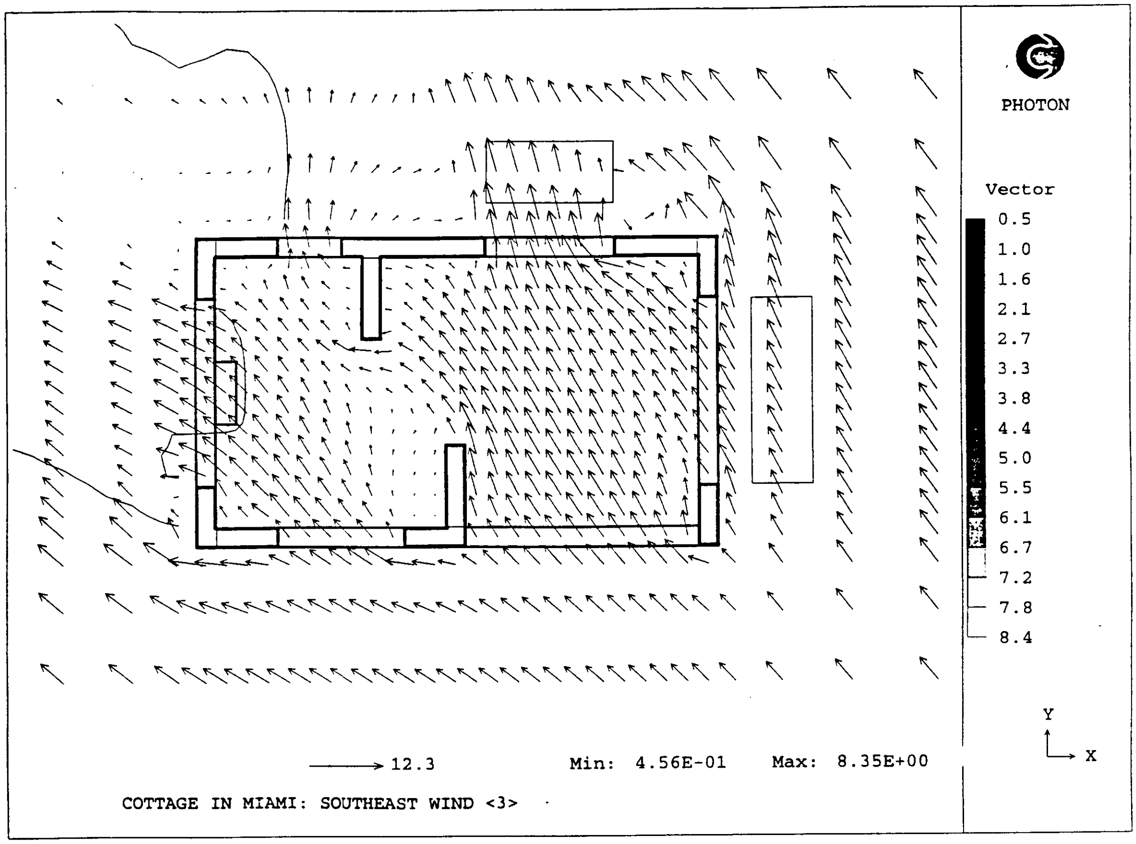


Figure 4.11 Airflow simulation of northeast wind for the third scheme



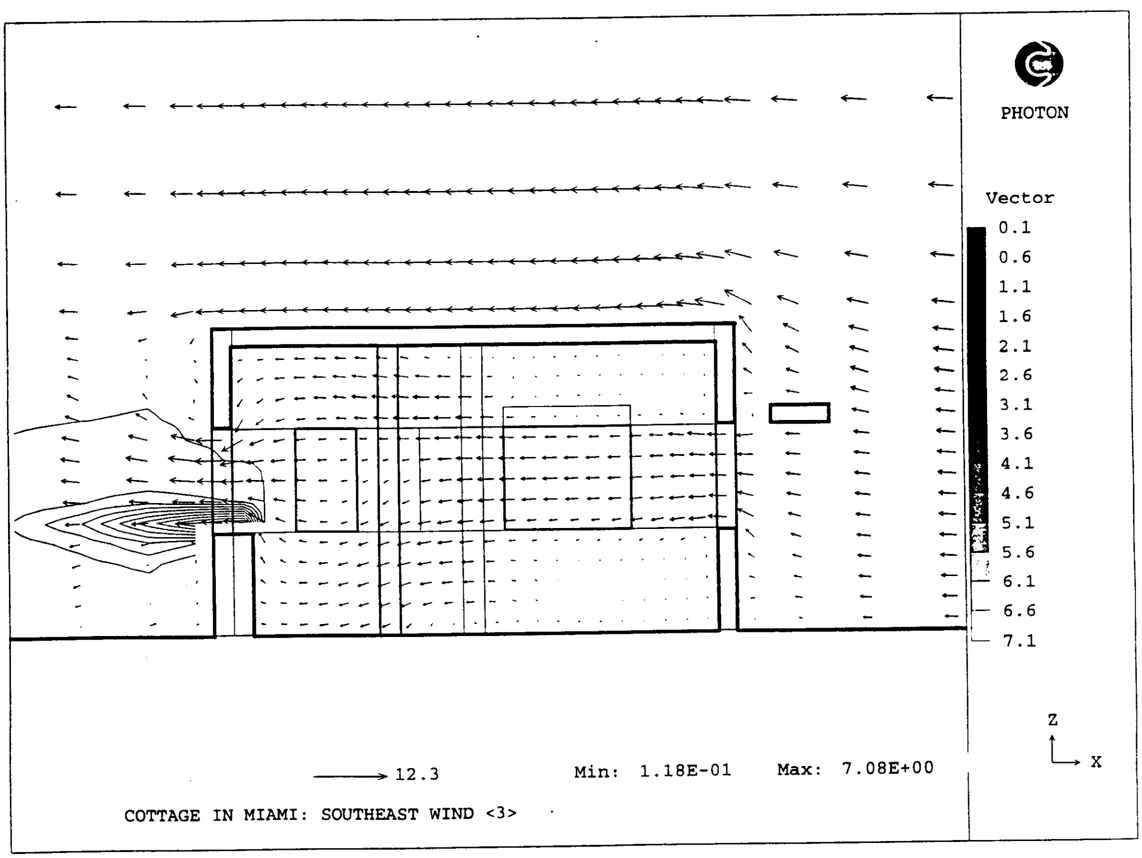


Figure 4.12 Airflow simulation of southeast wind for the third scheme

After the shift of the partition walls, the distribution of wind in the kitchen is wider than in the previous scheme under northeast wind. Wind velocities in all four corners are increased. However, the airflow pattern in the kitchen does not improve under the east wind. The air velocities in the north and south portions of the kitchen are still too low.

In the sectional view, the slot between the overhang and window does create a little downward pressure. Unfortunately, this pressure is too little that it does not change the air profile in the inlet window. Wind velocity in the lower portion of the living room is still too low.

As a result, to increase the wind velocity in the north and south portions of the kitchen and in the lower portion of the living room is the most critical problem for the next scheme.

Fourth Design Scheme

In the fourth scheme, the design emphasizes introduces wind entering the northern and southern parts of the kitchen, and pushes the air stream to the lower portion of the living room. In order to solve the problem in the kitchen, the design adds a vertical fin to the west jamb of the kitchen's north window. The function of the fin is to guide east wind into the kitchen when the wind is parallel to the window.

Another strategy is to lower the overhangs by 0,2 m (0.66 ft) in order to increase the size of the slot between the overhangs and the windows. The purpose is to increase downward air pressure to push more air to the lower portion of the living room. The geometry of this scheme is constructed in CONPOR commands as:

```
** East wall
       20% of opening on the east wall area
CONPOR(EUPPER,0.0,cell,-35,-35,-8,-22,-11,-15)
CONPOR(ELOWER,0.0,cell,-35,-35,-8,-22,-1,-5)
CONPOR(ELEFT,0.0,cell,-35,-35,-8,-10,-6,-10)
CONPOR(ERIGHT,0.0,cell,-35,-35,-20,-22,-6,-10)
```

```
CONPOR(ESHADE,0.0,cell,-37,-37,-11,-19,-10,-10)
  ** South wall
       40% of opening on the south wall area
CONPOR(SUPPER,0.0,cell,-12,-34,-8,-8,-11,-15)
CONPOR(SLOWER,0.0,cell,-12,-34,-8,-8,-1,-5)
CONPOR(SLEFT,0.0,cell,-12,-14,-8,-8,-6,-10)
CONPOR(SCENTER,0.0,cell,-21,-23,-8,-8,-6,-10)
  ** West wall
       20% of opening on the west wall area
CONPOR(WUPPER,0.0,cell,-11,-11,-8,-22,-11,-15)
CONPOR(WLOWER,0.0,cell,-11,-11,-8,-22,-1,-5)
CONPOR(WLEFT,0.0,cell,-11,-11,-8,-10,-6,-10)
CONPOR(WRIGHT,0.0,cell,-11,-11,-20,-22,-6,-10)
  ** North wall
       20% of opening on the north wall area
CONPOR(NUPPER,0.0,cell,-12,-34,-22,-22,-11,-15)
CONPOR(NLOWER,0.0,cell,-12,-34,-22,-22,-1,-5)
CONPOR(NLEFT,0.0,cell,-12,-14,-22,-22,-6,-10)
CONPOR(NCENTER,0.0,cell,-18,-24,-22,-22,-6,-10)
CONPOR(NRIGHT,0.0,cell,-31,-34,-22,-22,-6,-10)
CONPOR(NSHADE,0.0,cell,-25,-30,-24,-24,-10,-10)
CONPOR(NBLOCK,0.0,cell,-14,-14,-23,-24,-6,-10)
  ** Roof
CONPOR(ROOF,0.0,cell,-12,-34,-9,-21,-15,-15)
  ** Partition
CONPOR(PARTI1,0.0,cell,-23,-23,-9,-12,-1,-14)
CONPOR(PARTI2,0.0,cell,-19,-19,-18,-21,-1,-14)
  ** Table
CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
```

The plan and elevations of this scheme are shown in Figure 4.13, and the printouts of the simulation are shown in Figure 4.14 ~ 4.16.

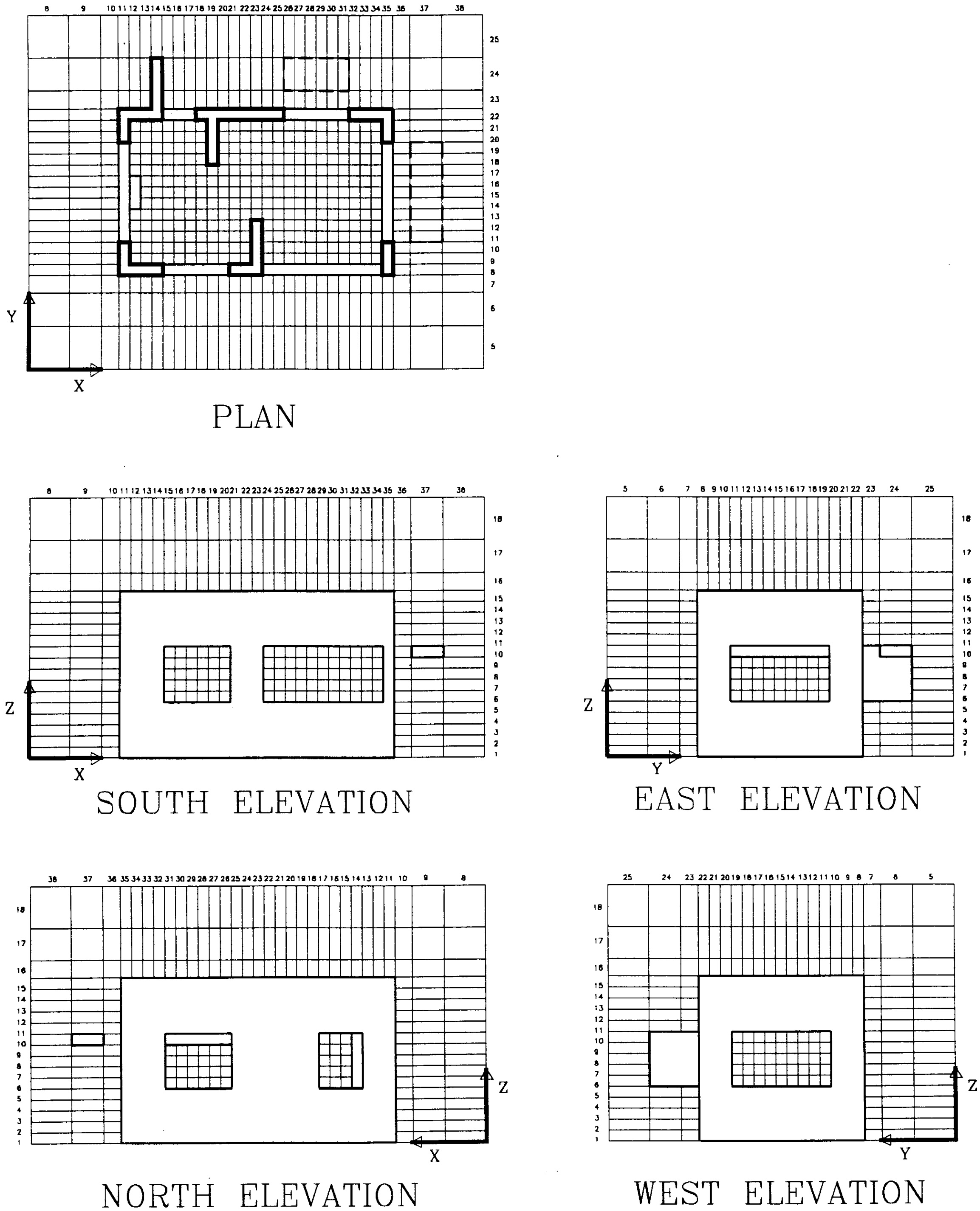
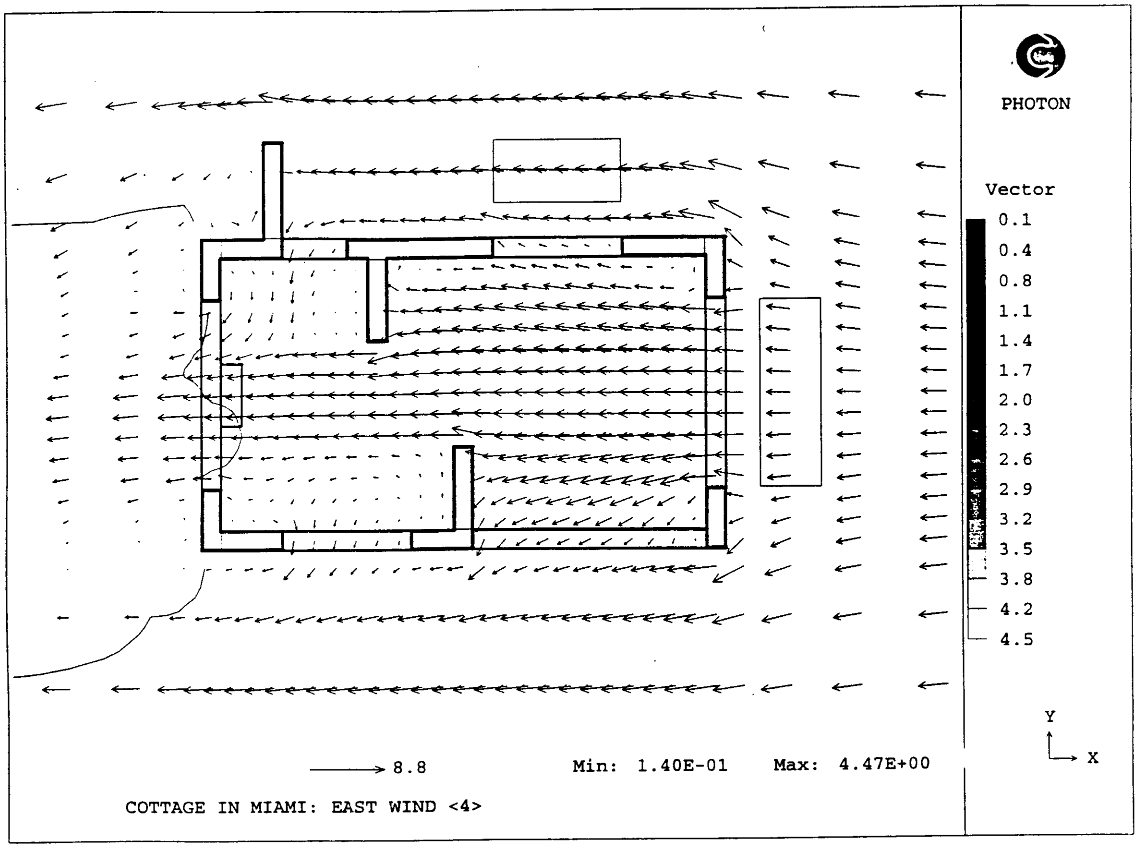


Figure 4.13 Plan and elevations of the fourth scheme



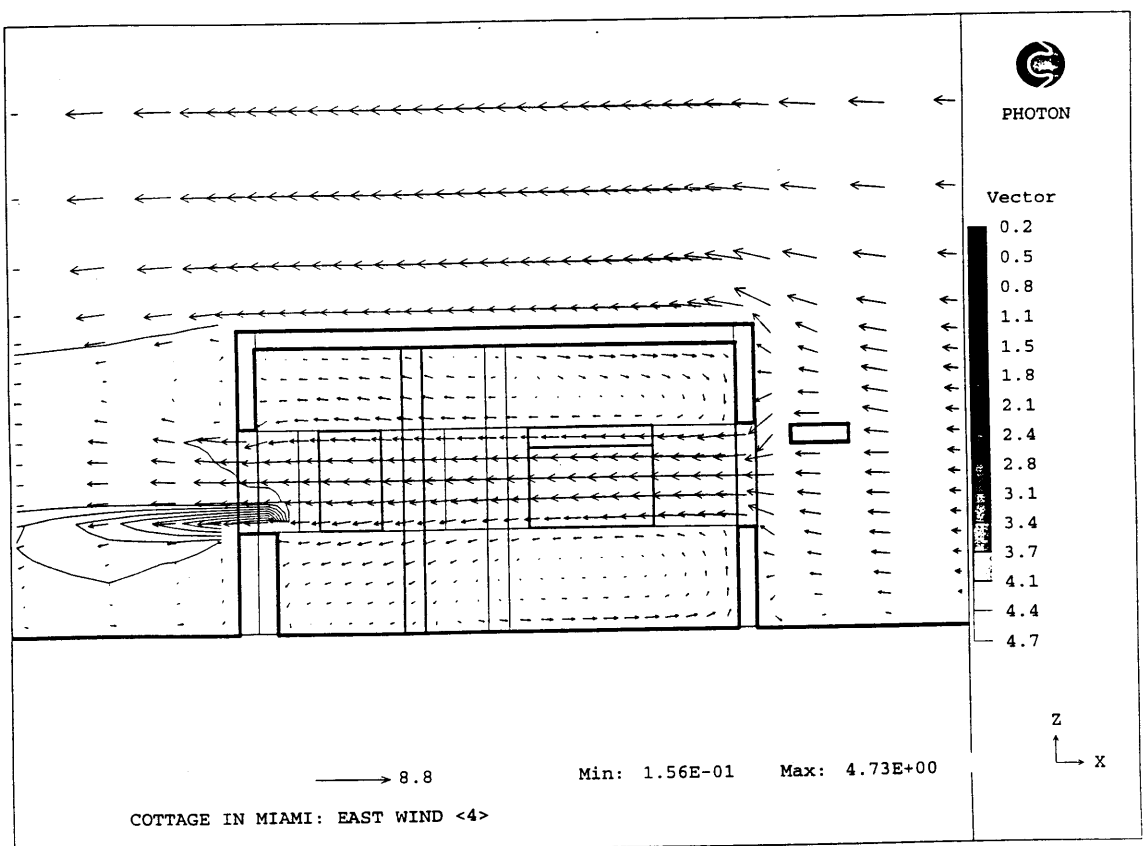
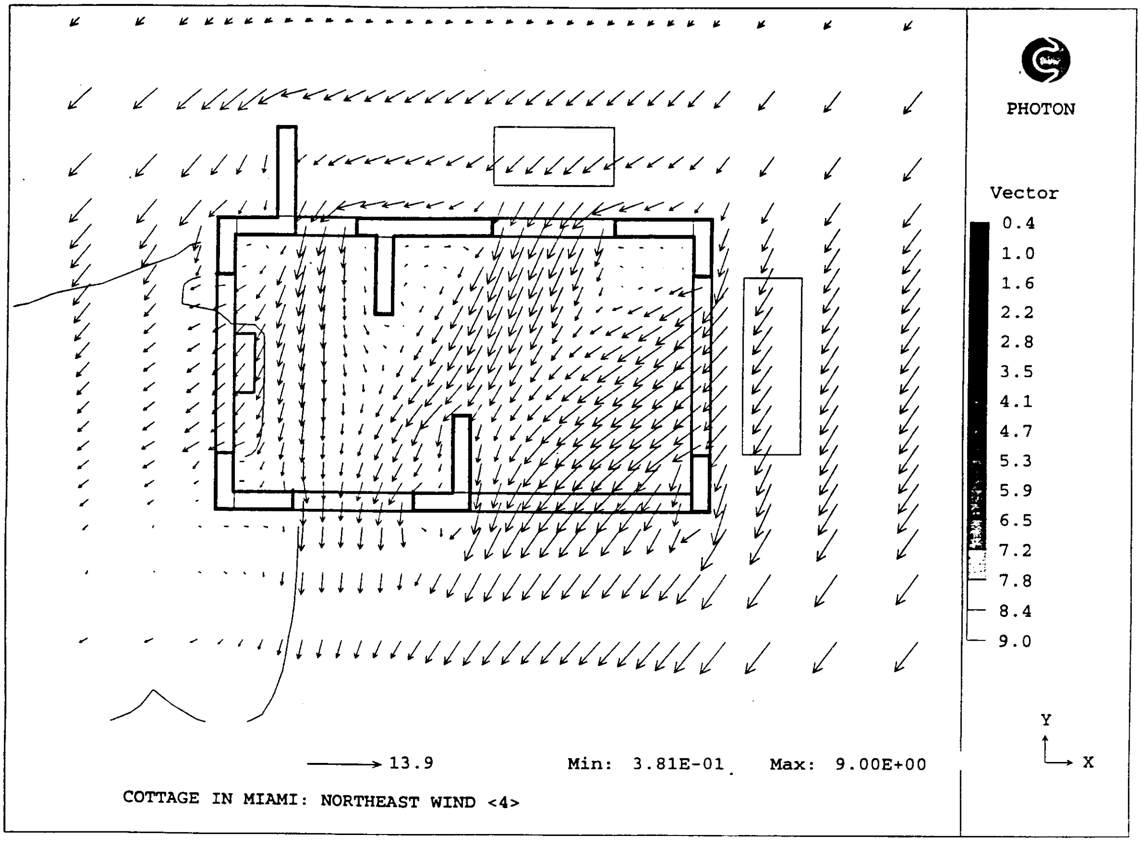


Figure 4.14 Airflow simulation of east wind for the fourth scheme



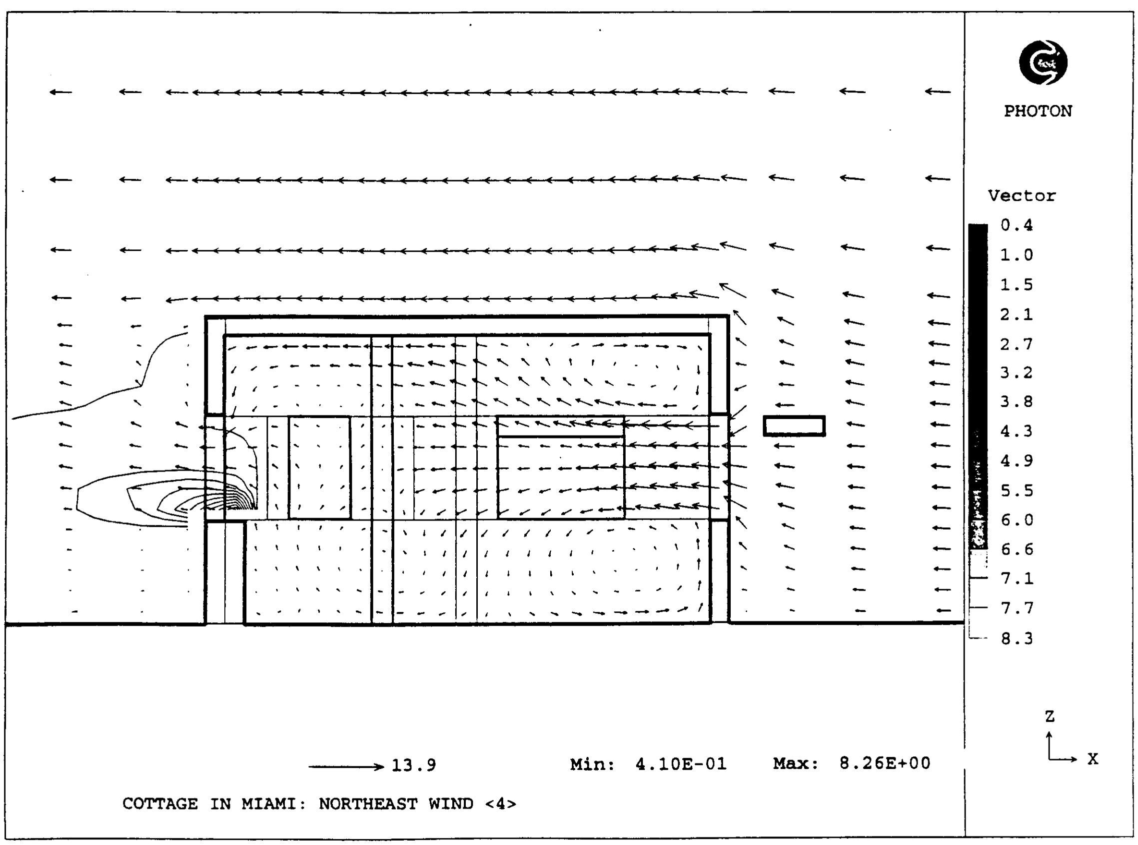


Figure 4.15 Airflow simulation of northeast wind for the fourth scheme

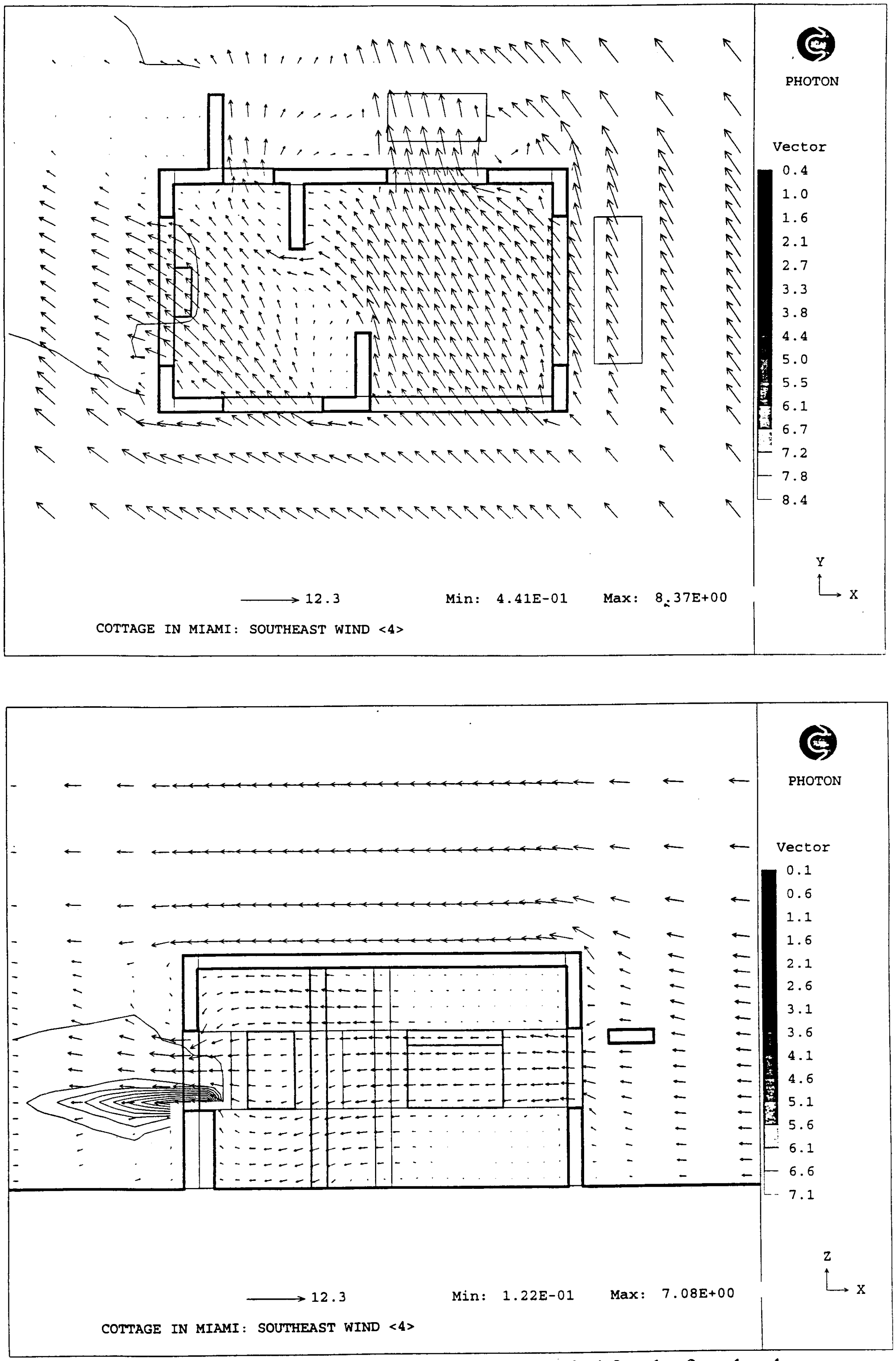


Figure 4.16 Airflow simulation of southeast wind for the fourth scheme

The printout of the plan shows some improvement in the kitchen's airflow pattern under east wind. The vertical fin in north-facing wall guides some wind into the kitchen and largely improves the airflow pattern in the kitchen. The air stream coming from the north window not only changes the wind velocity in the north portion of the kitchen but also pushes some air moving toward the south portion of the kitchen. As a result, most of the kitchen area has wind velocity higher than 0.4 m/s (78.7 ft/m).

In some small areas in the plan, the air velocity is still too low under northeast and southeast wind. When wind comes from the northeast, the two northern corners of the living room have very little air movement. When wind comes from the southeast, the southeast corner of the kitchen has little air movement.

The strategy to improve the air pattern in the sectional view is not successful. For wind coming from all three directions, the wind velocity in the lower part of the living room is still too low. In the next scheme, a different strategy should be used to solve the problem in the sectional view. Also, some change in the plan is necessary to evenly distribute the airflow pattern in the entire cottage.

Fifth Design Scheme

In the fifth design scheme, the shapes of east and north facing windows in the living room are changed in order to increase wind velocity in the lower portion of the room. A series of narrow windows replaces the original horizontal windows to bring wind into the lower part of the room. The east facing window is replaced with five 0.2 m (0.66 ft) by 1.8 m (5.9 ft) vertical windows. The lower sill of the windows is 0.2 m (0.66 ft) above ground. The north facing window of the living room is divided into three 0.4 m (1.3 ft) by 1 m (3.3ft) small windows.

The south-facing window in the kitchen is moved 0.2 m (0.66 ft) to the east in order to allow southeast wind entering the southeast corner. The CONPOR commands to construct this scheme are:

```
** East wall
      20% of opening on the east wall area
CONPOR(EUPPER,0.0,cell,-35,-35,-8,-22,-11,-15)
CONPOR(ELOWER,0.0,cell,-35,-35,-8,-22,-1,-1)
CONPOR(ELEFT,0.0,cell,-35,-35,-8,-10,-2,-10)
CONPOR(ECTR1,0.0,cell,-35,-35,-12,-12,-2,-10)
CONPOR(ECTR2,0.0,cell,-35,-35,-14,-14,-2,-10)
CONPOR(ECTR3,0.0,cell,-35,-35,-16,-16,-2,-10)
CONPOR(ECTR4,0.0,cell,-35,-35,-18,-18,-2,-10)
CONPOR(ERIGHT,0.0,cell,-35,-35,-20,-22,-2,-10)
CONPOR(ESHADE,0.0,cell,-37,-37,-11,-19,-10,-10)
  ** South wall
      40% of opening on the south wall area
CONPOR(SUPPER,0.0,cell,-12,-34,-8,-8,-11,-15)
CONPOR(SLOWER,0.0,cell,-12,-34,-8,-8,-1,-5)
CONPOR(SLEFT,0.0,cell,-12,-15,-8,-8,-6,-10)
CONPOR(SCENTER,0.0,cell,-22,-23,-8,-8,-6,-10)
  ** West wall
      20% of opening on the west wall area
CONPOR(WUPPER,0.0,cell,-11,-11,-8,-22,-11,-15)
CONPOR(WLOWER,0.0,cell,-11,-11,-8,-22,-1,-5)
CONPOR(WLEFT,0.0,cell,-11,-11,-8,-10,-6,-10)
CONPOR(WRIGHT,0.0,cell,-11,-11,-20,-22,-6,-10)
  ** North wall
      20% of opening on the north wall area
CONPOR(NUPPER,0.0,cell,-12,-34,-22,-22,-11,-15)
CONPOR(NLOWER,0.0,cell,-12,-34,-22,-22,-1,-5)
CONPOR(NLEFT,0.0,cell,-12,-15,-22,-22,-6,-10)
CONPOR(NCTR1,0.0,cell,-19,-22,-22,-22,-6,-10)
CONPOR(NCRT2,0.0,cell,-25,-26,-22,-22,-6,-10)
CONPOR(NCTR3,0.0,cell,-29,-30,-22,-22,-6,-10)
CONPOR(NRIGHT,0.0,cell,-33,-34,-22,-22,-6,-10)
CONPOR(NSHADE,0.0,cell,-23,-32,-24,-24,-10,-10)
CONPOR(NBLOCK,0.0,cell,-15,-15,-23,-24,-6,-10)
  ** Roof
CONPOR(ROOF,0.0,cell,-12,-34,-9,-21,-15,-15)
  ** Partition
CONPOR(PARTI1,0.0,cell,-23,-23,-9,-12,-1,-14)
CONPOR(PARTI2,0.0,cell,-19,-19,-18,-21,-1,-14)
  ** Table
CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
```

The plan and elevations of this scheme are shown in Figure 4.17, and the printouts of the simulation are shown in Figure 4.18 ~ 4.20.

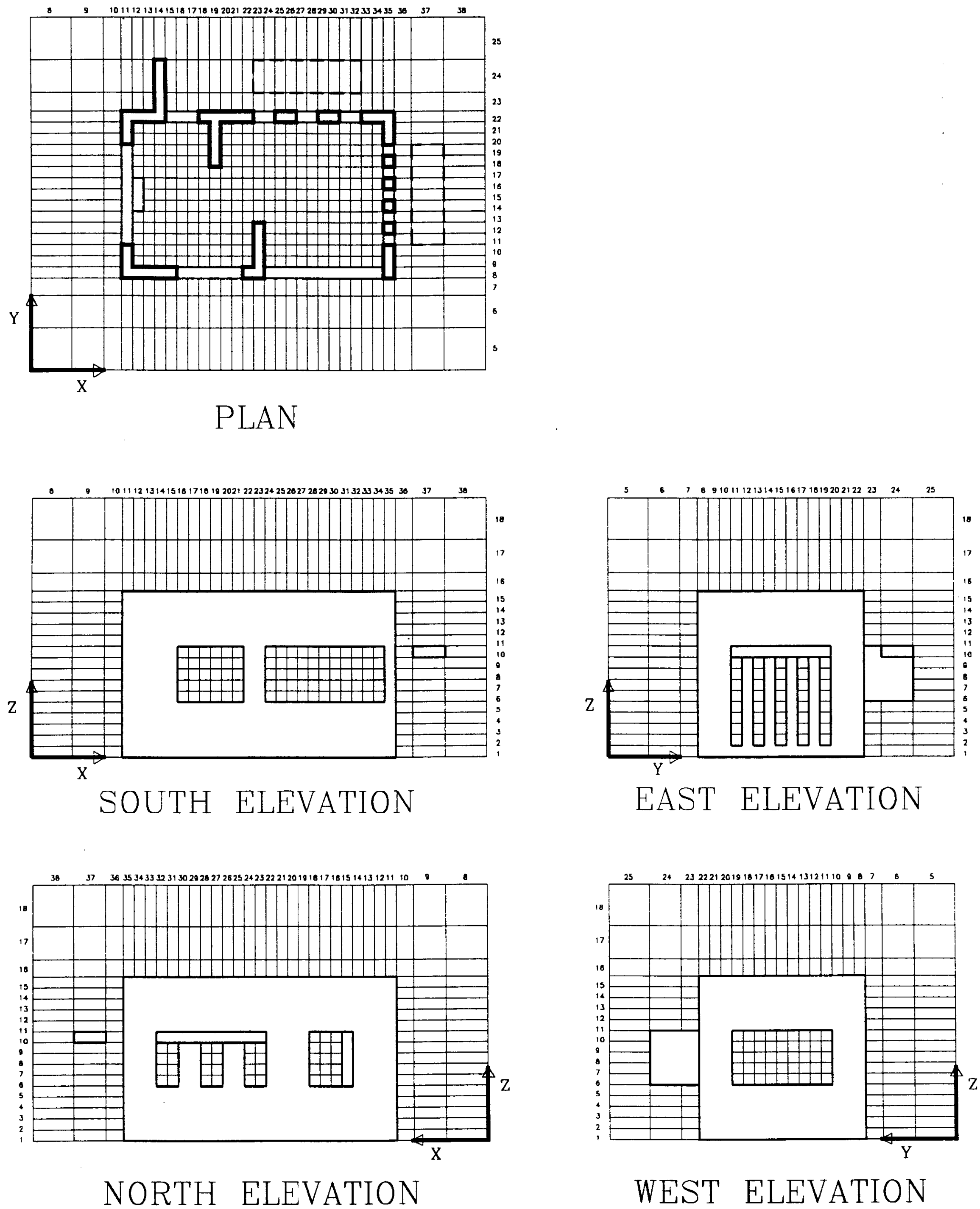
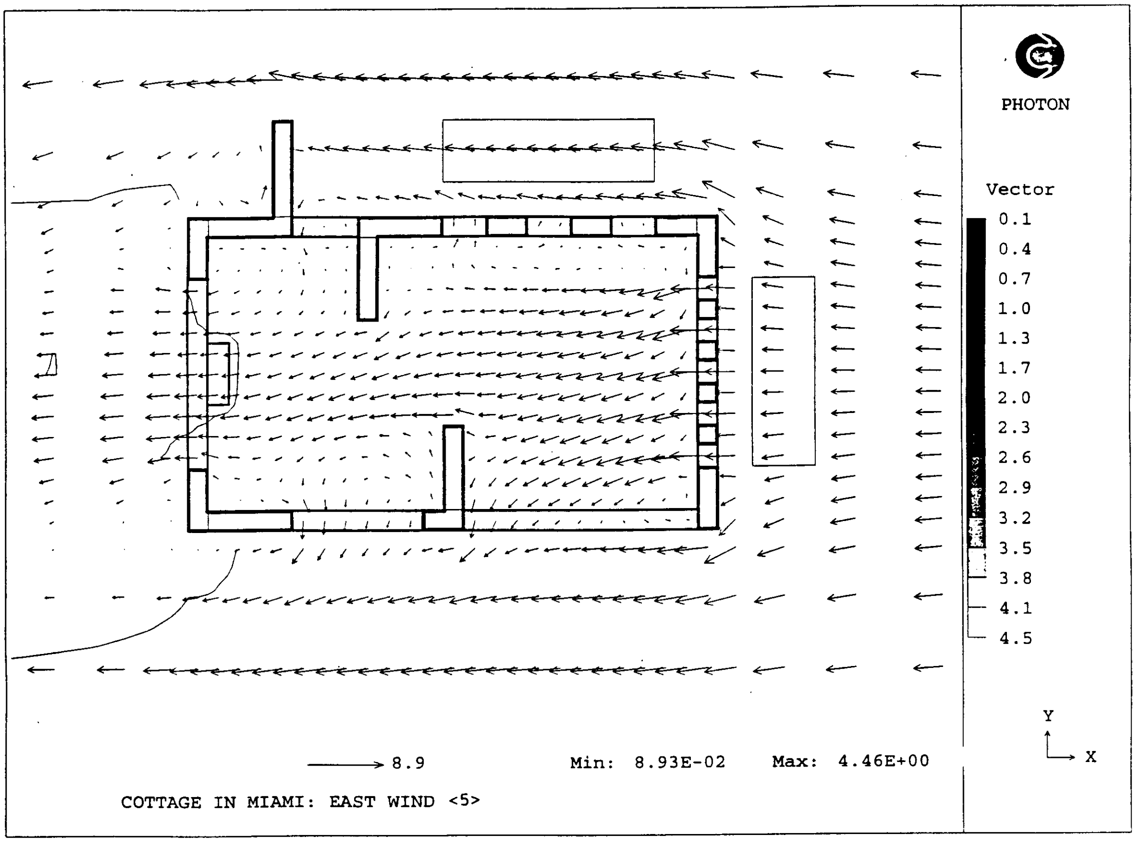


Figure 4.17 Plan and elevations of the fifth scheme



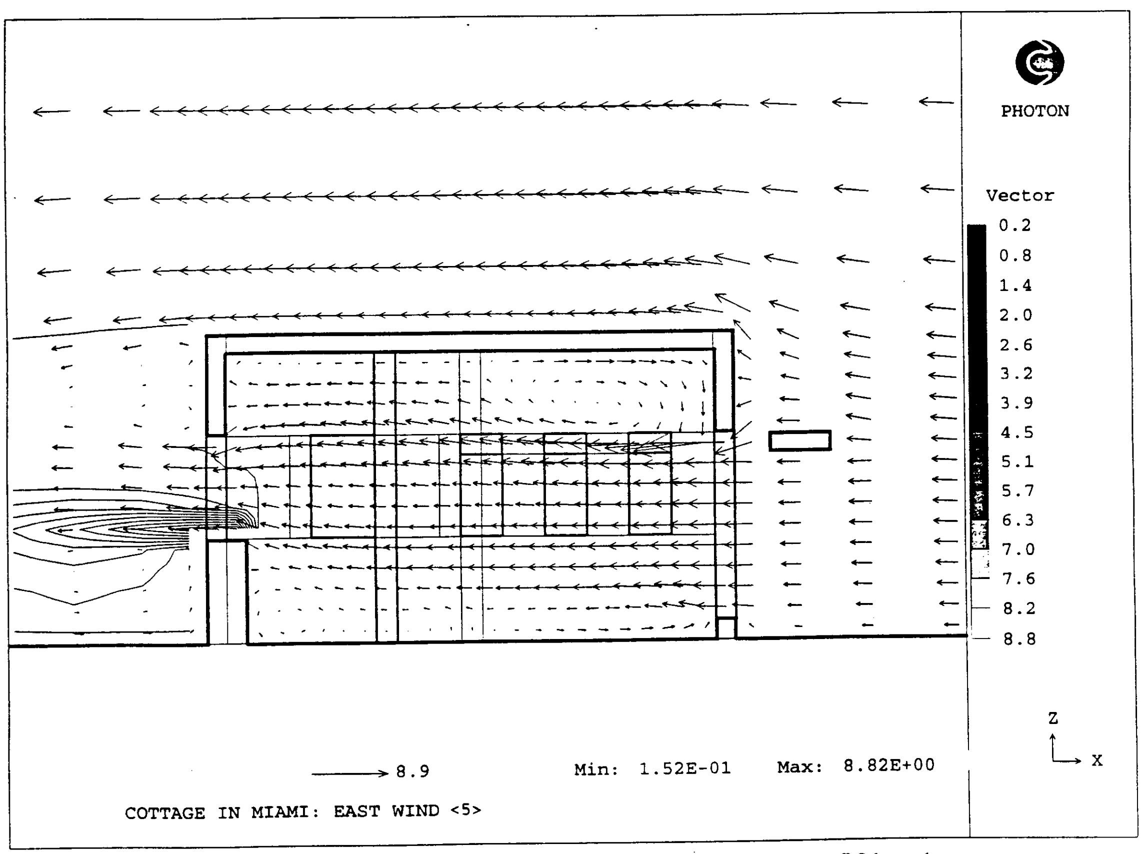


Figure 4.18 Airflow simulation of east wind for the fifth scheme

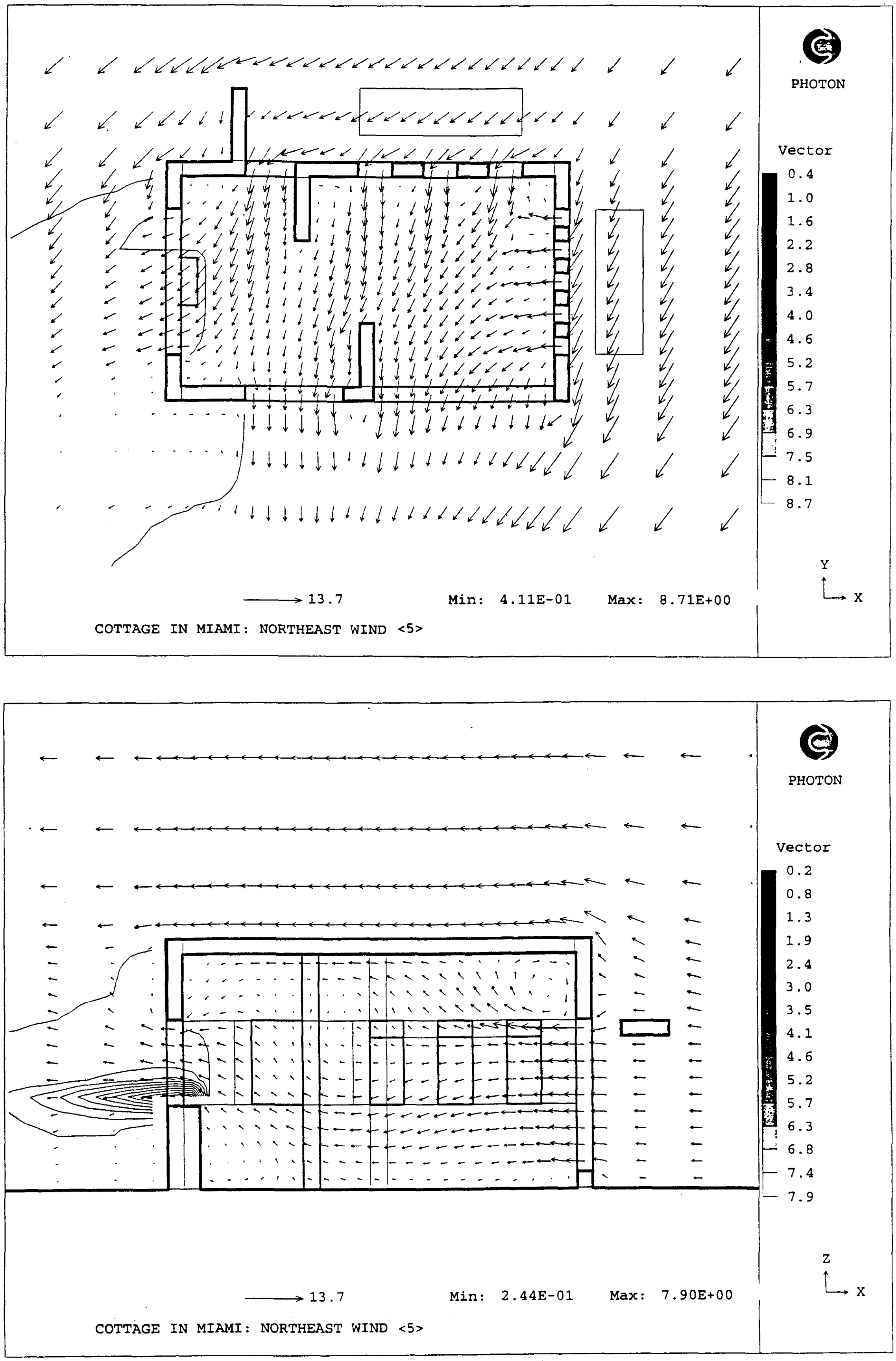
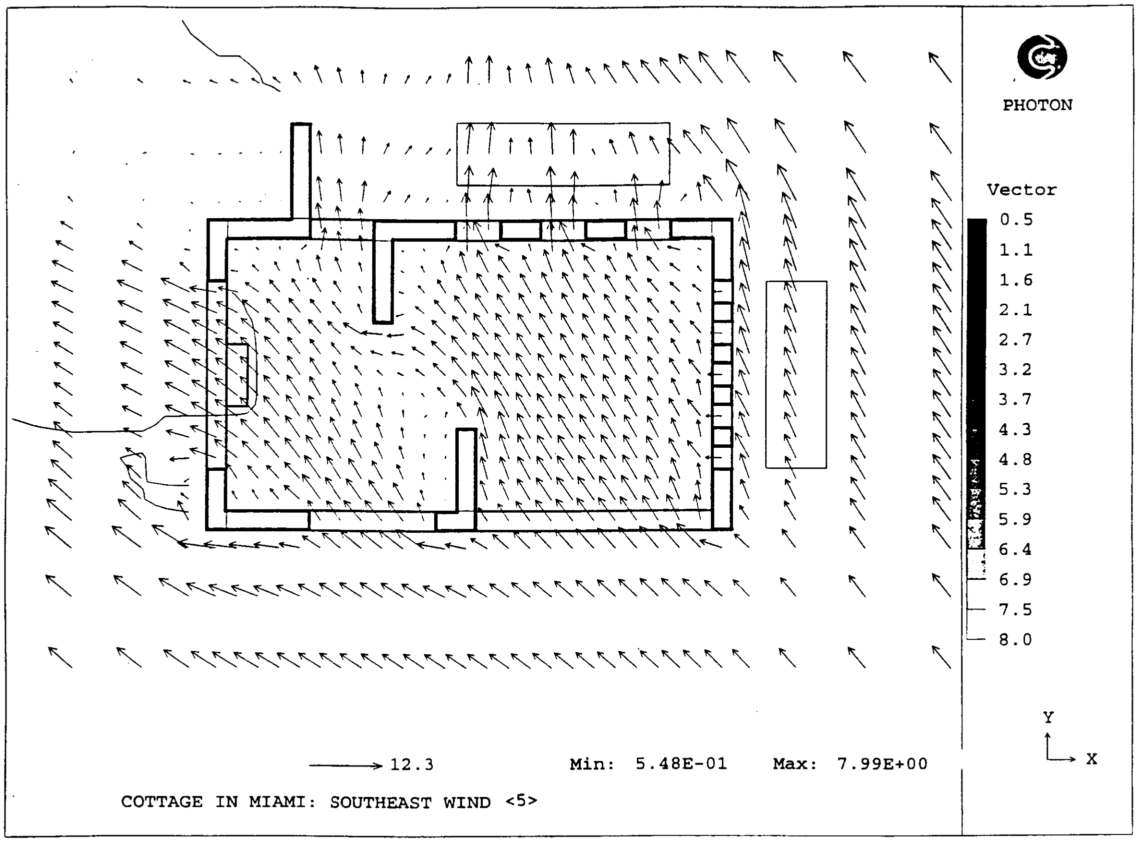


Figure 4.19 Airflow simulation of northeast wind for the fifth scheme



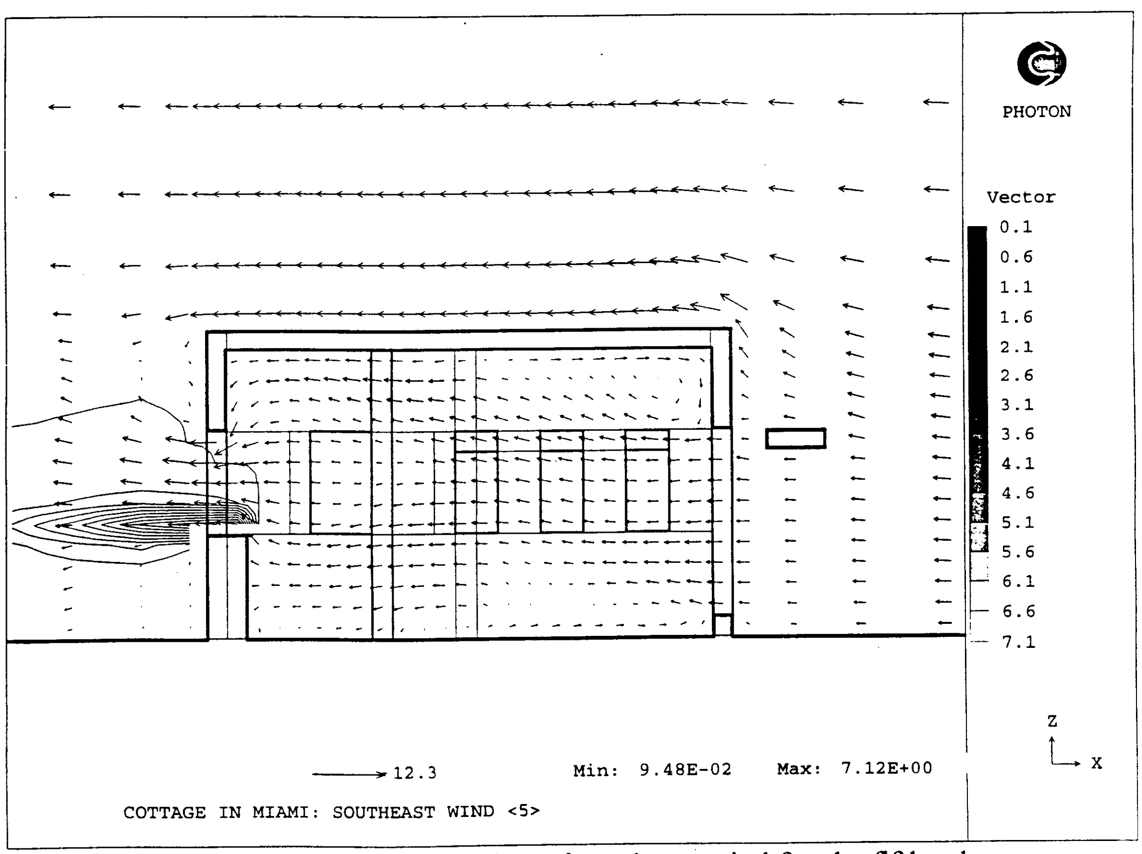


Figure 4.20 Airflow simulation of southeast wind for the fifth scheme

The printouts of simulation show a very nice airflow pattern in this scheme. Most of the problems regarding airflow are solved. Under east wind, the wind velocity is smaller than in previous schemes but the distribution is wide. Even when the wind velocity is small, it is still in the range of a comfortable velocity of 0.5 m/s to 2.03 m/s. The southeast corner of the kitchen has some air movement now. The sectional views shows a present air movement all around the cottage. Under all three wind directions, the airflow patterns are evenly distributed in the entire cottage. People can have pleasent, gentle wind when they sit in the living room.

The CFD modeling successfully represents the wind behavior in three directions for all five schemes. This small design of a cottage shows the possibility of using this CFD tool to represent the potential problems in airflow pattern. It helps the designer to find the problems and to find proper solutions. The next chapter discusses the design of a pavilion in Washington, DC using the CFD program to predict the airflow behavior.

5 Case Study: The Visitors Sports Pavilion in Washington, DC

5.1 Design of the Pavilion

Program

The CFD program was used to study an architectural project "The Visitor Sports Pavilion in Washington, DC," designed by Professor Andrew Scott at the Massachusetts Institute of Technology for the Building Integrated Photovoltaics Competition. The scope of this project is a sports museum that integrates architecture with the new technology of photovoltaics (PV), a thin-film, solid-state material which absorbs solar energy to generate electricity. The plan and section of this project are:

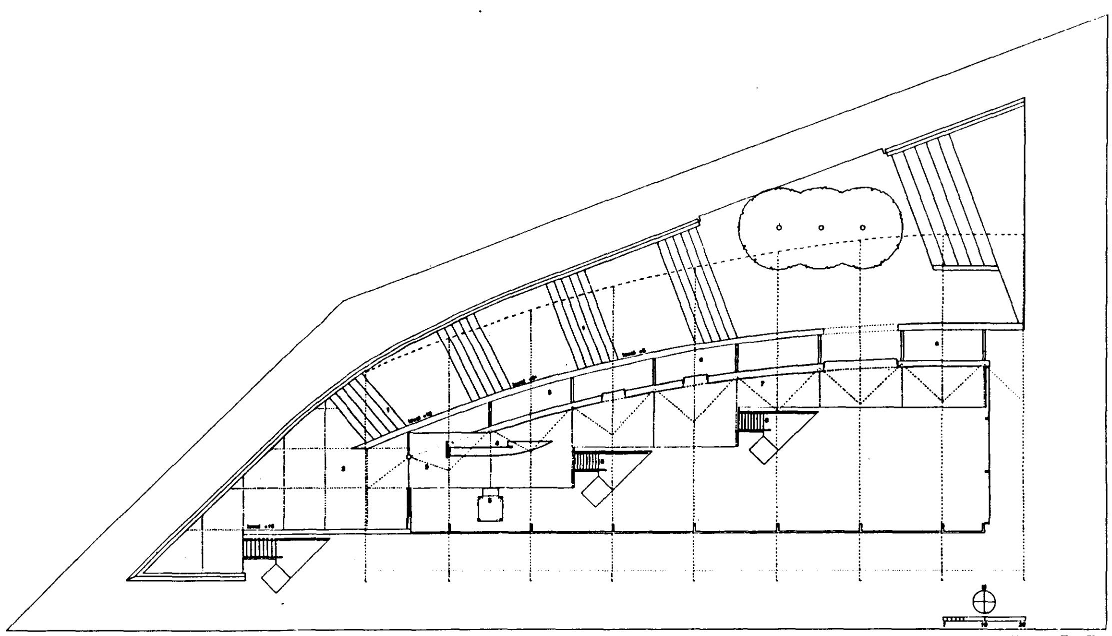


Figure 5.1 Plan of the Visitors Sports Pavilion

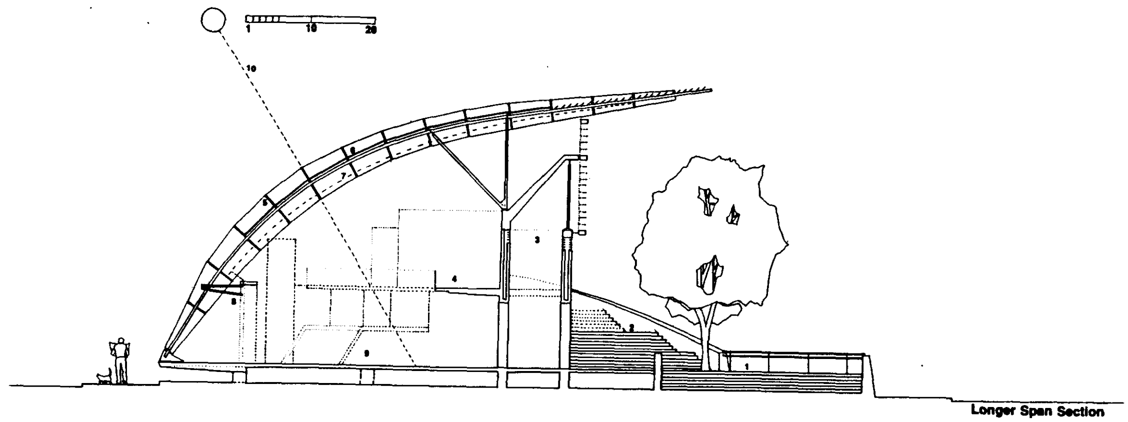


Figure 5.2 Section of the Visitors Sports Pavilion

Design Strategies

The designer developed the form of the pavilion to maximize natural ventilation. This intention was recorded in the competition proposal as presented:

> The sectional form of the building responds directly to many environmental issues. The form of the tensile trusses and membrane were generated to create a continuous passage of air through the space. The roof structure and the form of the 'ventilation chimney' provide for the movement of air to the highest levels of the section, while the trusses are shaped along their length to provide maximum material efficiency of the structural members. The prevailing summer winds enter through a vertically folding wall on the south elevation and are pulled through the space (via the underside of the fabric roof membrane or the chimney by the negative wind pressure that is generated on the north side of the building by the roof configuration.

The following diagrams exhibit the designer's intention of evenly distributed airflow in the space in both conditions of wind-driven convection with south wind and buoyancy-driven convection with no wind. In the case of wind-driven convection, the designer expects that the form of the roof will generate an evenly distribution of airflow in space. In the case of buoyancy-driven convection, the designer expects the high temperature of the PV film to drive an upward wind.

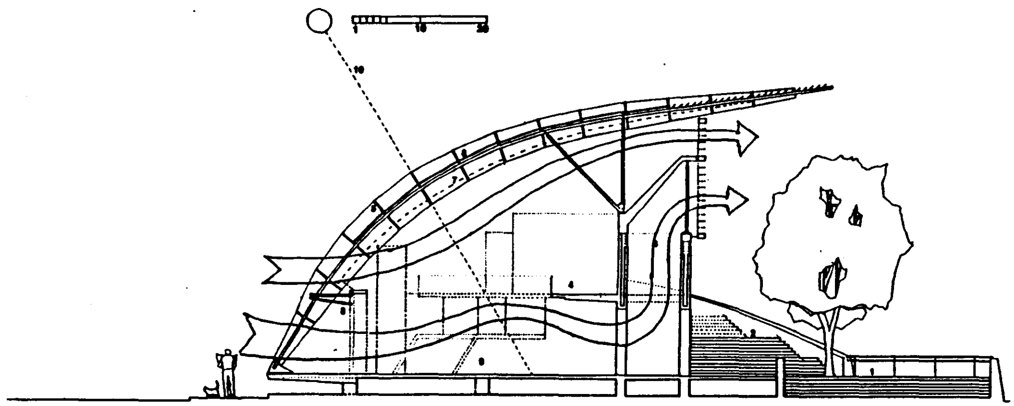


Figure 5.3 Intention of the airflow pattern for wind-driven convection

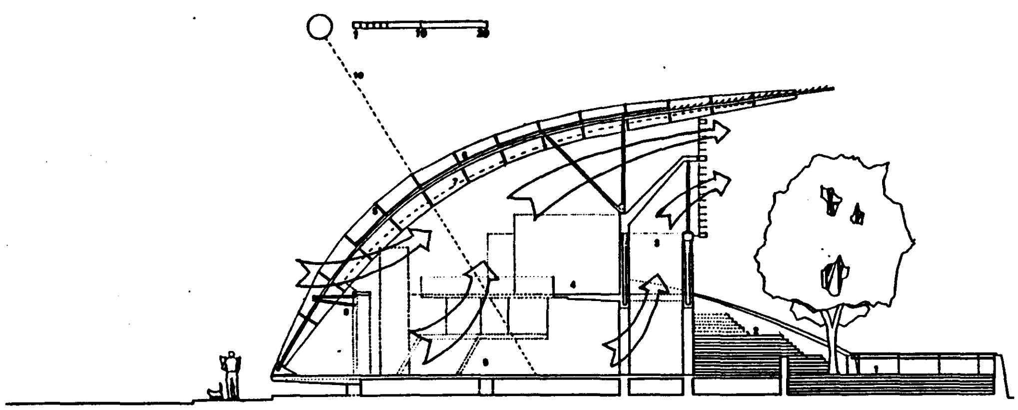


Figure 5.4 Intention of the airflow pattern for buoyancy-driven convection

5.2 CFD Simulations

Environmental Parameters

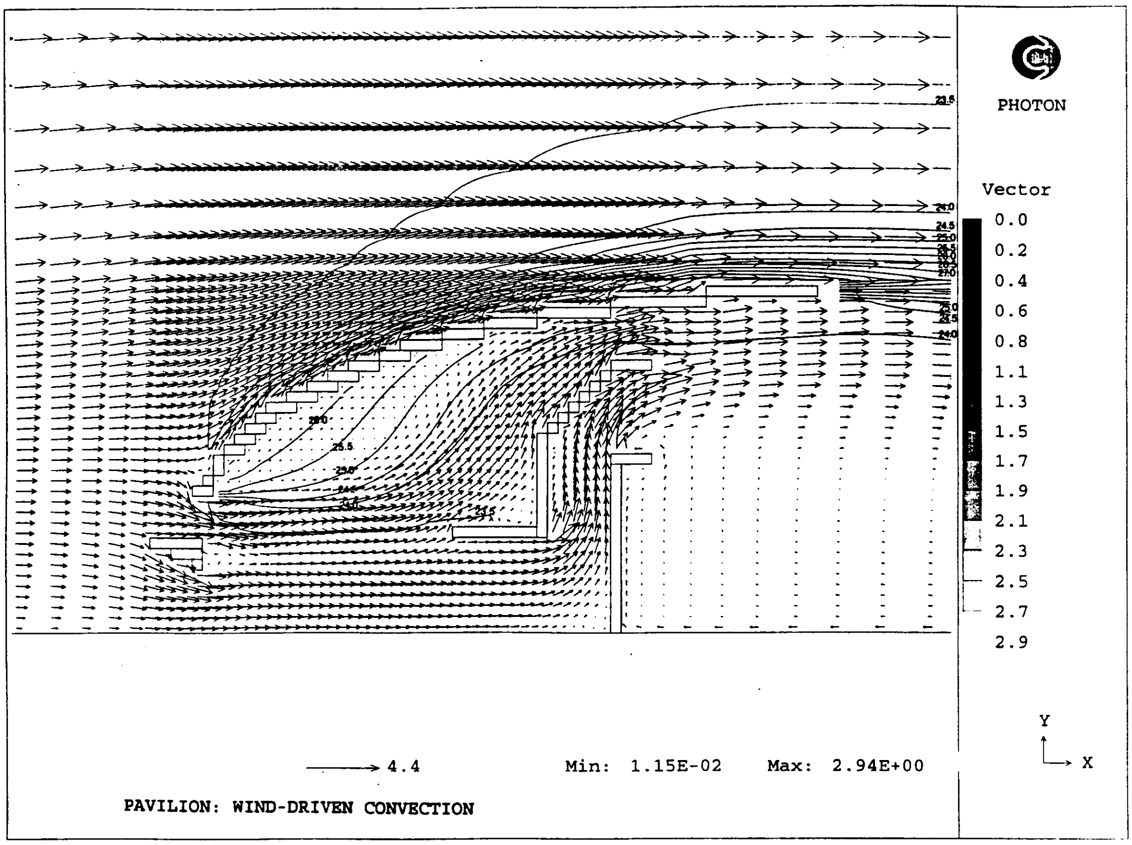
The CFD program tests the designer's idea of airflow in the pavilion. Because of the building's linear shape, a sectional study is sufficient to understand the airflow profile of the building. As result, two CFD models of two-dimension are developed to study the section of the pavilion. One is for the wind-driven convection with south wind, and the other is for buoyancy-driven convection without wind. The two q1 files are reported in Appendix D and E.

The pavilion only opens from May to September; therefore, the environmental parameters are constrained within these months. The environmental parameters of the q1 files are representative of the average weather condition in Washington, DC from May to September.

<u>Environmental Parameters</u>	
Wind direction	South
Wind velocity	2.6 m/s
Air temperature	23°C
PV film temperature (upper surface)	43°C
PV film temperature (lower surface)	33°C (Estimated from the design proposal)

Result

Two graphical printouts are exhibited here for the case of wind-driven convection. The first one plots air velocity in vectors and air temperature in contours. Each contour represents an air temperature of 0.5°C. The second one shows air velocities in vectors and air pressure in contours. The measures of the temperature and pressure are reported as numbers next to the contours in both printouts.



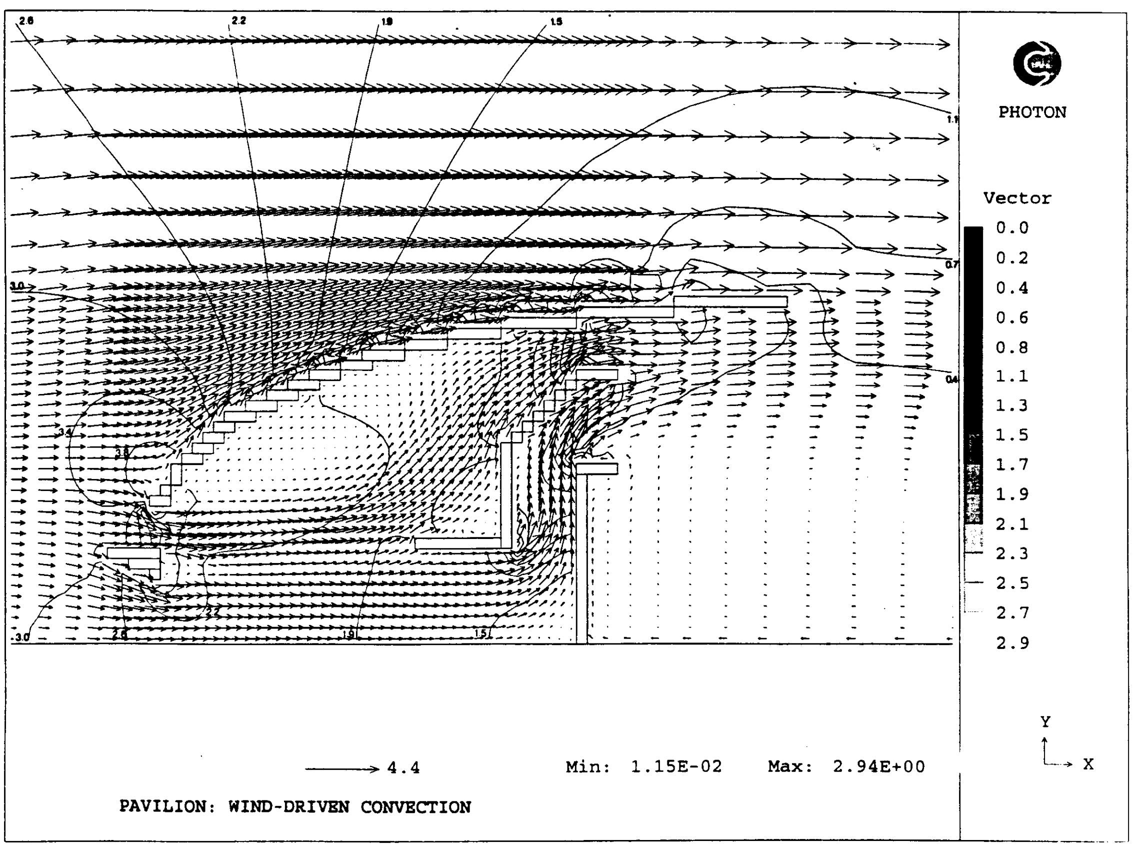


Figure 5.5 Airflow simulations of the Pavilion for wind-driven convection

The printouts display some differences between the designer's original proposal and the CFD simulation. In the case of wind-driven convection, the designer expects an evenly distribution of airflow in the entire space. However, the simulation exhibits that the building form generates a space under the roof where an eddy with very low air velocity is formed. Fortunately, this space of the eddy is not for people's activity and the small air velocity does not affect the thermal comfort of the visitors in the museum.

The designer also expected a negative pressure in the leeward side of the pavilion generated by the building form. The simulation shows a result very similar to what the designer expected. A pressure of 0 kg/m^2 is plotted in the north side of the pavilion which is 3.8 kg/m^2 lesser than the pressure in the south side.

Another printout of simulation shows the result of air velocity and temperature in the case of buoyancy-driven convection.

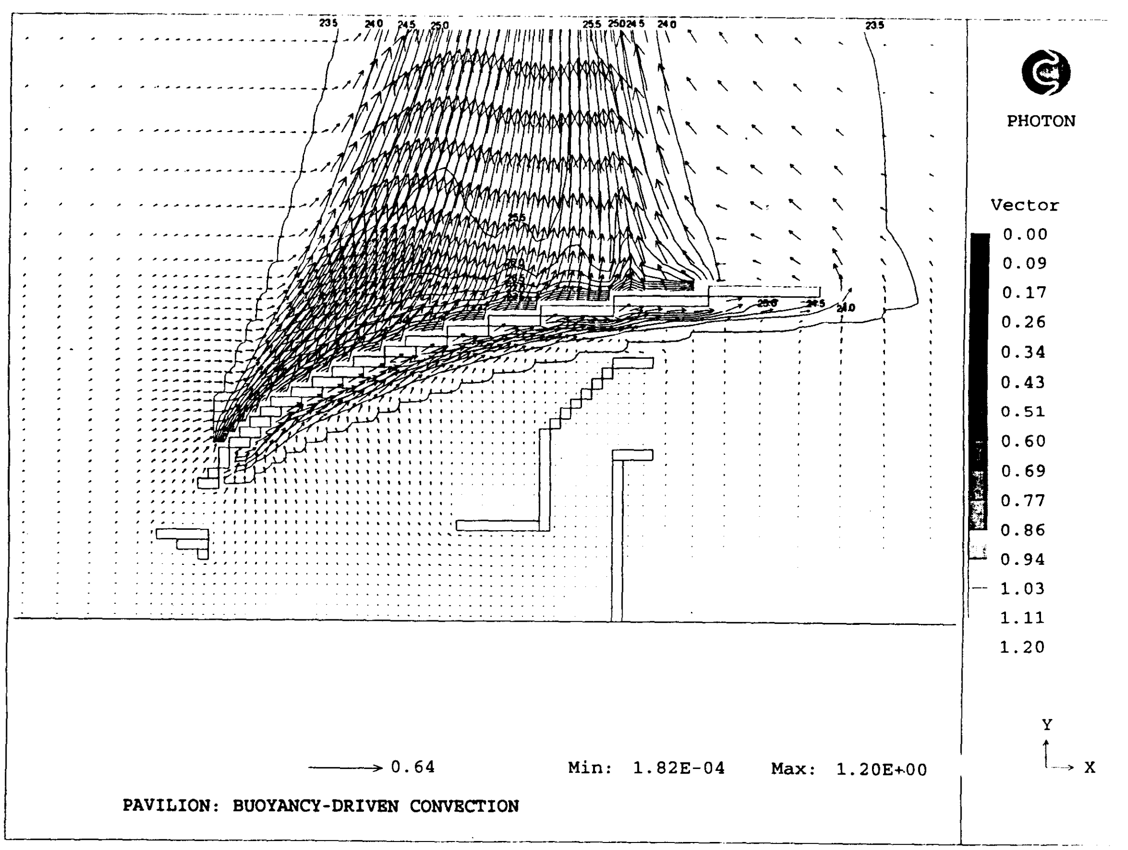


Figure 5.6 Airflow simulation of the Pavilion for buoyancy-driven convection

In the case of buoyancy-driven convection, the high temperature of PV film successfully drives some airflow in space, and the pattern of the airflow is very similar to what the designer proposed. However, the CFD simulation shows that the temperature under the PV film is not high enough to generate a strong upward wind. The air velocities in both the ground level and mezzanine are less than 0.02 m/s that are too low for thermal comfort. These velocities will cause occupant's complaint of stagnation.

This study exemplifies the capability of CFD models in presenting the problems of architectural design in a practical case. CFD program can provide various objective results which may be very different from the designer's subjective imaginations and provide possible improvement of the design. The next chapter discusses problems encountered with CFD modeling during development of these simulations.

6 Problems in Developing CFD Models

6.1 Boundary

Several problems occurred in the process of developing these CFD models. Some of the problems came from typing the wrong arguments of boundaries in q1 files. Others came from the convergence of the calculation. This chapter discusses these mistakes and problems.

CFD programs are extremely sensitive to the boundaries defined. A very little mistake in defining the boundaries can result in a significant error. In this research, some mistakes have been made in the boundaries. One mistake is in defining the geometry of the patch, another is in defining the number of region, and the third is in defining the temperature.

Patch Geometry

The first mistake was made when modifying the first basic model to the northeast and southeast wind model. When the north boundaries are defined as inlets, one of the patches was typed incorrectly as:

```
PATCH(NB12,NORTH,NX,NX,1,NY,12,12,1,1)
```

when it should be:

```
PATCH(NB12,NORTH,1,NX,NY,NY,12,12,1,1)
```

Because the geometry of the patch was defined incorrectly, the boundary NB12 became a one cell patch in the north boundary when it should be a long patch with a row of cells on the north boundary with height from 2.2 m to 2.4 m. The other mistake was made to be a wrong direction as:

```
PATCH(SB6,EAST,1,NX,1,1,6,6,1,1)
```

when it should be:

```
PATCH(SB6,SOUTH,1,NX,1,1,6,6,1,1)
```

This mistake made a one cell patch in the east boundary when it should be a patch with a row of cells in the south boundary from 1 m to 1.2 m in height. Both mistakes change the profile of the inlet air. In these wrong patches, the inlet air velocity become smaller, and the directions of the inlet air in adjacent patches are affected.

Number of Region

In the example of the Visitor Sports Pavilion in Washington, DC, a mistake was made in defining the region. Since the model is two dimensional, there are only two axes X and Y. In Y direction, there are only two regions for the building itself and for the atmosphere above the building. The number of region was typed incorrectly as:

```
NREGY=3
IREGY=1;GRDPWR(Y,33,6.6,1)
IREGY=2;GRDPWR(Y,15,13.4,1.5)
```

When it should be:

```
NREGY=2
IREGY=1;GRDPWR(Y,33,6.6,1)
IREGY=2;GRDPWR(Y,15,13.4,1.5)
```

The third region was defined automatically with some default arguments by PHOENICS. The result is an extra patch that is one cell height above the two defined regions. A default air pressure was defined by the computer and resulting in a strong downward pressure in the space.

Temperature

In the case of the Visitor Sports Pavilion in Washington, DC for natural convection without wind, a mistake in setting the temperature changes the complete output.

```
** Thermal buoyancy
BUOYB=-9.8; BUOYD=-1./300.; BUOYE=-BUOYD*27.
```

Because the actuarial air temperature is 23°C, the command should be:

```
** Thermal buoyancy
BUOYB=-9.8; BUOYD=-1./300.; BUOYE=-BUOYD*23.
```

Even though the difference in temperature is only 4°C, the resulting airflow is completely wrong and unreasonable. All of these mistakes in boundaries are very simple, but they happened very frequently in developing CFD models. They are very difficult to be found in the long q1 files and should be carefully avoided.

6.2 Convergence

Residual

When all the boundaries in q1 file are correctly defined, PHOENICS can start the calculations. However, a correct q1 file does not promise a complete calculation the first time. Because CFD programs calculate fluid flow by interatively reducing errors in the solutions to equations, the errors must approach a residual small enough that the result is acceptable. Therefore, residuals are the indicator of the completeness of the calculation. The residual sum of the final sweep is recorded in the result file as:

```
Whole-field residual sum(s) before solution
 Resref values determined by EARTH
 resfac  = 1.000E-03
  variable   resref  (res sum)/resref
     P1     2.953E-03   1.471E+02
     U1     4.173E-03   3.143E+02
     V1     2.305E-05   2.099E+03
     W1     3.537E-05   1.050E+05
     KE     9.796E-06   2.253E+02
     EP     1.918E-05   1.160E+02
     TEM1   4.184E+01   9.876E+00
```

The residual sums are calculated from the above data as:

	Residual Sum
P1	4.34E-01
U1	1.31E+00
V1	4.84E-02
W1	3.71E+00
KE	2.21E-03
EP	2.22E-03
TEM1	4.13E+02

Usually, the completeness of the calculation is defined in the following definitions:

Variables	Definitions	
P1	(res sum) / (RHO1×U1×YLENGTH×ZLENGTH)	< 1%
U1	(res sum) / (RHO1×U1^2×YLENGTH×ZLENGTH)	< 5%
V1	(res sum) / (RHO1×U1^2×YLENGTH×ZLENGTH)	< 5%
W1	(res sum) / (RHO1×U1^2×YLENGTH×ZLENGTH)	< 5%
KE	(res sum) / (RHO1×U1×KE×YLENGTH×ZLENGTH)	< 5%
EP	(res sum) / (RHO1×U1×EP×YLENGTH×ZLENGTH)	< 5%
TEM1	(res sum) / (RHO1×U1×TEM1×Cp×YLENGTH×ZLENGTH)	< 10%

where Cp is the specific heat of air (1005 J/kg·K).

The result of these calculations are:

Variable	Result
P1	7.72E-04
U1	5.37E-04
V1	1.98E-05
W1	1.52E-03
KE	4.78E-07
EP	3.45E-08
TEM1	2.46E-06

Since all these results are smaller then the definitions, the calculation is convergent. Another way of observing the convergence is from the following chart in the result file:

```
************************************************************
 residuals vs sweep or iteration number

   VARIABLE        P1         U1         V1         W1         KE
     MINVAL=  5.302E+00  5.997E+00  7.989E+00  1.184E+01  5.852E+00
     MAXVAL=  1.285E+01  2.386E+01  1.359E+01  2.256E+01  2.672E+01
   VARIABLE        EP        TEM1
     MINVAL=  5.109E+00  2.283E+00
     MAXVAL=  3.001E+01  2.420E+01
1.00 T..V.+....+....+....+....+....+....+....+....+....+
     .                                                 .
0.90 +    V  V                                         +
     .                                                 .
0.80 +          V                                      +
     .            V                                    .
0.70 +  P P          V                                 +
     .       P         V                               .
0.60 V          P         V                            +
     .            P          V                         .
0.50 +               P P       V                       +
     .    W               P       V                    .
0.40 +  W    W  W            P       V                 +
     .  K K       W  W         P       V               .
0.30 +  E U  K  K      W  W       P  P                 +
     .    E  E  E K          W W       P  V            .
0.20 +            E  K K          W  W    P V          +
     .               E E  E  E K       W  W P  V       .
0.10 +                         E  E  E K    W  W  V    +
     .                                 E  E E  E  K W  .
0.00 +..T.T..T.+T.T.+T.T.+T..T+T..T+.T.T+.T.T+.T..T.T..T
     0   .1   .2   .3   .4   .5   .6   .7   .8   .9  1.0
the abscissa is      ISWP.  min= 1.00E+00 max= 2.85E+03

************************************************************
```

In this chart, letter P's represent the residuals of P1, letter U's represent the residuals of U1, letter V's represent the residuals of V1, letter W's represent the residuals of W1, letter K's represent the residuals of KE, letter E's represent the residuals of EP, and letter T's represent the residuals of TEM1. When all the residuals of all these variables approaches 0.00 as the integration number increases, the calculation is convergent.

In the above chart, if all the variables approaches 0.0 before the final sweep, the number of LSWEEP in the q1 file may decrease and the calculation time will reduce. To reduce the calculation time is very important in CFD calculations. It will be discussed in the next chapter.

If the calculation is not convergent, the following steps can solve the problem. The first step is to make sure all the boundaries in the q1 file are defined correctly. The last section discusses some mistakes occurred in the development in this thesis. If the boundaries are correct, the size of false-time-step (DTF) in group 17 should be changed. The purpose of changing the DTF number is to make the calculaiotn stable. Usually, the first try is to multiply the DTF number by 0.1. If the calculation is not convergent yet, the DTF number may decrease again until it converges. In some cases, when the residuals are decreasing very slowly, the DTF should increase. Decreasing the DTF number can make the calculation converge easier while increasing the DTF number can make the calculation converge in fewer sweeps. In the basic model of northeast wind in Miami, the DTF decreases to make the calculation converge.

In the case of designing a cottage in Miami, after the first three models are established and calculations are convergent, very few problems appeared regarding convergence. All the calculations are convergent when different schemes change the building geometry. This makes possible the use of CFD tool for design. As long as the basic model is developed correctly, the designer can easily change the building geometry and have a reliable result without worrying the convergence of the calculation.

7 Conclusion

This research demonstrates the possibility of using the CFD programs as design tools. CFD programs calculate the airflow behavior in both indoor and outdoor spaces and also provides architects an objective result for airflow and temperature. Recently, many architects design the airflow pattern through subjective imagination which is unreliable. The design of the Visitor Sports Pavilion in Washington, DC exemplifies the difference between the designer's proposal and the result through calculation.

On the other hand, CFD modeling can also present problems in application. The main concern of the architects is the length of the calculation time. Time is always a major factor in practical application and limitation of current hardware technology creates a restraint to use this program. During the development of different schemes in the housing design in Miami, each model requires approximately ten hours to calculate with a Silicon Graphics Indi work station. Three models for three different wind directions requires about thirty hours. The hours are long when compared to the extremely small size of the building. The reason for the lengthy calculation time is due to the large number of cells in a three dimensional model. Three dimensional models are essential to architects since architectural design involves three dimensional thinking. The only solution to this problem is to enhance the hardware capability; however, the high price of more powerful mechines is another limitation in applying the CFD program in architectural design.

In most cases, the CFD programs can provide reliable results in simulations. However, in some complicated cases, CFD modeling may need some physical experiments to validate its result. A wind tunnel is a good tool to analyze the result. The physical experiment of wind tunnel is beyond the scope of this research and is recommended for a future research topic.

Appendix A

The q1 file of the basic model for east wind in Miami, Florida.

```
 TALK=F;RUN( 1, 1);VDU=X11-TERM
    GROUP 1. Run title and other preliminaries
       A title up to 40 characters can be used.
TEXT(MIAMI: EAST WIND)
       THE AIRFLOW PATTERN WITH EAST WIND IN MIAMI.
TITLE
       This basic model represents the east wind in Miami.  It will be
       used for further development of building form.
REAL(XLENGTH,YLENGTH,ZLENGTH,TKEIN,EPSIN)
       Assign values to the variables declared.
       The length, width and height of outdoor space are 25 m (82.5
       ft), 15 m (50 ft), 9 m (30 ft) respectively.
XLENGTH=25;YLENGTH=15;ZLENGTH=9
NX=45;NY=29;NZ=22
    GROUP 2. Transience; time-step specification
    GROUP 3. X-direction grid specification
       Total region number in the X-direction is 3.
       10 cells are in the first region, west of the building area.
       25 cells are in the second region, the building area.
       10 cells are in the third region, east of the building area.
       The dimension in X-direction is 10 m (33 ft), 5 m (16.5 ft),
       and 10 m (33 ft) in three regions.
       The cells are evenly divided in the second region.
       The dimensions of the cells become bigger when they are away
       from the building area.
NREGX=3
IREGX=1;GRDPWR(X,10,10,-1.5)
IREGX=2;GRDPWR(X,25,5,1)
IREGX=3;GRDPWR(X,10,10,1.5)
     GROUP 4. Y-direction grid specification
       Total region number in the Y-direction is 3.
       7 cells are in the first region, south of the building area.
       15 cells are in the second region, the building area.
       7 cells are in the third region, north of the building area.
       The dimension in Y-direction is 6 m (20 ft), 3 m (10 ft),
       and 6 m (20 ft) in three regions.
       The cells are evenly divided in the second region.
       The dimensions of the cells become wider when they are away
       from the building area.
NREGY=3
IREGY=1;GRDPWR(Y,7,6,-1.5)
IREGY=2;GRDPWR(Y,15,3,1)
IREGY=3;GRDPWR(Y,7,6,1.5)
    GROUP 5. Z-direction grid specification
       Total region number in the Z-direction is 2.
       15 cells are in the first region, the atmosphere above the
       building area.
```

```
        7 cells are in the second region, the building area.
        The dimension in Z-direction is 3 m (10 ft) and 6 m (20 ft)
        in the two regions.
        The cells are evenly divided in the first region.
        The dimensions of the cells become wider when they are away
        from the building area.
NREGZ=2
IREGZ=1;GRDPWR(Z,15,3,1)
IREGZ=2;GRDPWR(Z,7,6,1.5)
    GROUP 6. Body-fitted coordinates or grid distortion
    GROUP 7. Variables stored, solved & named
        Solve the following variables:
        P1 - The first phase pressure.
        U1 - The first phase velocity in X-direction.
        V1 - The first phase velocity in Y-direction.
        W1 - The first phase velocity in Z-direction.
        TEM1 - The first phase temperature.
SOLVE(P1,U1,V1,W1,TEM1)
TURMOD(KEMODL)
    GROUP 8. Terms (in differential equations) & devices
    GROUP 9. Properties of the medium (or media)
        Set the laminar kinetic viscosity of air as 1.5E-5.
        Set the density of air as 1.2.
        Set the turbulent Prandtl number of air as 0.9.
        Set the laminar Prandtl number of air as 0.7.
ENUL=1.5E-5
RHO1=1.2
PRT(TEM1)=0.9
PRNDTL(TEM1)=0.7
    GROUP 10. Inter-phase-transfer processes and properties
    GROUP 11. Initialization of variable or porosity fields
        Set initial air velocity 4.34 m/s (854 f/m).
        Set initial air temperature 24 C (75.4 F).
FIINIT(U1)=-4.34
FIINIT(TEM1)=24.
PRESS0=1.0E5
TEMP0=273.15
  ** Calculation of KE
TKEIN=0.018*0.25*4.34*4.34
  ** Calculation of EP
EPSIN=TKEIN**1.5*0.1643/3.429E-3
FIINIT(KE)=TKEIN
FIINIT(EP)=EPSIN
  ** East wall
CONPOR(ELOWER,0.0,cell,-35,-35,-8,-22,-1,-5)
  ** Table
CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
    GROUP 12. Patchwise adjustment of terms
    GROUP 13. Boundary conditions and special sources
        Use Boussinesq approximation.
        BUOYA - gravity in X-direction.
        BUOYB - gravity in Y-direction.
        BUOYC - gravity in Z-direction.
        BUOYD - air expansion coefficient (=1/T in Kelvin).
        BUOYE - BUOYD * Reference temperature (in Celsius).
```

```
  ** Thermal buoyancy
BUOYC=-9.8; BUOYD=-1./300; BUOYE=-BUOYD*24.
       Define the space and time the boundary condition to be applied.
PATCH(BUOY,PHASEM,1,NX,1,NY,1,NZ,1,LSTEP)
       Apply the Buossinesq approximation (GRND3).
COVAL(BUOY,W1,FIXFLU,GRND3)
  ** East boundary
       Define the space and time the boundary condition to be applied.
PATCH(EB1,EAST,NX,NX,1,NY,1,1,1,1)
       Use non-slip boundary condition for U1 and V1.
COVAL(EB1,P1,FIXFLU,2.79*RHO1)
COVAL(EB1,U1,ONLYMS,-2.79)
COVAL(EB1,KE,ONLYMS,TKEIN)
COVAL(EB1,EP,ONLYMS,EPSIN)
       Set air temperature to 24 C (75.4 F).
COVAL(EB1,TEM1,ONLYMS,24.)
       Set coastal boundary condition by changing U1.
PATCH(EB2,EAST,NX,NX,1,NY,2,2,1,1)
COVAL(EB2,P1,FIXFLU,3.11*RHO1)
COVAL(EB2,U1,ONLYMS,-3.11)
COVAL(EB2,KE,ONLYMS,TKEIN)
COVAL(EB2,EP,ONLYMS,EPSIN)
COVAL(EB2,TEM1,ONLYMS,24.)
PATCH(EB3,EAST,NX,NX,1,NY,3,3,1,1)
COVAL(EB3,P1,FIXFLU,3.27*RHO1)
COVAL(EB3,U1,ONLYMS,-3.27)
COVAL(EB3,KE,ONLYMS,TKEIN)
COVAL(EB3,EP,ONLYMS,EPSIN)
COVAL(EB3,TEM1,ONLYMS,24.)
PATCH(EB4,EAST,NX,NX,1,NY,4,4,1,1)
COVAL(EB4,P1,FIXFLU,3.38*RHO1)
COVAL(EB4,U1,ONLYMS,-3.38)
COVAL(EB4,KE,ONLYMS,TKEIN)
COVAL(EB4,EP,ONLYMS,EPSIN)
COVAL(EB4,TEM1,ONLYMS,24.)
PATCH(EB5,EAST,NX,NX,1,NY,5,5,1,1)
COVAL(EB5,P1,FIXFLU,3.47*RHO1)
COVAL(EB5,U1,ONLYMS,-3.47)
COVAL(EB5,KE,ONLYMS,TKEIN)
COVAL(EB5,EP,ONLYMS,EPSIN)
COVAL(EB5,TEM1,ONLYMS,24.)
PATCH(EB6,EAST,NX,NX,1,NY,6,6,1,1)
COVAL(EB6,P1,FIXFLU,3.54*RHO1)
COVAL(EB6,U1,ONLYMS,-3.54)
COVAL(EB6,KE,ONLYMS,TKEIN)
COVAL(EB6,EP,ONLYMS,EPSIN)
COVAL(EB6,TEM1,ONLYMS,24.)
PATCH(EB7,EAST,NX,NX,1,NY,7,7,1,1)
COVAL(EB7,P1,FIXFLU,3.6*RHO1)
COVAL(EB7,U1,ONLYMS,-3.6)
COVAL(EB7,KE,ONLYMS,TKEIN)
COVAL(EB7,EP,ONLYMS,EPSIN)
COVAL(EB7,TEM1,ONLYMS,24.)
PATCH(EB8,EAST,NX,NX,1,NY,8,8,1,1)
COVAL(EB8,P1,FIXFLU,3.65*RHO1)
```

```
COVAL(EB8,U1,ONLYMS,-3.65)
COVAL(EB8,KE,ONLYMS,TKEIN)
COVAL(EB8,EP,ONLYMS,EPSIN)
COVAL(EB8,TEM1,ONLYMS,24.)
PATCH(EB9,EAST,NX,NX,1,NY,9,9,1,1)
COVAL(EB9,P1,FIXFLU,3.7*RHO1)
COVAL(EB9,U1,ONLYMS,-3.7)
COVAL(EB9,KE,ONLYMS,TKEIN)
COVAL(EB9,EP,ONLYMS,EPSIN)
COVAL(EB9,TEM1,ONLYMS,24.)
PATCH(EB10,EAST,NX,NX,1,NY,10,10,1,1)
COVAL(EB10,P1,FIXFLU,3.74*RHO1)
COVAL(EB10,U1,ONLYMS,-3.74)
COVAL(EB10,KE,ONLYMS,TKEIN)
COVAL(EB10,EP,ONLYMS,EPSIN)
COVAL(EB10,TEM1,ONLYMS,24.)
PATCH(EB11,EAST,NX,NX,1,NY,11,11,1,1)
COVAL(EB11,P1,FIXFLU,3.78*RHO1)
COVAL(EB11,U1,ONLYMS,-3.78)
COVAL(EB11,KE,ONLYMS,TKEIN)
COVAL(EB11,EP,ONLYMS,EPSIN)
COVAL(EB11,TEM1,ONLYMS,24.)
PATCH(EB12,EAST,NX,NX,1,NY,12,12,1,1)
COVAL(EB12,P1,FIXFLU,3.81*RHO1)
COVAL(EB12,U1,ONLYMS,-3.81)
COVAL(EB12,KE,ONLYMS,TKEIN)
COVAL(EB12,EP,ONLYMS,EPSIN)
COVAL(EB12,TEM1,ONLYMS,24.)
PATCH(EB13,EAST,NX,NX,1,NY,13,13,1,1)
COVAL(EB13,P1,FIXFLU,3.84*RHO1)
COVAL(EB13,U1,ONLYMS,-3.84)
COVAL(EB13,KE,ONLYMS,TKEIN)
COVAL(EB13,EP,ONLYMS,EPSIN)
COVAL(EB13,TEM1,ONLYMS,24.)
PATCH(EB14,EAST,NX,NX,1,NY,14,14,1,1)
COVAL(EB14,P1,FIXFLU,3.87*RHO1)
COVAL(EB14,U1,ONLYMS,-3.87)
COVAL(EB14,KE,ONLYMS,TKEIN)
COVAL(EB14,EP,ONLYMS,EPSIN)
COVAL(EB14,TEM1,ONLYMS,24.)
PATCH(EB15,EAST,NX,NX,1,NY,15,15,1,1)
COVAL(EB15,P1,FIXFLU,3.9*RHO1)
COVAL(EB15,U1,ONLYMS,-3.9)
COVAL(EB15,KE,ONLYMS,TKEIN)
COVAL(EB15,EP,ONLYMS,EPSIN)
COVAL(EB15,TEM1,ONLYMS,24.)
PATCH(EB16,EAST,NX,NX,1,NY,16,16,1,1)
COVAL(EB16,P1,FIXFLU,3.93*RHO1)
COVAL(EB16,U1,ONLYMS,-3.93)
COVAL(EB16,KE,ONLYMS,TKEIN)
COVAL(EB16,EP,ONLYMS,EPSIN)
COVAL(EB16,TEM1,ONLYMS,24.)
PATCH(EB17,EAST,NX,NX,1,NY,17,17,1,1)
COVAL(EB17,P1,FIXFLU,3.99*RHO1)
COVAL(EB17,U1,ONLYMS,-3.99)
```

```
COVAL(EB17,KE,ONLYMS,TKEIN)
COVAL(EB17,EP,ONLYMS,EPSIN)
COVAL(EB17,TEM1,ONLYMS,24.)
PATCH(EB18,EAST,NX,NX,1,NY,18,18,1,1)
COVAL(EB18,P1,FIXFLU,4.06*RHO1)
COVAL(EB18,U1,ONLYMS,-4.06)
COVAL(EB18,KE,ONLYMS,TKEIN)
COVAL(EB18,EP,ONLYMS,EPSIN)
COVAL(EB18,TEM1,ONLYMS,24.)
PATCH(EB19,EAST,NX,NX,1,NY,19,19,1,1)
COVAL(EB19,P1,FIXFLU,4.13*RHO1)
COVAL(EB19,U1,ONLYMS,-4.13)
COVAL(EB19,KE,ONLYMS,TKEIN)
COVAL(EB19,EP,ONLYMS,EPSIN)
COVAL(EB19,TEM1,ONLYMS,24.)
PATCH(EB20,EAST,NX,NX,1,NY,20,20,1,1)
COVAL(EB20,P1,FIXFLU,4.2*RHO1)
COVAL(EB20,U1,ONLYMS,-4.2)
COVAL(EB20,KE,ONLYMS,TKEIN)
COVAL(EB20,EP,ONLYMS,EPSIN)
COVAL(EB20,TEM1,ONLYMS,24.)
PATCH(EB21,EAST,NX,NX,1,NY,21,21,1,1)
COVAL(EB21,P1,FIXFLU,4.27*RHO1)
COVAL(EB21,U1,ONLYMS,-4.27)
COVAL(EB21,KE,ONLYMS,TKEIN)
COVAL(EB21,EP,ONLYMS,EPSIN)
COVAL(EB21,TEM1,ONLYMS,24.)
PATCH(EB22,EAST,NX,NX,1,NY,22,22,1,1)
COVAL(EB22,P1,FIXFLU,4.34*RHO1)
COVAL(EB22,U1,ONLYMS,-4.34)
COVAL(EB22,KE,ONLYMS,TKEIN)
COVAL(EB22,EP,ONLYMS,EPSIN)
COVAL(EB22,TEM1,ONLYMS,24.)
  ** South boundary
PATCH(SB,SOUTH,1,NX,1,1,1,NZ,1,1)
COVAL(SB,TEM1,0.0,24.)
  ** West boundary
PATCH(WB,WEST,1,1,1,NY,1,NZ,1,1)
COVAL(WB,P1,FIXP,0.0)
COVAL(WB,TEM1,0.0,24.)
COVAL(WB,KE,0.0,1.E-5)
COVAL(WB,EP,0.0,1.E-5)
  ** North boundary
PATCH(NB,NORTH,1,NX,NY,NY,1,NZ,1,1)
COVAL(NB,TEM1,0.0,24.)
  ** Upper boundary
PATCH(UPPER,HIGH,1,NX,1,NY,NZ,NZ,1,1)
COVAL(UPPER,TEM1,0.0,24.)
  ** Ground
PATCH(GROUND,LWALL,1,NX,1,NY,1,1,1,1)
COVAL(GROUND,U1,GRND2,0.0)
COVAL(GROUND,V1,GRND2,0.0)
COVAL(GROUND,TEM1,GRND2,24.)
COVAL(GROUND,KE,GRND2,GRND2)
COVAL(GROUND,EP,GRND2,GRND2)
```

```
  ** Stove
PATCH(STOVE,LOW,12,12,14,16,6,6,1,1)
COVAL(STOVE,TEM1,FIXFLU,4.*200.)
    GROUP 14. Downstream pressure for PARAB=.TRUE.
    GROUP 15. Termination of sweeps
       Total iteration number.
LSWEEP=3000
       Print the iteration number during runsat.
LSWEEP
    GROUP 16. Termination of iterations
    GROUP 17. Under-relaxation devices
       Determine false-time-step.
REAL(DTF, MINCELL, MAXV)
MINCELL=0.2
MAXV=4.34
DTF=1.*MINCELL/MAXV
DTF
       Under-relaxation factor for P1 is 0.8.
RELAX(P1,LINRLX,0.8)
RELAX(U1,FALSDT,DTF)
RELAX(V1,FALSDT,DTF)
RELAX(W1,FALSDT,DTF)
RELAX(TEM1,FALSDT,DTF)
RELAX(KE,FALSDT,DTF)
RELAX(EP,FALSDT,DTF)
    GROUP 18. Limits on variables or increments to them
    GROUP 19. Data communicated by satellite to GROUND
    GROUP 20. Preliminary print-out
       Echo printout of the q1 file in the result file.
ECHO=T
    GROUP 21. Print-out of variables
    GROUP 22. Spot-value print-out
IXMON=NX/2;IYMON=NY/2;IZMON=NZ
    GROUP 23. Field print-out and plot control
       Set print out of the residual in every 20 sweeps.
TSTSWP=LSWEEP/20
STOP
```

Appendix B

The q1 file of the basic model for northeast wind in Miami, Florida.

```
 TALK=F;RUN( 1, 1);VDU=X11-TERM
    GROUP 1. Run title and other preliminaries
       A title up to 40 characters can be used.
TEXT(MIAMI: NORTHEAST WIND)
       THE AIRFLOW PATTERN WITH NORTHEAST WIND IN MIAMI.
TITLE
       This model represents the northeast wind in Miami.  It will be
       used for further development of building form.
REAL(XLENGTH,YLENGTH,ZLENGTH,TKEIN,EPSIN)
       Assign values to the variables declared.
       The length, height and width of outdoor space are 25 m (82.5 ft),
       15 m (50 ft), 9 m (30 ft) respectively.
XLENGTH=25;YLENGTH=15;ZLENGTH=9
NX=45;NY=29;NZ=22
    GROUP 2. Transience; time-step specification
    GROUP 3. X-direction grid specification
       Total region number in the X-direction is 3.
       10 cells are in the first region, west of the building area.
       25 cells are in the second region, the building area.
       10 cells are in the third region, east of the building area.
       The dimension in X-direction is 10 m (33 ft), 5 m (16.5 ft),
       and 10 m (33 ft) in three regions.
       The cells are evenly divided in the second region.
       The dimensions of the cells become bigger when they are away
       from the building area.
NREGX=3
IREGX=1;GRDPWR(X,10,10,-1.5)
IREGX=2;GRDPWR(X,25,5,1)
IREGX=3;GRDPWR(X,10,10,1.5)
    GROUP 4. Y-direction grid specification
       Total region number in the Y-direction is 3.
       7 cells are in the first region, south of the building area.
       15 cells are in the second region, the building area.
       7 cells are in the third region, north of the building area.
       The dimension in Y-direction is 6 m (20 ft), 3 m (10 ft), and
       6 m (20 ft) in the second region.
       The cells are evenly divided in the building area.
       The dimensions of the cells become wider when they are away
       from the building area.
NREGY=3
IREGY=1;GRDPWR(Y,7,6,-1.5)
IREGY=2;GRDPWR(Y,15,3,1)
IREGY=3;GRDPWR(Y,7,6,1.5)
    GROUP 5. Z-direction grid specification
       Total region number in the Z-direction is 2.
       15 cells are in the first region, the atmosphere above the
       building area.
       7 cells are in the second region, the building area.
```

```
        The dimension in Z-direction is 3 m (10 ft) and 6 m (20 ft)
        in the two regions.
        The cells are evenly divided in the first region.
        The dimensions of the cells become wider when they are away
        from the building area.
NREGZ=2
IREGZ=1;GRDPWR(Z,15,3,1)
IREGZ=2;GRDPWR(Z,7,6,1.5)
    GROUP 6. Body-fitted coordinates or grid distortion
    GROUP 7. Variables stored, solved & named
        Solve the following variables:
        P1 - The first phase pressure.
        U1 - The first phase velocity in X-direction.
        V1 - The first phase velocity in Y-direction.
        W1 - The first phase velocity in Z-direction.
        TEM1 - The first phase temperature.
SOLVE(P1,U1,V1,W1,TEM1)
TURMOD(KEMODL)
    GROUP 8. Terms (in differential equations) & devices
    GROUP 9. Properties of the medium (or media)
        Set the laminar kinetic viscosity of air as 1.5E-5.
        Set the density of air as 1.2.
        Set the turbulent Prandtl number of air as 0.9.
        Set the laminar Prandtl number of air as 0.7.
ENUL=1.5E-5
RHO1=1.2
PRT(TEM1)=0.9
PRNDTL(TEM1)=0.7
    GROUP 10. Inter-phase-transfer processes and properties
    GROUP 11. Initialization of variable or porosity fields
        Set initial air velocity 3.22 m/s (634 ft/m).
        Set initial air temperature 24 C (75.4 F).
FIINIT(U1)=-3.22
FIINIT(V1)=-3.22
FIINIT(TEM1)=24.
PRESS0=1.0E5
TEMP0=273.15
  ** Calculation of KE
TKEIN=0.018*0.25*4.55*4.55
  ** Calculation of EP
EPSIN=TKEIN**1.5*0.1643/3.429E-3
FIINIT(KE)=TKEIN
FIINIT(EP)=EPSIN
  ** East wall
CONPOR(ELOWER,0.0,cell,-35,-35,-8,-22,-1,-5)
  ** Table
CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
    GROUP 12. Patchwise adjustment of terms
    GROUP 13. Boundary conditions and special sources
        Use Boussinesq approximation.
        BUOYA - gravity in X-direction.
        BUOYB - gravity in Y-direction.
        BUOYC - gravity in Z-direction.
        BUOYD - air expansion coefficient (=1/T in Kelvin).
        BUOYE - BUOYD * Reference temperature (in Celsius).
```

```
  ** Thermal buoyancy
BUOYC=-9.8; BUOYD=-1./300; BUOYE=-BUOYD*24.
       Define the space and time the boundary condition to be applied.
PATCH(BUOY,PHASEM,1,NX,1,NY,1,NZ,1,LSTEP)
       Apply the Buossinesq approximation (GRND3).
COVAL(BUOY,W1,FIXFLU,GRND3)
  ** East boundary
       Define the space and time the boundary condition to be applied.
PATCH(EB1,EAST,NX,NX,1,NY,1,1,1,1)
       Use non-slip boundary condition for U1 and V1.
COVAL(EB1,P1,FIXFLU,2.92*RHO1)
COVAL(EB1,U1,ONLYMS,-2.07)
COVAL(EB1,V1,ONLYMS,-2.07)
COVAL(EB1,KE,ONLYMS,TKEIN)
COVAL(EB1,EP,ONLYMS,EPSIN)
       Set air temperature to 24 C (75.4 F).
COVAL(EB1,TEM1,ONLYMS,24.)
       Set coastal boundary condition by changing U1.
PATCH(EB2,EAST,NX,NX,1,NY,2,2,1,1)
COVAL(EB2,P1,FIXFLU,3.26*RHO1)
COVAL(EB2,U1,ONLYMS,-2.31)
COVAL(EB2,V1,ONLYMS,-2.31)
COVAL(EB2,KE,ONLYMS,TKEIN)
COVAL(EB2,EP,ONLYMS,EPSIN)
COVAL(EB2,TEM1,ONLYMS,24.)
PATCH(EB3,EAST,NX,NX,1,NY,3,3,1,1)
COVAL(EB3,P1,FIXFLU,3.43*RHO1)
COVAL(EB3,U1,ONLYMS,-2.43)
COVAL(EB3,V1,ONLYMS,-2.43)
COVAL(EB3,KE,ONLYMS,TKEIN)
COVAL(EB3,EP,ONLYMS,EPSIN)
COVAL(EB3,TEM1,ONLYMS,24.)
PATCH(EB4,EAST,NX,NX,1,NY,4,4,1,1)
COVAL(EB4,P1,FIXFLU,3.55*RHO1)
COVAL(EB4,U1,ONLYMS,-2.51)
COVAL(EB4,V1,ONLYMS,-2.51)
COVAL(EB4,KE,ONLYMS,TKEIN)
COVAL(EB4,EP,ONLYMS,EPSIN)
COVAL(EB4,TEM1,ONLYMS,24.)
PATCH(EB5,EAST,NX,NX,1,NY,5,5,1,1)
COVAL(EB5,P1,FIXFLU,3.64*RHO1)
COVAL(EB5,U1,ONLYMS,-2.57)
COVAL(EB5,V1,ONLYMS,-2.57)
COVAL(EB5,KE,ONLYMS,TKEIN)
COVAL(EB5,EP,ONLYMS,EPSIN)
COVAL(EB5,TEM1,ONLYMS,24.)
PATCH(EB6,EAST,NX,NX,1,NY,6,6,1,1)
COVAL(EB6,P1,FIXFLU,3.71*RHO1)
COVAL(EB6,U1,ONLYMS,-2.63)
COVAL(EB6,V1,ONLYMS,-2.63)
COVAL(EB6,KE,ONLYMS,TKEIN)
COVAL(EB6,EP,ONLYMS,EPSIN)
COVAL(EB6,TEM1,ONLYMS,24.)
PATCH(EB7,EAST,NX,NX,1,NY,7,7,1,1)
COVAL(EB7,P1,FIXFLU,3.77*RHO1)
```

```
COVAL(EB7,U1,ONLYMS,-2.67)
COVAL(EB7,V1,ONLYMS,-2.67)
COVAL(EB7,KE,ONLYMS,TKEIN)
COVAL(EB7,EP,ONLYMS,EPSIN)
COVAL(EB7,TEM1,ONLYMS,24.)
PATCH(EB8,EAST,NX,NX,1,NY,8,8,1,1)
COVAL(EB8,P1,FIXFLU,3.83*RHO1)
COVAL(EB8,U1,ONLYMS,-2.71)
COVAL(EB8,V1,ONLYMS,-2.71)
COVAL(EB8,KE,ONLYMS,TKEIN)
COVAL(EB8,EP,ONLYMS,EPSIN)
COVAL(EB8,TEM1,ONLYMS,24.)
PATCH(EB9,EAST,NX,NX,1,NY,9,9,1,1)
COVAL(EB9,P1,FIXFLU,3.88*RHO1)
COVAL(EB9,U1,ONLYMS,-2.74)
COVAL(EB9,V1,ONLYMS,-2.74)
COVAL(EB9,KE,ONLYMS,TKEIN)
COVAL(EB9,EP,ONLYMS,EPSIN)
COVAL(EB9,TEM1,ONLYMS,24.)
PATCH(EB10,EAST,NX,NX,1,NY,10,10,1,1)
COVAL(EB10,P1,FIXFLU,3.92*RHO1)
COVAL(EB10,U1,ONLYMS,-2.77)
COVAL(EB10,V1,ONLYMS,-2.77)
COVAL(EB10,KE,ONLYMS,TKEIN)
COVAL(EB10,EP,ONLYMS,EPSIN)
COVAL(EB10,TEM1,ONLYMS,24.)
PATCH(EB11,EAST,NX,NX,1,NY,11,11,1,1)
COVAL(EB11,P1,FIXFLU,3.96*RHO1)
COVAL(EB11,U1,ONLYMS,-2.8)
COVAL(EB11,V1,ONLYMS,-2.8)
COVAL(EB11,KE,ONLYMS,TKEIN)
COVAL(EB11,EP,ONLYMS,EPSIN)
COVAL(EB11,TEM1,ONLYMS,24.)
PATCH(EB12,EAST,NX,NX,1,NY,12,12,1,1)
COVAL(EB12,P1,FIXFLU,4.0*RHO1)
COVAL(EB12,U1,ONLYMS,-2.83)
COVAL(EB12,V1,ONLYMS,-2.83)
COVAL(EB12,KE,ONLYMS,TKEIN)
COVAL(EB12,EP,ONLYMS,EPSIN)
COVAL(EB12,TEM1,ONLYMS,24.)
PATCH(EB13,EAST,NX,NX,1,NY,13,13,1,1)
COVAL(EB13,P1,FIXFLU,4.03*RHO1)
COVAL(EB13,U1,ONLYMS,-2.85)
COVAL(EB13,V1,ONLYMS,-2.85)
COVAL(EB13,KE,ONLYMS,TKEIN)
COVAL(EB13,EP,ONLYMS,EPSIN)
COVAL(EB13,TEM1,ONLYMS,24.)
PATCH(EB14,EAST,NX,NX,1,NY,14,14,1,1)
COVAL(EB14,P1,FIXFLU,4.06*RHO1)
COVAL(EB14,U1,ONLYMS,-2.87)
COVAL(EB14,V1,ONLYMS,-2.87)
COVAL(EB14,KE,ONLYMS,TKEIN)
COVAL(EB14,EP,ONLYMS,EPSIN)
COVAL(EB14,TEM1,ONLYMS,24.)
PATCH(EB15,EAST,NX,NX,1,NY,15,15,1,1)
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```
COVAL(EB15,P1,FIXFLU,4.09*RHO1)
COVAL(EB15,U1,ONLYMS,-2.89)
COVAL(EB15,V1,ONLYMS,-2.89)
COVAL(EB15,KE,ONLYMS,TKEIN)
COVAL(EB15,EP,ONLYMS,EPSIN)
COVAL(EB15,TEM1,ONLYMS,24.)
PATCH(EB16,EAST,NX,NX,1,NY,16,16,1,1)
COVAL(EB16,P1,FIXFLU,4.12*RHO1)
COVAL(EB16,U1,ONLYMS,-2.92)
COVAL(EB16,V1,ONLYMS,-2.92)
COVAL(EB16,KE,ONLYMS,TKEIN)
COVAL(EB16,EP,ONLYMS,EPSIN)
COVAL(EB16,TEM1,ONLYMS,24.)
PATCH(EB17,EAST,NX,NX,1,NY,17,17,1,1)
COVAL(EB17,P1,FIXFLU,4.18*RHO1)
COVAL(EB17,U1,ONLYMS,-2.96)
COVAL(EB17,V1,ONLYMS,-2.96)
COVAL(EB17,KE,ONLYMS,TKEIN)
COVAL(EB17,EP,ONLYMS,EPSIN)
COVAL(EB17,TEM1,ONLYMS,24.)
PATCH(EB18,EAST,NX,NX,1,NY,18,18,1,1)
COVAL(EB18,P1,FIXFLU,4.25*RHO1)
COVAL(EB18,U1,ONLYMS,-3.01)
COVAL(EB18,V1,ONLYMS,-3.01)
COVAL(EB18,KE,ONLYMS,TKEIN)
COVAL(EB18,EP,ONLYMS,EPSIN)
COVAL(EB18,TEM1,ONLYMS,24.)
PATCH(EB19,EAST,NX,NX,1,NY,19,19,1,1)
COVAL(EB19,P1,FIXFLU,4.33*RHO1)
COVAL(EB19,U1,ONLYMS,-3.06)
COVAL(EB19,V1,ONLYMS,-3.06)
COVAL(EB19,KE,ONLYMS,TKEIN)
COVAL(EB19,EP,ONLYMS,EPSIN)
COVAL(EB19,TEM1,ONLYMS,24.)
PATCH(EB20,EAST,NX,NX,1,NY,20,20,1,1)
COVAL(EB20,P1,FIXFLU,4.41*RHO1)
COVAL(EB20,U1,ONLYMS,-3.12)
COVAL(EB20,V1,ONLYMS,-3.12)
COVAL(EB20,KE,ONLYMS,TKEIN)
COVAL(EB20,EP,ONLYMS,EPSIN)
COVAL(EB20,TEM1,ONLYMS,24.)
PATCH(EB21,EAST,NX,NX,1,NY,21,21,1,1)
COVAL(EB21,P1,FIXFLU,4.48*RHO1)
COVAL(EB21,U1,ONLYMS,-3.17)
COVAL(EB21,V1,ONLYMS,-3.17)
COVAL(EB21,KE,ONLYMS,TKEIN)
COVAL(EB21,EP,ONLYMS,EPSIN)
COVAL(EB21,TEM1,ONLYMS,24.)
PATCH(EB22,EAST,NX,NX,1,NY,22,22,1,1)
COVAL(EB22,P1,FIXFLU,4.55*RHO1)
COVAL(EB22,U1,ONLYMS,-3.22)
COVAL(EB22,V1,ONLYMS,-3.22)
COVAL(EB22,KE,ONLYMS,TKEIN)
COVAL(EB22,EP,ONLYMS,EPSIN)
COVAL(EB22,TEM1,ONLYMS,24.)
```

```
  ** South boundary
PATCH(SB,SOUTH,1,NX,1,1,1,NZ,1,1)
COVAL(SB,P1,FIXP,0.0)
COVAL(SB,TEM1,0.0,24.)
COVAL(SB,KE,0.0,1.E-5)
COVAL(SB,EP,0.0,1.E-5)
  ** West boundary
PATCH(WB,WEST,1,1,1,NY,1,NZ,1,1)
COVAL(WB,P1,FIXP,0.0)
COVAL(WB,TEM1,0.0,24.)
COVAL(WB,KE,0.0,1.E-5)
COVAL(WB,EP,0.0,1.E-5)
  ** North boundary
PATCH(NB1,NORTH,1,NX,NY,NY,1,1,1,1)
COVAL(NB1,P1,FIXFLU,2.92*RHO1)
COVAL(NB1,U1,ONLYMS,-2.07)
COVAL(NB1,V1,ONLYMS,-2.07)
COVAL(NB1,KE,ONLYMS,TKEIN)
COVAL(NB1,EP,ONLYMS,EPSIN)
COVAL(NB1,TEM1,ONLYMS,24.)
PATCH(NB2,NORTH,1,NX,NY,NY,2,2,1,1)
COVAL(NB2,P1,FIXFLU,3.26*RHO1)
COVAL(NB2,U1,ONLYMS,-2.31)
COVAL(NB2,V1,ONLYMS,-2.31)
COVAL(NB2,KE,ONLYMS,TKEIN)
COVAL(NB2,EP,ONLYMS,EPSIN)
COVAL(NB2,TEM1,ONLYMS,24.)
PATCH(NB3,NORTH,1,NX,NY,NY,3,3,1,1)
COVAL(NB3,P1,FIXFLU,3.43*RHO1)
COVAL(NB3,U1,ONLYMS,-2.43)
COVAL(NB3,V1,ONLYMS,-2.43)
COVAL(NB3,KE,ONLYMS,TKEIN)
COVAL(NB3,EP,ONLYMS,EPSIN)
COVAL(NB3,TEM1,ONLYMS,24.)
PATCH(NB4,NORTH,1,NX,NY,NY,4,4,1,1)
COVAL(NB4,P1,FIXFLU,3.55*RHO1)
COVAL(NB4,U1,ONLYMS,-2.51)
COVAL(NB4,V1,ONLYMS,-2.51)
COVAL(NB4,KE,ONLYMS,TKEIN)
COVAL(NB4,EP,ONLYMS,EPSIN)
COVAL(NB4,TEM1,ONLYMS,24.)
PATCH(NB5,NORTH,1,NX,NY,NY,5,5,1,1)
COVAL(NB5,P1,FIXFLU,3.64*RHO1)
COVAL(NB5,U1,ONLYMS,-2.57)
COVAL(NB5,V1,ONLYMS,-2.57)
COVAL(NB5,KE,ONLYMS,TKEIN)
COVAL(NB5,EP,ONLYMS,EPSIN)
COVAL(NB5,TEM1,ONLYMS,24.)
PATCH(NB6,NORTH,1,NX,NY,NY,6,6,1,1)
COVAL(NB6,P1,FIXFLU,3.71*RHO1)
COVAL(NB6,U1,ONLYMS,-2.63)
COVAL(NB6,V1,ONLYMS,-2.63)
COVAL(NB6,KE,ONLYMS,TKEIN)
COVAL(NB6,EP,ONLYMS,EPSIN)
COVAL(NB6,TEM1,ONLYMS,24.)
```

```
PATCH(NB7,NORTH,1,NX,NY,NY,7,7,1,1)
COVAL(NB7,P1,FIXFLU,3.77*RHO1)
COVAL(NB7,U1,ONLYMS,-2.67)
COVAL(NB7,V1,ONLYMS,-2.67)
COVAL(NB7,KE,ONLYMS,TKEIN)
COVAL(NB7,EP,ONLYMS,EPSIN)
COVAL(NB7,TEM1,ONLYMS,24.)
PATCH(NB8,NORTH,1,NX,NY,NY,8,8,1,1)
COVAL(NB8,P1,FIXFLU,3.83*RHO1)
COVAL(NB8,U1,ONLYMS,-2.71)
COVAL(NB8,V1,ONLYMS,-2.71)
COVAL(NB8,KE,ONLYMS,TKEIN)
COVAL(NB8,EP,ONLYMS,EPSIN)
COVAL(NB8,TEM1,ONLYMS,24.)
PATCH(NB9,NORTH,1,NX,NY,NY,9,9,1,1)
COVAL(NB9,P1,FIXFLU,3.88*RHO1)
COVAL(NB9,U1,ONLYMS,-2.74)
COVAL(NB9,V1,ONLYMS,-2.74)
COVAL(NB9,KE,ONLYMS,TKEIN)
COVAL(NB9,EP,ONLYMS,EPSIN)
COVAL(NB9,TEM1,ONLYMS,24.)
PATCH(NB10,NORTH,1,NX,NY,NY,10,10,1,1)
COVAL(NB10,P1,FIXFLU,3.92*RHO1)
COVAL(NB10,U1,ONLYMS,-2.77)
COVAL(NB10,V1,ONLYMS,-2.77)
COVAL(NB10,KE,ONLYMS,TKEIN)
COVAL(NB10,EP,ONLYMS,EPSIN)
COVAL(NB10,TEM1,ONLYMS,24.)
PATCH(NB11,NORTH,1,NX,NY,NY,11,11,1,1)
COVAL(NB11,P1,FIXFLU,3.96*RHO1)
COVAL(NB11,U1,ONLYMS,-2.8)
COVAL(NB11,V1,ONLYMS,-2.8)
COVAL(NB11,KE,ONLYMS,TKEIN)
COVAL(NB11,EP,ONLYMS,EPSIN)
COVAL(NB11,TEM1,ONLYMS,24.)
PATCH(NB12,NORTH,1,NX,NY,NY,12,12,1,1)
COVAL(NB12,P1,FIXFLU,4.0*RHO1)
COVAL(NB12,U1,ONLYMS,-2.83)
COVAL(NB12,V1,ONLYMS,-2.83)
COVAL(NB12,KE,ONLYMS,TKEIN)
COVAL(NB12,EP,ONLYMS,EPSIN)
COVAL(NB12,TEM1,ONLYMS,24.)
PATCH(NB13,NORTH,1,NX,NY,NY,13,13,1,1)
COVAL(NB13,P1,FIXFLU,4.03*RHO1)
COVAL(NB13,U1,ONLYMS,-2.85)
COVAL(NB13,V1,ONLYMS,-2.85)
COVAL(NB13,KE,ONLYMS,TKEIN)
COVAL(NB13,EP,ONLYMS,EPSIN)
COVAL(NB13,TEM1,ONLYMS,24.)
PATCH(NB14,NORTH,1,NX,NY,NY,14,14,1,1)
COVAL(NB14,P1,FIXFLU,4.06*RHO1)
COVAL(NB14,U1,ONLYMS,-2.87)
COVAL(NB14,V1,ONLYMS,-2.87)
COVAL(NB14,KE,ONLYMS,TKEIN)
COVAL(NB14,EP,ONLYMS,EPSIN)
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```
COVAL(NB14,TEM1,ONLYMS,24.)
PATCH(NB15,NORTH,1,NX,NY,NY,15,15,1,1)
COVAL(NB15,P1,FIXFLU,4.09*RHO1)
COVAL(NB15,U1,ONLYMS,-2.89)
COVAL(NB15,V1,ONLYMS,-2.89)
COVAL(NB15,KE,ONLYMS,TKEIN)
COVAL(NB15,EP,ONLYMS,EPSIN)
COVAL(NB15,TEM1,ONLYMS,24.)
PATCH(NB16,NORTH,1,NX,NY,NY,16,16,1,1)
COVAL(NB16,P1,FIXFLU,4.12*RHO1)
COVAL(NB16,U1,ONLYMS,-2.92)
COVAL(NB16,V1,ONLYMS,-2.92)
COVAL(NB16,KE,ONLYMS,TKEIN)
COVAL(NB16,EP,ONLYMS,EPSIN)
COVAL(NB16,TEM1,ONLYMS,24.)
PATCH(NB17,NORTH,1,NX,NY,NY,17,17,1,1)
COVAL(NB17,P1,FIXFLU,4.18*RHO1)
COVAL(NB17,U1,ONLYMS,-2.96)
COVAL(NB17,V1,ONLYMS,-2.96)
COVAL(NB17,KE,ONLYMS,TKEIN)
COVAL(NB17,EP,ONLYMS,EPSIN)
COVAL(NB17,TEM1,ONLYMS,24.)
PATCH(NB18,NORTH,1,NX,NY,NY,18,18,1,1)
COVAL(NB18,P1,FIXFLU,4.25*RHO1)
COVAL(NB18,U1,ONLYMS,-3.01)
COVAL(NB18,V1,ONLYMS,-3.01)
COVAL(NB18,KE,ONLYMS,TKEIN)
COVAL(NB18,EP,ONLYMS,EPSIN)
COVAL(NB18,TEM1,ONLYMS,24.)
PATCH(NB19,NORTH,1,NX,NY,NY,19,19,1,1)
COVAL(NB19,P1,FIXFLU,4.33*RHO1)
COVAL(NB19,U1,ONLYMS,-3.06)
COVAL(NB19,V1,ONLYMS,-3.06)
COVAL(NB19,KE,ONLYMS,TKEIN)
COVAL(NB19,EP,ONLYMS,EPSIN)
COVAL(NB19,TEM1,ONLYMS,24.)
PATCH(NB20,NORTH,1,NX,NY,NY,20,20,1,1)
COVAL(NB20,P1,FIXFLU,4.41*RHO1)
COVAL(NB20,U1,ONLYMS,-3.12)
COVAL(NB20,V1,ONLYMS,-3.12)
COVAL(NB20,KE,ONLYMS,TKEIN)
COVAL(NB20,EP,ONLYMS,EPSIN)
COVAL(NB20,TEM1,ONLYMS,24.)
PATCH(NB21,NORTH,1,NX,NY,NY,21,21,1,1)
COVAL(NB21,P1,FIXFLU,4.48*RHO1)
COVAL(NB21,U1,ONLYMS,-3.17)
COVAL(NB21,V1,ONLYMS,-3.17)
COVAL(NB21,KE,ONLYMS,TKEIN)
COVAL(NB21,EP,ONLYMS,EPSIN)
COVAL(NB21,TEM1,ONLYMS,24.)
PATCH(NB22,NORTH,1,NX,NY,NY,22,22,1,1)
COVAL(NB22,P1,FIXFLU,4.55*RHO1)
COVAL(NB22,U1,ONLYMS,-3.22)
COVAL(NB22,V1,ONLYMS,-3.22)
COVAL(NB22,KE,ONLYMS,TKEIN)
```

```
COVAL(NB22,EP,ONLYMS,EPSIN)
COVAL(NB22,TEM1,ONLYMS,24.)
  ** Upper boundary
PATCH(UPPER,HIGH,1,NX,1,NY,NZ,NZ,1,1)
COVAL(UPPER,TEM1,0.0,24.)
  ** Ground
PATCH(GROUND,LWALL,1,NX,1,NY,1,1,1,1)
COVAL(GROUND,U1,GRND2,0.0)
COVAL(GROUND,V1,GRND2,0.0)
COVAL(GROUND,TEM1,GRND2,24.)
COVAL(GROUND,KE,GRND2,GRND2)
COVAL(GROUND,EP,GRND2,GRND2)
  ** Stove
PATCH(STOVE,LOW,12,12,14,16,6,6,1,1)
COVAL(STOVE,TEM1,FIXFLU,4.*200.)
    GROUP 14. Downstream pressure for PARAB=.TRUE.
    GROUP 15. Termination of sweeps
       Total iteration number.
LSWEEP=3000
       Print the iteration number during runsat.
LSWEEP
    GROUP 16. Termination of iterations
    GROUP 17. Under-relaxation devices
       Determine false-time-step.
REAL(DTF, MINCELL, MAXV)
MINCELL=0.2
MAXV=3.22
DTF=.1*MINCELL/MAXV
DTF
       Under-relaxation factor for P1 is 0.8.
RELAX(P1,LINRLX,0.8)
RELAX(U1,FALSDT,DTF)
RELAX(V1,FALSDT,DTF)
RELAX(W1,FALSDT,DTF)
RELAX(TEM1,FALSDT,DTF)
RELAX(KE,FALSDT,DTF)
RELAX(EP,FALSDT,DTF)
    GROUP 18. Limits on variables or increments to them
    GROUP 19. Data communicated by satellite to GROUND
    GROUP 20. Preliminary print-out
       Echo printout of the q1 file in the result file.
ECHO=T
    GROUP 21. Print-out of variables
    GROUP 22. Spot-value print-out
IXMON=NX/2;IYMON=NY/2;IZMON=NZ
    GROUP 23. Field print-out and plot control
       Set print out of the residual in every 20 sweeps.
TSTSWP=LSWEEP/20
STOP
```

Appendix C

The q1 file of the basic model for southeast wind in Miami, Florida.

```
 TALK=F;RUN( 1, 1);VDU=X11-TERM
    GROUP 1. Run title and other preliminaries
       A title up to 40 characters can be used.
TEXT(MIAMI: SOUTHEAST WIND)
       THE AIRFLOW PATTERN WITH SOUTHEAST WIND IN MIAMI.
TITLE
       This model represents the southeast wind in Miami.  It will be
       used for further development of building form.
REAL(XLENGTH,YLENGTH,ZLENGTH,TKEIN,EPSIN)
       Assign values to the variables declared.
       The length, height and width of outdoor space are 25 m (82.5
       ft), 15 m (50 ft), 9 m (30 ft) respectively.
XLENGTH=25;YLENGTH=15;ZLENGTH=9
NX=45;NY=29;NZ=22
    GROUP 2. Transience; time-step specification
    GROUP 3. X-direction grid specification
       Total region number in the X-direction is 3.
       10 cells are in the first region, west of the building area.
       25 cells are in the second region, the building area.
       10 cells are in the third region, east of the building area.
       The dimension in X-direction is 10 m (33 ft), 5 m (16.5 ft),
       and 10 m (33 ft) in three regions.
       The cells are evenly divided in the second region.
       The dimensions of the cells become bigger when they are away
       from the building area.
NREGX=3
IREGX=1;GRDPWR(X,10,10,-1.5)
IREGX=2;GRDPWR(X,25,5,1)
IREGX=3;GRDPWR(X,10,10,1.5)
    GROUP 4. Y-direction grid specification
       Total region number in the Y-direction is 3.
       7 cells are in the first region, south of the building area.
       15 cells are in the second region, the building area.
       7 cells are in the third region, north of the building area.
       The dimension in Y-direction is 6 m (20 ft), 3 m (10 ft), and
       6 m (20 ft) in the second region.
       The cells are evenly divided in the building area.
       The dimensions of the cells become wider when they are away
       from the building area.
NREGY=3
IREGY=1;GRDPWR(Y,7,6,-1.5)
IREGY=2;GRDPWR(Y,15,3,1)
IREGY=3;GRDPWR(Y,7,6,1.5)
    GROUP 5. Z-direction grid specification
       Total region number in the Z-direction is 2.
       15 cells are in the first region, the atmosphere above the
       building area.
       7 cells are in the second region, the building area.
```

```
       The dimension in Z-direction is 3 m (10 ft) and 6 m (20 ft)
       in the two regions.
       The cells are evenly divided in the first region.
       The dimensions of the cells become wider when they are away
       from the building area.
NREGZ=2
IREGZ=1;GRDPWR(Z,15,3,1)
IREGZ=2;GRDPWR(Z,7,6,1.5)
    GROUP 6. Body-fitted coordinates or grid distortion
    GROUP 7. Variables stored, solved & named
       Solve the following variables:
       P1 - The first phase pressure.
       U1 - The first phase velocity in X-direction.
       V1 - The first phase velocity in Y-direction.
       W1 - The first phase velocity in Z-direction.
       TEM1 - The first phase temperature.
SOLVE(P1,U1,V1,W1,TEM1)
TURMOD(KEMODL)
    GROUP 8. Terms (in differential equations) & devices
    GROUP 9. Properties of the medium (or media)
       Set the laminar kinetic viscosity of air as 1.5E-5.
       Set the density of air as 1.2.
       Set the turbulent Prandtl number of air as 0.9.
       Set the laminar Prandtl number of air as 0.7.
ENUL=1.5E-5
RHO1=1.2
PRT(TEM1)=0.9
PRNDTL(TEM1)=0.7
    GROUP 10. Inter-phase-transfer processes and properties
    GROUP 11. Initialization of variable or porosity fields
       Set initial air velocity 2.87 m/s (565 ft/m).
       Set initial air temperature 24 C (75.4 F).
FIINIT(U1)=-2.87
FIINIT(V1)=-2.87
FIINIT(TEM1)=24
PRESS0=1.0E5
TEMP0=273.15
  ** Calculation of KE
TKEIN=0.018*0.25*4.06*4.06
  ** Calculation of EP
EPSIN=TKEIN**1.5*0.1643/3.429E-3
FIINIT(KE)=TKEIN
FIINIT(EP)=EPSIN
  ** East wall
CONPOR(ELOWER,0.0,cell,-35,-35,-8,-22,-1,-5)
  ** Table
CONPOR(TABLE,0.0,cell,-12,-12,-14,-16,-1,-5)
    GROUP 12. Patchwise adjustment of terms
    GROUP 13. Boundary conditions and special sources
       Use Boussinesq approximation.
       BUOYA - gravity in X-direction.
       BUOYB - gravity in Y-direction.
       BUOYC - gravity in Z-direction.
       BUOYD - air expansion coefficient (=1/T in Kelvin).
       BUOYE - BUOYD * Reference temperature (in Celsius).
```

```
  ** Thermal buoyancy
BUOYC=-9.8; BUOYD=-1./300; BUOYE=-BUOYD*24.
       Define the space and time the boundary condition to be applied.
PATCH(BUOY,PHASEM,1,NX,1,NY,1,NZ,1,LSTEP)
       Apply the Buossinesq approximation (GRND3).
COVAL(BUOY,W1,FIXFLU,GRND3)
  ** East boundary
       Define the space and time the boundary condition to be applied.
PATCH(EB1,EAST,NX,NX,1,NY,1,1,1,1)
       Use non-slip boundary condition for U1 and V1.
COVAL(EB1,P1,FIXFLU,2.61*RHO1)
COVAL(EB1,U1,ONLYMS,-1.84)
COVAL(EB1,V1,ONLYMS,1.84)
COVAL(EB1,KE,ONLYMS,TKEIN)
COVAL(EB1,EP,ONLYMS,EPSIN)
       Set air temperature to 24 C (75.4 F).
COVAL(EB1,TEM1,ONLYMS,24.)
       Set coastal boundary condition by changing U1.
PATCH(EB2,EAST,NX,NX,1,NY,2,2,1,1)
COVAL(EB2,P1,FIXFLU,2.91*RHO1)
COVAL(EB2,U1,ONLYMS,-2.06)
COVAL(EB2,V1,ONLYMS,2.06)
COVAL(EB2,KE,ONLYMS,TKEIN)
COVAL(EB2,EP,ONLYMS,EPSIN)
COVAL(EB2,TEM1,ONLYMS,24.)
PATCH(EB3,EAST,NX,NX,1,NY,3,3,1,1)
COVAL(EB3,P1,FIXFLU,3.06*RHO1)
COVAL(EB3,U1,ONLYMS,-2.17)
COVAL(EB3,V1,ONLYMS,2.17)
COVAL(EB3,KE,ONLYMS,TKEIN)
COVAL(EB3,EP,ONLYMS,EPSIN)
COVAL(EB3,TEM1,ONLYMS,24.)
PATCH(EB4,EAST,NX,NX,1,NY,4,4,1,1)
COVAL(EB4,P1,FIXFLU,3.17*RHO1)
COVAL(EB4,U1,ONLYMS,-2.24)
COVAL(EB4,V1,ONLYMS,2.24)
COVAL(EB4,KE,ONLYMS,TKEIN)
COVAL(EB4,EP,ONLYMS,EPSIN)
COVAL(EB4,TEM1,ONLYMS,24.)
PATCH(EB5,EAST,NX,NX,1,NY,5,5,1,1)
COVAL(EB5,P1,FIXFLU,3.25*RHO1)
COVAL(EB5,U1,ONLYMS,-2.30)
COVAL(EB5,V1,ONLYMS,2.30)
COVAL(EB5,KE,ONLYMS,TKEIN)
COVAL(EB5,EP,ONLYMS,EPSIN)
COVAL(EB5,TEM1,ONLYMS,24.)
PATCH(EB6,EAST,NX,NX,1,NY,6,6,1,1)
COVAL(EB6,P1,FIXFLU,3.31*RHO1)
COVAL(EB6,U1,ONLYMS,-2.34)
COVAL(EB6,V1,ONLYMS,2.34)
COVAL(EB6,KE,ONLYMS,TKEIN)
COVAL(EB6,EP,ONLYMS,EPSIN)
COVAL(EB6,TEM1,ONLYMS,24.)
PATCH(EB7,EAST,NX,NX,1,NY,7,7,1,1)
COVAL(EB7,P1,FIXFLU,3.37*RHO1)
```

```
COVAL(EB7,U1,ONLYMS,-2.38)
COVAL(EB7,V1,ONLYMS,2.38)
COVAL(EB7,KE,ONLYMS,TKEIN)
COVAL(EB7,EP,ONLYMS,EPSIN)
COVAL(EB7,TEM1,ONLYMS,24.)
PATCH(EB8,EAST,NX,NX,1,NY,8,8,1,1)
COVAL(EB8,P1,FIXFLU,3.42*RHO1)
COVAL(EB8,U1,ONLYMS,-2.42)
COVAL(EB8,V1,ONLYMS,2.42)
COVAL(EB8,KE,ONLYMS,TKEIN)
COVAL(EB8,EP,ONLYMS,EPSIN)
COVAL(EB8,TEM1,ONLYMS,24.)
PATCH(EB9,EAST,NX,NX,1,NY,9,9,1,1)
COVAL(EB9,P1,FIXFLU,3.46*RHO1)
COVAL(EB9,U1,ONLYMS,-2.45)
COVAL(EB9,V1,ONLYMS,2.45)
COVAL(EB9,KE,ONLYMS,TKEIN)
COVAL(EB9,EP,ONLYMS,EPSIN)
COVAL(EB9,TEM1,ONLYMS,24.)
PATCH(EB10,EAST,NX,NX,1,NY,10,10,1,1)
COVAL(EB10,P1,FIXFLU,3.50*RHO1)
COVAL(EB10,U1,ONLYMS,-2.48)
COVAL(EB10,V1,ONLYMS,2.48)
COVAL(EB10,KE,ONLYMS,TKEIN)
COVAL(EB10,EP,ONLYMS,EPSIN)
COVAL(EB10,TEM1,ONLYMS,24.)
PATCH(EB11,EAST,NX,NX,1,NY,11,11,1,1)
COVAL(EB11,P1,FIXFLU,3.54*RHO1)
COVAL(EB11,U1,ONLYMS,-2.5)
COVAL(EB11,V1,ONLYMS,2.5)
COVAL(EB11,KE,ONLYMS,TKEIN)
COVAL(EB11,EP,ONLYMS,EPSIN)
COVAL(EB11,TEM1,ONLYMS,24.)
PATCH(EB12,EAST,NX,NX,1,NY,12,12,1,1)
COVAL(EB12,P1,FIXFLU,3.57*RHO1)
COVAL(EB12,U1,ONLYMS,-2.52)
COVAL(EB12,V1,ONLYMS,2.52)
COVAL(EB12,KE,ONLYMS,TKEIN)
COVAL(EB12,EP,ONLYMS,EPSIN)
COVAL(EB12,TEM1,ONLYMS,24.)
PATCH(EB13,EAST,NX,NX,1,NY,13,13,1,1)
COVAL(EB13,P1,FIXFLU,3.60*RHO1)
COVAL(EB13,U1,ONLYMS,-2.54)
COVAL(EB13,V1,ONLYMS,2.54)
COVAL(EB13,KE,ONLYMS,TKEIN)
COVAL(EB13,EP,ONLYMS,EPSIN)
COVAL(EB13,TEM1,ONLYMS,24.)
PATCH(EB14,EAST,NX,NX,1,NY,14,14,1,1)
COVAL(EB14,P1,FIXFLU,3.63*RHO1)
COVAL(EB14,U1,ONLYMS,-2.56)
COVAL(EB14,V1,ONLYMS,2.56)
COVAL(EB14,KE,ONLYMS,TKEIN)
COVAL(EB14,EP,ONLYMS,EPSIN)
COVAL(EB14,TEM1,ONLYMS,24.)
PATCH(EB15,EAST,NX,NX,1,NY,15,15,1,1)
```

```
COVAL(EB15,P1,FIXFLU,3.65*RHO1)
COVAL(EB15,U1,ONLYMS,-2.58)
COVAL(EB15,V1,ONLYMS,2.58)
COVAL(EB15,KE,ONLYMS,TKEIN)
COVAL(EB15,EP,ONLYMS,EPSIN)
COVAL(EB15,TEM1,ONLYMS,24.)
PATCH(EB16,EAST,NX,NX,1,NY,16,16,1,1)
COVAL(EB16,P1,FIXFLU,3.68*RHO1)
COVAL(EB16,U1,ONLYMS,-2.60)
COVAL(EB16,V1,ONLYMS,2.60)
COVAL(EB16,KE,ONLYMS,TKEIN)
COVAL(EB16,EP,ONLYMS,EPSIN)
COVAL(EB16,TEM1,ONLYMS,24.)
PATCH(EB17,EAST,NX,NX,1,NY,17,17,1,1)
COVAL(EB17,P1,FIXFLU,3.73*RHO1)
COVAL(EB17,U1,ONLYMS,-2.64)
COVAL(EB17,V1,ONLYMS,2.64)
COVAL(EB17,KE,ONLYMS,TKEIN)
COVAL(EB17,EP,ONLYMS,EPSIN)
COVAL(EB17,TEM1,ONLYMS,24.)
PATCH(EB18,EAST,NX,NX,1,NY,18,18,1,1)
COVAL(EB18,P1,FIXFLU,3.80*RHO1)
COVAL(EB18,U1,ONLYMS,-2.69)
COVAL(EB18,V1,ONLYMS,2.69)
COVAL(EB18,KE,ONLYMS,TKEIN)
COVAL(EB18,EP,ONLYMS,EPSIN)
COVAL(EB18,TEM1,ONLYMS,24.)
PATCH(EB19,EAST,NX,NX,1,NY,19,19,1,1)
COVAL(EB19,P1,FIXFLU,3.87*RHO1)
COVAL(EB19,U1,ONLYMS,-2.73)
COVAL(EB19,V1,ONLYMS,2.73)
COVAL(EB19,KE,ONLYMS,TKEIN)
COVAL(EB19,EP,ONLYMS,EPSIN)
COVAL(EB19,TEM1,ONLYMS,24.)
PATCH(EB20,EAST,NX,NX,1,NY,20,20,1,1)
COVAL(EB20,P1,FIXFLU,3.93*RHO1)
COVAL(EB20,U1,ONLYMS,-2.78)
COVAL(EB20,V1,ONLYMS,2.78)
COVAL(EB20,KE,ONLYMS,TKEIN)
COVAL(EB20,EP,ONLYMS,EPSIN)
COVAL(EB20,TEM1,ONLYMS,24.)
PATCH(EB21,EAST,NX,NX,1,NY,21,21,1,1)
COVAL(EB21,P1,FIXFLU,4.00*RHO1)
COVAL(EB21,U1,ONLYMS,-2.83)
COVAL(EB21,V1,ONLYMS,2.83)
COVAL(EB21,KE,ONLYMS,TKEIN)
COVAL(EB21,EP,ONLYMS,EPSIN)
COVAL(EB21,TEM1,ONLYMS,24.)
PATCH(EB22,EAST,NX,NX,1,NY,22,22,1,1)
COVAL(EB22,P1,FIXFLU,4.06*RHO1)
COVAL(EB22,U1,ONLYMS,-2.87)
COVAL(EB22,V1,ONLYMS,2.87)
COVAL(EB22,KE,ONLYMS,TKEIN)
COVAL(EB22,EP,ONLYMS,EPSIN)
COVAL(EB22,TEM1,ONLYMS,24.)
```

```
  ** North boundary
PATCH(NB,NORTH,1,NX,NY,NY,1,NZ,1,1)
COVAL(NB,P1,FIXP,0.0)
COVAL(NB,TEM1,0.0,24.)
COVAL(NB,KE,0.0,1.E-5)
COVAL(NB,EP,0.0,1.E-5)
  ** West boundary
PATCH(WB,WEST,1,1,1,NY,1,NZ,1,1)
COVAL(WB,P1,FIXP,0.0)
COVAL(WB,TEM1,0.0,24.)
COVAL(WB,KE,0.0,1.E-5)
COVAL(WB,EP,0.0,1.E-5)
  ** South boundary
PATCH(SB1,SOUTH,1,NX,1,1,1,1,1,1)
COVAL(SB1,P1,FIXFLU,2.61*RHO1)
COVAL(SB1,U1,ONLYMS,-1.84)
COVAL(SB1,V1,ONLYMS,1.84)
COVAL(SB1,KE,ONLYMS,TKEIN)
COVAL(SB1,EP,ONLYMS,EPSIN)
COVAL(SB1,TEM1,ONLYMS,24.)
PATCH(SB2,SOUTH,1,NX,1,1,2,2,1,1)
COVAL(SB2,P1,FIXFLU,2.91*RHO1)
COVAL(SB2,U1,ONLYMS,-2.06)
COVAL(SB2,V1,ONLYMS,2.06)
COVAL(SB2,KE,ONLYMS,TKEIN)
COVAL(SB2,EP,ONLYMS,EPSIN)
COVAL(SB2,TEM1,ONLYMS,24.)
PATCH(SB3,SOUTH,1,NX,1,1,3,3,1,1)
COVAL(SB3,P1,FIXFLU,3.06*RHO1)
COVAL(SB3,U1,ONLYMS,-2.17)
COVAL(SB3,V1,ONLYMS,2.17)
COVAL(SB3,KE,ONLYMS,TKEIN)
COVAL(SB3,EP,ONLYMS,EPSIN)
COVAL(SB3,TEM1,ONLYMS,24.)
PATCH(SB4,SOUTH,1,NX,1,1,4,4,1,1)
COVAL(SB4,P1,FIXFLU,3.17*RHO1)
COVAL(SB4,U1,ONLYMS,-2.24)
COVAL(SB4,V1,ONLYMS,2.24)
COVAL(SB4,KE,ONLYMS,TKEIN)
COVAL(SB4,EP,ONLYMS,EPSIN)
COVAL(SB4,TEM1,ONLYMS,24.)
PATCH(SB5,SOUTH,1,NX,1,1,5,5,1,1)
COVAL(SB5,P1,FIXFLU,3.25*RHO1)
COVAL(SB5,U1,ONLYMS,-2.30)
COVAL(SB5,V1,ONLYMS,2.30)
COVAL(SB5,KE,ONLYMS,TKEIN)
COVAL(SB5,EP,ONLYMS,EPSIN)
COVAL(SB5,TEM1,ONLYMS,24.)
PATCH(SB6,SOUTH,1,NX,1,1,6,6,1,1)
COVAL(SB6,P1,FIXFLU,3.31*RHO1)
COVAL(SB6,U1,ONLYMS,-2.34)
COVAL(SB6,V1,ONLYMS,2.34)
COVAL(SB6,KE,ONLYMS,TKEIN)
COVAL(SB6,EP,ONLYMS,EPSIN)
COVAL(SB6,TEM1,ONLYMS,24.)
```

```
PATCH(SB7,SOUTH,1,NX,1,1,7,7,1,1)
COVAL(SB7,P1,FIXFLU,3.37*RHO1)
COVAL(SB7,U1,ONLYMS,-2.38)
COVAL(SB7,V1,ONLYMS,2.38)
COVAL(SB7,KE,ONLYMS,TKEIN)
COVAL(SB7,EP,ONLYMS,EPSIN)
COVAL(SB7,TEM1,ONLYMS,24.)
PATCH(SB8,SOUTH,1,NX,1,1,8,8,1,1)
COVAL(SB8,P1,FIXFLU,3.42*RHO1)
COVAL(SB8,U1,ONLYMS,-2.42)
COVAL(SB8,V1,ONLYMS,2.42)
COVAL(SB8,KE,ONLYMS,TKEIN)
COVAL(SB8,EP,ONLYMS,EPSIN)
COVAL(SB8,TEM1,ONLYMS,24.)
PATCH(SB9,SOUTH,1,NX,1,1,9,9,1,1)
COVAL(SB9,P1,FIXFLU,3.46*RHO1)
COVAL(SB9,U1,ONLYMS,-2.45)
COVAL(SB9,V1,ONLYMS,2.45)
COVAL(SB9,KE,ONLYMS,TKEIN)
COVAL(SB9,EP,ONLYMS,EPSIN)
COVAL(SB9,TEM1,ONLYMS,24.)
PATCH(SB10,SOUTH,1,NX,1,1,10,10,1,1)
COVAL(SB10,P1,FIXFLU,3.50*RHO1)
COVAL(SB10,U1,ONLYMS,-2.48)
COVAL(SB10,V1,ONLYMS,2.48)
COVAL(SB10,KE,ONLYMS,TKEIN)
COVAL(SB10,EP,ONLYMS,EPSIN)
COVAL(SB10,TEM1,ONLYMS,24.)
PATCH(SB11,SOUTH,1,NX,1,1,11,11,1,1)
COVAL(SB11,P1,FIXFLU,3.54*RHO1)
COVAL(SB11,U1,ONLYMS,-2.5)
COVAL(SB11,V1,ONLYMS,2.5)
COVAL(SB11,KE,ONLYMS,TKEIN)
COVAL(SB11,EP,ONLYMS,EPSIN)
COVAL(SB11,TEM1,ONLYMS,24.)
PATCH(SB12,SOUTH,1,NX,1,1,12,12,1,1)
COVAL(SB12,P1,FIXFLU,3.57*RHO1)
COVAL(SB12,U1,ONLYMS,-2.52)
COVAL(SB12,V1,ONLYMS,2.52)
COVAL(SB12,KE,ONLYMS,TKEIN)
COVAL(SB12,EP,ONLYMS,EPSIN)
COVAL(SB12,TEM1,ONLYMS,24.)
PATCH(SB13,SOUTH,1,NX,1,1,13,13,1,1)
COVAL(SB13,P1,FIXFLU,3.60*RHO1)
COVAL(SB13,U1,ONLYMS,-2.54)
COVAL(SB13,V1,ONLYMS,2.54)
COVAL(SB13,KE,ONLYMS,TKEIN)
COVAL(SB13,EP,ONLYMS,EPSIN)
COVAL(SB13,TEM1,ONLYMS,24.)
PATCH(SB14,SOUTH,1,NX,1,1,14,14,1,1)
COVAL(SB14,P1,FIXFLU,3.63*RHO1)
COVAL(SB14,U1,ONLYMS,-2.56)
COVAL(SB14,V1,ONLYMS,2.56)
COVAL(SB14,KE,ONLYMS,TKEIN)
COVAL(SB14,EP,ONLYMS,EPSIN)
```

```
COVAL(SB14,TEM1,ONLYMS,24.)
PATCH(SB15,SOUTH,1,NX,1,1,15,15,1,1)
COVAL(SB15,P1,FIXFLU,3.65*RHO1)
COVAL(SB15,U1,ONLYMS,-2.58)
COVAL(SB15,V1,ONLYMS,2.58)
COVAL(SB15,KE,ONLYMS,TKEIN)
COVAL(SB15,EP,ONLYMS,EPSIN)
COVAL(SB15,TEM1,ONLYMS,24.)
PATCH(SB16,SOUTH,1,NX,1,1,16,16,1,1)
COVAL(SB16,P1,FIXFLU,3.68*RHO1)
COVAL(SB16,U1,ONLYMS,-2.60)
COVAL(SB16,V1,ONLYMS,2.60)
COVAL(SB16,KE,ONLYMS,TKEIN)
COVAL(SB16,EP,ONLYMS,EPSIN)
COVAL(SB16,TEM1,ONLYMS,24.)
PATCH(SB17,SOUTH,1,NX,1,1,17,17,1,1)
COVAL(SB17,P1,FIXFLU,3.73*RHO1)
COVAL(SB17,U1,ONLYMS,-2.64)
COVAL(SB17,V1,ONLYMS,2.64)
COVAL(SB17,KE,ONLYMS,TKEIN)
COVAL(SB17,EP,ONLYMS,EPSIN)
COVAL(SB17,TEM1,ONLYMS,24.)
PATCH(SB18,SOUTH,1,NX,1,1,18,18,1,1)
COVAL(SB18,P1,FIXFLU,3.80*RHO1)
COVAL(SB18,U1,ONLYMS,-2.69)
COVAL(SB18,V1,ONLYMS,2.69)
COVAL(SB18,KE,ONLYMS,TKEIN)
COVAL(SB18,EP,ONLYMS,EPSIN)
COVAL(SB18,TEM1,ONLYMS,24.)
PATCH(SB19,SOUTH,1,NX,1,1,19,19,1,1)
COVAL(SB19,P1,FIXFLU,3.87*RHO1)
COVAL(SB19,U1,ONLYMS,-2.73)
COVAL(SB19,V1,ONLYMS,2.73)
COVAL(SB19,KE,ONLYMS,TKEIN)
COVAL(SB19,EP,ONLYMS,EPSIN)
COVAL(SB19,TEM1,ONLYMS,24.)
PATCH(SB20,SOUTH,1,NX,1,1,20,20,1,1)
COVAL(SB20,P1,FIXFLU,3.93*RHO1)
COVAL(SB20,U1,ONLYMS,-2.78)
COVAL(SB20,V1,ONLYMS,2.78)
COVAL(SB20,KE,ONLYMS,TKEIN)
COVAL(SB20,EP,ONLYMS,EPSIN)
COVAL(SB20,TEM1,ONLYMS,24.)
PATCH(SB21,SOUTH,1,NX,1,1,21,21,1,1)
COVAL(SB21,P1,FIXFLU,4.00*RHO1)
COVAL(SB21,U1,ONLYMS,-2.83)
COVAL(SB21,V1,ONLYMS,2.83)
COVAL(SB21,KE,ONLYMS,TKEIN)
COVAL(SB21,EP,ONLYMS,EPSIN)
COVAL(SB21,TEM1,ONLYMS,24.)
PATCH(SB22,SOUTH,1,NX,1,1,22,22,1,1)
COVAL(SB22,P1,FIXFLU,4.06*RHO1)
COVAL(SB22,U1,ONLYMS,-2.87)
COVAL(SB22,V1,ONLYMS,2.87)
COVAL(SB22,KE,ONLYMS,TKEIN)
```

```
COVAL(SB22,EP,ONLYMS,EPSIN)
COVAL(SB22,TEM1,ONLYMS,24.)
  ** Upper boundary
PATCH(UPPER,HIGH,1,NX,1,NY,NZ,NZ,1,1)
COVAL(UPPER,TEM1,0.0,24.)
  ** Ground
PATCH(GROUND,LWALL,1,NX,1,NY,1,1,1,1)
COVAL(GROUND,U1,GRND2,0.0)
COVAL(GROUND,V1,GRND2,0.0)
COVAL(GROUND,TEM1,GRND2,24.)
COVAL(GROUND,KE,GRND2,GRND2)
COVAL(GROUND,EP,GRND2,GRND2)
  ** Stove
PATCH(STOVE,LOW,12,12,14,16,6,6,1,1)
COVAL(STOVE,TEM1,FIXFLU,4.*200.)
    GROUP 14. Downstream pressure for PARAB=.TRUE.
    GROUP 15. Termination of sweeps
       Total iteration number.
LSWEEP=3000
       Print the iteration number during runsat.
LSWEEP
    GROUP 16. Termination of iterations
    GROUP 17. Under-relaxation devices
       Determine false-time-step
REAL(DTF, MINCELL, MAXV)
MINCELL=0.2
MAXV=2.87
DTF=.1*MINCELL/MAXV
DTF
       Under-relaxation factor for P1 is 0.8.
RELAX(P1,LINRLX,0.8)
RELAX(U1,FALSDT,DTF)
RELAX(V1,FALSDT,DTF)
RELAX(W1,FALSDT,DTF)
RELAX(TEM1,FALSDT,DTF)
RELAX(KE,FALSDT,DTF)
RELAX(EP,FALSDT,DTF)
    GROUP 18. Limits on variables or increments to them
    GROUP 19. Data communicated by satellite to GROUND
    GROUP 20. Preliminary print-out
       Echo printout of the q1 file in the result file.
ECHO=T
    GROUP 21. Print-out of variables
    GROUP 22. Spot-value print-out
IXMON=NX/2;IYMON=NY/2;IZMON=NZ
    GROUP 23. Field print-out and plot control
       Set print out of the residual in every 20 sweeps.
TSTSWP=LSWEEP/20
STOP
```

Appendix D

The q1 file for the Visitors Sports Pavilion in Washington, DC with forced convection.

```
 TALK=F;RUN( 1, 1);VDU=X11-TERM
    GROUP 1. Run title and other preliminaries
       A title up to 40 characters can be used.
TEXT(PAVILION: WIND-DRIVEN CONVECTION)
       A section of the pavilion in Washington, DC.
TITLE
       This model represents the natural ventilation in the Pavilion in
       Washington, DC when south wind exists.
REAL(XLENGTH,YLENGTH,TKEIN,EPSIN)
       Assign values to the variables declared.
       The width and height of outdoor space are 45 m (150 ft) and 20 m
       (66 ft) respectively.
XLENGTH=45;YLENGTH=20
NX=85;NY=48
    GROUP 2. Transience; time-step specification
    GROUP 3. X-direction grid specification
       Total region number in the X-direction is 3.
       20 cells are in the first region, the south outdoor space.
       45 cells are in the second region, the building area.
       20 cells are in the third region, the north outdoor space.
       The dimension in X-direction is 18 m (60 ft), 9 m( 30 ft), and 18
       m (60 ft) in the regions.
       The cells are evenly divided in the building area.
       The dimensions of the cells become bigger when they are away from
       the building area.
NREGX=3
IREGX=1;GRDPWR(X,20,18,-1.5)
IREGX=2;GRDPWR(X,45,9,1)
IREGX=3;GRDPWR(X,20,18,1.5)
    GROUP 4. Y-direction grid specification
       Total region number in the Y-direction is 2.
       33 cells are in the first region, the building area.
       15 cells are in the second region, the atmosphere above the
       building area.
       The dimension in Y-direction is 6.6 m (22 ft) and 13.4 m (43 ft)
       the regions.
       The cells are evenly divided in the building area.
       The dimensions of the cells become wider when they are away
       from the building area.
NREGY=2
IREGY=1;GRDPWR(Y,33,6.6,1)
IREGY=2;GRDPWR(Y,15,13.4,1.5)
    GROUP 5. Z-direction grid specification
    GROUP 6. Body-fitted coordinates or grid distortion
    GROUP 7. Variables stored, solved & named
```

```
        Solve the following variables:
        P1 - The first phase pressure.
        U1 - The first phase velocity in X-direction.
        V1 - The first phase velocity in Y-direction.
        W1 - The first phase velocity in Z-direction.
        TEM1 - The first phase temperature.
SOLVE(P1,U1,V1,TEM1)
TURMOD(KEMODL)
    GROUP 8. Terms (in differential equations) & devices
    GROUP 9. Properties of the medium (or media)
        Set laminar kinetic viscosity of air as 1.5E-5.
        Set density of air as 1.2.
ENUL=1.5E-5
RHO1=1.2
    GROUP 10. Inter-phase-transfer processes and properties
    GROUP 11. Initialization of variable or porosity fields
        Set initial air velocity 1.5 m/s (295 f/m).
        Set initial air temperature 23 C (73.4 F).
FIINIT(U1)=1.5
FIINIT(TEM1)=23.
PRESS0=1.0E5
TEMP0=273.15
PRT(TEM1)=0.9;PRNDTL(TEM1)=0.7
  ** Calculation of KE
TKEIN=0.018*0.25*1.5*1.5
  ** Calculation of EP
EPSIN=TKEIN**1.5*0.1643/3.429E-3
FIINIT(KE)=TKEIN
FIINIT(EP)=EPSIN
  ** Thermal walls
        Define the geometry of walls.
CONPOR(TW1,0.0,cell,-58,-58,-10,-19,-1,-1)
CONPOR(TW2,0.0,cell,-65,-65,-1,-16,-1,-1)
  ** Roof
        Define the geometry of roof.
CONPOR(ROOF1,0.0,cell,-59,-59,-20,-20,-1,-1)
CONPOR(ROOF2,0.0,cell,-60,-60,-21,-21,-1,-1)
CONPOR(ROOF3,0.0,cell,-61,-61,-22,-22,-1,-1)
CONPOR(ROOF4,0.0,cell,-62,-62,-23,-23,-1,-1)
CONPOR(ROOF5,0.0,cell,-63,-63,-24,-24,-1,-1)
CONPOR(ROOF6,0.0,cell,-64,-64,-25,-25,-1,-1)
CONPOR(ROOF7,0.0,cell,-65,-67,-26,-26,-1,-1)
CONPOR(ROOF8,0.0,cell,-65,-67,-17,-17,-1,-1)
  ** Mezzanine
        Define the geometry of mezzanine.
CONPOR(MEZZ,0.0,cell,-50,-57,-10,-10,-1,-1)
  ** Opening
        Define the geometry of south facing opening.
CONPOR(OPEN1,0.0,cell,-21,-25,-9,-9,-1,-1)
CONPOR(OPEN2,0.0,cell,-23,-25,-8,-8,-1,-1)
CONPOR(OPEN3,0.0,cell,-25,-25,-7,-7,-1,-1)
  ** Canopy
        Define the geometry of canopy.
CONPOR(CANOPY1,0.0,cell,-25,-26,-14,-14,-1,-1)
CONPOR(CANOPY2,0.0,cell,-26,-26,-15,-15,-1,-1)
```

```
CONPOR(CANOPY3,0.0,cell,-27,-27,-16,-17,-1,-1)
CONPOR(CANOPY4,0.0,cell,-28,-29,-18,-18,-1,-1)
CONPOR(CANOPY5,0.0,cell,-29,-30,-19,-19,-1,-1)
CONPOR(CANOPY6,0.0,cell,-30,-31,-20,-20,-1,-1)
CONPOR(CANOPY7,0.0,cell,-31,-32,-21,-21,-1,-1)
CONPOR(CANOPY8,0.0,cell,-32,-34,-22,-22,-1,-1)
CONPOR(CANOPY9,0.0,cell,-34,-36,-23,-23,-1,-1)
CONPOR(CANOPY10,0.0,cell,-36,-38,-24,-24,-1,-1)
CONPOR(CANOPY11,0.0,cell,-38,-40,-25,-25,-1,-1)
CONPOR(CANOPY12,0.0,cell,-40,-42,-26,-26,-1,-1)
CONPOR(CANOPY13,0.0,cell,-43,-45,-27,-27,-1,-1)
CONPOR(CANOPY14,0.0,cell,-45,-48,-28,-28,-1,-1)
CONPOR(CANOPY15,0.0,cell,-49,-52,-29,-29,-1,-1)
CONPOR(CANOPY16,0.0,cell,-53,-57,-30,-30,-1,-1)
CONPOR(CANOPY17,0.0,cell,-58,-64,-31,-31,-1,-1)
CONPOR(CANOPY18,0.0,cell,-65,-69,-32,-32,-1,-1)
CONPOR(CANOPY19,0.0,cell,-70,-72,-33,-33,-1,-1)
    GROUP 12. Patchwise adjustment of terms (in differential equation
    GROUP 13. Boundary conditions and special sources
       Use Boussinesq approximation.
       BUOYA - gravity in X-direction.
       BUOYB - gravity in Y-direction.
       BUOYC - gravity in Z-direction.
       BUOYD - air expansion coefficient (=1/T in Kelvin).
       BUOYE - BUOYD * Reference temperature (in Celsius).
  ** Thermal buoyancy
BUOYB=-9.8; BUOYD=-1./300.; BUOYE=-BUOYD*23.
       Define the space and time the boundary condition to be applied
PATCH(BUOY,PHASEM,1,NX,1,NY,1,1,1,LSTEP)
       Apply the Buossinesq approximation (GRND3).
COVAL(BUOY,V1,FIXFLU,GRND3)
  ** South boundary
       Define the space and time the boundary condition to be applied.
PATCH(SB1,WEST,1,1,1,1,1,1,1,1)
       Use non-slip boundary condition for U1 and V1.
COVAL(SB1,P1,FIXFLU,0.46*RHO1)
COVAL(SB1,U1,ONLYMS,0.46)
COVAL(SB1,KE,ONLYMS,TKEIN)
COVAL(SB1,EP,ONLYMS,EPSIN)
       Set air temperature to 23 C (73.4 F).
COVAL(SB1,TEM1,ONLYMS,23.)
       Set coastal boundary condition by changing U1.
PATCH(SB2,WEST,1,1,2,2,1,1,1,1)
COVAL(SB2,P1,FIXFLU,0.66*RHO1)
COVAL(SB2,U1,ONLYMS,0.66)
COVAL(SB2,KE,ONLYMS,TKEIN)
COVAL(SB2,EP,ONLYMS,EPSIN)
COVAL(SB2,TEM1,ONLYMS,23.)
PATCH(SB3,WEST,1,1,3,3,1,1,1,1)
COVAL(SB3,P1,FIXFLU,0.78*RHO1)
COVAL(SB3,U1,ONLYMS,0.78)
COVAL(SB3,KE,ONLYMS,TKEIN)
COVAL(SB3,EP,ONLYMS,EPSIN)
COVAL(SB3,TEM1,ONLYMS,23.)
PATCH(SB4,WEST,1,1,4,4,1,1,1,1)
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COVAL(SB4,P1,FIXFLU,0.87*RHO1)
COVAL(SB4,U1,ONLYMS,0.87)
COVAL(SB4,KE,ONLYMS,TKEIN)
COVAL(SB4,EP,ONLYMS,EPSIN)
COVAL(SB4,TEM1,ONLYMS,23.)
PATCH(SB5,WEST,1,1,5,5,1,1,1,1)
COVAL(SB5,P1,FIXFLU,0.95*RHO1)
COVAL(SB5,U1,ONLYMS,0.95)
COVAL(SB5,KE,ONLYMS,TKEIN)
COVAL(SB5,EP,ONLYMS,EPSIN)
COVAL(SB5,TEM1,ONLYMS,23.)
PATCH(SB6,WEST,1,1,6,6,1,1,1,1)
COVAL(SB6,P1,FIXFLU,1.01*RHO1)
COVAL(SB6,U1,ONLYMS,1.01)
COVAL(SB6,KE,ONLYMS,TKEIN)
COVAL(SB6,EP,ONLYMS,EPSIN)
COVAL(SB6,TEM1,ONLYMS,23.)
PATCH(SB7,WEST,1,1,7,7,1,1,1,1)
COVAL(SB7,P1,FIXFLU,1.07*RHO1)
COVAL(SB7,U1,ONLYMS,1.07)
COVAL(SB7,KE,ONLYMS,TKEIN)
COVAL(SB7,EP,ONLYMS,EPSIN)
COVAL(SB7,TEM1,ONLYMS,23.)
PATCH(SB8,WEST,1,1,8,8,1,1,1,1)
COVAL(SB8,P1,FIXFLU,1.12*RHO1)
COVAL(SB8,U1,ONLYMS,1.12)
COVAL(SB8,KE,ONLYMS,TKEIN)
COVAL(SB8,EP,ONLYMS,EPSIN)
COVAL(SB8,TEM1,ONLYMS,23.)
PATCH(SB9,WEST,1,1,9,9,1,1,1,1)
COVAL(SB9,P1,FIXFLU,1.17*RHO1)
COVAL(SB9,U1,ONLYMS,1.17)
COVAL(SB9,KE,ONLYMS,TKEIN)
COVAL(SB9,EP,ONLYMS,EPSIN)
COVAL(SB9,TEM1,ONLYMS,23.)
PATCH(SB10,WEST,1,1,10,10,1,1,1,1)
COVAL(SB10,P1,FIXFLU,1.21*RHO1)
COVAL(SB10,U1,ONLYMS,1.21)
COVAL(SB10,KE,ONLYMS,TKEIN)
COVAL(SB10,EP,ONLYMS,EPSIN)
COVAL(SB10,TEM1,ONLYMS,23.)
PATCH(SB11,WEST,1,1,11,11,1,1,1,1)
COVAL(SB11,P1,FIXFLU,1.25*RHO1)
COVAL(SB11,U1,ONLYMS,1.25)
COVAL(SB11,KE,ONLYMS,TKEIN)
COVAL(SB11,EP,ONLYMS,EPSIN)
COVAL(SB11,TEM1,ONLYMS,23.)
PATCH(SB12,WEST,1,1,12,12,1,1,1,1)
COVAL(SB12,P1,FIXFLU,1.29*RHO1)
COVAL(SB12,U1,ONLYMS,1.29)
COVAL(SB12,KE,ONLYMS,TKEIN)
COVAL(SB12,EP,ONLYMS,EPSIN)
COVAL(SB12,TEM1,ONLYMS,23.)
PATCH(SB13,WEST,1,1,13,13,1,1,1,1)
COVAL(SB13,P1,FIXFLU,1.32*RHO1)
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COVAL(SB13,U1,ONLYMS,1.32)
COVAL(SB13,KE,ONLYMS,TKEIN)
COVAL(SB13,EP,ONLYMS,EPSIN)
COVAL(SB13,TEM1,ONLYMS,23.)
PATCH(SB14,WEST,1,1,14,14,1,1,1,1)
COVAL(SB14,P1,FIXFLU,1.36*RHO1)
COVAL(SB14,U1,ONLYMS,1.36)
COVAL(SB14,KE,ONLYMS,TKEIN)
COVAL(SB14,EP,ONLYMS,EPSIN)
COVAL(SB14,TEM1,ONLYMS,23.)
PATCH(SB15,WEST,1,1,15,15,1,1,1,1)
COVAL(SB15,P1,FIXFLU,1.39*RHO1)
COVAL(SB15,U1,ONLYMS,1.39)
COVAL(SB15,KE,ONLYMS,TKEIN)
COVAL(SB15,EP,ONLYMS,EPSIN)
COVAL(SB15,TEM1,ONLYMS,23.)
PATCH(SB16,WEST,1,1,16,16,1,1,1,1)
COVAL(SB16,P1,FIXFLU,1.42*RHO1)
COVAL(SB16,U1,ONLYMS,1.42)
COVAL(SB16,KE,ONLYMS,TKEIN)
COVAL(SB16,EP,ONLYMS,EPSIN)
COVAL(SB16,TEM1,ONLYMS,23.)
PATCH(SB17,WEST,1,1,17,17,1,1,1,1)
COVAL(SB17,P1,FIXFLU,1.45*RHO1)
COVAL(SB17,U1,ONLYMS,1.45)
COVAL(SB17,KE,ONLYMS,TKEIN)
COVAL(SB17,EP,ONLYMS,EPSIN)
COVAL(SB17,TEM1,ONLYMS,23.)
PATCH(SB18,WEST,1,1,18,18,1,1,1,1)
COVAL(SB18,P1,FIXFLU,1.48*RHO1)
COVAL(SB18,U1,ONLYMS,1.48)
COVAL(SB18,KE,ONLYMS,TKEIN)
COVAL(SB18,EP,ONLYMS,EPSIN)
COVAL(SB18,TEM1,ONLYMS,23.)
PATCH(SB19,WEST,1,1,19,19,1,1,1,1)
COVAL(SB19,P1,FIXFLU,1.51*RHO1)
COVAL(SB19,U1,ONLYMS,1.51)
COVAL(SB19,KE,ONLYMS,TKEIN)
COVAL(SB19,EP,ONLYMS,EPSIN)
COVAL(SB19,TEM1,ONLYMS,23.)
PATCH(SB20,WEST,1,1,20,20,1,1,1,1)
COVAL(SB20,P1,FIXFLU,1.53*RHO1)
COVAL(SB20,U1,ONLYMS,1.53)
COVAL(SB20,KE,ONLYMS,TKEIN)
COVAL(SB20,EP,ONLYMS,EPSIN)
COVAL(SB20,TEM1,ONLYMS,23.)
PATCH(SB21,WEST,1,1,21,21,1,1,1,1)
COVAL(SB21,P1,FIXFLU,1.56*RHO1)
COVAL(SB21,U1,ONLYMS,1.56)
COVAL(SB21,KE,ONLYMS,TKEIN)
COVAL(SB21,EP,ONLYMS,EPSIN)
COVAL(SB21,TEM1,ONLYMS,23.)
PATCH(SB22,WEST,1,1,22,22,1,1,1,1)
COVAL(SB22,P1,FIXFLU,1.58*RHO1)
COVAL(SB22,U1,ONLYMS,1.58)
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COVAL(SB22,KE,ONLYMS,TKEIN)
COVAL(SB22,EP,ONLYMS,EPSIN)
COVAL(SB22,TEM1,ONLYMS,23.)
PATCH(SB23,WEST,1,1,23,23,1,1,1,1)
COVAL(SB23,P1,FIXFLU,1.61*RHO1)
COVAL(SB23,U1,ONLYMS,1.61)
COVAL(SB23,KE,ONLYMS,TKEIN)
COVAL(SB23,EP,ONLYMS,EPSIN)
COVAL(SB23,TEM1,ONLYMS,23.)
PATCH(SB24,WEST,1,1,24,24,1,1,1,1)
COVAL(SB24,P1,FIXFLU,1.63*RHO1)
COVAL(SB24,U1,ONLYMS,1.63)
COVAL(SB24,KE,ONLYMS,TKEIN)
COVAL(SB24,EP,ONLYMS,EPSIN)
COVAL(SB24,TEM1,ONLYMS,23.)
PATCH(SB25,WEST,1,1,25,25,1,1,1,1)
COVAL(SB25,P1,FIXFLU,1.65*RHO1)
COVAL(SB25,U1,ONLYMS,1.65)
COVAL(SB25,KE,ONLYMS,TKEIN)
COVAL(SB25,EP,ONLYMS,EPSIN)
COVAL(SB25,TEM1,ONLYMS,23.)
PATCH(SB26,WEST,1,1,26,26,1,1,1,1)
COVAL(SB26,P1,FIXFLU,1.68*RHO1)
COVAL(SB26,U1,ONLYMS,1.68)
COVAL(SB26,KE,ONLYMS,TKEIN)
COVAL(SB26,EP,ONLYMS,EPSIN)
COVAL(SB26,TEM1,ONLYMS,23.)
PATCH(SB27,WEST,1,1,27,27,1,1,1,1)
COVAL(SB27,P1,FIXFLU,1.7*RHO1)
COVAL(SB27,U1,ONLYMS,1.7)
COVAL(SB27,KE,ONLYMS,TKEIN)
COVAL(SB27,EP,ONLYMS,EPSIN)
COVAL(SB27,TEM1,ONLYMS,23.)
PATCH(SB28,WEST,1,1,28,28,1,1,1,1)
COVAL(SB28,P1,FIXFLU,1.72*RHO1)
COVAL(SB28,U1,ONLYMS,1.72)
COVAL(SB28,KE,ONLYMS,TKEIN)
COVAL(SB28,EP,ONLYMS,EPSIN)
COVAL(SB28,TEM1,ONLYMS,23.)
PATCH(SB29,WEST,1,1,29,29,1,1,1,1)
COVAL(SB29,P1,FIXFLU,1.74*RHO1)
COVAL(SB29,U1,ONLYMS,1.74)
COVAL(SB29,KE,ONLYMS,TKEIN)
COVAL(SB29,EP,ONLYMS,EPSIN)
COVAL(SB29,TEM1,ONLYMS,23.)
PATCH(SB30,WEST,1,1,30,30,1,1,1,1)
COVAL(SB30,P1,FIXFLU,1.76*RHO1)
COVAL(SB30,U1,ONLYMS,1.76)
COVAL(SB30,KE,ONLYMS,TKEIN)
COVAL(SB30,EP,ONLYMS,EPSIN)
COVAL(SB30,TEM1,ONLYMS,23.)
PATCH(SB31,WEST,1,1,31,31,1,1,1,1)
COVAL(SB31,P1,FIXFLU,1.78*RHO1)
COVAL(SB31,U1,ONLYMS,1.78)
COVAL(SB31,KE,ONLYMS,TKEIN)
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COVAL(SB31,EP,ONLYMS,EPSIN)
COVAL(SB31,TEM1,ONLYMS,23.)
PATCH(SB32,WEST,1,1,32,32,1,1,1,1)
COVAL(SB32,P1,FIXFLU,1.8*RHO1)
COVAL(SB32,U1,ONLYMS,1.8)
COVAL(SB32,KE,ONLYMS,TKEIN)
COVAL(SB32,EP,ONLYMS,EPSIN)
COVAL(SB32,TEM1,ONLYMS,23.)
PATCH(SB33,WEST,1,1,33,33,1,1,1,1)
COVAL(SB33,P1,FIXFLU,1.82*RHO1)
COVAL(SB33,U1,ONLYMS,1.82)
COVAL(SB33,KE,ONLYMS,TKEIN)
COVAL(SB33,EP,ONLYMS,EPSIN)
COVAL(SB33,TEM1,ONLYMS,23.)
PATCH(SB34,WEST,1,1,34,34,1,1,1,1)
COVAL(SB34,P1,FIXFLU,1.83*RHO1)
COVAL(SB34,U1,ONLYMS,1.83)
COVAL(SB34,KE,ONLYMS,TKEIN)
COVAL(SB34,EP,ONLYMS,EPSIN)
COVAL(SB34,TEM1,ONLYMS,23.)
PATCH(SB35,WEST,1,1,35,35,1,1,1,1)
COVAL(SB35,P1,FIXFLU,1.86*RHO1)
COVAL(SB35,U1,ONLYMS,1.86)
COVAL(SB35,KE,ONLYMS,TKEIN)
COVAL(SB35,EP,ONLYMS,EPSIN)
COVAL(SB35,TEM1,ONLYMS,23.)
PATCH(SB36,WEST,1,1,36,36,1,1,1,1)
COVAL(SB36,P1,FIXFLU,1.9*RHO1)
COVAL(SB36,U1,ONLYMS,1.9)
COVAL(SB36,KE,ONLYMS,TKEIN)
COVAL(SB36,EP,ONLYMS,EPSIN)
COVAL(SB36,TEM1,ONLYMS,23.)
PATCH(SB37,WEST,1,1,37,37,1,1,1,1)
COVAL(SB37,P1,FIXFLU,1.95*RHO1)
COVAL(SB37,U1,ONLYMS,1.95)
COVAL(SB37,KE,ONLYMS,TKEIN)
COVAL(SB37,EP,ONLYMS,EPSIN)
COVAL(SB37,TEM1,ONLYMS,23.)
PATCH(SB38,WEST,1,1,38,38,1,1,1,1)
COVAL(SB38,P1,FIXFLU,2.01*RHO1)
COVAL(SB38,U1,ONLYMS,2.01)
COVAL(SB38,KE,ONLYMS,TKEIN)
COVAL(SB38,EP,ONLYMS,EPSIN)
COVAL(SB38,TEM1,ONLYMS,23.)
PATCH(SB39,WEST,1,1,39,39,1,1,1,1)
COVAL(SB39,P1,FIXFLU,2.06*RHO1)
COVAL(SB39,U1,ONLYMS,2.06)
COVAL(SB39,KE,ONLYMS,TKEIN)
COVAL(SB39,EP,ONLYMS,EPSIN)
COVAL(SB39,TEM1,ONLYMS,23.)
PATCH(SB40,WEST,1,1,40,40,1,1,1,1)
COVAL(SB40,P1,FIXFLU,2.12*RHO1)
COVAL(SB40,U1,ONLYMS,2.12)
COVAL(SB40,KE,ONLYMS,TKEIN)
COVAL(SB40,EP,ONLYMS,EPSIN)
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COVAL(SB40,TEM1,ONLYMS,23.)
PATCH(SB41,WEST,1,1,41,41,1,1,1,1)
COVAL(SB41,P1,FIXFLU,2.18*RHO1)
COVAL(SB41,U1,ONLYMS,2.18)
COVAL(SB41,KE,ONLYMS,TKEIN)
COVAL(SB41,EP,ONLYMS,EPSIN)
COVAL(SB41,TEM1,ONLYMS,23.)
PATCH(SB42,WEST,1,1,42,42,1,1,1,1)
COVAL(SB42,P1,FIXFLU,2.24*RHO1)
COVAL(SB42,U1,ONLYMS,2.24)
COVAL(SB42,KE,ONLYMS,TKEIN)
COVAL(SB42,EP,ONLYMS,EPSIN)
COVAL(SB42,TEM1,ONLYMS,23.)
PATCH(SB43,WEST,1,1,43,43,1,1,1,1)
COVAL(SB43,P1,FIXFLU,2.32*RHO1)
COVAL(SB43,U1,ONLYMS,2.32)
COVAL(SB43,KE,ONLYMS,TKEIN)
COVAL(SB43,EP,ONLYMS,EPSIN)
COVAL(SB43,TEM1,ONLYMS,23.)
PATCH(SB44,WEST,1,1,44,44,1,1,1,1)
COVAL(SB44,P1,FIXFLU,2.36*RHO1)
COVAL(SB44,U1,ONLYMS,2.36)
COVAL(SB44,KE,ONLYMS,TKEIN)
COVAL(SB44,EP,ONLYMS,EPSIN)
COVAL(SB44,TEM1,ONLYMS,23.)
PATCH(SB45,WEST,1,1,45,45,1,1,1,1)
COVAL(SB45,P1,FIXFLU,2.42*RHO1)
COVAL(SB45,U1,ONLYMS,2.42)
COVAL(SB45,KE,ONLYMS,TKEIN)
COVAL(SB45,EP,ONLYMS,EPSIN)
COVAL(SB45,TEM1,ONLYMS,23.)
PATCH(SB46,WEST,1,1,46,46,1,1,1,1)
COVAL(SB46,P1,FIXFLU,2.48*RHO1)
COVAL(SB46,U1,ONLYMS,2.48)
COVAL(SB46,KE,ONLYMS,TKEIN)
COVAL(SB46,EP,ONLYMS,EPSIN)
COVAL(SB46,TEM1,ONLYMS,23.)
PATCH(SB47,WEST,1,1,47,47,1,1,1,1)
COVAL(SB47,P1,FIXFLU,2.54*RHO1)
COVAL(SB47,U1,ONLYMS,2.54)
COVAL(SB47,KE,ONLYMS,TKEIN)
COVAL(SB47,EP,ONLYMS,EPSIN)
COVAL(SB47,TEM1,ONLYMS,23.)
PATCH(SB48,WEST,1,1,48,48,1,1,1,1)
COVAL(SB48,P1,FIXFLU,2.6*RHO1)
COVAL(SB48,U1,ONLYMS,2.6)
COVAL(SB48,KE,ONLYMS,TKEIN)
COVAL(SB48,EP,ONLYMS,EPSIN)
COVAL(SB48,TEM1,ONLYMS,23.)
  ** North boundary
PATCH(NB,EAST,NX,NX,1,NY,1,1,1,1)
COVAL(NB,P1,FIXP,0.0)
COVAL(NB,TEM1,0.0,23.)
COVAL(NB,KE,0.0,1.E-5)
COVAL(NB,EP,0.0,1.E-5)
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  ** Upper boundary
PATCH(UPPER,NORTH,1,NX,1,NY,1,1,1,1)
    COVAL(UPPER,P1,FIXP,0.0)
COVAL(UPPER,TEM1,0.0,23.)
  ** Ground
PATCH(GROUND,SWALL,1,NX,1,1,1,1,1,1)
COVAL(GROUND,U1,GRND2,0.0)
COVAL(GROUND,TEM1,GRND2,23.)
COVAL(GROUND,KE,GRND2,GRND2)
COVAL(GROUND,EP,GRND2,GRND2)
  ** Solar panels
PATCH(SP3L,SOUTH,27,27,18,18,1,1,1,1)
COVAL(SP3L,TEM1,FIXFLU,30.*20.)
PATCH(SP4L,SOUTH,28,28,19,19,1,1,1,1)
COVAL(SP4L,TEM1,FIXFLU,30.*20.)
PATCH(SP5L,SOUTH,29,29,20,20,1,1,1,1)
COVAL(SP5L,TEM1,FIXFLU,30.*20)
PATCH(SP6L,SOUTH,30,30,21,21,1,1,1,1)
COVAL(SP6L,TEM1,FIXFLU,30.*20.)
PATCH(SP7L,SOUTH,31,31,22,22,1,1,1,1)
COVAL(SP7L,TEM1,FIXFLU,30.*20.)
PATCH(SP8L,SOUTH,32,33,23,23,1,1,1,1)
COVAL(SP8L,TEM1,FIXFLU,30.*20.)
PATCH(SP9L,SOUTH,34,35,24,24,1,1,1,1)
COVAL(SP9L,TEM1,FIXFLU,30.*20.)
PATCH(SP10L,SOUTH,36,37,25,25,1,1,1,1)
COVAL(SP10L,TEM1,FIXFLU,30.*20.)
PATCH(SP11L,SOUTH,38,39,26,26,1,1,1,1)
COVAL(SP11L,TEM1,FIXFLU,30.*20.)
PATCH(SP12L,SOUTH,40,42,27,27,1,1,1,1)
COVAL(SP12L,TEM1,FIXFLU,30.*20.)
PATCH(SP13L,SOUTH,43,44,28,28,1,1,1,1)
COVAL(SP13L,TEM1,FIXFLU,30.*20.)
PATCH(SP14L,SOUTH,45,48,29,29,1,1,1,1)
COVAL(SP14L,TEM1,FIXFLU,30.*20.)
PATCH(SP15L,SOUTH,49,52,30,30,1,1,1,1)
COVAL(SP15L,TEM1,FIXFLU,30.*20.)
PATCH(SP16L,SOUTH,53,57,31,31,1,1,1,1)
COVAL(SP16L,TEM1,FIXFLU,30.*20.)
PATCH(SP17L,SOUTH,58,64,32,32,1,1,1,1)
COVAL(SP17L,TEM1,FIXFLU,30.*20.)
PATCH(SP18L,SOUTH,65,69,33,33,1,1,1,1)
COVAL(SP18L,TEM1,FIXFLU,30.*20.)
PATCH(SP3S,EAST,27,27,18,18,1,1,1,1)
COVAL(SP3S,TEM1,FIXFLU,30.*20.)
PATCH(SP4S,EAST,28,28,19,19,1,1,1,1)
COVAL(SP4S,TEM1,FIXFLU,30.*20.)
PATCH(SP5S,EAST,29,29,20,20,1,1,1,1)
COVAL(SP5S,TEM1,FIXFLU,30.*20.)
PATCH(SP6S,EAST,30,30,21,21,1,1,1,1)
COVAL(SP6S,TEM1,FIXFLU,30.*20.)
PATCH(SP7S,EAST,31,31,22,22,1,1,1,1)
COVAL(SP7S,TEM1,FIXFLU,30.*20.)
PATCH(SP8S,EAST,32,33,23,23,1,1,1,1)
COVAL(SP8S,TEM1,FIXFLU,30.*20.)
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PATCH(SP9S,EAST,34,35,24,24,1,1,1,1)
COVAL(SP9S,TEM1,FIXFLU,30.*20.)
PATCH(SP10S,EAST,36,37,25,25,1,1,1,1)
COVAL(SP10S,TEM1,FIXFLU,30.*20.)
PATCH(SP11S,EAST,38,39,26,26,1,1,1,1)
COVAL(SP11S,TEM1,FIXFLU,30.*20.)
PATCH(SP12S,EAST,40,42,27,27,1,1,1,1)
COVAL(SP12S,TEM1,FIXFLU,30.*20.)
PATCH(SP13S,EAST,43,44,28,28,1,1,1,1)
COVAL(SP13S,TEM1,FIXFLU,30.*20.)
PATCH(SP14S,EAST,45,48,29,29,1,1,1,1)
COVAL(SP14S,TEM1,FIXFLU,30.*20.)
PATCH(SP15S,EAST,49,52,30,30,1,1,1,1)
COVAL(SP15S,TEM1,FIXFLU,30.*20.)
PATCH(SP16S,EAST,53,57,31,31,1,1,1,1)
COVAL(SP16S,TEM1,FIXFLU,30.*20.)
PATCH(SP17S,EAST,58,64,32,32,1,1,1,1)
COVAL(SP17S,TEM1,FIXFLU,30.*20.)
PATCH(SP18S,EAST,65,69,33,33,1,1,1,1)
COVAL(SP18S,TEM1,FIXFLU,30.*20.)
  ** Ceiling
PATCH(CL3H,NORTH,27,27,15,15,1,1,1,1)
COVAL(CL3H,TEM1,FIXFLU,4.*20.)
PATCH(CL4H,NORTH,28,29,16,17,1,1,1,1)
COVAL(CL4H,TEM1,FIXFLU,4.*20.)
PATCH(CL5H,NORTH,30,30,18,18,1,1,1,1)
COVAL(CL5H,TEM1,FIXFLU,4.*20.)
PATCH(CL6H,NORTH,31,31,19,19,1,1,1,1)
COVAL(CL6H,TEM1,FIXFLU,4.*20.)
PATCH(CL7H,NORTH,32,32,20,20,1,1,1,1)
COVAL(CL7H,TEM1,FIXFLU,4.*20.)
PATCH(CL8H,NORTH,33,34,21,21,1,1,1,1)
COVAL(CL8H,TEM1,FIXFLU,4.*20.)
PATCH(CL9H,NORTH,35,36,22,22,1,1,1,1)
COVAL(CL9H,TEM1,FIXFLU,4.*20.)
PATCH(CL10H,NORTH,37,38,23,23,1,1,1,1)
COVAL(CL10H,TEM1,FIXFLU,4.*20.)
PATCH(CL11H,NORTH,39,40,24,24,1,1,1,1)
COVAL(CL11H,TEM1,FIXFLU,4.*20.)
PATCH(CL12H,NORTH,41,42,25,25,1,1,1,1)
COVAL(CL12H,TEM1,FIXFLU,4.*20.)
PATCH(CL13H,NORTH,43,45,26,26,1,1,1,1)
COVAL(CL13H,TEM1,FIXFLU,4.*20.)
PATCH(CL14H,NORTH,46,48,27,27,1,1,1,1)
COVAL(CL14H,TEM1,FIXFLU,4.*20.)
PATCH(CL15H,NORTH,49,52,28,28,1,1,1,1)
COVAL(CL15H,TEM1,FIXFLU,4.*20.)
PATCH(CL16H,NORTH,53,57,29,29,1,1,1,1)
COVAL(CL16H,TEM1,FIXFLU,4.*20.)
PATCH(CL17H,NORTH,58,64,30,30,1,1,1,1)
COVAL(CL17H,TEM1,FIXFLU,4.*20.)
PATCH(CL18H,NORTH,65,69,31,31,1,1,1,1)
COVAL(CL18H,TEM1,FIXFLU,4.*20.)
PATCH(CL4N,WEST,28,29,16,17,1,1,1,1)
COVAL(CL4N,TEM1,FIXFLU,4.*20.)
```

```
PATCH(CL5N,WEST,30,30,18,18,1,1,1,1)
COVAL(CL5N,TEM1,FIXFLU,4.*20.)
PATCH(CL6N,WEST,31,31,19,19,1,1,1,1)
COVAL(CL6N,TEM1,FIXFLU,4.*20.)
PATCH(CL7N,WEST,32,32,20,20,1,1,1,1)
COVAL(CL7N,TEM1,FIXFLU,4.*20.)
PATCH(CL8N,WEST,33,34,21,21,1,1,1,1)
COVAL(CL8N,TEM1,FIXFLU,4.*20.)
PATCH(CL9N,WEST,35,36,22,22,1,1,1,1)
COVAL(CL9N,TEM1,FIXFLU,4.*20.)
PATCH(CL10N,WEST,37,38,23,23,1,1,1,1)
COVAL(CL10N,TEM1,FIXFLU,4.*20.)
PATCH(CL11N,WEST,39,40,24,24,1,1,1,1)
COVAL(CL11N,TEM1,FIXFLU,4.*20.)
PATCH(CL12N,WEST,41,42,25,25,1,1,1,1)
COVAL(CL12N,TEM1,FIXFLU,4.*20.)
PATCH(CL13N,WEST,43,45,26,26,1,1,1,1)
COVAL(CL13N,TEM1,FIXFLU,4.*20.)
PATCH(CL14N,WEST,46,48,27,27,1,1,1,1)
COVAL(CL14N,TEM1,FIXFLU,4.*20.)
PATCH(CL15N,WEST,49,52,28,28,1,1,1,1)
COVAL(CL15N,TEM1,FIXFLU,4.*20.)
PATCH(CL16N,WEST,53,57,29,29,1,1,1,1)
COVAL(CL16N,TEM1,FIXFLU,4.*20.)
PATCH(CL17N,WEST,58,64,30,30,1,1,1,1)
COVAL(CL17N,TEM1,FIXFLU,4.*20.)
PATCH(CL18N,WEST,65,69,31,31,1,1,1,1)
COVAL(CL18N,TEM1,FIXFLU,4.*20.)
    GROUP 14. Downstream pressure for PARAB=.TRUE.
    GROUP 15. Termination of sweeps
       Total iteration number.
LSWEEP=3000
       Print the iteration number during runsat.
LSWEEP
    GROUP 16. Termination of iterations
    GROUP 17. Under-relaxation devices
       Determine false-time-step.
REAL(DTF, MINCELL, MAXV)
MINCELL=0.2
MAXV=2.6
DTF=1.*MINCELL/MAXV
DTF
       Under-relaxation factor for P1 is 0.8.
RELAX(P1,LINRLX,0.8)
RELAX(U1,FALSDT,DTF)
RELAX(V1,FALSDT,DTF)
RELAX(TEM1,FALSDT,DTF)
RELAX(KE,FALSDT,DTF)
RELAX(EP,FALSDT,DTF)
    GROUP 18. Limits on variables or increments to them
    GROUP 19. Data communicated by satellite to GROUND
    GROUP 20. Preliminary print-out
       Echo printout of the q1 file in the result file.
ECHO=T
    GROUP 21. Print-out of variables
```

```
    GROUP 22. Spot-value print-out
IXMON=NX/2;IYMON=NY/2
    GROUP 23. Field print-out and plot control
TSTSWP=-1
STOP
```

Appendix E

The q1 file for the Visitors Sports Pavilion in Washington, DC for natural convection without wind.

```
 TALK=F;RUN( 1, 1);VDU=X11-TERM
    GROUP 1. Run title and other preliminaries
       A title up to 40 characters can be used.
TEXT(PAVILION: BUOYANCY-DRIVEN CONVECTION)
       A section of the pavilion in Washington, DC.
TITLE
       This model represents the natural ventilation in the Pavilion in
       Washington, DC when no wind exist.
REAL(XLENGTH,YLENGTH,TKEIN,EPSIN)
       Assign values to the variables declared.
       The width and height of outdoor space are 45 m (150 ft) and 20 m
       (66 ft) respectively.
XLENGTH=45;YLENGTH=20
NX=85;NY=48
    GROUP 2. Transience; time-step specification
    GROUP 3. X-direction grid specification
       Total region number in the X-direction is 3.
       20 cells are in the first region, the south outdoor space.
       45 cells are in the second region, the building area.
       20 cells are in the third region, the north outdoor space.
       The dimension in X-direction is 18 m (60 ft), 9 m( 30 ft), and 18
       m (60 ft) in the regions.
       The cells are evenly divided in the building area.
       The dimensions of the cells become bigger when they are away
       building area.
NREGX=3
IREGX=1;GRDPWR(X,20,18,-1.5)
IREGX=2;GRDPWR(X,45,9,1)
IREGX=3;GRDPWR(X,20,18,1.5)
    GROUP 4. Y-direction grid specification
       Total region number in the Y-direction is 3.
       33 cells are in the first region, the building area.
       15 cells are in the second region, the atomosphere above the
       building area.
       The dimension in Y-direction is 6.6 m (22 ft) and 13.4 m (43 ft)
       the regions.
       The cells are evenly divided in the building area.
       The dimensions of the cells become wider when they are away
       from the building area.
NREGY=2
IREGY=1;GRDPWR(Y,33,6.6,1)
IREGY=2;GRDPWR(Y,15,13.4,1.5)
    GROUP 5. Z-direction grid specification
    GROUP 6. Body-fitted coordinates or grid distortion
    GROUP 7. Variables stored, solved & named
```

```
       Solve the following variables:
       P1 - The first phase pressure.
       U1 - The first phase velocity in X-direction.
       V1 - The first phase velocity in Y-direction.
       W1 - The first phase velocity in Z-direction.
       TEM1 -The first phase temperature.
SOLVE(P1,U1,V1,TEM1)
TURMOD(KEMODL)
    GROUP 8. Terms (in differential equations) & devices
    GROUP 9. Properties of the medium (or media)
       Set laminar kinetic viscosity of air as 1.5E-5.
       Set density of air as 1.2.
ENUL=1.5E-5
RHO1=1.2
    GROUP 10. Inter-phase-transfer processes and properties
    GROUP 11. Initialization of variable or porosity fields
       Set initial air temperature 29 C (48 F).
FIINIT(TEM1)=29
PRESS0=1.0E5
TEMP0=273.15
PRT(TEM1)=0.9;PRNDTL(TEM1)=0.7
  ** Calculation of KE
TKEIN=0.018*0.25*1.5*1.5
  ** Calculation of EP
EPSIN=TKEIN**1.5*0.1643/3.429E-3
FIINIT(KE)=TKEIN
FIINIT(EP)=EPSIN
  ** Thermal walls
CONPOR(TW1,0.0,cell,-58,-58,-10,-19,-1,-1)
CONPOR(TW2,0.0,cell,-65,-65,-1,-16,-1,-1)
  ** Roof
CONPOR(ROOF1,0.0,cell,-59,-59,-20,-20,-1,-1)
CONPOR(ROOF2,0.0,cell,-60,-60,-21,-21,-1,-1)
CONPOR(ROOF3,0.0,cell,-61,-61,-22,-22,-1,-1)
CONPOR(ROOF4,0.0,cell,-62,-62,-23,-23,-1,-1)
CONPOR(ROOF5,0.0,cell,-63,-63,-24,-24,-1,-1)
CONPOR(ROOF6,0.0,cell,-64,-64,-25,-25,-1,-1)
CONPOR(ROOF7,0.0,cell,-65,-67,-26,-26,-1,-1)
CONPOR(ROOF8,0.0,cell,-65,-67,-17,-17,-1,-1)
  ** Mezzanine
CONPOR(MEZZ,0.0,cell,-50,-57,-10,-10,-1,-1)
  ** Opening
CONPOR(OPEN1,0.0,cell,-21,-25,-9,-9,-1,-1)
CONPOR(OPEN2,0.0,cell,-23,-25,-8,-8,-1,-1)
CONPOR(OPEN3,0.0,cell,-25,-25,-7,-7,-1,-1)
  ** Canopy
CONPOR(CANOPY1,0.0,cell,-25,-26,-14,-14,-1,-1)
CONPOR(CANOPY2,0.0,cell,-26,-26,-15,-15,-1,-1)
CONPOR(CANOPY3,0.0,cell,-27,-27,-16,-17,-1,-1)
CONPOR(CANOPY4,0.0,cell,-28,-29,-18,-18,-1,-1)
CONPOR(CANOPY5,0.0,cell,-29,-30,-19,-19,-1,-1)
CONPOR(CANOPY6,0.0,cell,-30,-31,-20,-20,-1,-1)
CONPOR(CANOPY7,0.0,cell,-31,-32,-21,-21,-1,-1)
CONPOR(CANOPY8,0.0,cell,-32,-34,-22,-22,-1,-1)
CONPOR(CANOPY9,0.0,cell,-34,-36,-23,-23,-1,-1)
```

```
CONPOR(CANOPY10,0.0,cell,-36,-38,-24,-24,-1,-1)
CONPOR(CANOPY11,0.0,cell,-38,-40,-25,-25,-1,-1)
CONPOR(CANOPY12,0.0,cell,-40,-42,-26,-26,-1,-1)
CONPOR(CANOPY13,0.0,cell,-43,-45,-27,-27,-1,-1)
CONPOR(CANOPY14,0.0,cell,-45,-48,-28,-28,-1,-1)
CONPOR(CANOPY15,0.0,cell,-49,-52,-29,-29,-1,-1)
CONPOR(CANOPY16,0.0,cell,-53,-57,-30,-30,-1,-1)
CONPOR(CANOPY17,0.0,cell,-58,-64,-31,-31,-1,-1)
CONPOR(CANOPY18,0.0,cell,-65,-69,-32,-32,-1,-1)
CONPOR(CANOPY19,0.0,cell,-70,-72,-33,-33,-1,-1)
    GROUP 12. Patchwise adjustment of terms (in differential equation
    GROUP 13. Boundary conditions and special sources
       Use Boussinesq approximation
       BUOYA - gravity in X-direction.
       BUOYB - gravity in Y-direction.
       BUOYC - gravity in Z-direction.
       BUOYD - air expansion coefficient (=1/T in Kelvin).
       BUOYE - BUOYD * Reference temperature (in Celsius).
  ** Thermal buoyancy
BUOYB=-9.8; BUOYD=-1./300.; BUOYE=-BUOYD*29.
       Define the space and time the boundary condition to be applied.
PATCH(BUOY,PHASEM,1,NX,1,NY,1,1,1,LSTEP)
       Apply the Buossinesq approximation (GRND3).
COVAL(BUOY,V1,FIXFLU,GRND3)
  ** South boundary
       Define the space and time the boundary condition to be applied.
PATCH(SB1,WEST,1,1,1,NY,1,1,1,1)
       Use non-slip boundary condition for U1 and V1.
COVAL(SB1,P1,FIXP,0.0)
COVAL(SB1,KE,ONLYMS,TKEIN)
COVAL(SB1,EP,ONLYMS,EPSIN)
       Set air temperature to 29 C (73.5 F).
COVAL(SB1,TEM1,ONLYMS,29)
  ** North boundary
PATCH(NB,EAST,NX,NX,1,NY,1,1,1,1)
COVAL(NB,P1,FIXP,0.0)
COVAL(NB,TEM1,0.0,29)
COVAL(NB,KE,0.0,1.E-5)
COVAL(NB,EP,0.0,1.E-5)
  ** Upper boundary
PATCH(UPPER,NORTH,1,NX,1,NY,1,1,1,1)
COVAL(UPPER,P1,FIXP,0.0)
COVAL(UPPER,TEM1,0.0,29)
  ** Ground
PATCH(GROUND,SWALL,1,NX,1,1,1,1,1,1)
COVAL(GROUND,U1,GRND2,0.0)
COVAL(GROUND,TEM1,GRND2,29)
COVAL(GROUND,KE,GRND2,GRND2)
COVAL(GROUND,EP,GRND2,GRND2)
  ** Solar panels
PATCH(SP3L,SOUTH,27,27,18,18,1,1,1,1)
COVAL(SP3L,TEM1,FIXFLU,30.*20.)
PATCH(SP4L,SOUTH,28,28,19,19,1,1,1,1)
COVAL(SP4L,TEM1,FIXFLU,30.*20.)
PATCH(SP5L,SOUTH,29,29,20,20,1,1,1,1)
```

```
COVAL(SP5L,TEM1,FIXFLU,30.*20)
PATCH(SP6L,SOUTH,30,30,21,21,1,1,1,1)
COVAL(SP6L,TEM1,FIXFLU,30.*20.)
PATCH(SP7L,SOUTH,31,31,22,22,1,1,1,1)
COVAL(SP7L,TEM1,FIXFLU,30.*20.)
PATCH(SP8L,SOUTH,32,33,23,23,1,1,1,1)
COVAL(SP8L,TEM1,FIXFLU,30.*20.)
PATCH(SP9L,SOUTH,34,35,24,24,1,1,1,1)
COVAL(SP9L,TEM1,FIXFLU,30.*20.)
PATCH(SP10L,SOUTH,36,37,25,25,1,1,1,1)
COVAL(SP10L,TEM1,FIXFLU,30.*20.)
PATCH(SP11L,SOUTH,38,39,26,26,1,1,1,1)
COVAL(SP11L,TEM1,FIXFLU,30.*20.)
PATCH(SP12L,SOUTH,40,42,27,27,1,1,1,1)
COVAL(SP12L,TEM1,FIXFLU,30.*20.)
PATCH(SP13L,SOUTH,43,44,28,28,1,1,1,1)
COVAL(SP13L,TEM1,FIXFLU,30.*20.)
PATCH(SP14L,SOUTH,45,48,29,29,1,1,1,1)
COVAL(SP14L,TEM1,FIXFLU,30.*20.)
PATCH(SP15L,SOUTH,49,52,30,30,1,1,1,1)
COVAL(SP15L,TEM1,FIXFLU,30.*20.)
PATCH(SP16L,SOUTH,53,57,31,31,1,1,1,1)
COVAL(SP16L,TEM1,FIXFLU,30.*20.)
PATCH(SP17L,SOUTH,58,64,32,32,1,1,1,1)
COVAL(SP17L,TEM1,FIXFLU,30.*20.)
PATCH(SP18L,SOUTH,65,69,33,33,1,1,1,1)
COVAL(SP18L,TEM1,FIXFLU,30.*20.)
PATCH(SP3S,EAST,27,27,18,18,1,1,1,1)
COVAL(SP3S,TEM1,FIXFLU,30.*20.)
PATCH(SP4S,EAST,28,28,19,19,1,1,1,1)
COVAL(SP4S,TEM1,FIXFLU,30.*20.)
PATCH(SP5S,EAST,29,29,20,20,1,1,1,1)
COVAL(SP5S,TEM1,FIXFLU,30.*20.)
PATCH(SP6S,EAST,30,30,21,21,1,1,1,1)
COVAL(SP6S,TEM1,FIXFLU,30.*20.)
PATCH(SP7S,EAST,31,31,22,22,1,1,1,1)
COVAL(SP7S,TEM1,FIXFLU,30.*20.)
PATCH(SP8S,EAST,32,33,23,23,1,1,1,1)
COVAL(SP8S,TEM1,FIXFLU,30.*20.)
PATCH(SP9S,EAST,34,35,24,24,1,1,1,1)
COVAL(SP9S,TEM1,FIXFLU,30.*20.)
PATCH(SP10S,EAST,36,37,25,25,1,1,1,1)
COVAL(SP10S,TEM1,FIXFLU,30.*20.)
PATCH(SP11S,EAST,38,39,26,26,1,1,1,1)
COVAL(SP11S,TEM1,FIXFLU,30.*20.)
PATCH(SP12S,EAST,40,42,27,27,1,1,1,1)
COVAL(SP12S,TEM1,FIXFLU,30.*20.)
PATCH(SP13S,EAST,43,44,28,28,1,1,1,1)
COVAL(SP13S,TEM1,FIXFLU,30.*20.)
PATCH(SP14S,EAST,45,48,29,29,1,1,1,1)
COVAL(SP14S,TEM1,FIXFLU,30.*20.)
PATCH(SP15S,EAST,49,52,30,30,1,1,1,1)
COVAL(SP15S,TEM1,FIXFLU,30.*20.)
PATCH(SP16S,EAST,53,57,31,31,1,1,1,1)
COVAL(SP16S,TEM1,FIXFLU,30.*20.)
```

```
PATCH(SP17S,EAST,58,64,32,32,1,1,1,1)
COVAL(SP17S,TEM1,FIXFLU,30.*20.)
PATCH(SP18S,EAST,65,69,33,33,1,1,1,1)
COVAL(SP18S,TEM1,FIXFLU,30.*20.)
  ** Ceiling
PATCH(CL3H,NORTH,27,27,15,15,1,1,1,1)
COVAL(CL3H,TEM1,FIXFLU,4.*10)
PATCH(CL4H,NORTH,28,29,16,17,1,1,1,1)
COVAL(CL4H,TEM1,FIXFLU,4.*10)
PATCH(CL5H,NORTH,30,30,18,18,1,1,1,1)
COVAL(CL5H,TEM1,FIXFLU,4.*10)
PATCH(CL6H,NORTH,31,31,19,19,1,1,1,1)
COVAL(CL6H,TEM1,FIXFLU,4.*10)
PATCH(CL7H,NORTH,32,32,20,20,1,1,1,1)
COVAL(CL7H,TEM1,FIXFLU,4.*10)
PATCH(CL8H,NORTH,33,34,21,21,1,1,1,1)
COVAL(CL8H,TEM1,FIXFLU,4.*10)
PATCH(CL9H,NORTH,35,36,22,22,1,1,1,1)
COVAL(CL9H,TEM1,FIXFLU,4.*10)
PATCH(CL10H,NORTH,37,38,23,23,1,1,1,1)
COVAL(CL10H,TEM1,FIXFLU,4.*10)
PATCH(CL11H,NORTH,39,40,24,24,1,1,1,1)
COVAL(CL11H,TEM1,FIXFLU,4.*10)
PATCH(CL12H,NORTH,41,42,25,25,1,1,1,1)
COVAL(CL12H,TEM1,FIXFLU,4.*10)
PATCH(CL13H,NORTH,43,45,26,26,1,1,1,1)
COVAL(CL13H,TEM1,FIXFLU,4.*10)
PATCH(CL14H,NORTH,46,48,27,27,1,1,1,1)
COVAL(CL14H,TEM1,FIXFLU,4.*10)
PATCH(CL15H,NORTH,49,52,28,28,1,1,1,1)
COVAL(CL15H,TEM1,FIXFLU,4.*10)
PATCH(CL16H,NORTH,53,57,29,29,1,1,1,1)
COVAL(CL16H,TEM1,FIXFLU,4.*10)
PATCH(CL17H,NORTH,58,64,30,30,1,1,1,1)
COVAL(CL17H,TEM1,FIXFLU,4.*10)
PATCH(CL18H,NORTH,65,69,31,31,1,1,1,1)
COVAL(CL18H,TEM1,FIXFLU,4.*10)
PATCH(CL4N,WEST,28,29,16,17,1,1,1,1)
COVAL(CL4N,TEM1,FIXFLU,4.*10)
PATCH(CL5N,WEST,30,30,18,18,1,1,1,1)
COVAL(CL5N,TEM1,FIXFLU,4.*10)
PATCH(CL6N,WEST,31,31,19,19,1,1,1,1)
COVAL(CL6N,TEM1,FIXFLU,4.*10)
PATCH(CL7N,WEST,32,32,20,20,1,1,1,1)
COVAL(CL7N,TEM1,FIXFLU,4.*10)
PATCH(CL8N,WEST,33,34,21,21,1,1,1,1)
COVAL(CL8N,TEM1,FIXFLU,4.*10)
PATCH(CL9N,WEST,35,36,22,22,1,1,1,1)
COVAL(CL9N,TEM1,FIXFLU,4.*10)
PATCH(CL10N,WEST,37,38,23,23,1,1,1,1)
COVAL(CL10N,TEM1,FIXFLU,4.*10)
PATCH(CL11N,WEST,39,40,24,24,1,1,1,1)
COVAL(CL11N,TEM1,FIXFLU,4.*10)
PATCH(CL12N,WEST,41,42,25,25,1,1,1,1)
COVAL(CL12N,TEM1,FIXFLU,4.*10)
```

```
PATCH(CL13N,WEST,43,45,26,26,1,1,1,1)
COVAL(CL13N,TEM1,FIXFLU,4.*10)
PATCH(CL14N,WEST,46,48,27,27,1,1,1,1)
COVAL(CL14N,TEM1,FIXFLU,4.*10)
PATCH(CL15N,WEST,49,52,28,28,1,1,1,1)
COVAL(CL15N,TEM1,FIXFLU,4.*10)
PATCH(CL16N,WEST,53,57,29,29,1,1,1,1)
COVAL(CL16N,TEM1,FIXFLU,4.*10)
PATCH(CL17N,WEST,58,64,30,30,1,1,1,1)
COVAL(CL17N,TEM1,FIXFLU,4.*10)
PATCH(CL18N,WEST,65,69,31,31,1,1,1,1)
COVAL(CL18N,TEM1,FIXFLU,4.*10)
    GROUP 14. Downstream pressure for PARAB=.TRUE.
    GROUP 15. Termination of sweeps
       Total iteration number.
LSWEEP=3000
       Print the iteration number during runsat.
LSWEEP
    GROUP 16. Termination of iterations
    GROUP 17. Under-relaxation devices
       Determine false-time-step.
REAL(DTF, MINCELL, MAXV)
MINCELL=0.2
MAXV=2.6
DTF=1.*MINCELL/MAXV
DTF
       Under-relaxation factor for P1 is 0.8.
RELAX(P1,LINRLX,0.8)
RELAX(U1,FALSDT,DTF)
RELAX(V1,FALSDT,DTF)
RELAX(TEM1,FALSDT,DTF)
RELAX(KE,FALSDT,DTF)
RELAX(EP,FALSDT,DTF)
    GROUP 18. Limits on variables or increments to them
    GROUP 19. Data communicated by satellite to GROUND
    GROUP 20. Preliminary print-out
       Echo printout of the q1 file in the result file.
ECHO=T
    GROUP 21. Print-out of variables
    GROUP 22. Spot-value print-out
IXMON=NX/2;IYMON=NY/2
    GROUP 23. Field print-out and plot control.
TSTSWP=-1
STOP
```

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Acknowledgments

To my parents, Chuan-Chang and Shu-Huo, who supported me in every thing I did in these years.

To my advisor, Leslie Keith Norford, who inspired my interest in energy conscious design.

To my teacher and thesis reader, Qingyan Chen, who taught me computational fluid dynamics and many other things.

To my thesis reader, Andrew Scott, who gave me many insightful comments.

To my friend, Weiran Xu, who helped me to solve the problems in computation and fluid mechanics.

To my best friend, Rick Chen, who provided me with all kinds of assistance in these years I studied in the United States.

And to my love, An-Chen, who spent all the hard working nights with me.