PROTOCOL

Equivalent Building Dimensions and Excessive Concentration Demonstration For Northeast Utilities Merrimack Generating Station

CPP Project 95-1290

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CPP

CPP

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CPP

1.0 INTRODUCTION

This protocol describes a wind tunnel study that will be conducted for Northeast Utilities Service Company's (NUSCO) Merrimack Generating Station (MGS). The wind tunnel study has the following two objectives:

- demonstrate through the procedures specified in the EPA Stack Height Regulation that the existing stacks can be raised to the mathematical "good engineering practice" (GEP) stack height, and
- determine equivalent building dimensions (EBD) for input into the Industrial Source Complex (ISC) model.

The Merrimack Station is located in Bow, NH and is a two-unit, coal-fired electric generating station with emissions exhausted through two-sub-GEP stacks. The Unit 1 stack height is 69 m (227 ft) and the Unit 2 stack height is 97 m (319 ft). The tallest building in the station complex is the Unit 2 Boiler whose steel work rises 55.5 m (182 ft) above grade. The topography near the station is characterized by the north-northwest to south-southeast Merrimack River valley with a narrow flood plain on the west side of the river. The terrain rises to about the height of the Unit 1 stack within 1 to 2 km of the stack. Table 1 summarizes the source characteristics relevant to this study.

NUSCO has been asked by Region I of the Environmental Protection Agency (EPA) to demonstrate through dispersion modeling that the National Ambient Air Quality Standards (NAAQS) for sulfur dioxide are not violated as a result of emissions from MGS. This may require an increase in stack heights for the station. When a source wants to increase the existing stack height up to the formula GEP stack height (and receive credit in the modeling for the increased stack height), the stack height regulation (40 CFR part 51) requires that wind-tunnel modeling first be conducted to demonstrate that building wakes and eddies are creating excessive concentrations. Once a source demonstrates an excessive concentration for an existing stack, regulatory credit may be received for construction of a new stack up to the formula GEP stack height, or a GEP height determined through physical modeling. Since heights in excess of the formula height are not being evaluated, no wind tunnel testing to determine the GEP stack height will be conducted.

Once an excessive concentration is demonstrated for the existing stacks, NUSCO will use regulatory modeling to evaluate compliance with NAAQS at the desired stack height (it is anticipated that this height will be at or below the FAA limit). One of the models used for this purpose will be the ISC model. The treatment of downwash in the ISC model is partially based on wind tunnel studies conducted by Huber and Snyder (1976, 1982) in which a solid structure with a width twice that of the height and depth was positioned directly upwind of a source stack as shown in Figure 1. While the downwash algorithm is appropriate for this simple configuration, it may not be appropriate for the more complex site configurations typically found at industrial facilities, such as when the structure is located some distance from the stack or is tiered, porous, non-rectangular or otherwise varies from the basic configuration assumed in the ISC downwash algorithm. A major enhancement to ISC, therefore, can be obtained by adjusting the building dimension input into ISC such that the new dimensions allow ISC to better replicate the actual downwash when the building configuration is not consistent with the Huber/Snyder geometry (see Figure 1). These adjusted building dimensions are referred to as "equivalent building dimensions" (EBD) and can be determined by wind tunnel modeling. Since the buildings near the stack at MGS are irregular in shape, some distance removed from the stack and lattice work in some instances, EBD will be determined for critical wind directions for ISC model input.

At present, the only method the Environmental Protection Agency (EPA) has concurred with for determining EBD is through the use of wind tunnel modeling. Petersen (1991, 1992) describes the first such study for which a protocol was reviewed and accepted by the EPA (Region V and RTP) and for which a permit was ultimately obtained (Blewitt, 1995). That study considered the effect of a nearby lattice type (porous) structure. More recently, the EPA (Tikvart, 1994) has approved the equivalent building concept (based on a study conducted by CPP, Petersen and Cochran, 1993) for regulatory modeling use on the basis that it is a source characterization study which is under the purview of the Regional Offices. Appendix A provides a copy of a paper that summarizes the results of the EBD study reviewed and approved by EPA. CPP has conducted other EBD studies (Petersen and Cochran, 1995a; 1995b) since the 1994 Tikvart memoranda that have also been reviewed and approved by local agencies (McBee, 1995; Thornton, 1995).

Although the terrain is complex around the MGS, this study will not consider terrain effects. The purpose of this study is to isolate the effect of the plant structures on dispersion and determine an equivalent building that can adequately replicate this effect. The effect of the terrain and buildings will then subsequently be evaluated using EPA approved dispersion models. This approach has been approved by EPA on a past study conducted by CPP (Petersen and Cochran, 1995a).

This protocol describes the technical aspects, project plan, and schedule for conducting the wind tunnel study designed to meet the stated project objectives. Appendix B includes a description of CPP's facilities and instrumentation that will be used to conduct the study. It should be pointed out that the procedures described in this protocol for conducting the excessive concentration study and the EBD study have been approved by EPA on numerous occasions. Table 7 provides a list of past projects CPP has conducted of a related nature. Most of these projects have had protocols reviewed and approved by the State and/or EPA.

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2.0 TECHNICAL CONSIDERATIONS

2.1 Determination of Equivalent Building Dimensions

The basic modeling approach for determining equivalent building dimensions is to first document, in the wind tunnel, the dispersion characteristics as a function of wind direction at the site with all significant nearby building wake effects included. Next, the dispersion is characterized, in the wind tunnel, with an equivalent building positioned directly upwind of the stack in place of all nearby buildings (i.e., the Huber/Snyder setup as shown in Figure 1). This testing is conducted for various equivalent buildings until an equivalent building is found that provides a profile of maximum ground level concentration versus downwind distance that is similar (within the constraints defined below) to that with all site structures in place.

The criteria for defining whether or not two concentration profiles are similar is to determine the smallest building which: 1) produces an overall maximum concentration exceeding 90 percent of the overall maximum concentration observed with all site structures in place; and 2) at all other longitudinal distances, produces ground-level concentrations which exceed the ground-level concentration observed with all site structures in place less 20 percent of the overall maximum ground-level concentration with all site structures in place. This criteria has been accepted on past EPA approved EBD studies (Petersen and Cochran, 1995a, 1995b; McBee, 1995; Thornton, 1995) and is a suggested approach in the Tikvart (1994) memorandum.

To demonstrate the method for specifying the equivalent building, consider Figure 2 which shows a typical result from a previous study. The figure shows the maximum ground level concentration versus downwind distance for five different equivalent buildings and the maximum concentration measured with site structures in place. Within this figure the concentration profile for EB2 meets the first criteria in that the maximum measured concentration is at least 90 percent of the maximum concentration measured with the site structures in place. However, the EB2 profile fails the second criteria at the third actual site data point (at approximately 200 m downwind) where the lower bound of the error bar exceeds the interpolated concentration value for EB2. Therefore, the equivalent building for the test case shown in Figure 2 is EB3, since EB3 is the smallest equivalent building which meets both criteria.

Modeling the Airflow and Dispersion

To simulate the airflow and dispersion around the buildings, the following criteria will be met as recommended by EPA (1981) or Snyder (1981):

- all buildings within a 518 m (1700 ft) radius of the stacks will be modeled at a 1:300 scale reduction. This ensures that all buildings whose critical dimension (lesser of height or width) exceeds 1/20th of the distance from the source are included in the model;

- the mean velocity profile through the entire depth of the boundary layer will be represented by a power law $U/U_\infty = (z/z_\infty)^n$ where the power law exponent, n, is dependent on the value of surface roughness, z_0, through the following equation:

$$n = 0.24 + 0.096 \log_{10} z_o + 0.016 \left(\log_{10} z_o\right)^2 \quad ; \qquad (6)$$

- Reynolds number independence will be ensured: the building Reynolds number ($Re_b = U_b H_b / \nu_a$; the product of the wind speed, U_b, at the building height, H_b, times the building height divided by the viscosity of air, ν_a) will be greater than 11,000 and Reynolds number independence tests will be conducted to determine the minimum acceptable operating conditions;

- the surfaces of buildings will not be covered with roughness elements, since the buildings are sharp edged and have many roughness protuberances; and

- a neutral atmospheric boundary layer will be established (Pasquill–Gifford C/D stability) by setting the bulk Richardson number (Ri_b) equal to zero in model and full scale.

Summary

Using the above criteria and the source characteristics shown in Table 1, the model test conditions were computed for the Units 1 and 2 stacks. The model test conditions were computed for D stability and an 11 m/s wind speed at the anemometer (100 m height) and are shown in Tables 2a and 2b for Units 1 and Unit 2 respectively. The wind speed used in the tables is the 2% wind speed, which is discussed in Section 2.6.

2.4 Emission Rates

Since no comparison with NAAQS is required for determining equivalent building dimensions, actual emission rates are not required. For convenience purposes, a 1 g/s emission rate will be used for this study. With this convention, the concentration results can be converted to full scale concentrations by multiplying the reported concentrations by the actual emission rates. For the excessive concentration demonstration tests, full scale concentrations will be computed using the existing emission rates as summarized in Table 1. Full scale concentrations are needed to show an exceedance of NAAQS for the excessive concentration demonstration.

2.5 Nearby Structures

To evaluate the effect of the nearby structures, tests are first conducted with all significant structures present in the model (referred to as "building in" tests). Next, the same meteorological conditions are simulated but all nearby structures are removed (referred to as "building out" tests). For the structures to be considered nearby for wind tunnel modeling purposes, the stack must be within 1/2 mile of the structure (see 40 CFR 51.1 (jj) (2)). For the purpose of applying the EPA formula, structures are classified as nearby when the stack is closer than 5 times the lesser of the height or width of the structure (L).

2.6 Test Wind Speed and Wind Direction

The EPA stack height guideline (EPA, 1981) recommends that the design wind speed for GEP stack height and excessive concentration evaluations be less than the 2 percent wind speed (the wind speed that is exceeded less than 2 percent of the time) unless it can be demonstrated that higher wind speeds cause an exceedance of NAAQS limits. This speed will be set as the limiting speed for all EBD and excessive concentration tests.

The 2 percent wind speed was determined by analyzing meteorological data collected at the site for the period January 1994 - November 1995 (23 months of data). The meteorological tower includes wind speed and wind direction sensors at 10, 70, and 100 m. The tower is located approximately 950 m south of the station at the same base elevation of 207 ft, MSL. The wind speeds at the 100 m level were selected as representative for this study since the stack heights under evaluation will be closest to this height.

Figure 3 shows the 1994 wind rose and Figure 4 shows the cumulative frequency distribution of wind speeds (includes all 23 months of data) at the 100 m level height. Figure 3 shows that the prevailing wind direction is NW and Figure 4 shows that the overall 2 % (98% percentile) wind speed is 11 m/s. Accordingly all testing to determine excessive concentrations and EBD will be conducted at speeds equal to or less than 11 m/s at the 100 m height.

Wind speeds in the tunnel will be set at a reference height of 300 m above plant grade. The speed at this reference height will be determined by scaling the nearby anemometer wind speed up to the reference height, 300 m above ground level, using the following power law equation:

$$U_r = U_{anem} \left(\frac{z_r}{z_{anem}} \right)^{ns} \tag{4}$$

where

U_r	=	wind speed at reference height (m/s),
z_r	=	reference height above plant grade (300 m),
U_{anem}	=	wind speed at the anemometer (m/s),
z_{anem}	=	height above grade for U_{anem} (m),
ns	=	wind power law exponent at the site (0.23) actually (0.233...)

It should be noted that the power law exponent was calculated using the following equation from Snyder (1981).

$$n = 0.24 + 0.096 \log_{10} z_o + 0.016 \left(\log_{10} z_o\right)^2 \tag{5}$$

A surface roughness length for the site was established in the Dispersion Modeling Protocol. The values prescribed were 0.5 m for winter, 1.0 m for spring, 1.3 m for summer and 0.8 m for fall. For the purpose of the wind tunnel study, a logarithmic average of the above values (0.85 m) will be used as the target surface roughness length.

2.7 Data Acquisition

The EPA stack height guideline (EPA, 1981) requires that certain information be collected for GEP stack height and excessive concentration demonstrations. Past precedent (Petersen and Cochran, 1993, 1995a, 1995b) suggests that this information is also needed for EBD type studies. Hence, the data that will be collected are summarized below.

- Three vertical profiles of mean velocity, and vertical and longitudinal turbulence intensity and shear stress—for Atmospheric Dispersion Comparability (ADC) and excessive concentration tests (see Section 3.3 for a discussion on the ADC tests).
- Lateral profiles of mean velocity and turbulence intensity along the model surface and at a height close to plume altitude near the stack location and near the end of the planned study area (six profiles)—for ADC and excessive concentration tests.
- Vertical and lateral concentration profiles through the plume centerline—three for ADC tests and four for excessive concentration tests.
- Ground-level longitudinal profiles of concentration along the plume centerline—for ADC, Reynolds number and excessive concentration tests.
- Two to four lateral ground-level concentration profiles including one at the position of maximum ground-level concentration—excessive concentration tests.

In addition to the required data, a series of ground-level concentration measurements will be obtained to define the excessive concentration and EBD. Table 3 summarizes the required measurements that will be obtained during this study. Tables 4, 5 and 6 summarize the concentration measurements that are planned. Visual documentation on all portions of the study will be obtained in the form of still photographs and video recording. The measurement plan is discussed in more detail in Section 3.

The wind tunnel and instrumentation that will be used to collect the data are described in Appendix B.

2.8 Quality Control

To ensure that accurate and reliable data are collected for assessing the plume transport and dispersion, certain quality control steps will be taken. These include:

- use of blended mixtures of pure gases or certified mixtures for stack source gas;
- multipoint calibration of hydrocarbon analyzer with certified standard gas;
- calibration of stack flow measuring device with soap bubble meter;
- calibration of velocity measuring device with mass flow meter;
- wind tunnel testing to show the Reynolds number independence of the concentration measurements;
- comparison of wind tunnel diffusion and velocity characteristics with those observed in the atmosphere;
- adjustment of tunnel roof so that blockage effects are less than 5 percent.

3.0 PROJECT PLAN

To meet the project objectives, a seven phase study is planned. The seven phases, which are discussed in detail below, are: 1) site visit and test protocol development; 2) model construction; 3) wind tunnel testing—documentation tests; 4) visualization and meeting at CPP; 5) wind tunnel testing—excessive concentration determination; 6) wind tunnel testing—equivalent building dimension determination; and 7) reporting. The details of each phase are described in more detail below.

3.1 Site Visit and Test Protocol Development

During this phase of the project, the test protocol will be developed and finalized. Before testing begins, protocol approval from NHDES and EPA Region I will be obtained.

Prior to developing the protocol, the project manager traveled to the site to obtain first hand knowledge about the site and to obtain site photographs that will subsequently be used to aid in the construction of the scale model. Also at that time, any missing information related to source characteristics and plant drawings was obtained or specified.

3.2 Model Construction

After the test protocol is approved, a 1:300 scale model of the MGS and surrounding structures will be constructed. The model will include all significant structures within a 518 m (1700 ft) radius of the center of the stacks under evaluation. The area to be modeled is shown in Figure 5 and a closeup view of the main structures is shown in Figure 6. The model will be placed on a turntable so that different wind directions can be easily evaluated. Roughness elements, for positioning upwind and downwind of the turntable, will be constructed to represent the upwind roughness configuration (a 0.85 m surface roughness length). Flow conditioning devices, consisting of a 2-dimensional trip and a pair of spires, will be placed upwind of the model to aid in the development of the boundary layer. This setup is shown schematically in Figure 7.

A set of solid structures, all with height to width ratios similar to those used by Huber and Snyder (1982) for development of the ISC downwash algorithm, will be fabricated for placement directly upwind of each stack. These structures will be used to determine the equivalent building dimensions. The MGS stacks and idealized buildings will be tested with the turntable model removed from the wind tunnel and a uniform roughness installed in its place. The uniform roughness will be constructed such that it provides the same surface roughness as the MGS model. Velocity profiles will be collected to verify the setup. A plan view of this setup in the wind tunnel is shown in Figure 8.

Stacks will be constructed of plexiglass or brass tubes and will be supplied with a premixed certified air–helium–hydrocarbon mixture of the appropriate density. Measures will be taken to ensure that the flow is fully turbulent upon exit. A precision gas flow meter will be used to monitor and regulate the discharge velocity. For some tests, both stacks will be operating simultaneously with a different tracer gas emitted from each stack (methane and ethane).

Concentration sampling taps will be installed on the surface of the model so that at least 45 locations will be sampled simultaneously for each simulation. A typical sampling grid consists of 5 to 7 receptors located in each of 7 rows that are spaced perpendicular to the wind direction. Two background samples are located upwind of the stacks. The lateral and longitudinal spacing of receptors is designed so that the maximum concentration is defined in the horizontal and downwind directions. Initial testing is conducted to confirm the grid design and to alter the design if necessary. A typical sampling grid is shown in Figure 9.

3.3 Wind Tunnel Testing—Documentation Tests

Before conducting the detailed wind tunnel testing, a series of wind tunnel documentation tests will be conducted as recommended by EPA (1981). The tests include: 1) atmospheric dispersion comparability (ADC) tests, and 2) Reynolds number tests. Tables 3 and 4 summarize the tests that will be conducted.

The ADC tests are conducted in the absence of buildings, other surface structures, large roughness and/or elevated terrain to show that dispersion in the wind tunnel is comparable to that described for the atmosphere by the basic Gaussian plume distribution. Concentration measurements for these tests must show comparability to field estimates for a similar surface roughness and stability—typically Pasquill/Gifford class C or D. The procedures for conducting these tests are specified in an EPA guideline and will be followed as appropriate.

For the Reynolds number tests, a scale model of the MGS and vicinity will be installed in the wind tunnel. A tracer gas will then be emitted from the model stacks. Ground-level concentration measurements will then be taken downwind of the stacks for three different wind speeds (i.e., Reynolds numbers). If Reynolds number effects are negligible, the normalized concentration results should be equivalent (within ±10 percent). The minimum test speed will be chosen such that Reynolds number effects are negligible.

3.4 Visualization and Meeting at CPP

After the documentation tests are completed, a visualization of plume behavior for various wind directions and speeds will be conducted. It is recommended that the client be present during this portion of the study. Representatives from NHDES and/or EPA Region I are also invited to attend the visualization. The visualization will provide a qualitative understanding of the effect of the structures on dispersion and will provide information that can be used to finalize the remaining phases of the study. At this time CPP's testing procedures can also be observed.

3.5 Wind Tunnel Testing—Excessive Concentration Demonstration

Before credit for stack height increases up to the GEP stack height can be obtained, the EPA requires that an excessive ground-level concentration be demonstrated for the existing stack. The two part definition of excessive concentration requires that the downwash, wakes or eddies induced by nearby structures result in increases in ground-level pollutants that:

1) are at least 40 percent in excess of concentrations projected to occur in the absence of nearby structures; and

2) cause or contribute to an exceedance of NAAQS.

To show whether excessive concentrations exist, tests will first be conducted for the existing stacks with all buildings present and then with all nearby buildings removed. If the ratio of the maximum concentration for each of the stacks under evaluation is at least 40 percent greater with the nearby buildings present than without the buildings present, then the first criteria will be satisfied.

Next, the maximum concentration due to the combined impact of the two stacks will be added to the background concentration for the region, and compared with NAAQS. If this concentration is greater than NAAQS, the second criteria for demonstrating an excessive concentration will have been satisfied. The EPA regulations then permit credit in regulatory modeling for stack height increases up to the GEP formula stack height. If a stack height taller than the formula is sought, a wind tunnel demonstration of the GEP height is required. Only heights at or below the formula height will be considered in this evaluation.

To determine whether excessive concentrations occur, the tests in Table 5 will be conducted. The first series of tests locate the wind direction and speed where an excessive concentration occurs. Once an excessive concentration is demonstrated, the documentation tests summarized in Table 3 and 5 will be conducted. These tests include:

- vertical and horizontal measurements of air flow characteristics within the region over which concentration measurements were obtained;
- repetitive tests with and without nearby structures present to demonstrate the tests were repeatable and that the maximum ground-level concentration was measured;
- elevated measurements of horizontal and vertical concentration distributions at several locations downwind of the stack under evaluation; and
- calculations of horizontal and vertical dispersion coefficients, and their variation with downwind distance.

3.6 Wind Tunnel Testing—Equivalent Building Dimensions

The purpose of this phase of the study is to define the equivalent building dimensions (EBD) that can be input into ISC for the new stacks. Previous experience has shown that equivalent building dimensions are insensitive to stack height or should decrease with increased stack height (Petersen and Cochran, 1993, 1995a, 1995b). For this reason, a stack shorter than the maximum that will be considered will be evaluated for the EBD determinations. This means that the resulting EBD values will be conservative (i.e., larger than if a taller stack height would have been evaluated).

Table 6 summarizes the equivalent building dimension concentration test matrix for the existing stacks. BPIP will first be run to determine the critical wind directions for building downwash effects. It has been assumed that this analysis will result in a reduced number of tests. It has been assumed that only 18 wind directions will be required for determining EBD. Two different tracer gases will be released from the two stacks and maximum ground-level concentrations

FIGURES

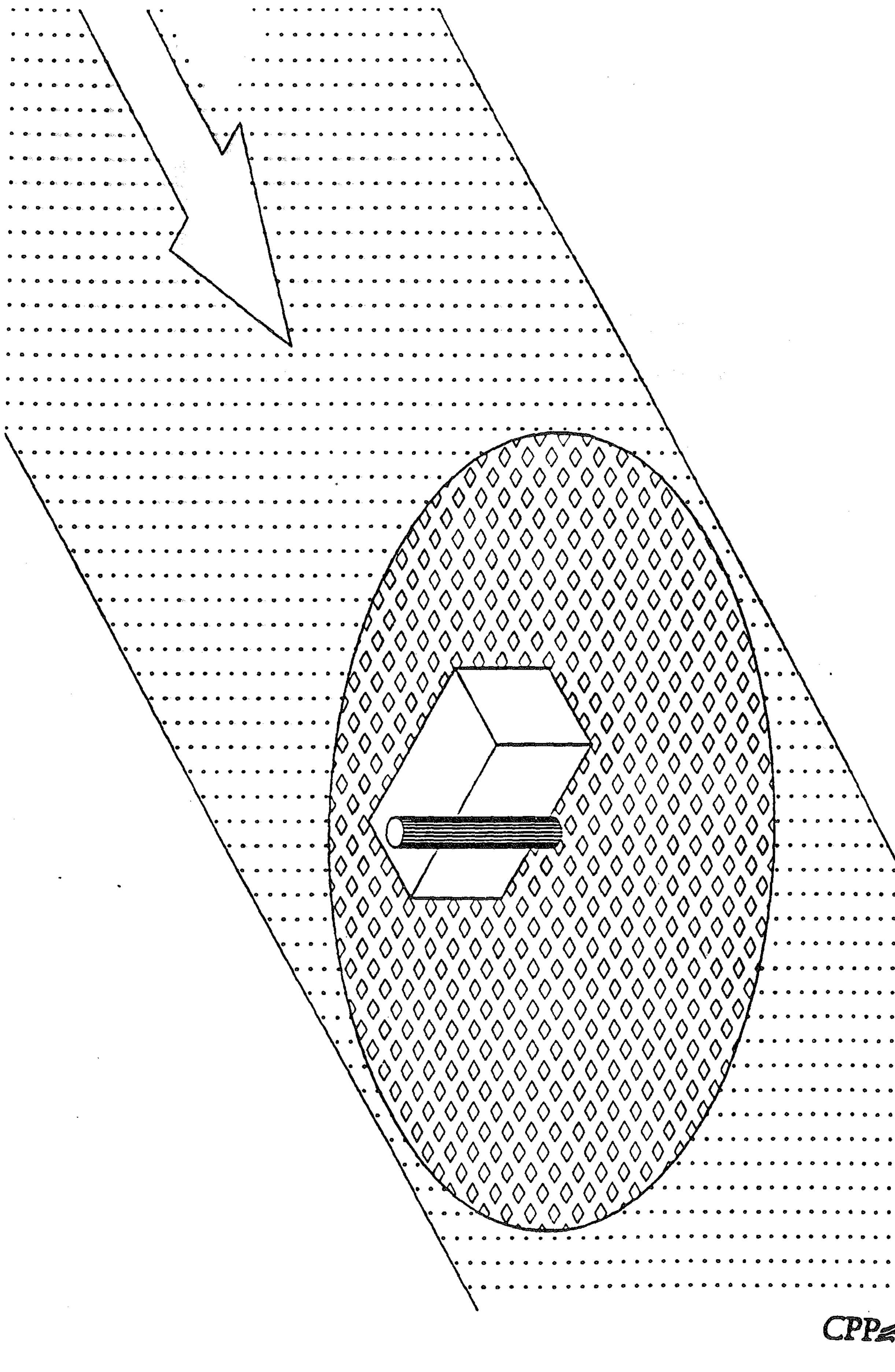

Figure 1. ISC idealized building and stack configuration and EBD wind tunnel setup.

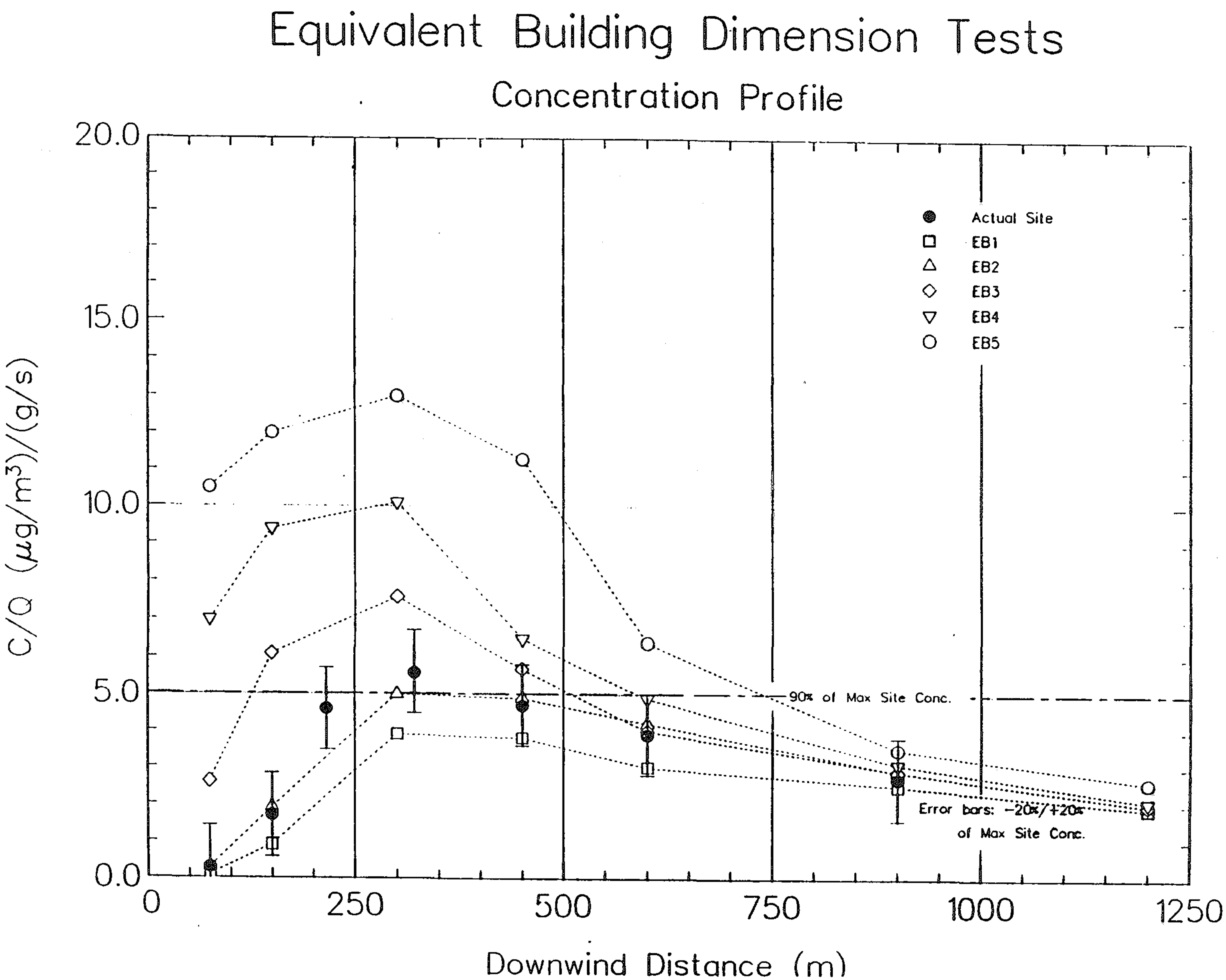

Figure 2. Typical results from a previous equivalent building determination.

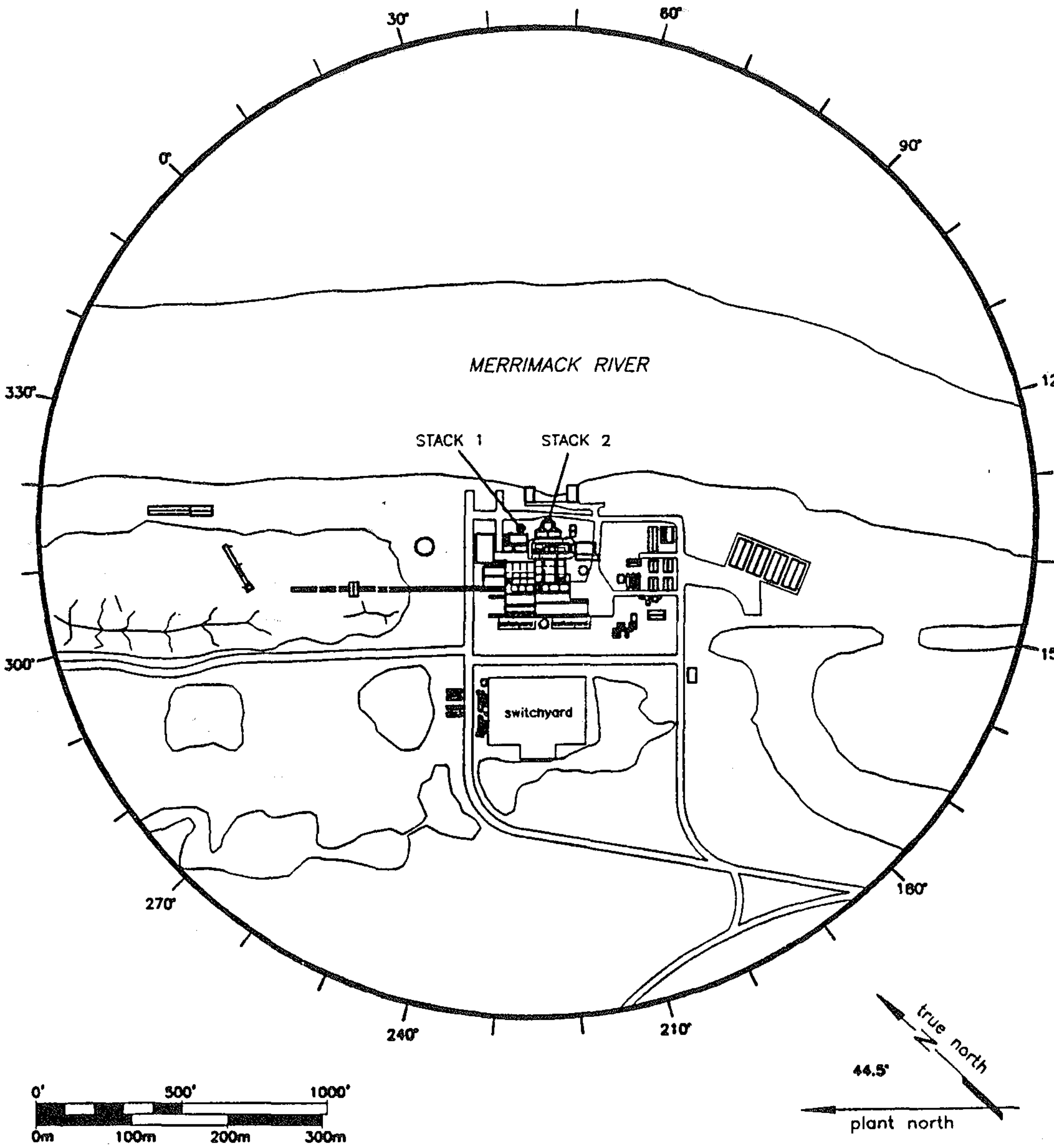

Figure 5. Site plan of area to be modeled in wind tunnel study.

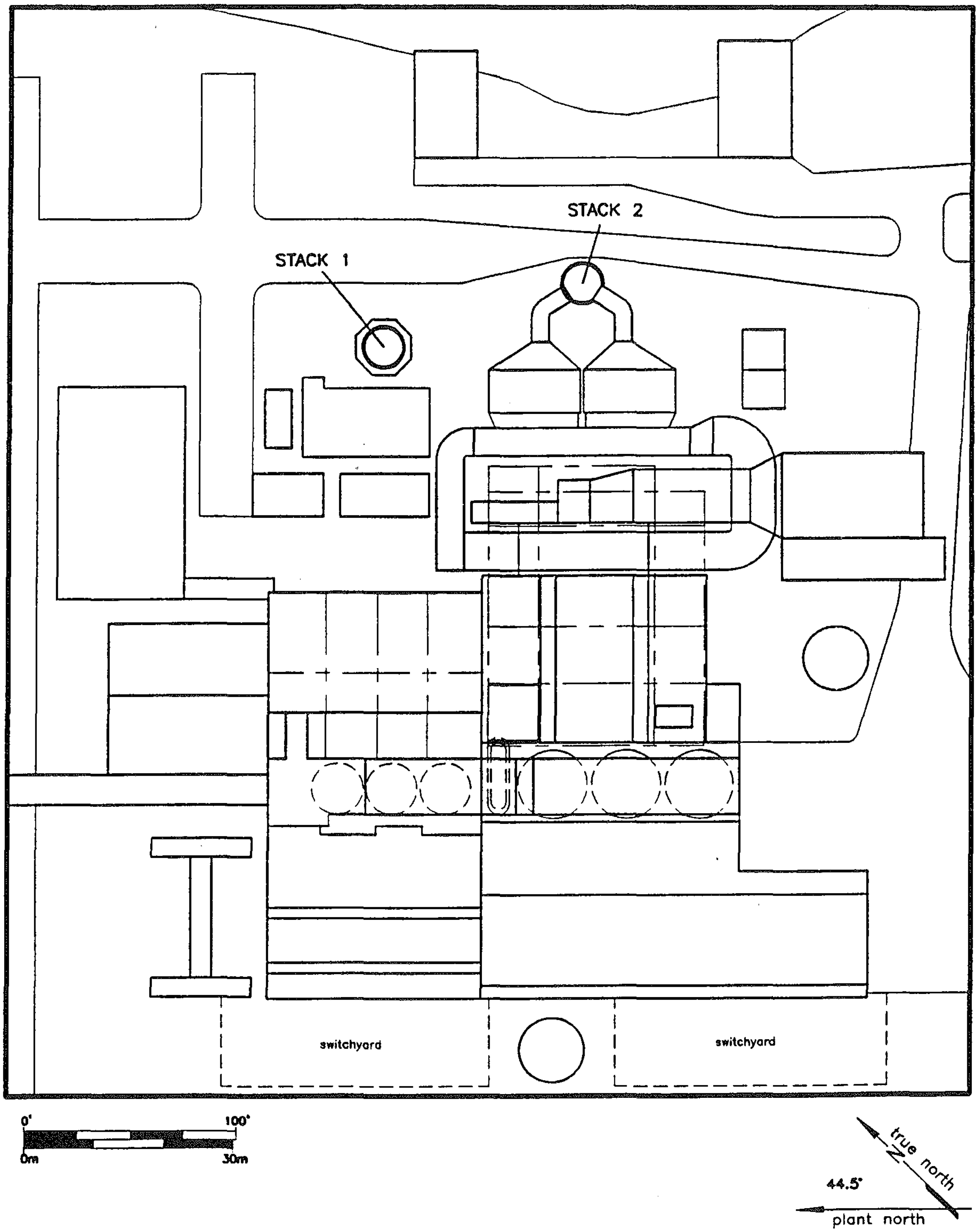

Figure 6. Plan view of the main structures that will be modeled.

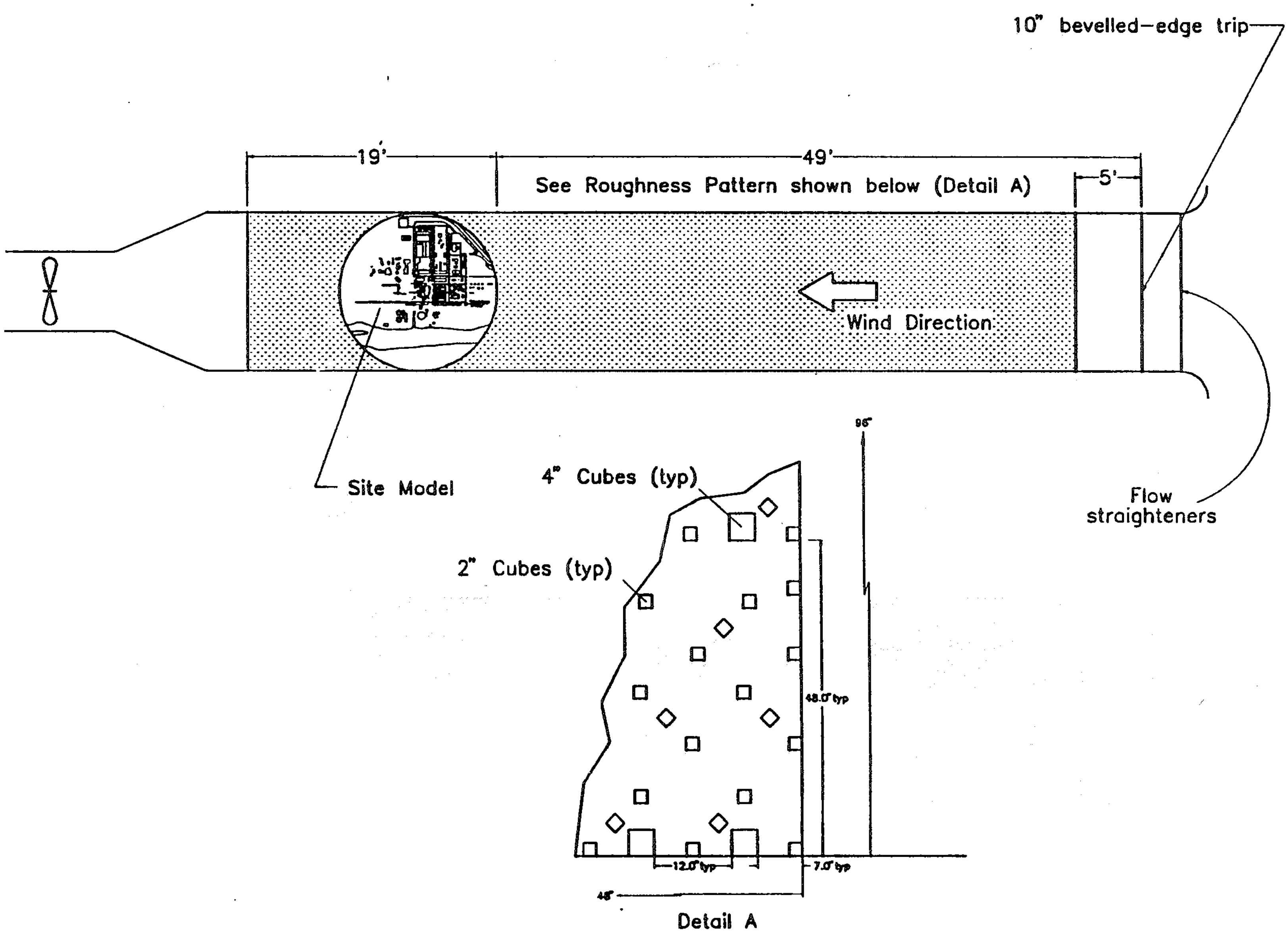

Figure 7. Wind tunnel setup for tests with site model

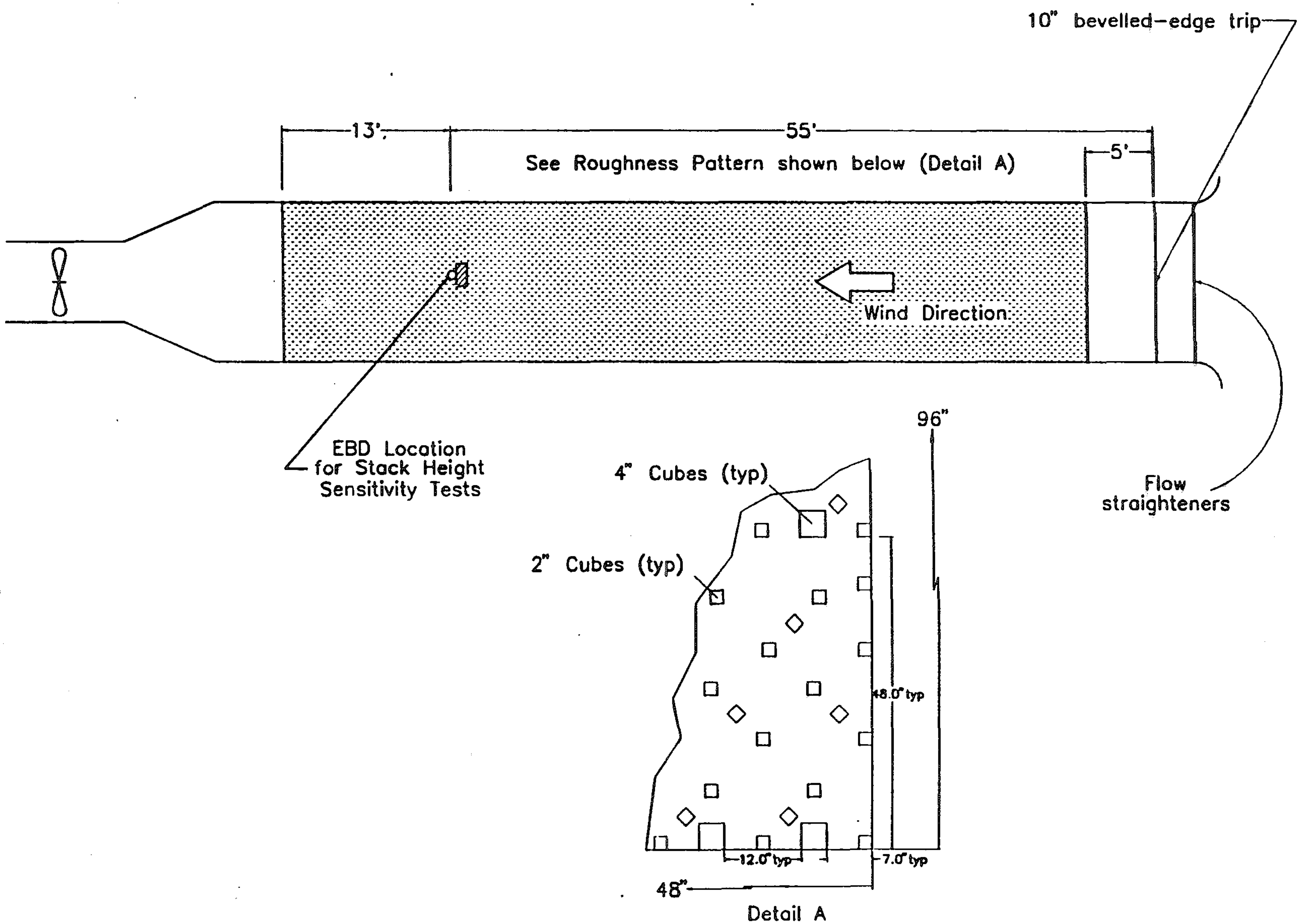

Figure 8. Wind tunnel setup for tests with equivalent buildings.

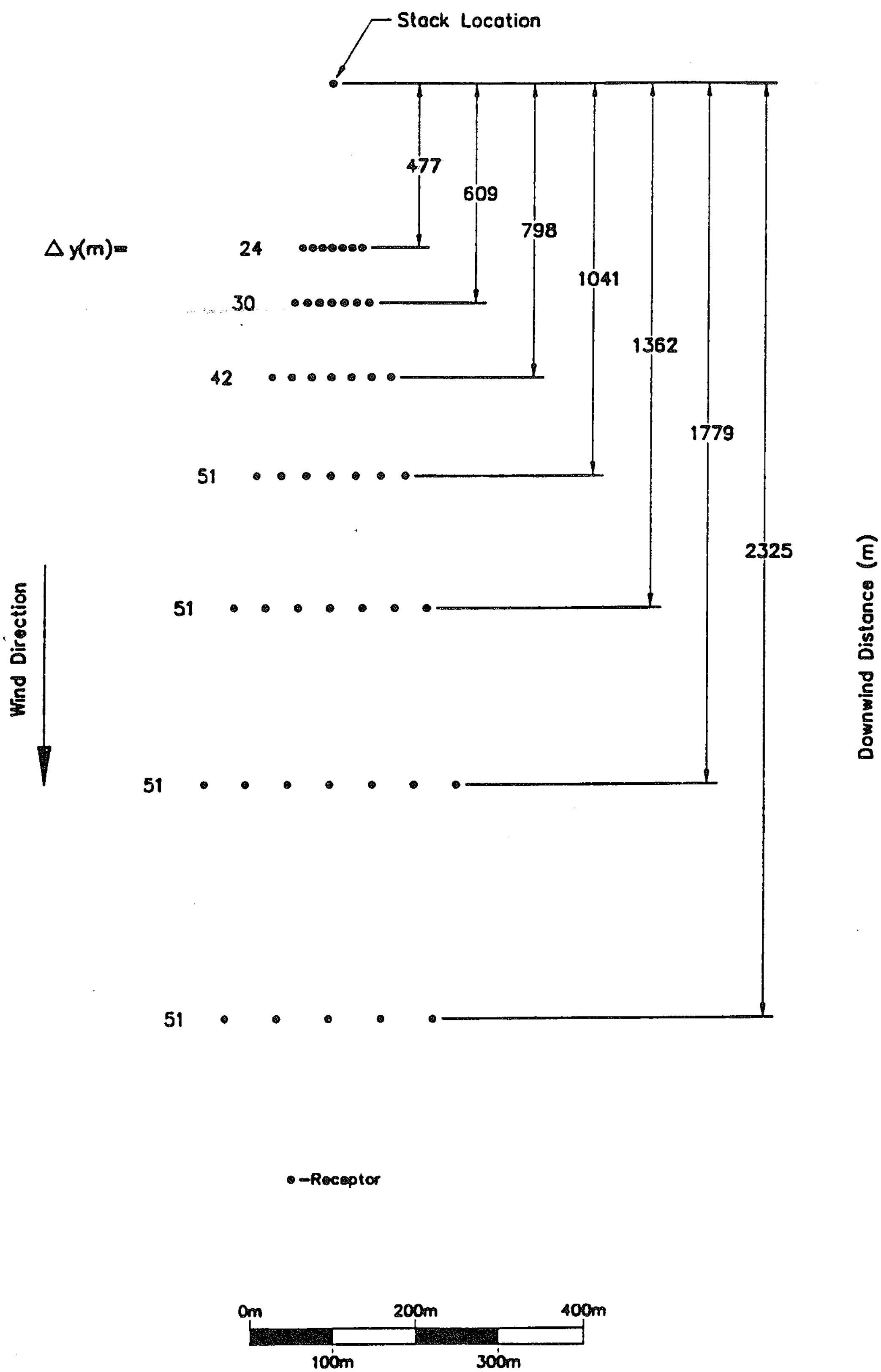

Figure 9. Typical ground-level concentration sampling grid.

TABLES

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Table 1
Source Parameters for Stack Being Evaluated

English Units

Source Description	Stack ID	Typical Building Height (ft)	Stack Height (ft)	Stack Base (ft, MSL)	Exit Diameter (ft)	Exit Temperature (deg F)	Volume Flow Rate (cfm)	Exit Velocity (fpm)	Emission Rates SO2 (lb/hr)
Merrimack Station Unit 1	MSU1	182	227.0	206.0	8.50	300.0	479,995	8458.8	3195.1
Merrimack Station Unit 2	MSU2	182	319.0	206.0	14.5	335.0	1,200,032	7267.2	9319.1

Metric Units

Source Description	Stack ID	Typical Building Height (m)	Stack Height (m)	Stack Base (m, MSL)	Exit Diameter (m)	Exit Temperature (deg K)	Volume Flow Rate (m3/s)	Exit Velocity (m/s)	Emission Rates SO2 (g/s)
Merrimack Station Unit 1	MSU1	55.49	69.2	62.8	2.59	422.0	226.5	43.0	402.9
Merrimack Station Unit 2	MSU2	55.49	97.2	62.8	4.42	441.5	566.4	36.9	1175.2

Notes:
1) Source information supplied in November 20, 1995 Proposal

Other Simulation Factors

1) Site Surface Roughness Length (m)	0.85
2) Anemometer Site Surface Roughness Length (m)	0.85
3) Reference Height ,Zr (m)	300
4) Anemometer Height, Zanem (m)	100
5) 2% Wind Speed at Anemometer (m/s)	11
6) Model Scale	300

Table 2a

Full and Model Scale Similarity Parameters

Anemometer Speed 11.0 (m/s)

Source Description: Merrimack Station Unit 1

		English Full-Scale	Full Scale	Model Scale
	Dimensional Parameters			
1 .	Building Height, Hb (m)	182.0 ft	55.5	0.1849
2 .	Base Elevation above Mean Sea Level, z = 0 (m)	206 ft	62.8	1524
3 .	Stack Height above grade, h (m)	227.0 ft	69.2	0.2306
4 .	Stack Inside Diameter, d (m)	8.5 ft	2.59	8.636E-03
5 .	Stack Inside Area, Ae (m2)	56.7 ft2	5.3	5.858E-05
6 .	Exit Velocity, Ve (m/s)	8459 fpm	43.0	12.093
7 .	Exit Temperature, Ts (K)	300.0 F	422.0	293.2
8 .	Volume Flow Rate, V (m3/s)	479,995 ft3/min	226.5	7.083E-04
9 .	Emission rate, Q (g/s)	3195.1 lb/hr	402.6	NA
10 .	Ambient Pressure, Pa (hPa)	0.99 Atm	1005	844
11 .	Ambient Temperature, Ta (K)	56.0 F	286.5	293.2
12 .	Air Density, Rho a (kg/m3)	0.076 lb/ft3	1.2	1.004
13 .	Exhaust Density, Rho s (kg/m3)	0.052 lb/ft3	0.8	0.681
14 .	Air Viscosity, Nu a (m2/s)	1.57E-04 ft2/s	1.46E-05	1.81E-05
15 .	Gas Viscosity, Nu s (m2/s)	3.08E-04 ft2/s	2.86E-05	1.72E-05
16 .	Free Stream Wind Speed, Uinf (m/s)	37.4 mph	16.71	4.702
17 .	Free Stream Height, Zinf (m)	1969 ft	600.00	2.00
18 .	Reference Wind Speed, Uref (m/s)	31.8 mph	14.21	4.000
19 .	Reference Height, Zref (m)	984 ft	300.00	1.00
20 .	Anemometer Wind Speed, Uanem (m/s)	24.6 mph	11.00	3.10
21 .	Anemometer Height, Zanem (m)	328.1 ft	100.00	0.333
22 .	Site Wind Speed, Usite (m/s)	24.6 mph	11.00	3.10
23 .	'Site Anemometer' Height, Zsite (m)	328.1 ft	100.00	0.333
24 .	Stack Height Speed, Uh (m/s)	22.6 mph	10.09	2.84
25 .	Building Height Speed, Ub (m/s)	21.4 mph	9.59	2.70
26 .	Anemometer Surface Roughness Length, Zo a (m)	2.79 ft	0.85	2.83E-03
27 .	Site Surface Roughness Length, Zo s (m)	2.79 ft	0.85	2.83E-03
28 .	Site Surface Friction Velocity, U* (m/s)	1.94 mph	0.87	0.24
	Dimensionless Parameters			
29 .	Length Scale, SF	300	300	1
30 .	Time Scale, TS	84.43	84.43	1.00
31 .	Anemometer Power Law Exponent, na	0.23	0.233	0.23
32 .	Site Power Law Exponent, ns	0.23	0.233	0.23
33 .	Velocity Ratio, R = Ve/Ur	3.02	3.02	3.02
34 .	Stack Velocity Ratio, Rs = Ve/Uh	4.26	4.26	4.26
35 .	Stack Height to Building Height Ratio, h/Hb	1.25	1.25	1.25
36 .	Diameter to Stack Height Ratio, d/h	0.037	0.037	0.037
37 .	Momentum Ratio, Mo	8.70E-03	8.70E-03	8.70E-03
38 .	Froude Number, Fr	12.39	12.39	60.40
39 .	Buoyancy Ratio, Bo	1.14E-03	1.14E-03	4.81E-05
40 .	Density Ratio, Lambda	0.6788	0.6788	0.6788
41 .	Stack Reynolds Number (Exterior), d Uh / Nu a	1.80E+06	1.80E+06	1358
42 .	Stack Flow Reynolds Number (Interior), Re s = d Ve / Nu s	3.89E+06	3.89E+06	6057
43 .	Building Reynolds Number, Re b = Hb Ub / Nu a	3.65E+07	3.65E+07	27613
44 .	Surface Reynolds Number, Zo s U* / Nu a	5.08E+04	5.08E+04	38
45 .	Site Friction Velocity Ratio, U*/Uinf	0.052	0.052	0.052

Table 2b
Full and Model Scale Similarity Parameters
Anemometer Speed 11.0 (m/s)
Source Description: Merrimack Station Unit 2

	English Full-Scale		Full Scale	Model Scale
Dimensional Parameters				
1 . Building Height, Hb (m)	182.0	ft	55.47	0.1849
2 . Base Elevation above Mean Sea Level, z = 0 (m)	206.0	ft	62.79	1524
3 . Stack Height above grade, h (m)	319.0	ft	97.23	0.3241
4 . Stack Inside Diameter, d (m)	14.50	ft	4.42	1.473E-02
5 . Stack Inside Area, Ae (m2)	165.13	ft2	15.34	1.705E-04
6 . Exit Velocity, Ve (m/s)	7267.2	fpm	36.92	10.389
7 . Exit Temperature, Ts (K)	335.0	F	441.48	293.2
8 . Volume Flow Rate, V (m3/s)	1200032	ft3/min	566.35	1.771E-03
9 . Emission rate, Q (g/s)	9319.1	lb/hr	1174.18	NA
10 . Ambient Pressure, Pa (hPa)	0.99	Atm	1005.41	844
11 . Ambient Temperature, Ta (K)	56.00	F	286.48	293.2
12 . Air Density, Rho a (kg/m3)	0.08	lb/ft3	1.22	1.004
13 . Exhaust Density, Rho s (kg/m3)	0.05	lb/ft3	0.79	0.651
14 . Air Viscosity, Nu a (m2/s)	0.00	ft2/s	0.00	1.81E-05
15 . Gas Viscosity, Nu s (m2/s)	0.00	ft2/s	0.00	1.36E-05
16 . Free Stream Wind Speed, Uinf (m/s)	37.38	mph	16.71	4.702
17 . Free Stream Height, Zinf (m)	1968.5	ft	600.00	2.00
18 . Reference Wind Speed, Uref (m/s)	31.80	mph	14.21	4.000
19 . Reference Height, Zref (m)	984.3	ft	300.00	1.00
20 . Anemometer Wind Speed, Uanem (m/s)	24.61	mph	11.00	3.10
21 . Anemometer Height, Zanem (m)	328.08	ft	100.00	0.333
22 . Site Wind Speed, Usite (m/s)	24.61	mph	11.00	3.10
23 . 'Site Anemometer' Height, Zsite (m)	328.08	ft	100.00	0.333
24 . Stack Height Speed, Uh (m/s)	24.45	mph	10.93	3.08
25 . Building Height Speed, Ub (m/s)	21.45	mph	9.59	2.70
26 . Anemometer Surface Roughness Length, Zo a (m)	2.79	ft	0.85	2.83E-03
27 . Site Surface Roughness Length, Zo s (m)	2.79	ft	0.85	2.83E-03
28 . Site Surface Friction Velocity, U* (m/s)	1.94	mph	0.87	0.24
Dimensionless Parameters				
29 . Length Scale, SF	300.0		300.0	1
30 . Time Scale, TS	84.4		84.4	1.00
31 . Anemometer Power Law Exponent, na	0.23		0.23	0.23
32 . Site Power Law Exponent, ns	0.23		0.23	0.23
33 . Velocity Ratio, R = Ve/Ur	2.60		2.60	2.60
34 . Stack Velocity Ratio, Rs = Ve/Uh	3.38		3.38	3.38
35 . Stack Height to Building Height Ratio, h/Hb	1.75		1.75	1.75
36 . Diameter to Stack Height Ratio, d/h	0.05		0.045	0.045
37 . Momentum Ratio, Mo	0.01		0.009	0.009
38 . Froude Number, Fr	7.62		7.62	37.15
39 . Buoyancy Ratio, Bo	0.00		0.00	9.36E-05
40 . Density Ratio, Lambda	0.65		0.65	0.6489
41 . Stack Reynolds Number (Exterior), d Uh / Nu a	3.32E+06		3.32E+06	2508
42 . Stack Flow Reynolds Number (Interior), Re s = d Ve / Nu s	5.29E+06		5.29E+06	11284
43 . Building Reynolds Number, Re b = Hb Ub / Nu a	3.65E+07		3.65E+07	27613
44 . Surface Reynolds Number, Zo s U* / Nu a	50757.09		50757.09	38
45 . Site Friction Velocity Ratio, U*/Uinf	0.05		0.05	0.052

Table 3
Summary of Test Measurements as Required by EPA (1981)

		Measurement Locations					
Test Type	Measured Quantity	x	y	z	Traverse Direction	No. of Tests	
Atmospheric	T[1]	0	0	v	z	1	
Dispersion	$U, U'/U, W'/U, U_*/U$	0,L/2,L	0	v	z	3	
Comparability	$U, U'/U$	0,L	v	h/2,h,1.5h	y	6	
(ADC)	C	1,2,3	v	v	y,z	3	
Tests	C	v	v	0	x,y	1	
Documentation	$U, U'/U, W'/U, U_*/U$	0,L/2,L	0	v	z	3	
with	$U, U'/U$	0,L	v	h/2,h,1.5h	y	6	
Buildings	C	1,2,3,4	v	v	y,z	4	
Present	C	v	v	0	x,y	3	repeats
Documentation	$U, U'/U, W'/U, U_*/U$	0,L/2,L	0	v	z	3	
with	$U, U'/U$	0,L	v	h/2,h,1.5h	y	6	
Buildings	C	1,2,3,4	v	v	y,z	4	
Removed	C	v	v	0	x,y	3	repeats

Notation:

T — Ambient Temperature

U — Mean Velocity

U'/U — Longitudinal Turbulence Intensity

W'/U — Vertical Turbulence Intensity

U_*/U — Normalized Friction Velocity

C — Concentration

h — Stack Height

L — Length of Test Area from Stack

v — Variable

1,2,3,4 — Locations to be Determined

x — Longitudinal

y — Lateral

z — Vertical

[1]May be omitted if U is greater than 3 m/s

Table 4
Concentration Measurement Test Plan
Wind Tunnel Documentation Tests

Run No.	Stack Tested 1	Stack Tested 2	Stack Tested 3	Stack Height (m) 1	Stack Height (m) 2	Bldg. Config.	Wind-Tunnel Speed (Uref) (m/s)	Wind Directio	Test Type	Application of test
Atmospheric Dispersion Comparability (ADC) Tests										
101	ADC			100		N/A	3	N/A	GL	Documentation
102	ADC			100		N/A	3	N/A	HV-1	Documentation
103	ADC			100		N/A	3	N/A	HV-2	Documentation
104	ADC			100		N/A	3	N/A	HV-3	Documentation
Reynolds Number Independence Tests										
201	MSU1	MSU2		69.2	97.2	In	1.25	WD	GL	Documentation
202	MSU1	MSU2		69.2	97.2	In	2.50	WD	GL	Documentation
203	MSU1	MSU2		69.2	97.2	In	5.00	WD	GL	Documentation
204	MSU1	MSU2		69.2	97.2	Out	1.25	WD	GL	Documentation
205	MSU1	MSU2		69.2	97.2	Out	2.50	WD	GL	Documentation
206	MSU1	MSU2		69.2	97.2	Out	5.00	WD	GL	Documentation

Note: GL and HV-# refer to ground-level and horizontal-vertical concentration measurement arrays, respectively.
WD is a wind direction which will be selected once the model is installed in the wind tunnel.

Table 5
Concentration Measurement Test Plan
Excessive Concentration Demonstration Tests

Run No.	Stack Tested 1	Stack Tested 2	Stack Height (m) 1	Stack Height (m) 2	Bldg. Config.	Anemometer Speed (Uanem) (m/s)	Wind Direction	Test Type	Application of test
Preliminary Tests with Existing Stacks									
301	MSU1	MSU2	69.2	97.2	In	11	WD1	GL	Worst wind direction
302	MSU1	MSU2	69.2	97.2	In	11	WD2	GL	Worst wind direction
303	MSU1	MSU2	69.2	97.2	In	11	WD3	GL	Worst wind direction
304	MSU1	MSU2	69.2	97.2	Out	11	WD1	GL	Worst wind direction
305	MSU1	MSU2	69.2	97.2	Out	11	WD2	GL	Worst wind direction
306	MSU1	MSU2	69.2	97.2	Out	11	WD3	GL	Worst wind direction
307	MSU1	MSU2	69.2	97.2	In	8	WWD	GL	Worst wind speed
308	MSU1	MSU2	69.2	97.2	In	5	WWD	GL	Worst wind speed
309	MSU1	MSU2	69.2	97.2	Out	8	WWD	GL	Worst wind speed
310	MSU1	MSU2	69.2	97.2	Out	5	WWD	GL	Worst wind speed
Excessive Concentration Documentation Tests									
401	MSU1	MSU2	69.2	97.2	In	WWS	WWD	GL	Documentation
402	MSU1	MSU2	69.2	97.2	In	WWS	WWD	GL	Documentation
403	MSU1	MSU2	69.2	97.2	In	WWS	WWD	GL	Documentation
404	MSU1	MSU2	69.2	97.2	In	WWS	WWD	H/V	Documentation
405	MSU1	MSU2	69.2	97.2	In	WWS	WWD	H/V	Documentation
406	MSU1	MSU2	69.2	97.2	In	WWS	WWD	H/V	Documentation
407	MSU1	MSU2	69.2	97.2	In	WWS	WWD	H/V	Documentation
408	MSU1	MSU2	69.2	97.2	Out	WWS	WWD	GL	Documentation
409	MSU1	MSU2	69.2	97.2	Out	WWS	WWD	GL	Documentation
410	MSU1	MSU2	69.2	97.2	Out	WWS	WWD	GL	Documentation
411	MSU1	MSU2	69.2	97.2	Out	WWS	WWD	H/V	Documentation
412	MSU1	MSU2	69.2	97.2	Out	WWS	WWD	H/V	Documentation
413	MSU1	MSU2	69.2	97.2	Out	WWS	WWD	H/V	Documentation
414	MSU1	MSU2	69.2	97.2	Out	WWS	WWD	H/V	Documentation

Note: GL refers to ground-level concentration measurement arrays.
H/V refers to horizontal and vertical arrays at various downwind distances.
WWS and WWD are the wind speed and wind direction that produce the highest ground-level concentrations.

Table 6
Concentration Measurement Test Plan
Equivalent Building Dimension Tests

Run No.	Stack Tested 1	Stack Tested 2	Stack Height (m) 1	Stack Height (m) 2	Bldg. Config.	Anemometer Speed (Uanem) (m/s)	Wind Direction	Test Type	Application of test
Site Characterization with Buildings Present - Existing Stacks									
501	MSU1	MSU2	TBD	TBD	In	11	1	GL	Documentation
502	MSU1	MSU2	TBD	TBD	In	11	2	GL	Documentation
503	MSU1	MSU2	TBD	TBD	In	11	3	GL	Documentation
504	MSU1	MSU2	TBD	TBD	In	11	4	GL	Documentation
505	MSU1	MSU2	TBD	TBD	In	11	5	GL	Documentation
506	MSU1	MSU2	TBD	TBD	In	11	6	GL	Documentation
507	MSU1	MSU2	TBD	TBD	In	11	7	GL	Documentation
508	MSU1	MSU2	TBD	TBD	In	11	8	GL	Documentation
509	MSU1	MSU2	TBD	TBD	In	11	9	GL	Documentation
510	MSU1	MSU2	TBD	TBD	In	11	10	GL	Documentation
511	MSU1	MSU2	TBD	TBD	In	11	11	GL	Documentation
512	MSU1	MSU2	TBD	TBD	In	11	12	GL	Documentation
513	MSU1	MSU2	TBD	TBD	In	11	13	GL	Documentation
514	MSU1	MSU2	TBD	TBD	In	11	14	GL	Documentation
515	MSU1	MSU2	TBD	TBD	In	11	15	GL	Documentation
516	MSU1	MSU2	TBD	TBD	In	11	16	GL	Documentation
517	MSU1	MSU2	TBD	TBD	In	11	17	GL	Documentation
518	MSU1	MSU2	TBD	TBD	In	11	18	GL	Documentation
Equivalent Building Dimension Tests - Modification 1									
601	MSU1		TBD		BH1	11	N/A	GL	Documentation
602	MSU1		TBD		BH2	11	N/A	GL	Documentation
603	MSU1		TBD		BH3	11	N/A	GL	Documentation
604	MSU1		TBD		BH4	11	N/A	GL	Documentation
605	MSU1		TBD		BH5	11	N/A	GL	Documentation
606		MSU2		TBD	BH1	11	N/A	GL	Documentation
607		MSU2		TBD	BH2	11	N/A	GL	Documentation
608		MSU2		TBD	BH3	11	N/A	GL	Documentation
609		MSU2		TBD	BH4	11	N/A	GL	Documentation
610		MSU2		TBD	BH5	11	N/A	GL	Documentation

Note: GL refers to ground-level concentration measurement arrays.

27	Milliken Station	NY State Electric & Gas	X		NY	1992
28	Titus Generating Station	Metropolitan Edison	X		PA	1992
29	Taunton Energy Center	HMM Assoc.	X		MA	1992
30	Louisville Gas & Elect.	LG&E	X		KY	1992
31	Gilbert Station	Jersey Central Power & Light	X	X	NJ	1993
32	Public Svc Elect & Gas	PSE&G		X	NJ	1993
33	Homer City Generating Station	Pennsylvania Electric Co.	X		PA	1993
34	Cape Industries Bldg Ht.	Radian Corp.		X	NC	1993
35	Cambridge Electric Plant	Com Electric		X	MA	1993
36	District Energy	Labno Env Cons.		X	MN	1993
37	Muscatine Power/Grain Processing	ENSR Consult. & Eng.		X	IA	1994
38	Celco Plant	Hoechst Celanese	X	X	VA	1994
39	Westvaco Plant	ENSR Consult. & Eng.	X	X	SC	1994
40	Canton Mill	Champion	X	X	NC	1994
41	Astoria Station	Consolidated Edison	X	X	NY	1995
42	Montana Sulphur	Goetz Madden et al.	X		MT	1995

APPENDIX A

EQUIVALENT BUILDING DIMENSIONS FOR ISC2 MODELING APPLICATIONS

CPP

95-WA75A.05

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Equivalent Building Dimensions for ISC2 Modeling Applications

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INTRODUCTION

The treatment of downwash in the ISC2[1] model is based on a simple configuration consisting of a single solid rectangular building located immediately adjacent to and upwind of an exhaust stack. The downwash algorithm is based on wind tunnel studies conducted by Huber and Snyder[2,3] in which a solid structure with a width twice that of the height and depth was positioned directly upwind of a source stack as shown in Figure 1. While the downwash algorithm is appropriate for this simple configuration, it may not be appropriate for the more complex site configurations typically found at industrial facilities, such as when the structure is located at a distance from the stack or is tiered, porous, non-rectangular or otherwise varies from the basic configuration assumed in the ISC2 downwash algorithm. The ISC2 User's Guide[1] acknowledges this building wake prediction problem with the following statement concerning the building wake algorithm:

> "Their suggestions (Huber and Snyder) are principally based on the results of wind-tunnel experiments using a model building with a crosswind dimension double that of the building height.... Thus, the data reported by Huber and Snyder reflect a specific stability, building shape and building orientation with respect to the mean wind direction. It follows that the ISC2 Model wake-effects evaluation procedures may not be strictly applicable to all situations."

The ISC2 User's Guide further requires using the dimensions of the largest nearby building for the building dimension input for each wind direction modeled. Nearby in this case is defined as 5 L_b upwind, 0.5 L_b crosswind and 2 L_b downwind where L_b is the lesser of the building height or crosswind width. Thus, the dominant building need not be adjacent to or even upwind of the modeled stack as assumed in the basic algorithm development. An example of this disparity can be demonstrated for an upwind building near the 5 L_b criteria. If the building is slightly greater than 5 L_b away from the stack it is assumed to have *no* downwash influence on the stack, while the same structure just under 5 L_b is assumed to have the *full* downwash influence. This clearly results in a discontinuity in the downwash treatment since the downwash influence of a building is expected to decrease gradually as the distance from a stack approaches 5 L_b. Any reduction in the downwash which actually takes place due to the separation distance between the building and the stack is not accounted for when following the ISC2 User's Guide procedures for defining the building dimension input.

The geometry of the building can also have a dramatic impact on the resulting vertical dispersion patterns. The ISC2 downwash algorithm inherently assumes that the vertical plume dispersion patterns of "squat" buildings (building width greater than or equal to the building height) do not change with building geometry. Results of wind tunnel measurements recently conducted by Snyder and Lawson[4] indicate that the downwind vertical flow patterns vary dramatically for rectangular buildings with width to height ratios ranging from 1.0 to 4.0. For a cubical structure the building wake is substantially smaller than for a structure with a width four times the height. Thus, this would suggest that the vertical plume dispersion would be less for cubical structures.

The building shape will also affect the building downwash and can be dramatized by investigating the wake region behind a cube and a cylinder. Flow around a cube will separate at the leading edge and results in a relatively large wake region and high dispersion coefficients downwind of the cube. For a cylinder exposed to a turbulent environment, the flow will separate slightly downwind of the center of the cylinder perpendicular to the flow. Therefore, the wake region and subsequently the dispersion coefficients behind a cylinder will be less than that behind a cube. Thus, applying the ISC2 downwash algorithm using the actual dimensions of cylindrical structures may result in overestimates in ground-level concentrations.

The effect of porosity on the flow pattern downwind of a 3-dimensional structure has not been fully investigated. However, wind tunnel tests documenting the wake structure downwind of 2-dimensional windbreaks[5] confirm the expected premise that the size of the wake region behind the structure is proportional to the porosity of the structure. Thus the effect of the building wake on plume dispersion should be diminished for porous structures.

Based on the above, it is clear that the input of the actual building dimensions according to criteria in the ISC2 User's Guide may give inaccurate concentration estimates for many situations. A major enhancement to ISC2, therefore, could be obtained by adjusting the building dimension input into ISC2 such that the new dimensions allow ISC2 to better replicate the actual downwash when the building configuration is not consistent with the Huber/Snyder[1,2] geometry (see Figure 1). These adjusted building dimensions are referred to as "equivalent building dimensions" and can be determined by wind tunnel modeling.

At present, the only method the Environmental Protection Agency (EPA) has approved for determining EBD is through the use of wind tunnel modeling. Petersen[6,7] describes the first such study for which the protocol was reviewed and accepted by the EPA (Region V and RTP) and for which a permit was ultimately obtained.[8] That study considered the effect of a nearby lattice type (porous) structure. More recently, the EPA[9] has approved the equivalent building concept for regulatory modeling use on the basis that it is a source characterization study which is under the purview of the Regional Offices.

APPLICATION OF EBD TO THE HOECHST CELANESE FACILITY IN WILMINGTON, NORTH CAROLINA

This paper describes the application of the equivalent building concept for a regulatory modeling study of the Hoechst Celanese Facility in Wilmington, North Carolina. Hoechst Celanese is in the process of evaluating current operations to define their baseline emissions inventory as part of a 5 year Waste and Release Reduction (WARR) program. The initial phase of the WARR program was to develop an accurate estimate of emissions from current operations. Future modifications and expansions of the facility rely on accurate estimates of ground-level concentrations from existing sources. In addition, Hoechst Celanese, along with the entire chemical manufacturing community, will be subjected to increasingly more stringent environmental controls as a result of current and future legislation. Therefore, the accuracy of the model used to determine emissions and subsequent compliance has become increasingly more important.

The Hoechst Celanese Facility (HCF) consists of several chemical processing lines, each of which contains one or more emission sources. Many of these exhaust stacks are either directly adjacent to, or nearby open lattice-type structures. These lattice type structures generally consist of piping racks, cylindrical process vessels, and support structure for the chemical production process. Initial dispersion modeling conducted with ISC2 using dimensions of the lattice type structures, assuming the structures occupied a similar space as a non-porous, solid structure (i.e., those determined using the suggested procedures in the ISC2 User's Guide[1]) showed that unrealistically high concentrations would result due to building downwash effects.

The equivalent building dimensions for different exhaust stacks located at HCF were determined through wind tunnel modeling of plume dispersion and the atmospheric boundary layer. A 1:240 scale model of HCF shown in Figure 2 was constructed and placed in CPP's open-circuit atmospheric boundary layer wind tunnel. The ISCST2 model was then run with the equivalent building dimension inputs to provide a more accurate assessment of the ground-level concentrations downwind of each of the exhaust stacks. This enhancement to the ISCST2 model allowed Hoechst Celanese the opportunity to evaluate future plant modifications and expansions using more accurate ground-level concentration estimates.

A draft fluid modeling protocol for this study[10] was prepared and submitted to the State of North Carolina Department of Environment, Health and Natural Resources (DEHNR) for review and approval. The study was then conducted and the final report was subsequently approved by the State and EPA Region IV[11].

TECHNICAL BACKGROUND

Determination of Equivalent Building Dimensions

As discussed in the introduction, the equivalent building dimensions are the dimensions (height and width) that should be input into the ISC2 model to allow the model to produce realistic concentration estimates for sites where the actual building geometry is not consistent with the assumptions in the ISC2 wake algorithm. Figure 3 illustrates the discrepancy between the downwash created by the actual building site and the assumed configuration. The figure shows the downwind concentration profile for an exhaust stack with the actual site configuration (open circles). For this wind direction the dominant building is a 24 m tall by 48 m wide lattice structure located approximately 50 m upwind of the stack. Following the ISC2 procedures, the downwash due to this structure would be modeled as if a 24 m × 48 m solid structure was located directly upwind of the stack. Figure 3 shows that the downwash resulting from this solid structure (solid triangles) overestimates the downwind concentrations. The figure also indicates that the actual concentration profile can be modeled accurately using an equivalent solid structure with dimensions 15.2 m × 30.5 m (open triangles).

To determine the equivalent building dimensions for HCF, wind tunnel tests were first conducted for 18 wind directions (at 20 degree increments) with all plant structures in place for each source. Ground-level concentration measurements were obtained at between 40 and 48 receptor locations along lateral grids at a minimum of 5 downwind distances. The 18 concentration tests were then repeated with the nearby structures removed (structures were classified as nearby when the stack is closer than five times the lesser of the height or width of the structure).

The initial determination of the EBD used the following EPA[12] definition for an excessive concentration:

> "A maximum ground-level concentration due to emissions from a stack due in part or whole to downwash, wakes, or eddy effects produced by nearby structures or terrain features which individually is at least 40% in excess of the maximum concentration experienced in the absence of such downwash, wakes, or eddy effects and which contributes to a total concentration due to emissions from all sources that is greater than an ambient air quality standard."

Therefore, when the maximum ground-level concentration with all structures in place was no more than 40% greater than the maximum ground-level concentration with the nearby structure removed, the concentration was not considered to be excessive for that specific exhaust stack/wind direction combination, and the EBD was set equal to zero. An example of this analysis is shown in Figure 4. In the plot, the maximum concentration with the structures present is less than 1.4 times the maximum concentration with the nearby structures removed. Hence, for this wind direction the downwash is not considered excessive and thus the equivalent building height is zero.

Following the actual site and nearby building-out concentration tests, the site model was removed from the wind tunnel and replaced with a uniform roughness that was representative of the plant roughness. A single rectangular building with height to width to depth ratios of 1:2:1 was then placed upwind of the stack under evaluation (similar to the configuration shown in Figure 1) and the ground-level concentrations versus downwind distance were measured. This setup was specifically designed to reproduce the wind tunnel configuration used by Huber and Snyder.[2,3] The process was repeated for various sized buildings until a building was found that gave a similar (as defined below) longitudinal ground-level concentration profile as that measured with the actual site present.

Figure 5 shows the ground-level concentration profile for an exhaust stack/wind direction combination for which an excessive concentration was observed. For this source, and all others where an excessive concentration was demonstrated to exist, the equivalent building was determined by first comparing the overall maximum concentration for the various equivalent building tests to the test with the actual site structures present. The equivalent building is then taken to be the smallest building that produces an overall maximum concentration that is greater than 0.9 of the overall maximum concentration with the actual site structures in place. The corresponding equivalent building for the exhaust stack/wind direction combination shown in Figure 5 is BH6 following this selection criteria.

Since this study was conducted, the EPA[9] has recommended a different procedure for determining EBD. The new procedure abolishes the use of the excessive concentration demonstration to define a zero building height and redefines the selection criteria for determining whether or not two concentration profiles are similar. Under the new provision, the equivalent building is defined as the smallest building for which: 1) the overall maximum concentration with the equivalent building configuration exceeds 90% of the overall maximum concentration observed with all site structures in place; and 2) the maximum concentration with the equivalent building configuration at all other longitudinal distances exceeds the maximum ground-level concentration observed at that distance with all site structures in place less ±20% of the overall maximum ground-level concentration with all site structures in place.

An example of this new selection criteria is shown in Figure 6 using the same data set shown in Figure 5. The figure indicates that the new EPA defined selection criteria has been met for both BH6 and BH7. Since BH6 is the smaller of the two buildings it is selected as the equivalent building, which gives the same result as the previous selection criteria. This will not necessarily be true for all cases but does indicate that the differences between the two criteria will be small.

Model Similarity Requirements

An accurate simulation of the boundary-layer winds and stack gas flow is an essential prerequisite to any wind tunnel study of diffusion from an industrial facility. The similarity requirements can be obtained from dimensional arguments derived from the equations governing fluid motion. A detailed discussion on these requirements is given in the EPA fluid modeling guideline.[13]

The gas flow simulation was designed around the criteria of matching momentum and exhaust density ratios. This criteria has been approved by the EPA[11] for use in equivalent building dimension studies and is consistent with the requirements for a "Good Engineering Practice" (GEP) stack height analysis. In both types of studies the wake structure and its influence on the subsequent plume behavior is evaluated rather than actual ground-level concentration values. The GEP guideline recommends neglecting plume buoyancy and setting the momentum ratio and density ratio equal in model and full scale. This approach allows the best simulation of the air flow characteristic around structures.

EXPERIMENTAL METHODS

Model Construction

A 1:240 scale model of HCF was designed and constructed. The model included all significant buildings and structures within a distance of 520 m radius of HCF. A photograph of the model is shown in Figure 2. Brass tubing was used for the each of the circular exhaust stacks. Each stack was supplied with a premixed helium–hydrocarbon mixture using a precision gas flow meter to monitor and regulate the discharge velocity. Where appropriate, in-stack trips were used to assure turbulent flow.

Wind Tunnel Configuration

After construction, the HCF model was placed in CPP's open circuit atmospheric boundary layer wind tunnel. Upwind and downwind of the model, roughness elements were installed to represent the surrounding roughness. Flow conditioning devices consisting of a 2-dimensional trip and a pair of spires were also placed upwind of the model to aid in the development of a representative boundary layer. Ground-level sampling taps were installed downwind of the exhaust stacks so that up to 48 locations were sampled simultaneously for each simulation.

The equivalent building dimensions were determined using a set of solid structures fabricated for placement directly upwind of each centrally located exhaust stack. The full scale building heights of the solid structures ranged from 9.15 m to 36.6 m with widths ranging from 18.3 m to 73.2 m. These structures were specifically designed to match the building height to width to depth ratio of 1:2:1 used by Huber and Snyder[2,3] in the validation study for the ISC2 downwash algorithm.

Concentration Measurement Techniques

After the desired atmospheric boundary layer was established in the wind tunnel, a mixture of inert gas and a tracer (ethane, methane and/or propane) of predetermined concentration was released from the stacks at the required rate to simulate plume rise. Samples of the gas were withdrawn from the receptor locations using a gas sampling system. The samples were then analyzed with a flame ionization gas chromatograph to determine the tracer gas concentration. The concentrations measured in the wind tunnel were related to full-scale concentrations using standard scaling techniques[13].

RESULTS

"Equivalent" building dimensions were determined for 18 wind directions in 20 degree increments for each exhaust stack using the procedures described in the preceding sections. Since ISC2 requires building dimension inputs for 36 wind directions. the equivalent building height for the remaining wind direction inputs were obtained based on the wind-tunnel determined results at the 18 primary wind directions. The building dimensions for the non-tested wind directions (10, 30, 50 degrees, etc.) were determined by using the dimensions of the larger of the EBD on either side (±10 degrees). For example, if the wind tunnel determined equivalent building at 0 degrees was 21.3 m × 42.7 m (BH5) and the equivalent building at 20 degrees was 24.4 m × 48.8 m (BH6), the equivalent building for 10 degrees is also 24.4 m × 48.8 m (BH6).

Comparison of Equivalent Building Dimensions Versus ISC2 Building Dimensions

A comparison between the equivalent building dimensions as determined using the wind tunnel simulation and the actual building dimensions for HCF as defined by the ISC2 User's Guide is presented in Figure 7 for three of the stacks evaluated. The figure illustrates that for many wind directions the equivalent building heights are substantially lower than the actual heights. In one rare instance the equivalent building was slightly taller than the ISC building. At this particular wind direction a large solid structure is located upwind of the stack at a distance slightly greater than 5 L_b.

Comparison of Concentration Estimates Using Equivalent Building Dimensions Versus ISC2 Building Dimensions

A comparison between ISCST2 modeled 3-hour concentrations for the Cape Industry Facility using the actual building dimension inputs and the equivalent building dimension inputs is presented in Table 1. The results indicate that using the equivalent building dimensions reduced the concentration estimates for the individual stacks by as much as a factor of 7.3 for this facility. For all eight stacks listed in Table 1 the concentration estimates using the equivalent building dimensions were lower than estimates using the actual building dimensions. Assuming the emission rate for all stacks is equivalent, Table 1 also indicates that overall concentration estimates for HCF were reduced by a factor of 2.7 using the equivalent building dimensions rather than the actual building dimensions for input into ISCST2.

CONCLUSIONS

The results of this study have indicated that the ISC2 approach of modeling the exhaust stacks at the Hoechst Celanese Facility using the actual dimensions of the surrounding structures (open lattice-type structures and/or buildings removed from the stack location) for building dimension input into ISCST2 does not represent the actual dispersion from sources. In addition, this study has demonstrated that the wind tunnel can be used, following an EPA approved protocol, to determine equivalent building dimensions.

The results of this study show that concentration estimates from individual stacks were lowered by as much as a factor of 7.3 when the equivalent building dimensions were used for input instead of the actual building dimensions for the Hoechst Celanese Facility. While these results are certainly site specific, similar reductions can be expected for facilities with building configurations similar to that evaluated in this study.

Since this study was conducted, the EPA has suggested a new criteria for selecting equivalent building dimensions. It appears that the impact of the new criteria does not significantly affect the results of this study.

From these findings it is clear that the input of the actual building dimensions according to criteria in the ISC2 User's Guide may give inaccurate concentration estimates when the building configuration is not consistent with the Huber/Snyder[1,2] geometry. A major enhancement to ISC2, therefore, can be obtained by adjusting the building dimension input into ISC2 such that the new dimensions allow ISC2 to better replicate the actual downwash. The EPA has currently recognized that these adjusted building dimensions, referred to as "equivalent building dimensions," can be determined through wind tunnel modeling.

REFERENCES

1. EPA, *User's Guide for the Industrial Source (ISC2) Dispersion Models*, EPA–450/4–92–008a, USEPA Office of Air Quality, Research Triangle Park, 1992.

2. A.H. Huber and W.H. Snyder, "Building Wake Effects on Short Stack Effluents," *Preprint Volume for the Third Symposium on Atmospheric Diffusion and Air Quality*, American Meteorological Society, Massachusetts, 1976.

3. A.H. Huber and W.H. Snyder, "Wind Tunnel Investigation of the Effects of a Rectangular-Shaped Building on Dispersion of Effluents from Short Adjacent Stacks," *Atmospheric Environment*, 16(12): 2837–2848 (1982).

4. W. H. Snyder and R.E. Lawson, Jr., "Wind-Tunnel Measurements of Flow Fields in the Vicinity of Buildings," *Eighth Joint Conference on Applications of Air Pollution Meteorology with AW&MA*, American Meteorological Society, 1994, pp 244–250.

5. B.J.B. Stunder and S.P.S. Arya, "Windbreak Effectiveness for Storage Pile Fugitive Dust Control: A Wind Tunnel Study," *JAPCA*, 38: 135–143 (1988).

6. R.L. Petersen, D.N. Blewitt and R. Panek, "Lattice Type Structure Building Height Determination for ISC Model Input," *85th Annual AWMA Conference*, Missouri, 1992.

7. R.L. Petersen and M.A. Ratcliff, "Site Specific Building Height Determination for Amoco's Whiting Refinery," Report No. 90–0703, CPP, Inc., Colorado, 1991.

8. D. Blewitt, AMOCO Corporation, IL, personal communication, 1995.

9. J. Tikvart, United States Environmental Protection Agency, NC, letter to Brenda Johnson, Regional Modeling Contact, Region IV and Douglas Neeley, Chief Air Programs Branch, Region IV, July 25, 1994.

10. Cermak Peterka Petersen, Inc., "Equivalent Building Height Determinations for Cape Industries of Wilmington, North Carolina," Protocol Report No. 93–0955, CPP, Inc., Colorado, 1993.

11. D. Neeley, United States Environmental Protection Agency, Region IV, GA, letter to Alan Klimek, Chief Air Quality Section Division of Environmental Management, North Carolina Department of Environment, Heath, and Natural Resources, July 28, 1994.

12. EPA. *Guideline for Determination of Good Engineering Practice Stack Height (Technical Support Document for the Stack Height Regulation)*. EPA–45014–80–023R. USEPA Office of Air Quality. Research Triangle Park. 1985.

13. W.H. Snyder. *Guideline for Fluid Modeling of Atmospheric Diffusion*. Report No. EPA600/ 8–81–009. USEPA. Environmental Sciences Research Laboratory, Research Triangle Park, 1981.

Table 1. Comparison of ISCST2 modeled concentrations using the actual building height (ISC–ACT) versus using the equivalent building dimensions (ISC–EBD).

	Maximum 3-hour Concentration @ 1 g/s Emission Rate*		
Source ID	Using ISC–ACT Dimensions (μg/m^3)	Using ISC–EBD Dimensions (μg/m^3)	Reduction Factor (ISC–ACT/ISC–EBD)
B1	47.0	15.5	3.0
B4	3.2	2.6	1.2
B5	3.1	2.4	1.3
H1	5.8	2.2	2.6
H3	4.4	4.1	1.1
H4	5.2	1.5	3.5
H5	3.1	2.1	1.5
TO	20.5	2.8	7.3

*Based upon meteorological data for 1991.

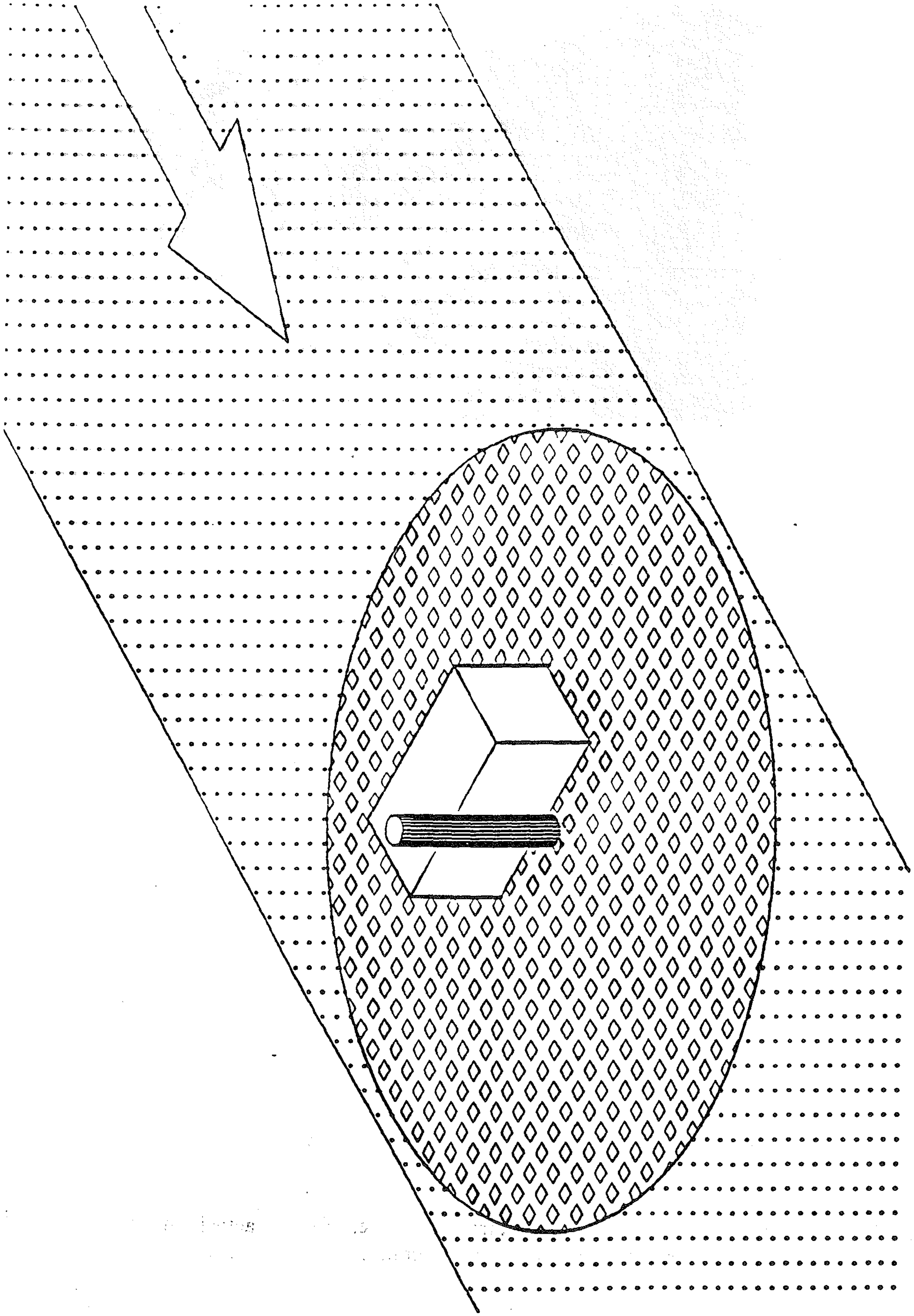


Figure 1. Building configuration (Huber/Snyder) assumed in ISC2 models.

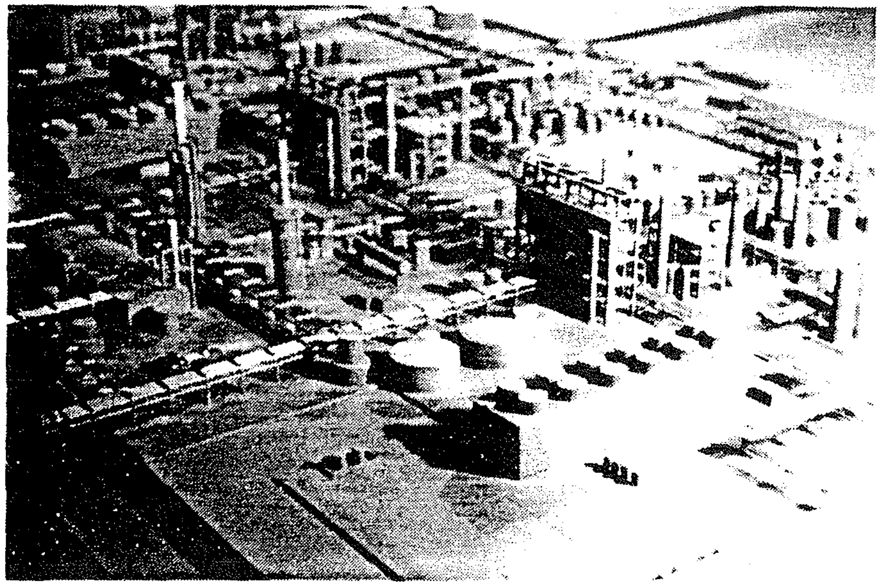


Figure 2. Photograph of Hoechst Celanese model.

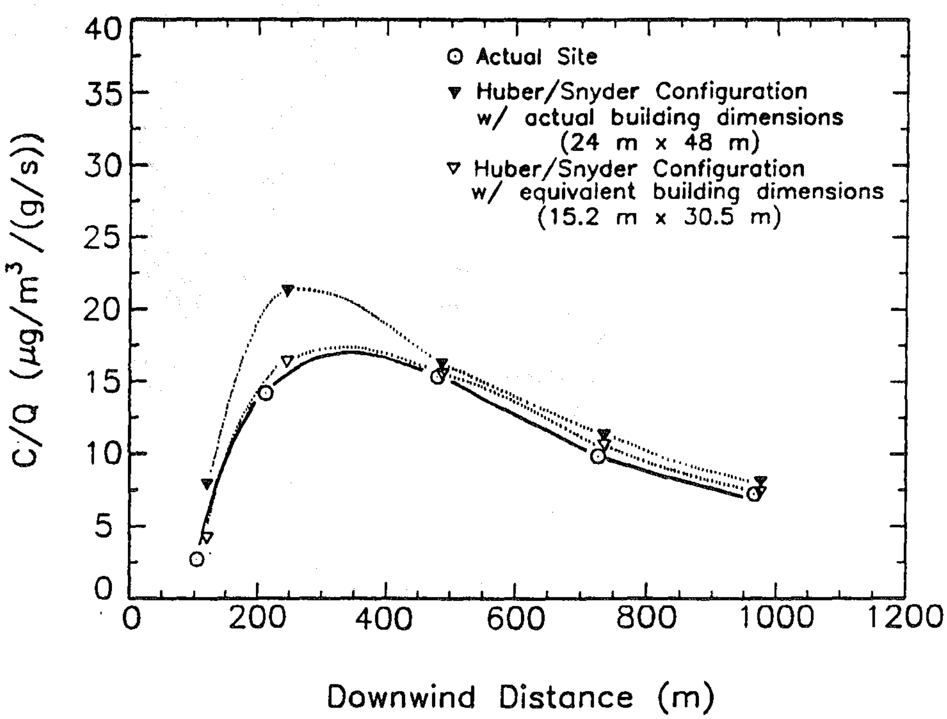


Figure 3. Longitudinal ground-level concentration profiles for an actual site and two different equivalent building (Huber/Snyder) configurations.

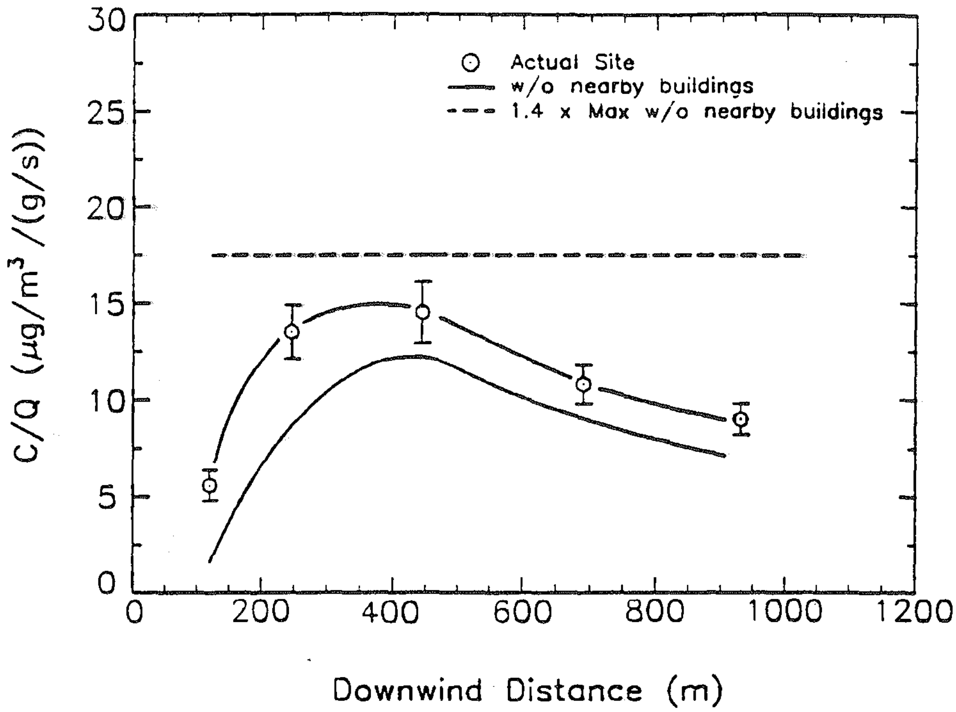


Figure 4. Example showing non-excessive concentrations where equivalent building is set equal to zero.

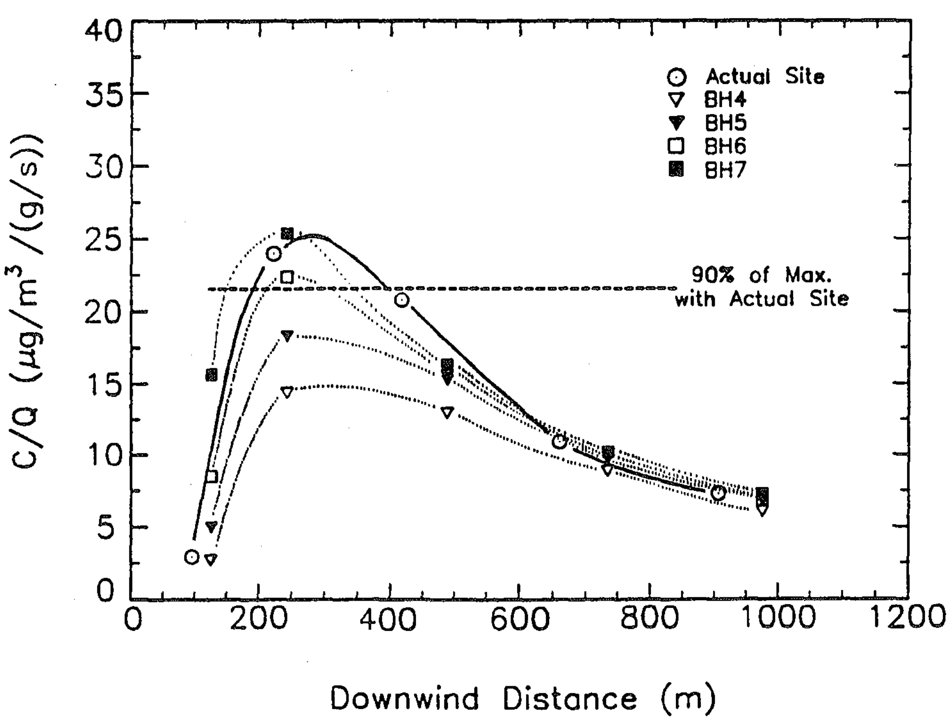


Figure 5. Longitudinal ground-level concentration profiles showing method for selecting the equivalent method.

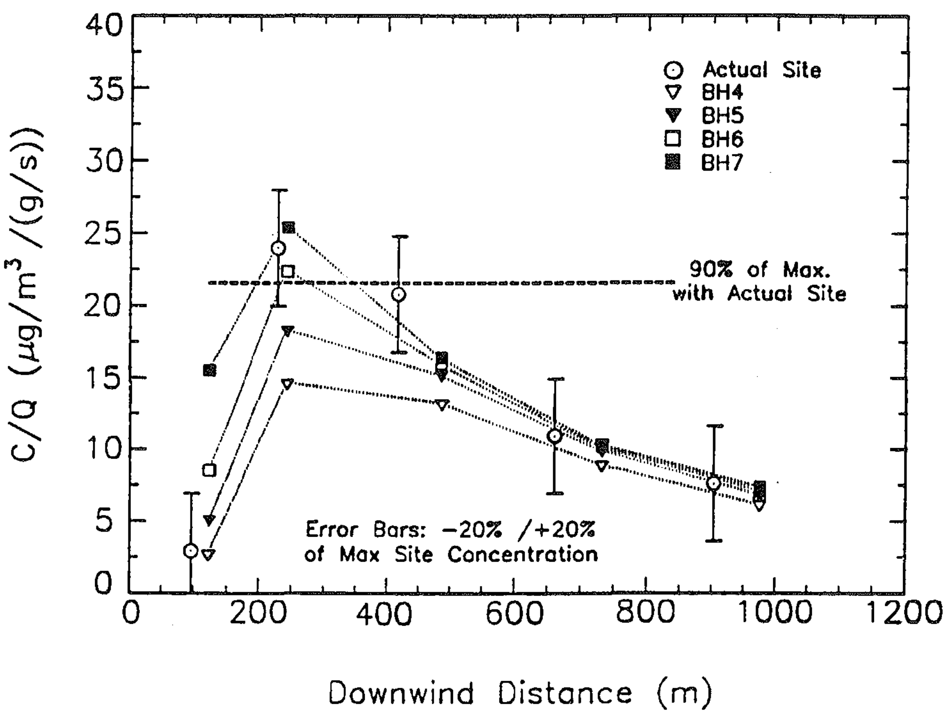
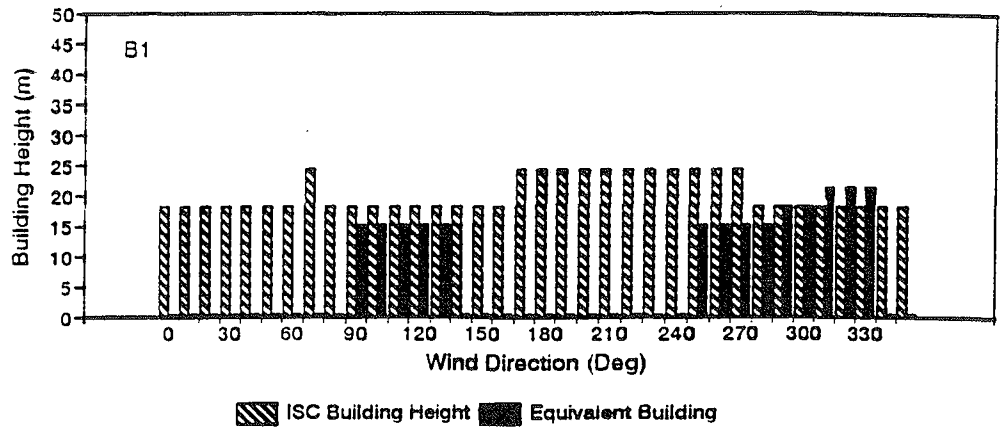
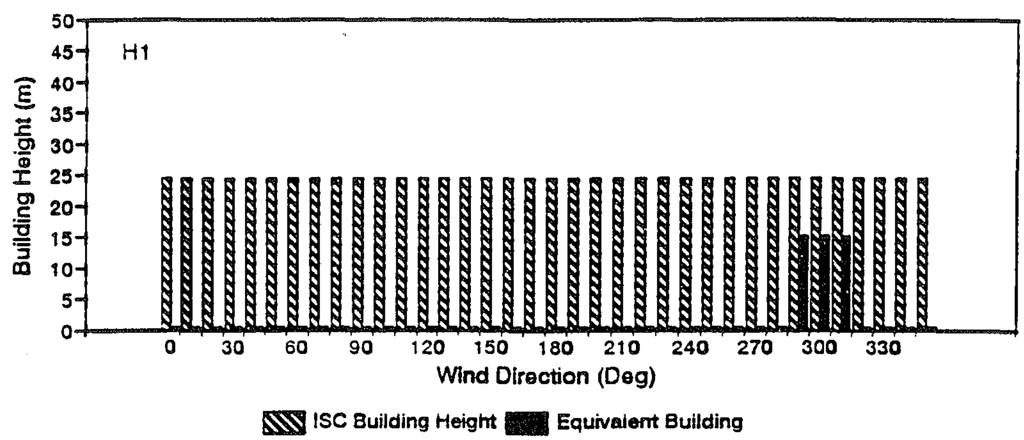


Figure 6. Showing revised method for selecting the equivalent building.



Note: EBD = 0 for directions with no black bar.



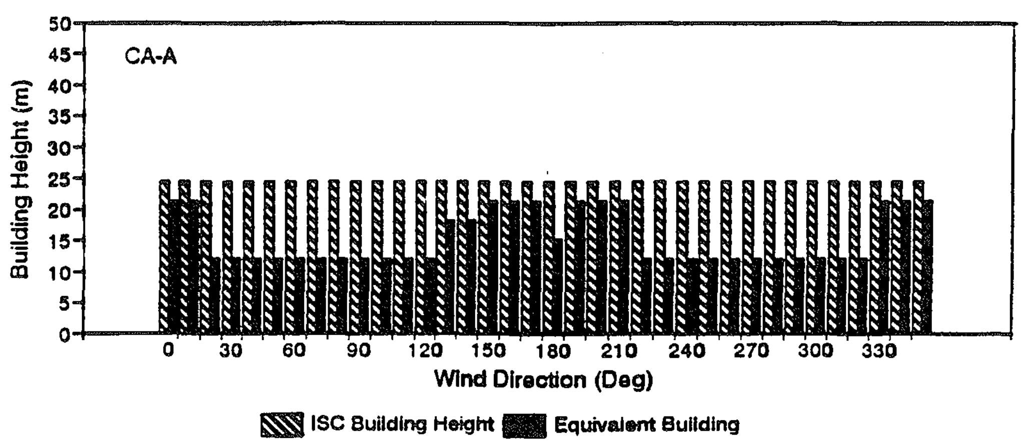


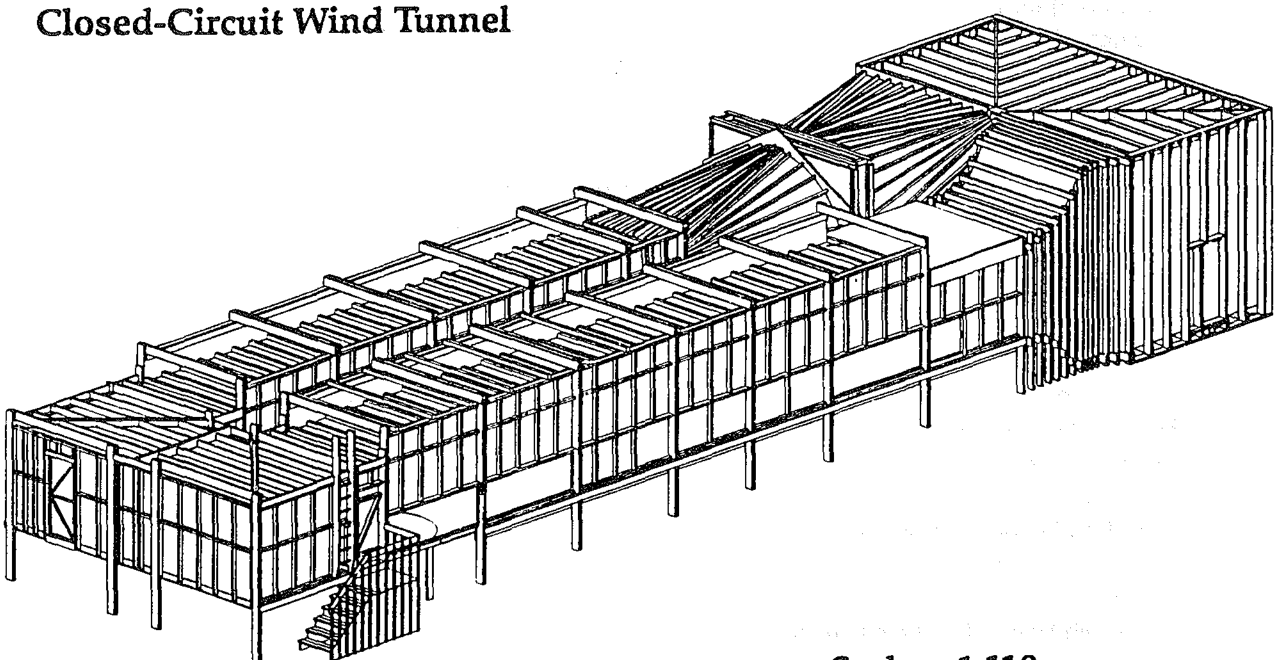
Figure 7. Wind direction specific equivalent building height versus actual (ISC) building heights.

APPENDIX B

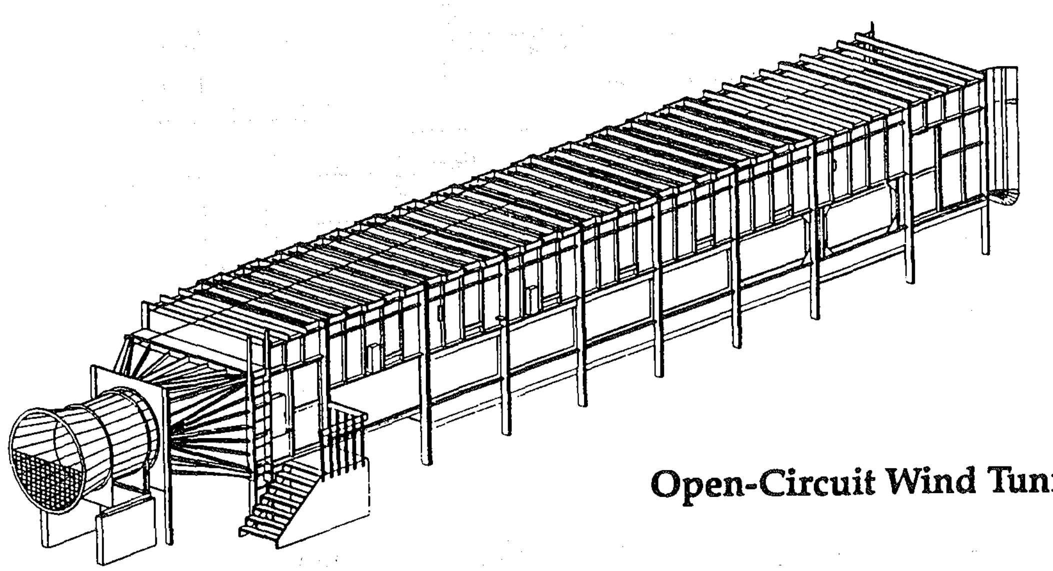
CPP FACILITIES AND INSTRUMENTATION

CPP, INCORPORATED
BOUNDARY LAYER WIND TUNNELS

Closed-Circuit Wind Tunnel



Scale = 1:110



Open-Circuit Wind Tunnel

PERFORMANCE CHARACTERISTICS OF THE CLOSED-CIRCUIT WIND TUNNEL

1. Dimensions

Test-Section Length	*68 ft (20.6 m)*
Test-Section Width	*10 ft (3.0 m)*
Contraction Ratio	*2.7:1*

2. Wind-Tunnel Drive

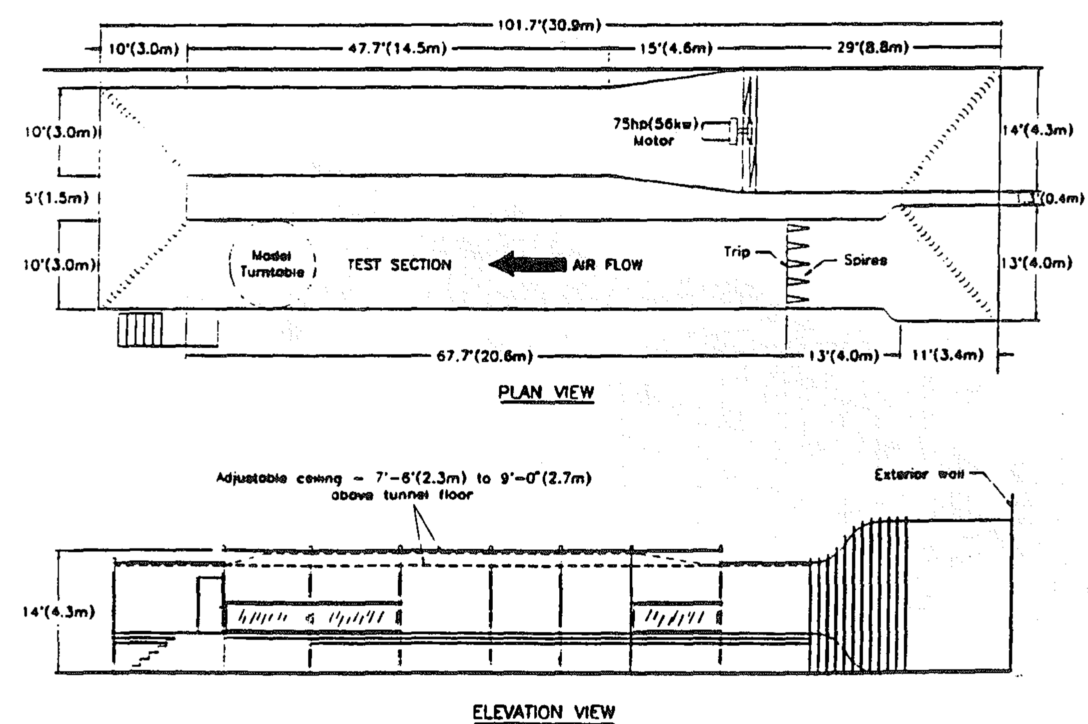
Total Power	*75 hp (56 kW)*
Type of Drive	*6 blade axial fan, single-speed motor*
Speed Control	*Variable-pitch fan*

3. Velocities

Mean Velocities	*Approximately 0 to 55 fps (0 to 16.8 m/s)*
*Boundary-Layer Thickness**	*Up to 60 inches (1.5 m)*
Turbulence Level	*About 2 percent at entrance*

4. Longitudinal Pressure Gradient — *Zeroed by ceiling adjustment*

*Function of boundary roughness and thickening devices at test-section entrance



CLOSED–CIRCUIT BOUNDARY–LAYER WIND TUNNEL

PERFORMANCE CHARACTERISTICS OF THE OPEN-CIRCUIT WIND TUNNEL

1. Dimensions

Test-Section Length	*74.5 ft (22.7 m)*
Test-Section Width	*12 ft (3.7 m)*
Ceiling Height	*Variable from 5.5 to 8.5 ft (1.7 m to 2.6 m)*

2. Wind-Tunnel Drive

Total Power	*20 hp (15 kW)*
Type of Drive	*8 blade axial fan, single-speed motor*
Speed Control: Coarse	*900/600 rpm, 2-speed motor*
Speed Control: Fine	*Pitch control*

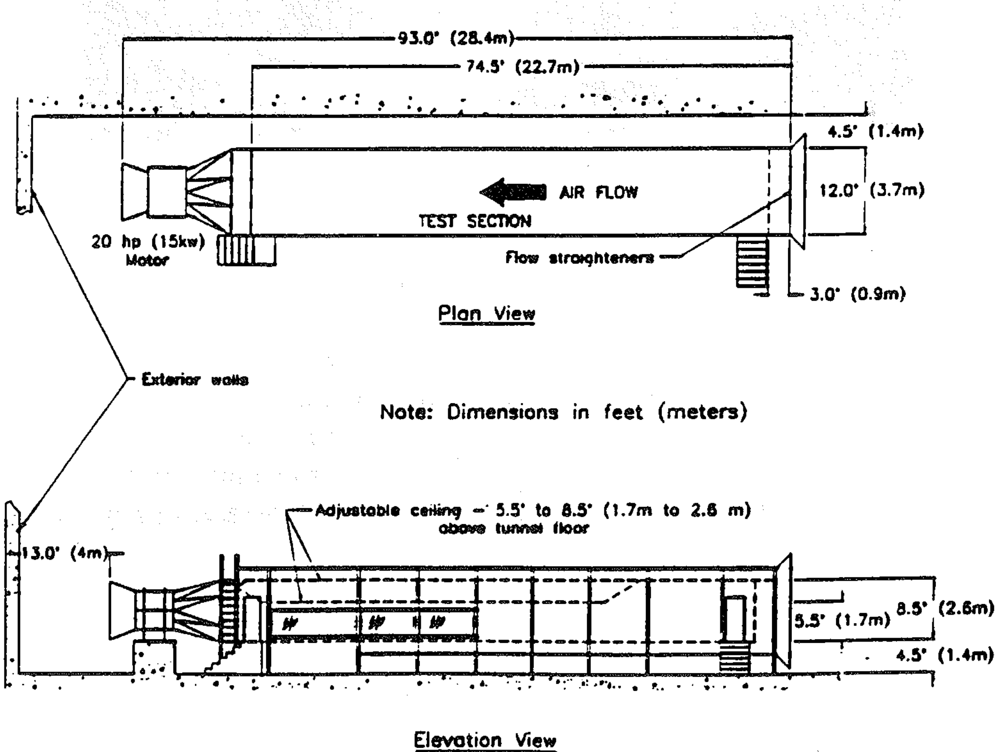
3. Temperature

Ambient Air	*Not controlled*
Surface	*−50 to 120°F (−46 to 49°C)*

4. Velocities

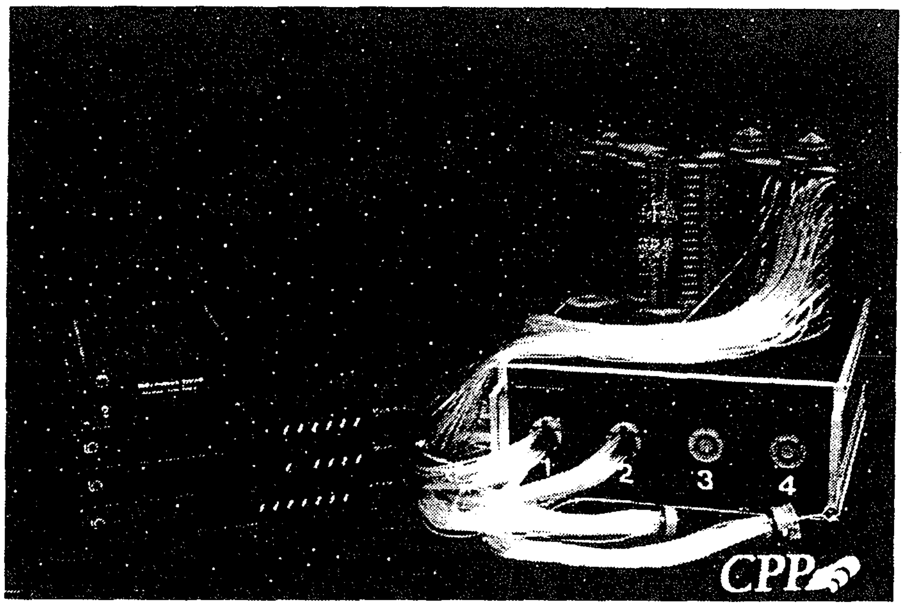
Mean Velocities	*0 to 30 fps (9.1 m/s)*
Boundary-Layer Thickness	*Up to 6 ft (1.8 m)*

5. Streamwise Pressure Gradient — *Zeroed by ceiling adjustment*



PRESSURE MEASUREMENT SYSTEM

Using a simultaneous pressure data collection system, 175 selected pressure measurement locations can simultaneously record pressure data across structural elements. The output from this sytem is processed through a microcomputer system outfitted with an analog-to-digital converter, multiplexers and controller. This ability to sample many channels at one time reduces data collection time and allows more useable data to be collected for the structural designer.

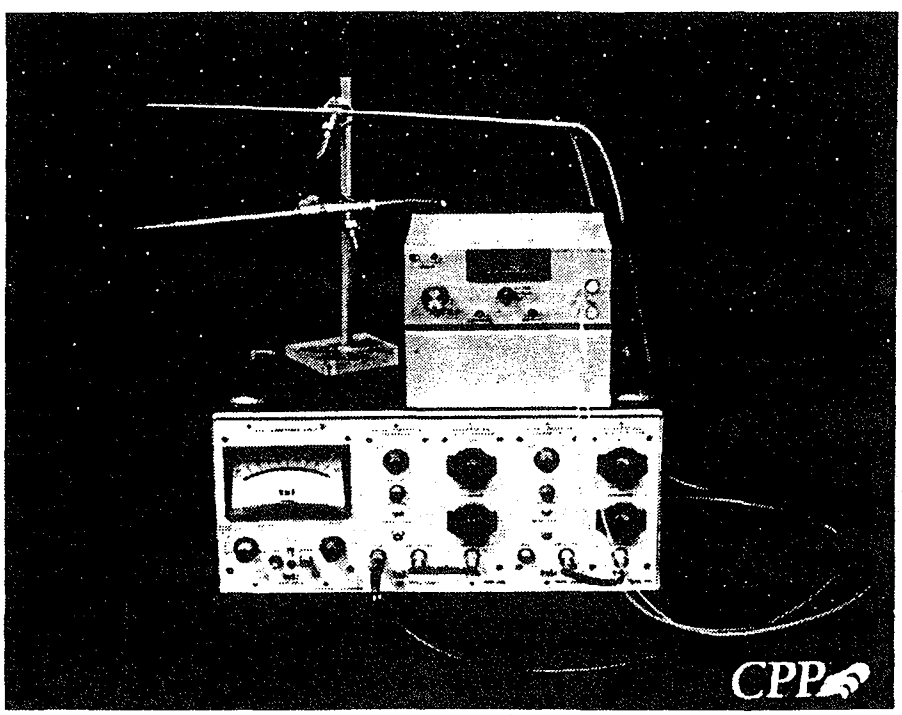


The ability to make repeated measurements in a given time period produces better estimates of peak pressure coefficients via the method of ensemble averaging. It also allows for greater capabilities in terms of differential pressure measurements across structural elements such as free standing walls or canopies. Additionally, the simultaneous pressure measurement capability permits integrated simultaneous pressure time series to be used to investigate the dynamic response of large areas, such as stadia and arena roofs.

VELOCITY / TEMPERATURE MEASUREMENT AND CALIBRATION SYSTEM

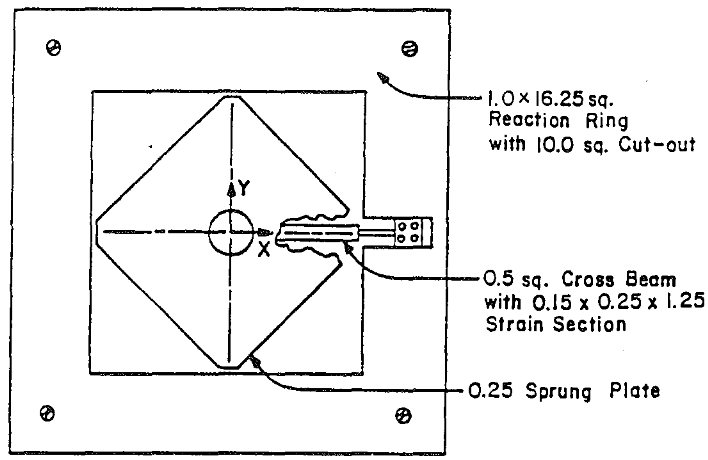
Complete instrumentation is available for the measurement of lateral, longitudinal, and vertical mean velocity and turbulence intensity, Reynolds stress, mean temperature, and turbulent temperature fluctuations. Prior to any measurement program, a detailed calibration of the velocity or temperature sensor is performed. The components of the system include:

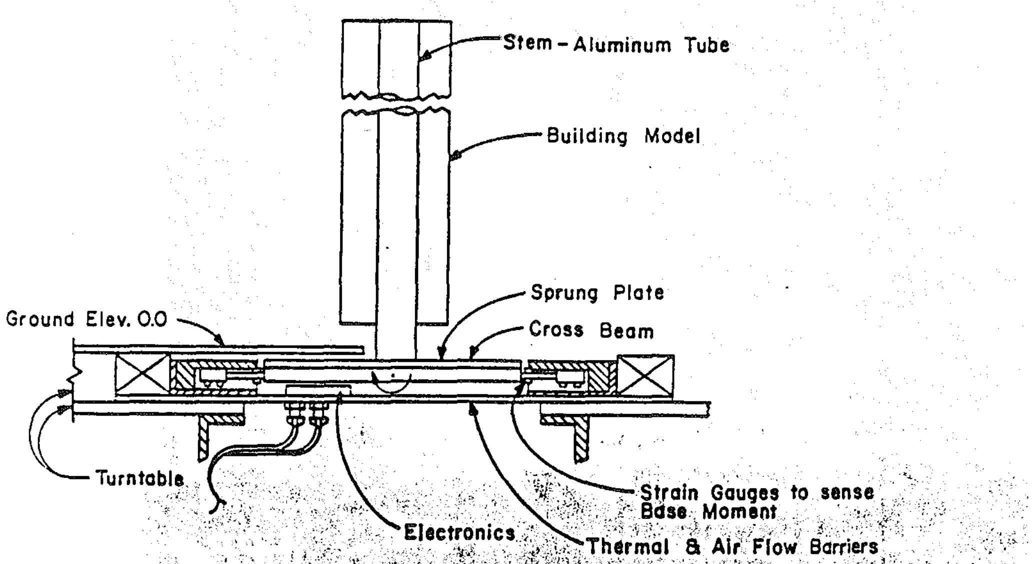
- *Five TSI model 1053B utility anemometers*
- *Five TSI model 1056 variable decade modules*
- *Three two-channel monitors and power supplies*
- *Temperature switching module - TSI model 1125*
- *Model 1125 TSI velocity calibrator*
- *Model 1210 hot-film velocity sensors*
- *Model 1211 hot-film velocity sensors*
- *Model 1287 split-film two-component velocity sensors*
- *Dwyer model 424 manometer*
- *Setra model 239 pressure transducer*
- *Pitot tube*



HIGH-FREQUENCY BASE BALANCE

The high-natural-frequency balance is used to measure overall fluctuating wind loads at the base of a model structure. The balance has fundamental natural frequencies of about 500 Hz, and can accommodate a model of nearly any size building at scales from 1:200 to 1:500, with resulting natural frequencies of about 80 Hz to 200 Hz. Together with associated instrumentation and computer software, this system can measure the power spectral density of the external dynamic wind load over a bandwidth from 0 Hz to 1/2 of the model's natural frequency. Additional computer software allows the dynamic response of the structure to be easily computed for a wide range of values for mass, stiffness and damping.

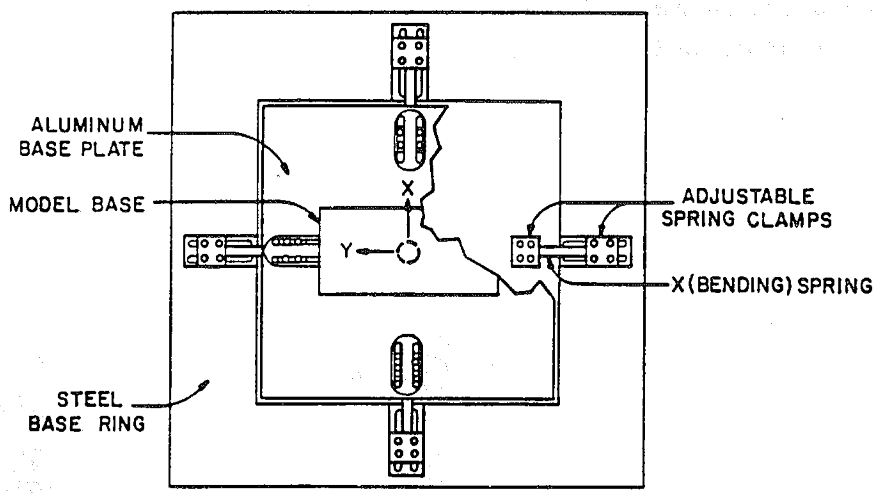




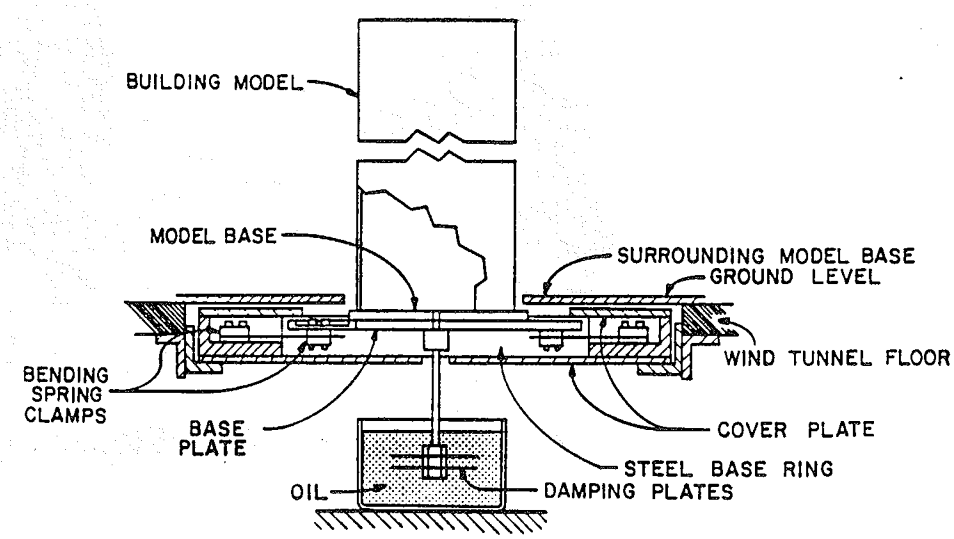
All Dimensions given in inches.

AEROELASTIC BALANCE

The aeroelastic balance is of a universal type on which various models can be easily mounted. Stiffness of the balance can be adjusted over a wide range to match the natural fequencies of the prototype. The balance is designed to model two fundamental rocking modes of motion and twisting motion about the vertical axis. Damping of the balance is adjustable over a range of expected prototype values. Strain gage bridges yield outputs for the data processing system which gives mean, rms and peak values of base moments and building-top deflections. Placement of accelerometers on the building enables direct measurement of rms and peak accelerations.



TOP VIEW

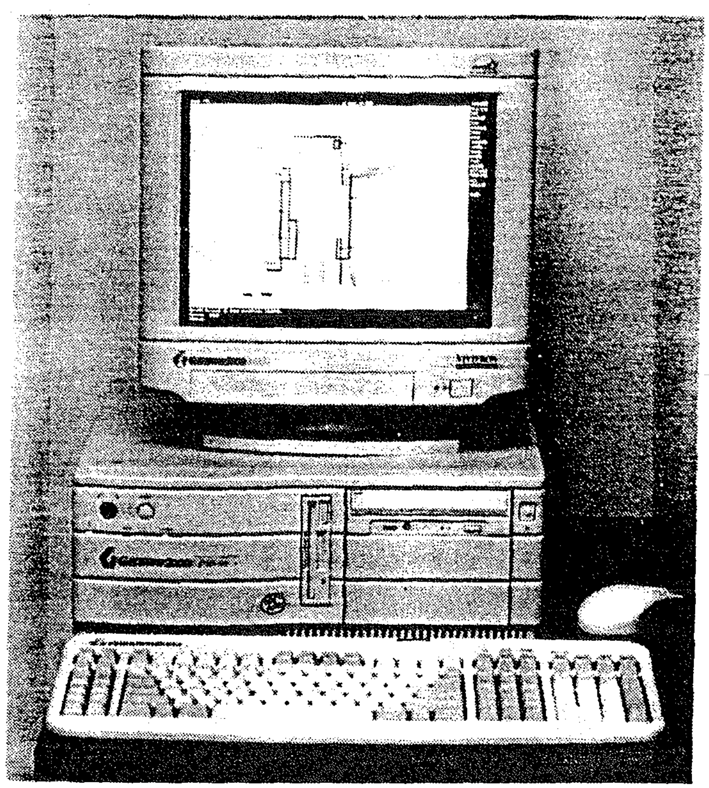


ELEVATION

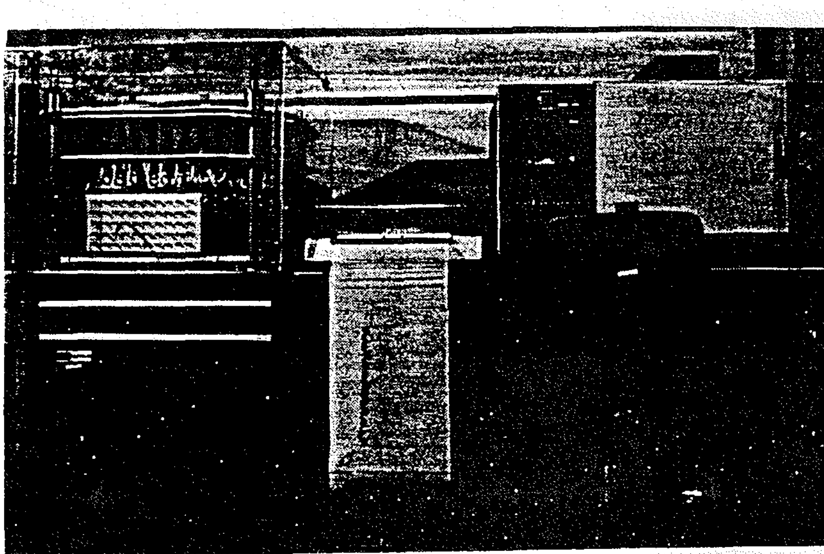
DATA ACQUISITION AND ANALYSIS SYSTEM

The CPP data acquisition and analysis system utilizes state-of-the-art microcomputer hardware combined with customized software to assure the end user of accuracy in data results. DOS-based computers are utilized throughout the laboratory not only for data acquisition purposes, but also for computerized drafting, analysis and report preparation. CPP takes pride in its drafting capabilities which allow us to use CAD drawings supplied by our clients or generate 2-D and 3-D CAD diagrams for use in model construction and reporting. Also available are telecommunications interface capabilities for communication with client computer facilities or commercial timesharing devices.

Pressure zone diagrams can be prepared on computer drafted building diagrams.



HYDROCARBON GAS TRACER SYSTEM



The Hydrocarbon Gas Tracer System consists of a Flame Ionization Gas Chromatograph and a CPP-designed gas-sampling system. The dual column gas chromatograph is equipped with:

- *Flame-ionization detector*
- *Automatic linear temperature programmer digital sensor pane (checks operating parameters)*
- *Automatic 2 cc sampling loops*

The gas chromatograph has the capability of operating four detectors simultaneously. These detectors are:

- *Flame ionization*
- *Flame photometric*
- *Electron capture*
- *Thermal conductivity*

Also in use at CPP is a High Frequency Response flame ionization detector which combines an accurate method of real time hydrocarbon measurement with the ability to track varying concentrations with an averaging time of less than 0.01 s. This equipment has two independent FID systems which can be used to determine concentration time series at two locations simultaneously.

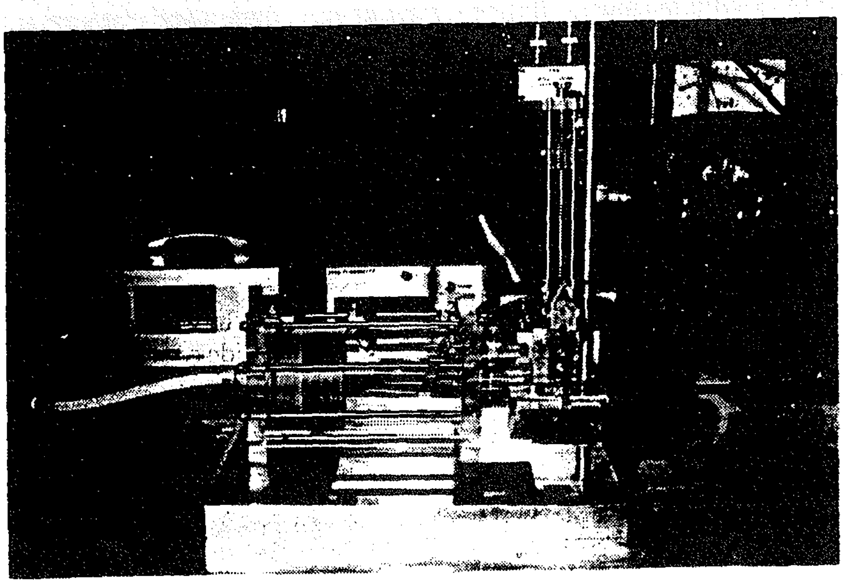
The gas-sampling system is a state-of-the-art system. It features isokinetic withdrawal of up to fifty samples simultaneously. Its non-contaminating design and isothermal temperature control assure stable performance, resulting in reproducible samples with excellent accuracy over a wide range of sample concentrations. The sample reproducibility is ±0.9 percent for 100 ppm and ±0.4 percent for 1,000 ppm ethane in He. The contamination in the form of hydrocarbons (C1 through C8) is less than 0.001 ppm.

Both the gas chromatograph and the gas sampling systems are interfaced with the CPP data acquisition and analysis system. Real-time data analysis is thus provided.

All gas mixtures used in testing are commercially certified. Further verification is provided by our scientific staff with our own chromatograph, which is calibrated using certified primary standards. The linearity of the chromatograph is verified using a wide concentration range of certified primary standards.

MISCELLANEOUS INSTRUMENTATION

- Chart Recorders
- Digital Multimeters
- Oscilloscopes
- Function Generators
- Positive-Displacement Flow Meters
- Digital Mass-Flow Meters
- Linear Flow Meters
- Power Supplies
- Still Photography and Movie Camera Equipment
- Video Recording System



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