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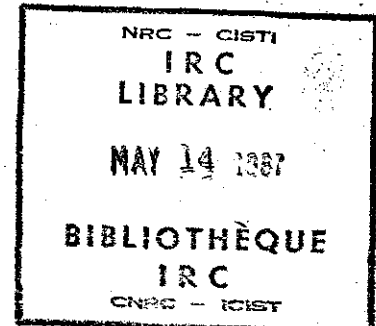
NRCC Experimental Fire Tower for Studies on Smoke Movement  
and Smoke Control in Tall Buildings

G.Y. Achakji

ANALYZED

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NRCC EXPERIMENTAL FIRE TOWER FOR STUDIES ON  
SMOKE MOVEMENT AND SMOKE CONTROL IN TALL BUILDINGS

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## ABSTRACT

A national experimental facility, the NRC National Fire Laboratory (NFL) - formerly the Fire Research Field Station (FRFS) - was designed, constructed and instrumented for conducting large scale fire experiments. The laboratory consists of two major experimental facilities; the burn hall and the 10-storey fire tower, which are interconnected by a service building. The fire tower is designed mainly for research on smoke movement and control methods in tall buildings. This report describes the fire tower, as part of the NFL, including the structure and layout, mechanical pressurization and exhaust systems, instrumentation and measuring techniques, data acquisition system, and the gas burner system used for fire simulation. The tower's research and development capabilities are also summarized.

## RÉSUMÉ

Un centre national d'expérimentation a été conçu, construit et équipé pour mener des expériences d'incendie à grande échelle; c'est le Laboratoire nationale de l'incendie (LNI) du CNRC, qui s'appelait auparavant la Station de recherche expérimentale sur l'incendie. Ce centre comprend deux grandes installations d'expérimentation: la salle de combustion et la tour d'incendie de 10 étages, qui sont reliées par un bâtiment de service. La tour d'incendie est surtout destinée aux recherches sur le déplacement de la fumée et les méthodes de désenfumage dans les bâtiments élevés. Ce rapport fournit une description de la tour d'incendie: structure et aménagement, systèmes mécaniques de mise en pression et d'évacuation, techniques d'instrumentation et de mesurage utilisées, dispositif de saisie de données, et système de brûleurs au gaz employé pour simuler des incendies. On y donne aussi un aperçu des ressources dont dispose cette installation au plan de la recherche-développement.

1. INTRODUCTION AND BACKGROUND

In high-rise buildings, smoke is the main cause of casualties during a fire; a large number of deaths<sup>1-4</sup> are caused by asphyxiation, smoke inhalation, and carbon monoxide poisoning. The smoke spreads rapidly from the fire compartment to other areas in the building, reduces the visibility, hinders the fire fighting, and interferes with the evacuation from the building. In tall buildings, the time available for total evacuation<sup>5,6</sup> before escape routes are filled with smoke is critical to life safety.

The Associate Committee on the National Building Code of Canada<sup>7</sup> recognized the hazard of smoke to life and introduced requirements for the control of smoke movement in high buildings in the 1970 edition of the NBC. The recommended methods of smoke control in high buildings are described in the Supplement to the NBC - Chapter 3, Measures for Fire Safety in High Buildings<sup>8</sup>. The Institute for Research in Construction (IRC) of NRC - formerly the Division of Building Research (DBR) has directed considerable effort towards the study of smoke movement and control methods to improve life safety in tall buildings. During the past several years, IRC has developed information using mathematical models<sup>9,10</sup>, and conducted field tests under non-fire conditions; a review of IRC/NRC studies on control of smoke has been presented by Tamura<sup>11</sup>. Such research techniques have proven to be valuable; however, the field tests do not take into account the effects of fire temperature and the results obtained are limited to a specific system and building configuration. On the other hand, the computer simulation programs have some assumptions with regard to smoke movement which need to be verified.

A specially designed facility, the NRC experimental fire tower, was developed to simulate the effect of fire temperature on the characteristics of smoke movement and on the performance of various smoke control measures. Measurements made in the tower can also be utilized to validate or verify the results of the mathematical models. Currently, research work is underway, using the facility to develop and assess concepts of smoke control systems which can offer effective protection of escape routes (stairshaft and elevator shaft) from smoke migration during fires.

The purpose of this report is to provide researchers and potential users with background technical information and guidelines on the tower facility and its capabilities. It will also serve as a reference for reporting work conducted in the facility. The report describes the

experimental fire tower as part of the NFL including the structure and layout, mechanical pressurization and exhaust systems, instrumentation and measuring techniques, data acquisition system, and gas burner system used for fire simulation, and provides a summary of the tower's research and development capabilities.

## 2.0 NATIONAL FIRE LABORATORY

NFL is located west of Ottawa between Carleton Place and Almonte, Ontario. The site is about 90 ha and relatively isolated from large concentrations of population, an aerial view of the NFL site is shown in Figure 1. The large site provides an adequate buffer zone between the laboratory and built-up areas, to prevent any adverse effects due to smoke from full-scale fire experiments. Dispersion calculations showed that air quality standards would be satisfied, provided that experiments were carried out under weather conditions permitting good dispersion and that burns were never conducted simultaneously in both buildings<sup>12</sup>.

NFL was officially opened on September 23, 1981. It comprises three buildings, a burn hall, a 10-storey experimental fire tower and a service unit as shown in Figures 2 and 3. The buildings are interconnected at ground floor level through the service unit for simulation of a large complex building and for convenience during winter operation.

### Service Unit

The service unit consists of; an air-conditioned data room provided with a PDP-11/73 mini-computer for recording and analyzing measurements, a control room for the operation of the tower's air handling and pressurization systems, a small chemistry laboratory, a mechanical room for the burn hall and the service unit, a workshop and offices. A floor plan of the service unit is shown in Figure 4.

### Burn Hall

The burn hall is an adaptable open-plan building with 1650 m<sup>2</sup> of column-free floor area, at 55 m long, 30 m wide and 12 m high to the fire resistant ceiling. The burn hall shelters large-scale fire experiments from the weather. The smoke removal from the Hall is provided by two means:

- a) Mechanically with four exhaust fans located in the corners below ceiling level. The total fan capacity is 56 m<sup>3</sup>/s.
- b) Power operated louvres extending the full length of each side of the building.

The fresh air to the burn hall is admitted through numerous doors along the exterior walls of the hall. The burn hall can accommodate a wide variety of experimental set-ups, including room and corridor arrangements, simulated apartment or hospital suites, atria and shopping malls, and 2-storey dwellings. The possible investigations include; fire and smoke spread in buildings and between buildings, the effect of ventilation and fuel loads on compartment fires, fire in cavity walls, and the production of toxic products of combustion. More detailed information, on the burn hall research activities and capabilities can be obtained from the NFL Manager.

### 3.0 EXPERIMENTAL FIRE TOWER

The experimental fire tower consists of an experimental tower and a protected service tower. Both are 10 storeys high and structurally independent for safety reasons. The construction is monolithic reinforced concrete with 200 mm wall and floor thickness which provides minimum air leakage through walls and floors. The structural elements of the tower are designed for 4 hour fire-resistance rating. To assure a long service life, additional protection is provided to the burn area on the second floor (fire floor) by the installation of high temperature insulation materials, and inside the smoke shaft by the installation of fire bricks. The major physical dimensions of the tower are also given in Table 1.

#### 3.1 Experimental Tower

The experimental tower, as shown in Figure 5, has a total area of 130 m<sup>2</sup> for each floor - including a central core area of 62.7 m<sup>2</sup>. Each floor has an open area (burn area) of about 36 m<sup>2</sup> where controlled experimental fires can be conducted. The first and second floors are 3.6 m high and the remainder are 2.6 m high.

The exterior cladding adjacent to the burn area is removable, permitting installation of typical building facades and window assemblies for study of exterior fire spread. Four openable sliding steel "panels" are located on the exterior walls around the corridors, a large one in the east and west wall and two small ones on the north wall. The south wall (viewing wall) separates the experimental and the service tower, and is provided with a double door and five viewing windows.

The central core contains several vertical shafts. They are the stair shaft, elevator shaft, service shaft, building supply air shaft, return/exhaust shaft, and smoke shaft. Also, there are three other vertical shafts; one for distributing pressurizing air to the stair shaft, another one for exhausting air from the stair shaft to outside at

the top, and a third one for supplying pressurization air to the elevator and the stair vestibules.

All shafts terminate at roof level. The stair, elevator and service shafts can be vented at the top or at the bottom of the shaft as required for experiments. The stairshaft exits to an outside door at the ground floor as shown in Figure 6, and the elevator and service shafts are also connected to outside doors at the basement level. A cross sectional elevation view of the tower and mechanical building is shown in Figure 7.

All the shafts have variable openings in the walls on each floor. The maximum areas of openings for all shafts are given in Table 2. The required amount of opening can be set by positioning shutter provided at each opening. On every floor, the stair and elevator shafts have a vestibule with a door to the burn area. Each stair vestibule is connected to the outside wall by a horizontal duct with a manual damper. The stair and the associated vestibule doors are provided with pneumatic door openers which can be manually operated remotely from the switch panel on the second floor, or programmed to operate automatically in a specified sequence with the data acquisition and control system. The automatic door operation will be used to simulate the use of the stair doors for evacuation during a fire.

### 3.2 Service Tower

The service tower provides a safe area from which to conduct and to observe tests in the experimental areas. It comprises a stairwell, a freight elevator, and observation area. The observation area is isolated from the smoke and toxic gases in the experimental areas, and provides safe working spaces for the instruments and the people. A propane gas service line, heat detector, hose reel, fire alarm and public address/intercom system with a start test warning alarm are installed on all floors. The service area is provided with a separate air pressurization system, with fan capacity of  $5.5 \text{ m}^3/\text{s}$ . This system which supplies 100% outside air is operated during an experiment to prevent combustion products from entering the observation area.

### 3.3 Features of the Tower

The following is a summary of the major features of the tower. They are described in detail in various sections of this report.

- Full scale simulation of a building in terms of:
  - air leakage characteristics
  - vertical shafts (stair, elevator, service, smoke)
  - heating and ventilation systems
  
- Provisions for experimental fires and fire temperature simulation with programmable gas burners
- Provisions for venting of fire floor
- Provisions for natural and mechanical pressurization of vertical shafts and floor spaces
- Stair doors with remote control for simulation of stair use during evacuation
- Sensors for measurement of pressure difference, air velocity, temperature, carbon dioxide, carbon monoxide and smoke density
- Automatic data acquisition system

The fire tests are conducted using two programmable gas burners, located in the burn area of the 2nd floor, capable of simulating various fire sizes up to 5 MW. The carbon dioxide produced by these burners represents smoke and toxic gas developed from a fire, and is monitored with infrared gas analyzers along with the measurements of pressure differences, temperatures and flow rates throughout the tower.

#### 4.0 MECHANICAL PRESSURIZATION AND EXHAUST SYSTEMS

The major approach to controlling smoke movement and protecting escape routes during a fire in tall buildings is based on controlling the pressure differences across the internal and external separations of a building by means of mechanical pressurization and exhaust of specific spaces depending on the method of smoke control used. The experimental fire tower is provided with mechanical air supply and exhaust systems to permit studies on the various methods of smoke control that are being installed in buildings. This section describes in detail the mechanical air handling systems and also the air flow measuring units associated with these systems.

##### 4.1 Air System Configuration

The experimental tower is provided with two major air systems, one for building heating and pressurization and the other for shaft pressurization. A schematic diagram of the air flow systems is shown in Figure 8 and a layout of the air handling equipment installed in the Tower's mechanical room is shown in Figure 9.

The building heating and pressurization system consists of supply fan #1 ( $14 \text{ m}^3/\text{s}$ ) which provides heated air to building air supply shaft #1, return fan #2 ( $17 \text{ m}^3/\text{s}$ ) which extracts air from the tower through return/exhaust shaft #2, and exhaust fan #3 ( $9 \text{ m}^3/\text{s}$ ) which exhausts air from the building through shaft #2 to outside at the roof. Fans #1 and #2 are located in the adjacent mechanical building and fan #3 is located at the roof on top of the return shaft. This system can operate as a central heating system for the tower during non-testing periods and can also be used for test purposes.

The shaft pressurization system consists of supply fan #4 ( $18 \text{ m}^3/\text{s}$ ) located in the mechanical building, and exhaust fan #5 ( $4 \text{ m}^3/\text{s}$ ) which is mounted on the roof of the stair exhaust shaft #6. The supply fan #4 provides tempered outside air at any or all floors through vertical distribution shaft to the experimental stairshaft, and through another vertical shaft to the elevator and stair vestibules, and also provides tempered outside air directly to the elevator shaft at the bottom of the shaft. Fan #5 exhausts air in the stairshaft at any or all floors.

The mechanical building which houses the fans and heating systems is located on the north side of the tower. The fan ducts from the mechanical building travel underground and connect to the various shafts at the basement level (Figure 7). The supply air for both systems is heated by gas-fired duct furnaces provided with discharge air temperature controller and other safety devices. In winter, the air supplied to the shafts can be heated to  $10^\circ\text{C}$  at an outside air temperature of  $-28^\circ\text{C}$ . The fan performance data is provided in Table 3.

#### 4.2 Air Flow Measuring System

The total air flow rates supplied or extracted from any individual shaft are measured by air flow measuring stations (AM1 to AM9) installed in the air ducts at positions as far away from the fan and duct bends as practicable (Figs. 8 and 9). Each station consists of multi point self-averaging total pressure tubes and their associated static pressure taps. An air straightener of honeycomb panel is located immediately upstream of the averaging tubes, the honeycomb cells reduce the air turbulence and directs the flow parallel to the ductwork. The total and static pressure signals are transmitted by plastic tubes to their respective air flow meters in the fan control room in the service unit and recorded by the data acquisition system. A typical installation of an air flow measuring station is shown in Figure 10. A view of the fan control panel is shown in Figure 11. The airflow measuring stations were calibrated using

the pitot traverse method<sup>13</sup>. The calibration curve for each station and the method used are given in Appendix A.

## 5.0 INSTRUMENTATION AND MEASURING TECHNIQUES

The instrumentation of the tower was designed to provide permanent instrumentation set-up for measuring and recording the basic parameters required for tests in the fire tower. The measurements include air/gas temperatures, pressure differentials, concentrations of carbon dioxide and carbon monoxide, air/gas velocity, and the airflow rates for building supply, shaft exhaust, and shaft and vestibule pressurization, barometric pressure at the ground floor, and wind speed and direction at the roof. In addition, there are provisions for adding other sensors such as smoke meters, heat flux meters, etc.

The instrumentation consists of the following three basic measuring systems that are typical on every floor - the locations of the measuring points are shown in Figure 12:

- 1) Temperature measurements - Temperatures are measured in 10 different locations on each floor using 20 gauge type K chromel - alumel thermocouples. Also, additional temperature measurements are made in the burn area of the 2nd floor at the ceiling, side walls, and at various heights above the floor as indicated in Figure 13 and just above the gas burners as indicated in Section 7.0.
- 2) Pressure differential measurements - Pressure differential across the various walls of the building are measured using 18 static pressure taps (of 6.3 mm O.D. copper tubing) flush mounted to the walls on each floor (Fig. 12). All pressure lines for each floor are connected to a twenty four-port scanivalve equipped with a pressure transducer located on the same floor in the service area.
- 3) Gas sampling measurements - Carbon dioxide gas concentrations are measured at 6 locations on each floor (Fig. 12); in the shafts, vestibules and the burn areas by copper sampling tubes. The sampling tubes on each floor are connected to a twelve-port samplivalve unit with an infrared gas analyzer, which are also located on the same floor in the service area. Additional CO<sub>2</sub> and CO gas concentrations are measured at the thermocouple stands in the burn area of the 2nd floor (Fig. 13).

All devices of the three systems are controlled and monitored by a computer based data acquisition and control system (DACS) described in the following section. A schematic representation of the instrumentation system for a typical floor is shown in Figure 14, and an illustration of the instrumentation arrangement in the 2nd floor service room is shown in Figure 15; also, close-up views of the pressure scanivalve and the gas samplivalve units are shown in Figs. 16 and 17, respectively. Detailed descriptions of the instrumentation and measuring techniques for temperature, pressure differentials, gas sampling, gas velocity measurements, and wind speed and direction are presented in Appendix B.

## 6.0 DATA ACQUISITION AND CONTROL SYSTEM

This section describes the data acquisition and control system (DACS) with emphasis on the fire tower system, and it includes the following: description of sensors and devices, system function, operator-system interface, system hardware and system software. The system software was designed by Systemhouse Ltd. (SHL), based on the Building Energy Management System Software (BEMS) which was modified to control the experimental devices and sensors, and to monitor, record and display data for experiments in both the experimental fire tower and the burn hall.

Extensive verification tests were performed on the computer-based data acquisition to ensure proper system operation and complete software/hardware integration. The tests included the following: i) wiring check out of all sensors and devices, ii) data structure and communications, to ensure that software programs are functioning correctly - this part included "Experiment Set-up Program, Monitor Function, Data Logging Function and Conversion Algorithms, Data Storage Functions, and Plot Features", iii) proper system operation and control of all devices and sensors (i.e. thermocouples, pressure scanivalves, gas samplivalves and door operation).

### 6.1 Description of Sensors and Devices

The sensors and devices provided for the Fire Tower are listed in Table 4 and they fall into the following categories:

1. Sensors that require no control and output an analog voltage;
  - a) Thermocouples - outputs a voltage as a function of the temperature of the sensor.
  - b) Gas Velocity Probe - outputs a voltage related to the velocity of gas flow at the sensor.

Provisions were also made in the system to accommodate other sensors in this category and they are photocells (smoke density), radiometers or heat flux gauges, load cells and strain gauges.

2. Sensors that require automatic control and output an analog voltage:

- a) Scanivalve - requires a signal to step to the next port of 24 pressure ports per floor. The pressure transducer outputs a voltage proportional to the differential pressure across the diaphragm of the transducer.
- b) Samplivalve - requires a signal to step to the next port of 12 gas ports per floor. The gas analyzer outputs a voltage proportional to the gas concentration.

3. Sensors that set a binary voltage level (i.e., open, closed):

- a) Samplivalve, Scanivalve - outputs a voltage level when the switch is in the 'home' position.
- b) Door sensor - outputs a voltage level indicating an open or closed state of a door.

The sensors and devices of the fire tower are connected to their corresponding data acquisition unit as described in Section 6.3.

## 6.2 System Function and User - System Interface

The experiments in the fire tower may involve several or all floors. It is possible to run the system and monitor data from any observation station in the fire tower or from the station in the burn hall.

In preparation for the experiment, a complete and correct initialization of the system database must be provided for all sensors required. The user will then perform a simple set up for the test specifying a particular parameter file. The system program provides a checklist of necessary user actions and menu of user commands.

At the beginning of any experiment, the user must specify the sensors required and the rates of collecting the readings. A set of readings can be taken in time intervals ranging from 10 to 30 seconds or longer, depending on the number of sensors required and the duration of the experiment. During the experiment, the user will be able to call up a

display of real-time sensor data from any sensor or combination of sensors (up to six sensors at one time), and a display of the system status.

The system software allows the user to log a message entry recording the time of any significant events (i.e., "start of fire", "start of evacuation ", etc.). It is also provided with alarm setting features which allows the user to set maximum or minimum limits (eg. maximum temperature, gas concentration, pressure difference, etc.), for any number of active sensors during the experiment. Further detailed information is provided in DACS User Manual - Ref. 14.

### Doors Operation

The door operation can be programmed to open and close according to user specified schedules. A data file provided in the database contains a schedule for opening or closing each door at specified times after the start of an experiment. The same schedule may be used for as many doors as desired. All door schedules can be examined or modified during the SET UP routine of an experiment. In modifying a schedule the user may select a regular or irregular schedule and can enter the time as elapsed time from the start of the experiment or as the interval time between successive open or close actions.

## 6.3 System Hardware

### 6.3.1 Computer Room

The computer room located in the service unit is used for experiments in both the fire tower and the burn hall. A schematic representation of the computer-based data acquisition and control system is given in Figure 18. The system has a DEC PDP-11/73 with 256 K bytes of memory. The data storage is provided by two RL01 rigid disks (5 MB each) for system and user software storage, a magnetic tape (TM 11), and two floppy disk units RX02 (512 K bytes each). A video terminal (VT52) and a hard copy terminal LA 120 serve as the system console and printer respectively. In addition, two remote vide screen terminals (ISC 8001I Colour graphics) provide computer control from the fire tower and burn hall.

### 6.3.2 Fire Tower Configuration

Five remote data acquisition and control units (DAU's) type Hewlett Packard HP3497A are located on floors 2,3,6,7, and 9 of the service tower.

Each DAU is capable of managing the sensors and devices of two floors (i.e., 20 thermocouples, 2 pressure scanivalves and 2 pressure transducers, 2 samplivalves and 2 gas analyzers). The distribution of sensors and devices in the fire tower is given in Table 5, and a schematic representation of the tower's data acquisition and control system - hardware configuration is shown in Figure 19.

Each DAU is identical, and includes a front panel keyboard, display, real time clock, and HP-IB interface. It also contains the following modules:

- a) Programmable digital voltmeter HP44420A
- b) 20 channel relay multiplexer with thermocouple compensation HP44422A for type K thermocouple input
- c) 20 channel relay multiplexer HP44421A for analog input
- d) 16 channel digital input assembly HP44425A
- e) 16 channel actuator/digital output assembly HP44428A.

DAU#1, on the second floor, is provided with an HP3498A extender unit, allowing the control of door operation and the additional sensors and devices of the 2nd floor.

The computer addresses each data acquisition unit as a separate 'logical unit', and the data transfer and communication between the DAU's are handled over the HP-IB 37203A bus extenders with Belden type 9248 coaxial cables. The interface between the DAU's and PDP 11/73 is made through a DEC IBV11A bus interface card. One cable and pair of extenders are used to connect the PDP 11/73 to DAU#1 on the ground floor of the tower. These lines transmit digital data and are isolated from external electrical interference using coaxial cables.

#### 6.4 System Software

##### 6.4.1 Operating System

The DEC PDP-11/73 computer is configured to run under the RSX-11M V4.1D operating system. The functions of command processing and task scheduling are performed by interaction with the operating system. The system responds to user input commands to call up and start the appropriate programs.

##### 6.4.2 Software Package

The SHL-BEMS software package is used to control the experimental devices and sensors, and to collect and display the experimental data. The

performance of the SHL-BEMS software is described in terms of the following services: Set-up, Monitor, Data Log, Store, and Display.

a) Set-Up

The set-up process allows the user to identify all active sensors, specify the data acquisition rates, the data conversion algorithms, the data recording rate, and specify any other relevant device parameters. It is also possible to use a previous set-up specification from a parameter file and optionally modify the values for the current experiment. These modified parameter values will be stored in a new parameter file at the termination of the set-up process. The set-up process must be completed before the start of any experiment. A user may request Set-Up before actually connecting the sensors and devices.

b) Monitor

The monitor process, when called up by the user, will access the active sensor list file, verify by passive data readings that all the active sensors are functioning, and provides the current data reading of all active sensors during an experiment. This also allows the user to check and verify the readings from calibration channels on pressure scanivalves and gas samplivalves prior to the start of the experiment.

c) Data Log

This process accesses all the active data sensors and the analog devices, at user specified rates. The data log also accesses the correct algorithm (specified by the user) for converting the raw sensor data to engineering units. In addition, as the data log is accessing the raw sensor data, it will be checking the values against the user pre-set alarm levels, and a message will be printed on the printer if any alarm level is reached.

d) Data Storage

The storage function is activated automatically at the start of the experiment, or by user command. This function stores the raw or converted data from the active sensors in data files on disk as specified by the user. There are five available data storage files, and six available groups of twenty slots within each file (a total of 600 points are available). Each slot refers to an individual measuring point (or data sensor) and can hold up to 1200 samples per sensor. The user must ensure that a suitable recording rate is selected so the recording capacity is not exceeded during the course

of an experiment, e.g., with a selected recording rate of 5 seconds (intervals), the recording capacity of the experiment will be 100 minutes, and with a rate of 10 seconds the capacity will be 200 minutes.

e) Plot

The plot program can produce up to six plots on a single display image on the ISC800II colour graphic terminal. Each of the plots may be a display of engineering units, or may be the result of a data transformation (integrated curve, logarithm, inverse or ratio of two selected sensor readings) selected by the user during plot initialization. All plots are displayed as a function of time. Real-time data and previously recorded data may be displayed simultaneously. Each of the six possible plots may have independent Y axis scaling. Although only two of the possible six Y axis scales are displayed at the screen, the user may step through all possible Y axis scale displays by pressing the function keys F1 or F2 on the keyboard.

#### 6.4.3 Instrument I/O Control

All I/O devices, described in section 6.2, provide raw sensor data which are then converted to engineering units for display purposes and for storage. All sensors and devices are controlled by the software handling routines described in the DACS System Management Manual<sup>15</sup>.

The samplivalve gas analyzer is serviced by two routines; one routine (digital output of the DACS) to step the samplivalve and the other routine (analog input of the DACS) to obtain the data reading from the gas analyzer. The scanivalve pressure is also serviced by two similar routines; one to step the scanivalve and another routine to obtain the data measurement from the pressure transducer. For other sensors and devices that require no control (i.e. thermocouples and velocity profiles) only one routine (the analog input) is required to obtain the data reading from the sensor.

#### 6.4.4 Database

The DACS is structured with a database which defines the data organization of all sensors and devices in the system and controls their operation through the various programs in the system. Within the database, there is a data table for every device or sensor in the system. The programs (and handling routines) in the system run independently of each

other and exchange data and control parameters through the database. All interactions with the database are handled through a Central Database Manager Program (CDBMGR). This modularity of the system software provides flexibility in changing the experimental set-up and allows easier system modification and development. Detailed information on the structure of the database is provided in the DACS Manual<sup>15</sup>.

A cross reference between all the points in the system and the assigned database numbers is kept in the KEY files. A typical database reference list, of the tower, is presented in Appendix C. The reference list includes all the data acquisition points which are connected to DAU#1 and indicates their associated system, floor level, slot number (on the DAU) and the assigned database number. All the points (in this list) are repeated identically for all DAU's in the tower, except for the points connected to the extender and the points with database numbers over 106.

#### 6.5 System Performance

Performance tests were conducted to determine the speed and accuracy of the data gathering and to verify the system operations with regard to the requirements of smoke control testing in the tower.

The following is the resulting experimental set-up and system performance, with all measuring points and devices enabled:

- 100 thermocouples - the data sampling interval is 30 seconds.
- 11 pressure scanivalves - with the stepping rate set at 10 seconds, the actual stepping is 10 to 13 seconds, and the data sampling interval is 10 seconds;
- 11 gas samplivalves and 11 gas analyzers - with the stepping rate set at 30 seconds, the actual stepping is 30 to 34 seconds, and the data sampling interval is 30 seconds;
- 20 doors operating at 60 seconds regular schedule;
- The data storage (recording) interval for all points is 30 seconds.

#### 7.0 FIRE SIMULATION USING GAS BURNERS

Various methods can be used for simulating a fire in a building by using solid, liquid, or gas fuels. The most representative method is the use of actual combustible materials with a distribution arrangement as in typical office, apartment or hotel room and a typical ventilation condition. Such a method would provide a realistic representation both quantitatively and qualitatively of a full-scale fire in terms of the heat released, the

rate of smoke produced, the temperature of combustion gas<sup>16</sup>, and the gas pressure developed in the fire compartment.

However, the use of actual combustible materials is not convenient for conducting experiments that would require reproducibility and control of the fire. In addition, burning of actual materials require time for preparation and clean up between the tests. In the fire tower, most of the experiments will be conducted using propane gas fuel mixed with air for combustion and in some fire tests, solid fuels will also be used as needed. The migration of smoke and other combustion products will be monitored by taking measurements of carbon dioxide gas concentrations in the fire compartment (burn area) and other areas of all floors of the tower, as described in Section 5.0 of Instrumentation.

The fire temperature is controlled by the burner controller according to a specified time-temperature curve. Curves of various fire severities can be set based on the standard fire test for building construction and materials NFPA 251 and data of actual temperature curves recorded in fire tests<sup>17,18,19</sup>.

#### 7.1 Burner System

A programmable gas burner system has a total capacity of 5 MW with gas fuel/air ratio of 1 to 24 by volume. The burner system consists of the following:

- Two sets of propane fired gas burners
- Two gas train stands
- Two set-point controllers
- A set-point programmer

The propane gas is stored in three tanks (4500 liters each) located outside the building for safety reasons. The propane is admitted through steel pipe lines to the gas train stands on the ground floor. Also, the supply air for combustion is provided from outside to the gas train stands (by a centrifugal fan). The propane gas flow rate and the combustion air supply are monitored and recorded during an experiment.

The gas flow rate is measured by a turbo flow meter (Rockwell model 2" TPL-9, turbo-meter) which is connected to a totalizer and flow rate indicator, (Rockwell model ACT-PAK 1000D). The totalizer accepts electronic pulses from the meter and provides an output in the form of visual displays of the cumulative volume flow and the instantaneous flow rate. The temperature and pressure of the propane gas supply are also measured and recorded during burner operation for the flow correction to standard

condition. The combustion air flow rate is measured using a velocity pressure averaging tubes installed in the inlet air duct located outside the tower and connected by tubing to a pressure transducer located inside the tower. The velocity pressure averaging tube system was calibrated using a pitot traverse<sup>13</sup>. A schematic representation of the gas burner system is provided in Figure 20; details of the burner system are described next.

#### 7.1.1 Burner stands

The two sets of propane fired gas burners are installed in the burn area of the second floor as shown in Figure 21. Each set consists of five ribbon type burners identified as number 1 to 5, as shown in Figure 22. Burner No. 1 is the pilot burner and is controlled by the flame safety controls. Burners 2, 3, 4, 5 are controlled individually, in sequence, by manual or automatic operation of the set point programmer. Temperature limit sensors are provided at each burner for proving the flame before the next sequenced burner is provided with combustion air and gas. The heat output of the burner is controlled by varying the amount of air supplied by the combustion air fan to the venturi tube (air/gas proportional mixer) which in turn controls the supply rate of propane gas. A motorized valve (downstream of the fan) is adjusted by electric signals sent to the damper motor by the controller. Position of the valve opening may be established by manual or automatic operation of the controller.

#### 7.1.2 Gas Train Stands

Two gas train stands, are installed on the ground floor, below the burner stands as shown in Figures 23 and 24. Steel pipes 4 inches in diameter connect the gas/air mixture outlets of the gas train rigs to the burners on the floor above. Each gas train stand is provided with the following:

- Combustion air fan; 0.76 m<sup>3</sup>/s at 657 mm water column pressure,
- Motorized air discharge damper for proportional control of combustion air,
- Propane gas pressure regulators and low and high pressure gas switches with manual resets,
- Low pressure gas regulator and solenoid valves for supply of gas to the air/gas mixers,
- Air/gas proportional mixer assembly consists of a venturi tube with a butterfly valve and a zero pressure cock for maintaining the gas/air ratio throughout the range of operation,
- Flame safety control valves,
- Flame safety and control panels,

### 7.1.3 Controllers

The burner system can be operated on manual or automatic mode using the two set-point controllers, type Barber-Colman 560 series microprocessor, and set-point programmer UP55 series which are located in the service area of the second floor, as shown in Figure 25. One controller is used to control the firing rate of each set of burners by adjusting the combustion air damper. The temperature required is referred to as the set point which can be entered either directly into the controller for manual operation or programmed through the programmer for automatic operation. The temperature achieved which is referred to as the process temperature is provided by the thermocouples installed at the ceiling above the burners. Both these temperatures are indicated continuously by the digital read-outs of the controllers. When the process temperature deviates from the set point temperature the controller signals the damper motor to reduce or increase the combustion air supply valve opening, thereby reducing or increasing the firing rate until the process temperature reaches the set point temperature.

### 7.1.4 Programmer

A set-point programmer is installed alongside the two controllers (Fig. 25) for automatic operation.

The programmer has two channels, one for each controller. Each channel has four event relays which are used to switch on and off burners number 2,3,4, and 5 of one burner set. The time-temperature curve is entered into the programmer, and during tests, the programmer sends set point signals to the controller(s), which adjust the firing rate so that process temperature follow the required curve. Further detailed information on the programming capability and the controllers are provided in the instruction manuals (Refs. 20, 21).

## 7.2 Safety features

The system is provided with safety interlock contacts designed to shut down the entire system, except for combustion air supply, if any of the following conditions exist during the burner operation:

- i) detection of propane gas in the gas train room (ground floor) or at the bottom of the smoke shaft at the basement level.
- ii) failure of the combustion air supply or air pressure switch
- iii) propane gas pressure is too low

iv) propane gas pressure is too high

In addition to the above, four temperature limit controls (relays) are provided in the consoles for the controllers. The purpose of these controllers is to assure flame and temperature are satisfactory before an additional burner is activated. The temperature is sensed by thermocouples installed at the burners (Figs. 21 & 22). The pilot burner of each burner set is provided with flame safety controls. Should the flame go out at any time for any reason then the gas will be shutoff at the gas train stand.

Also, the burners nos. 2, 3, 4, 5 will not light until two conditions are satisfied:

- the set temperature limit is achieved and the temperature relay operated to assure that the next burner is safe to ignite.
- the programmable controller has to be set at its proper point in the program, and the event relays have closed their contacts to allow the burners to be "on".

Further details on the system operation, procedures and emergency shut down are provided in NRC Gas Burners Instruction Manual.

#### 8.0 SUMMARY OF THE TOWER'S RESEARCH AND DEVELOPMENT CAPABILITIES

The Tower Facility has unique capabilities for conducting research and development in the smoke control area. Typical applications are:

- The concepts of smoke movement and control which involve studies of the effect of fire temperature on the movement of smoke, verification of mathematical models, development of various smoke control techniques involving mechanical pressurization of vertical shafts and floor spaces, and establishing design requirements, such as the design pressure difference and air velocity required to overcome the adverse pressure caused by the fire, *of*
- The study *of* methods of venting smoke and heat using the smoke shaft, exterior wall vents or mechanical exhaust, X
- Testing of various system components (e.g. smoke and fire dampers, air pressure relief dampers, fans, etc.),
- The development of guidelines for the commissioning of systems, acceptance of test procedures, test methods and measuring techniques,

- Training and demonstration purposes.

Studies other than smoke movements and control that can be conducted are exterior spread of fire from floor to floor, fire propagation and suppression in vertical shafts, and column performance under fire conditions. Also, studies of air flow around buildings involving determination of wind pressure coefficients and wind effects on the operation of ventilation and smoke control systems can be conducted.

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Table 1 Description of the Experimental Fire Tower

Height of Experimental Tower	28 m
Height of Service Tower and Penthouse	31.77 m
No. of Floors	10 floors
Floor Height:	
- first floor (ground floor)	3.6 m
- second floor	3.6 m
- typical floor (all others)	2.6 m
Typical Floor Dimensions:	
- Total inside	8.90 m x 14.65 m = 130.38 m <sup>2</sup>
- Core area (all shafts)	6.60 m x 9.50 m = 62.70 m <sup>2</sup>
- Floor dimension without corridors & core areas	8.90 m x 4.00 m = 35.60 m <sup>2</sup>
- Corridor east, or west	1.15 m x 9.50 m = 10.92 m <sup>2</sup> (each)
- Corridor north	1.15 m x 8.90 m = 10.23 m <sup>2</sup>
Outside wall area (Exp. Tower - inside dimensions):	
- First floor (Ground floor)	(8.90 + 14.65) x 2 x 3.6 = 169.56 m <sup>2</sup>
- Second floor	same = 169.56 m <sup>2</sup>
- Typical floor	(8.90 + 14.65) x 2 x 2.6 = 122.46 m <sup>2</sup>
Outside Windows:	
- Two sliding windows (east side & west side walls)	1.50 m x 1.50 m = 2.25 m <sup>2</sup> (each)
- Two sliding windows (north side wall)	0.50 m x 0.50 m = 0.25 m <sup>2</sup> (each)

Construction

Experimental Tower:

- Wall construction; - 200 mm poured concrete (reinforced)
- Burn area exterior walls; - removable precast concrete panels
- Floors; - 200 mm structural concrete slab
- Doors; - steel fire doors, four hours fire resistance

Service Tower:

- Towers' separation wall (viewing wall):
  - 200 mm concrete
  - 6 mm asbestos sheets fixed to concrete with mechanical clips
  - 102 mm metal 'E' studs @ 600 O/C
  - 89 mm rigid insulation between studs,
  - 12 mm fire rated code 'C' dry wall
  - 1 mm poly vapor barrier to warm side of insulation
- Outside wall: - same as the viewing wall but no asbestos sheet.

Table 2 Flow Area of Shafts and Wall Openings

No.	Shaft	Cross-sectional Areas			
		Shaft		Wall Opening Per Floor (max. opening) (dimensions)	
		[m <sup>2</sup> ]	[mm]	[m <sup>2</sup> ]	[mm]
1	Building Supply Shaft	3.90	3000 x 1300	0.42	600 x 700
2	Building Return /Exhaust Shaft	3.90	3000 x 1300	2.21	(2 openings)
	- Return	-		1.76	1600 x 1100
	- Exhaust	-		0.45	750 x 600
3	Smoke Shaft	2.52	1800 x 1400	1.44	1800 x 800
4	Elevator, Stair Vestibule Supply	1.44	1800 x 800	0.09	300 x 300
5	Stair Supply Shaft	1.40	2800 x 500	0.54	600 x 900
6	Stair Exhaust Shaft	1.00	2000 x 500	0.36	600 x 600
7	Service Shaft	5.88	2800 x 2100	1.08	900 x 1200
8	Elevator Shaft	7.84	2800 x 2800	0.18	600 x 300
9	Stairshaft	12.50	2500 x 5000	0.30	550 x 550
*	Stair vestibule opening to outside wall	-		0.35	1000 x 350

Table 3 Fan's Performance Data

Fan #	Service Area	Capacity (m <sup>3</sup> /s)	Static Press (Pa)	RPM at Max. Service
1	Bldg. supply & pressurization, shaft 1	14	600	940
2	Bldg. return, shaft 2	17	250	575
3	Bldg. exhaust return shaft 2	9	125	700
4	Shaft & vestibule pressurization, shaft 4, 5 & 8	18	650	880
5	Stair exhaust, shaft 6	4	125	885
6	Pressurization of service tower	5.5	375	1310

Note: -All fans are centrifugal type with variable speed drive except fan No. 6 which is single speed.

-All electrical motors are 575 V, 3 Phase, 60 Hz, and 1750 RPM.

Table 4 - Sensors and Devices Controlled by the  
Data Acquisition System of the Experimental Fire Tower

<u>Sensor/Device Description</u>	<u>Number of Points</u>	
	<u>Per Floor</u>	<u>Total</u>
1. Thermocouples	10	100
2. Air Pressure Ports to Scanivalves	24	288
3. Air Pressure Transducer	1	12
4. Scanivalve Selector	1	12
5. Gas Analyzer (CO <sub>2</sub> )	1	10
6. Gas Analyzer (CO)	-	1
7. Gas Samplivalve Ports (CO <sub>2</sub> and CO)	11	132
8. Gas Samplivalve Selector	1	11
9. Low Velocity Probe	-	5
10. Door Position	2	20
11. Smoke Meters (reserved but not connected)	5	50

Table 5 - Fire Tower Computer Lines

Floor No.	<u>ANALOG DATA INPUT</u>				<u>DIGITAL INPUT</u>			<u>DIGITAL OUTPUT</u>		
	Therm.	Gas	Pressure	Smoke*	Gas	Pressure	Doors	Gas	Pressure	Doors
10	10	1	1	5	1	1	2	1	1	2
9	10	1	1	5	1	1	2	1	1	2
<b>TOTAL:</b>	20	14			8			8		
8	10	1	1	5	1	1	2	1	1	2
7	10	1	1	5	1	1	2	1	1	2
<b>TOTAL:</b>	20	14			8			8		
6	10	1	1	5	1	1	2	1	1	2
5	10	1	1	5	1	1	2	1	1	2
<b>TOTAL:</b>	20	14			8			8		
4	10	1	1	5	1	1	2	1	1	2
3	10	1	1	5	1	1	2	1	1	2
<b>TOTAL:</b>	20	14			8			8		
2	10	2	2	5	2	2	2	2	2	2
1	10	1	2	5	1	2	2	1	2	2
<b>TOTAL:</b>	20	17			11			11		
<b>GRAND TOTAL:</b>	100	73			43			43		

Explanation for Digital Lines

Input: gas - home position on gas samplivalve  
 pressure - home position on pressure scanivalve  
 Doors - two doors open/closed status

Output: Gas - stepping gas samplivalve  
 Pressure - stepping pressure scanivalve  
 Doors - two door open/closed position

\* Reserved channels - not connected at present

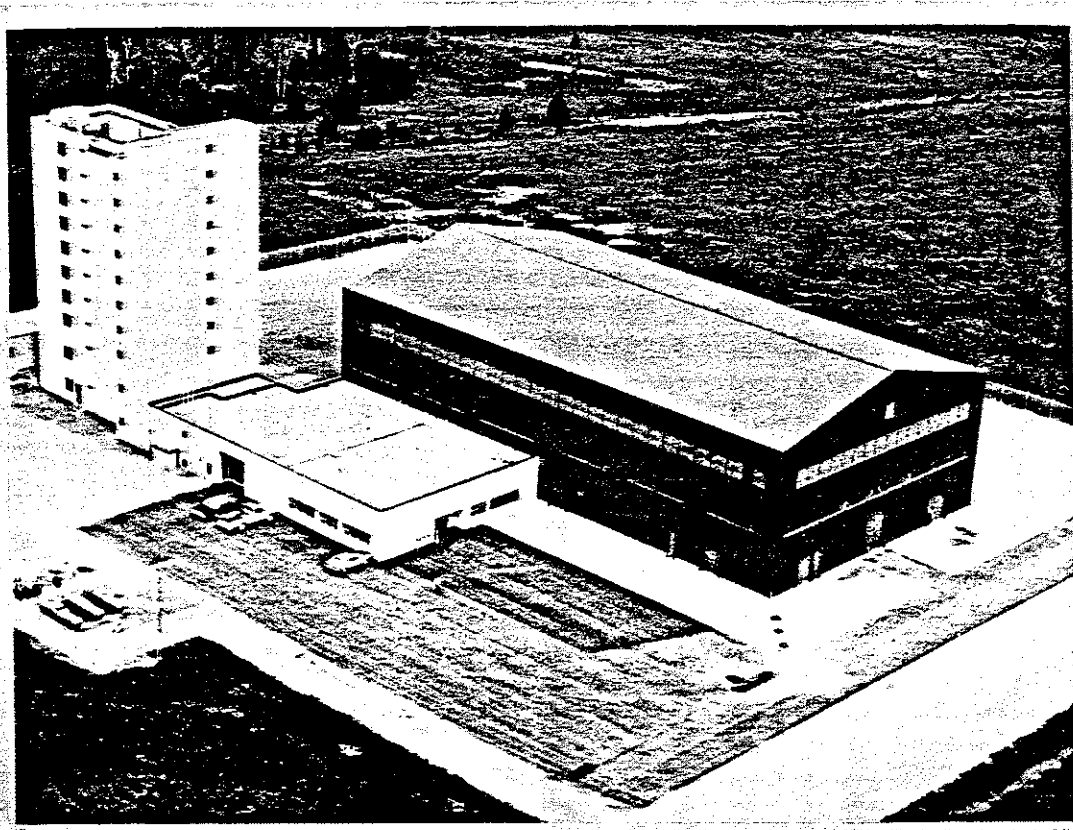
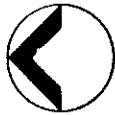
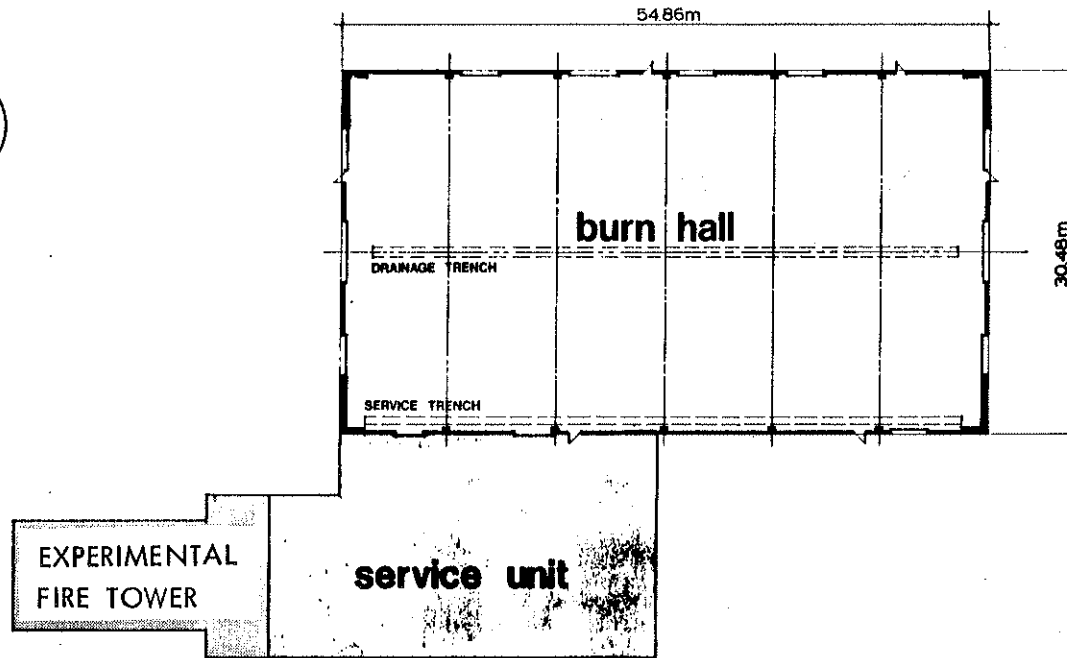


FIGURE 1 NRC NATIONAL FIRE LABORATORY

**N.R.C.**  
NATIONAL FIRE  
LABORATORY



mechanical



SCALE 1:200

FIGURE 2  
NRC NATIONAL FIRE LABORATORY - PLAN VIEW

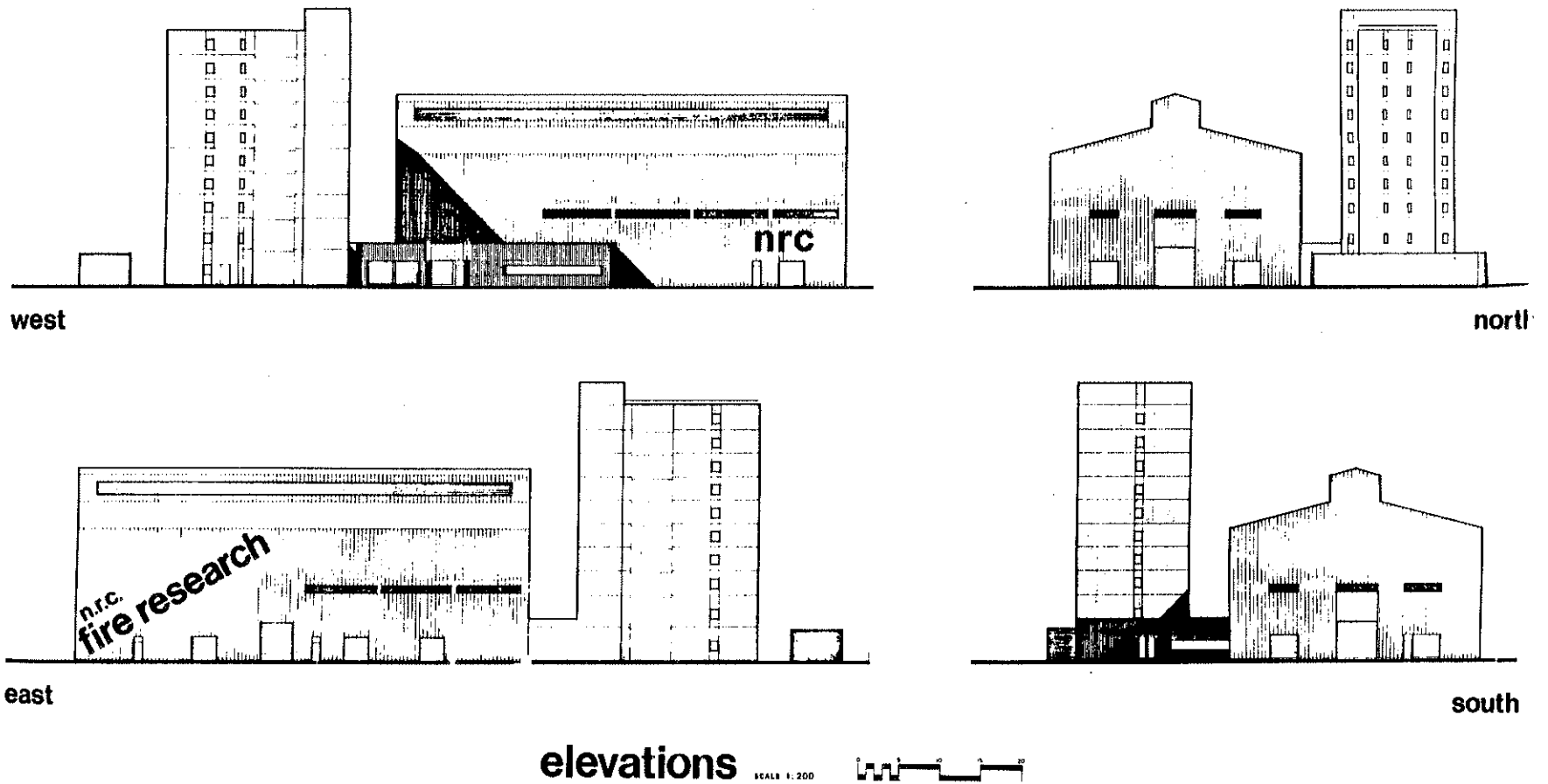
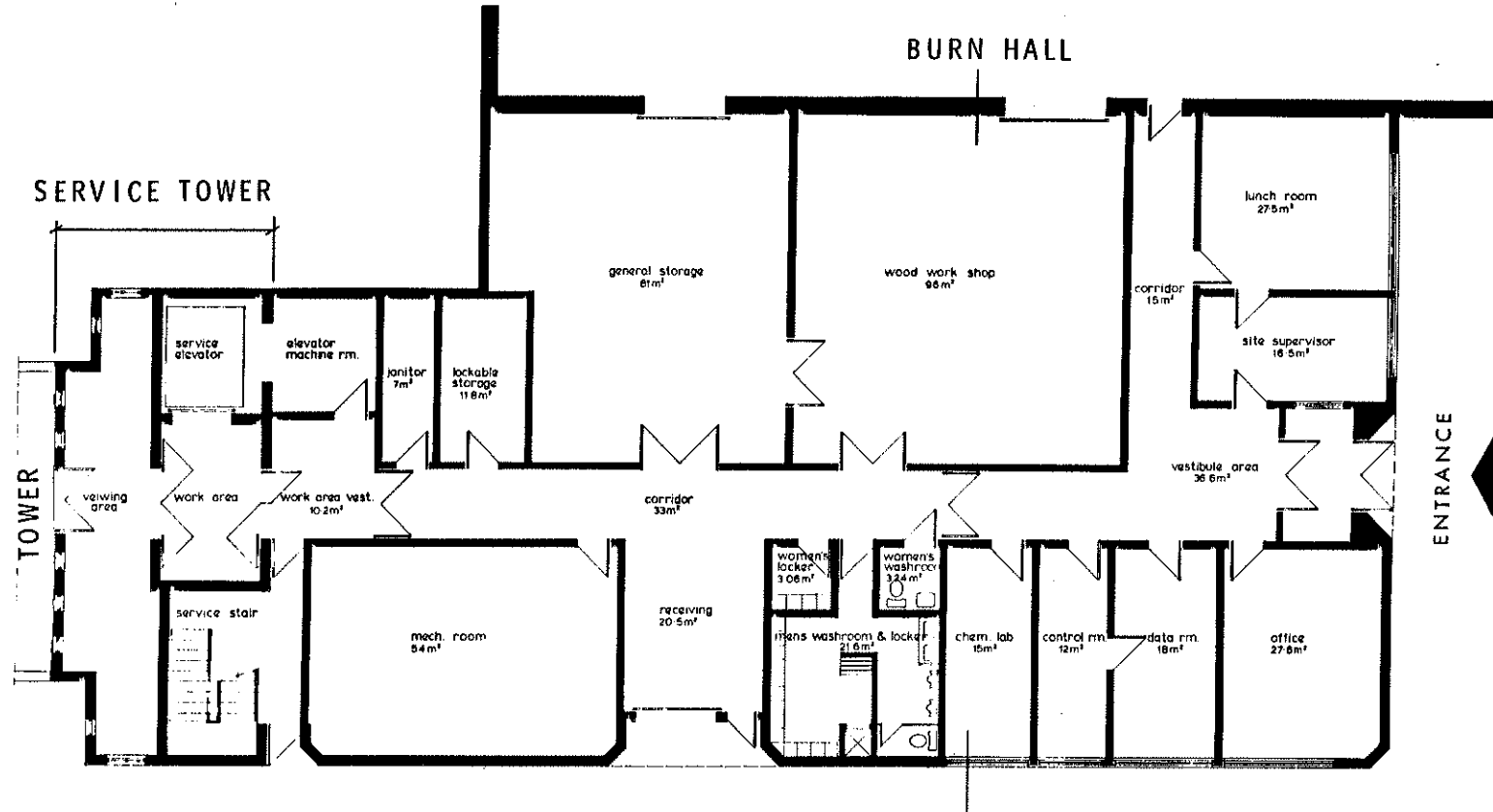


FIGURE 3 NRC NATIONAL FIRE LABORATORY



ground floor plan  
service unit

SCALE 1:100



FIGURE 4 SERVICE UNIT FLOOR PLAN

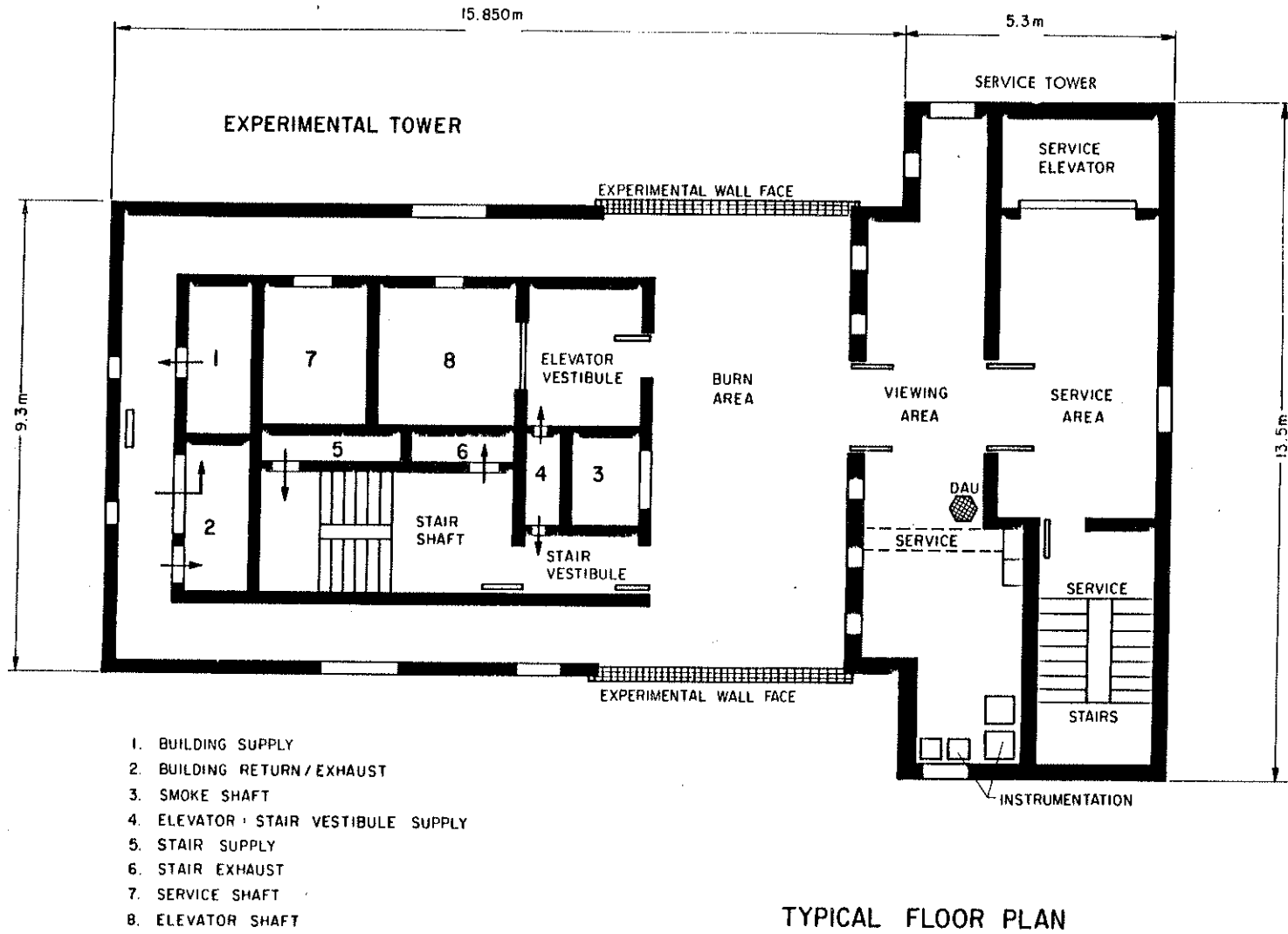
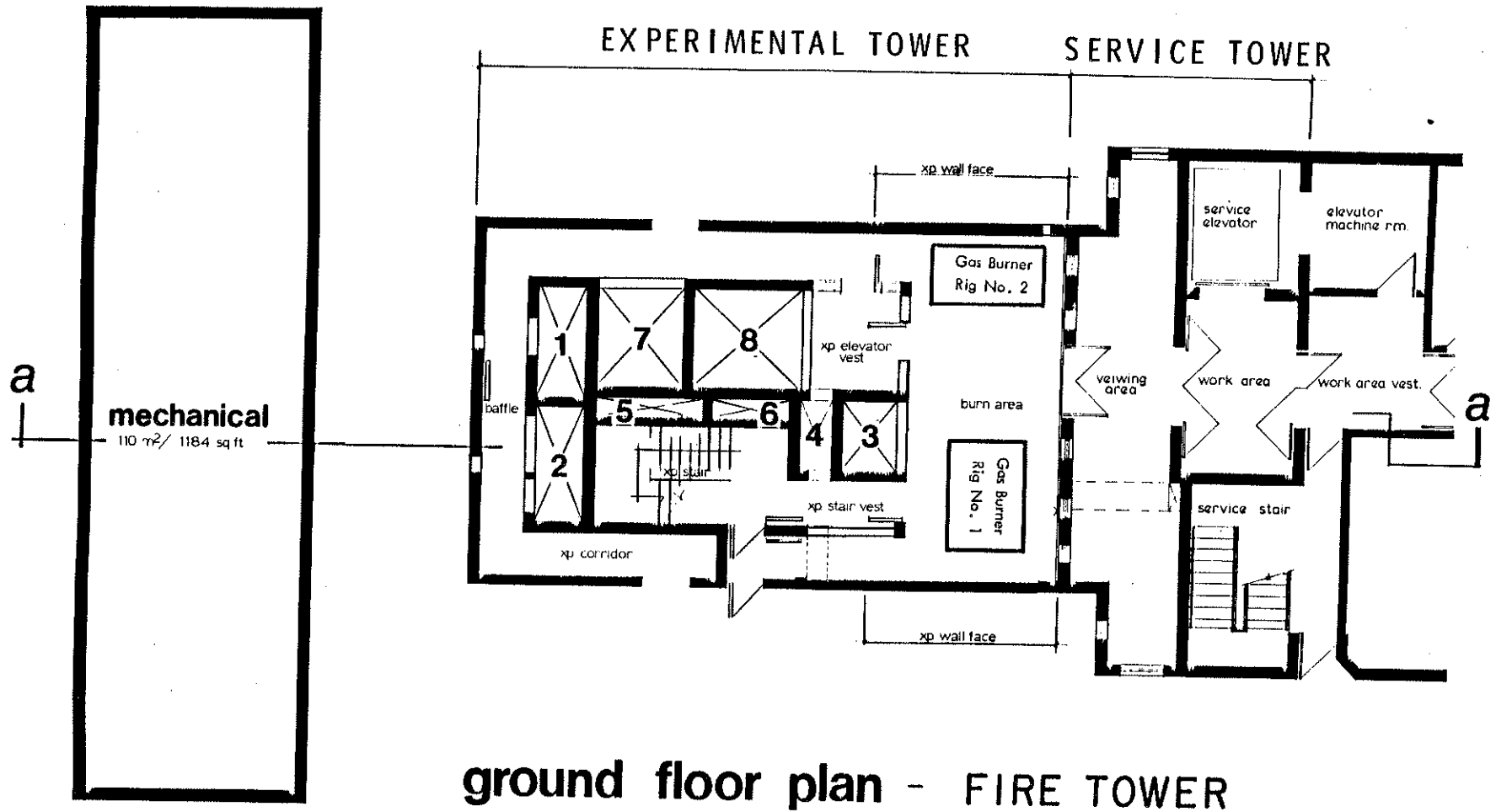
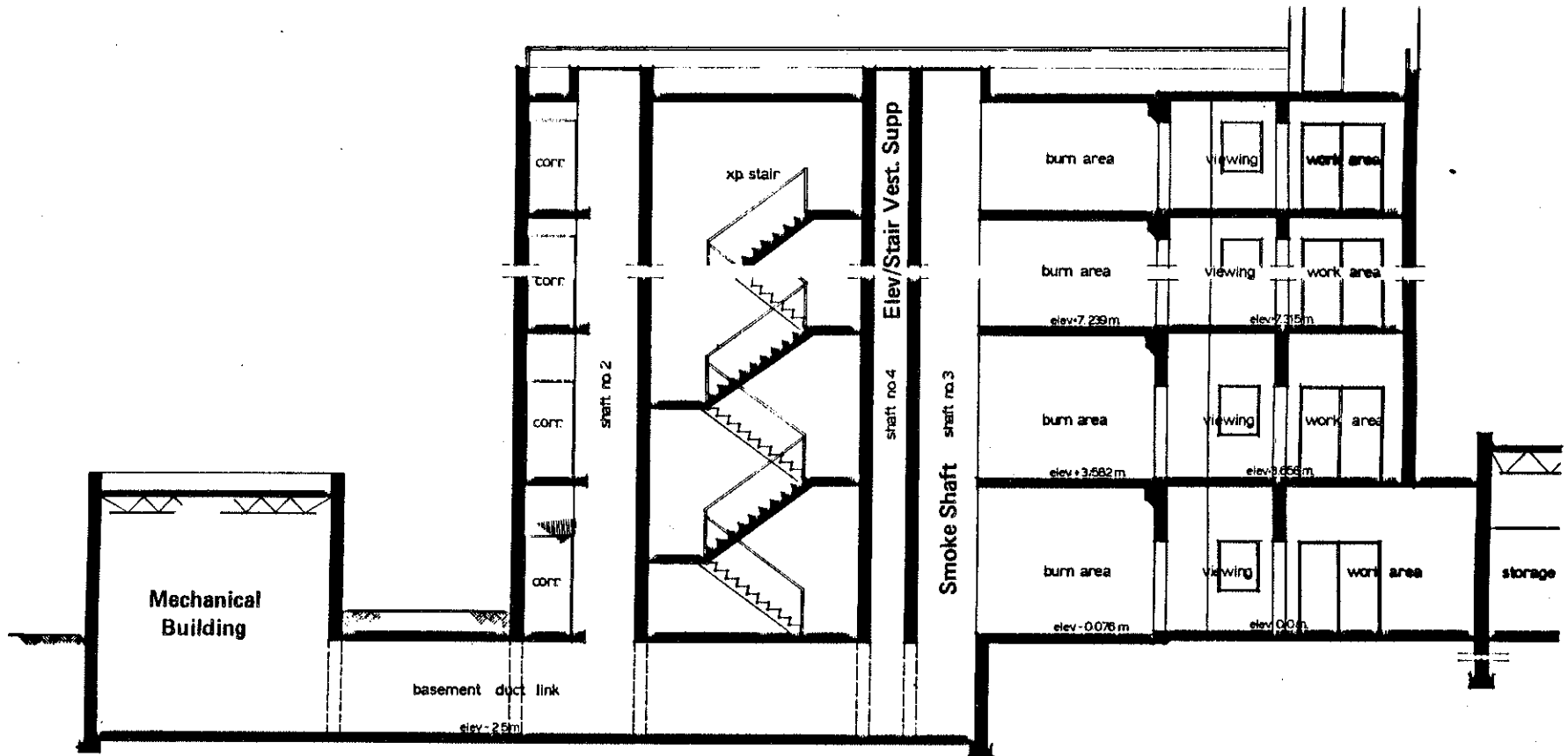


FIGURE 5 TYPICAL FLOOR PLAN - EXPERIMENTAL FIRE TOWER



**ground floor plan - FIRE TOWER**

**FIGURE 6 GROUND FLOOR PLAN VIEW**



**section a-a** scale 1:50

FIGURE 7

CROSS SECTIONAL ELEVATION VIEW OF THE TOWER AND MECHANICAL ROOM -West Side View-

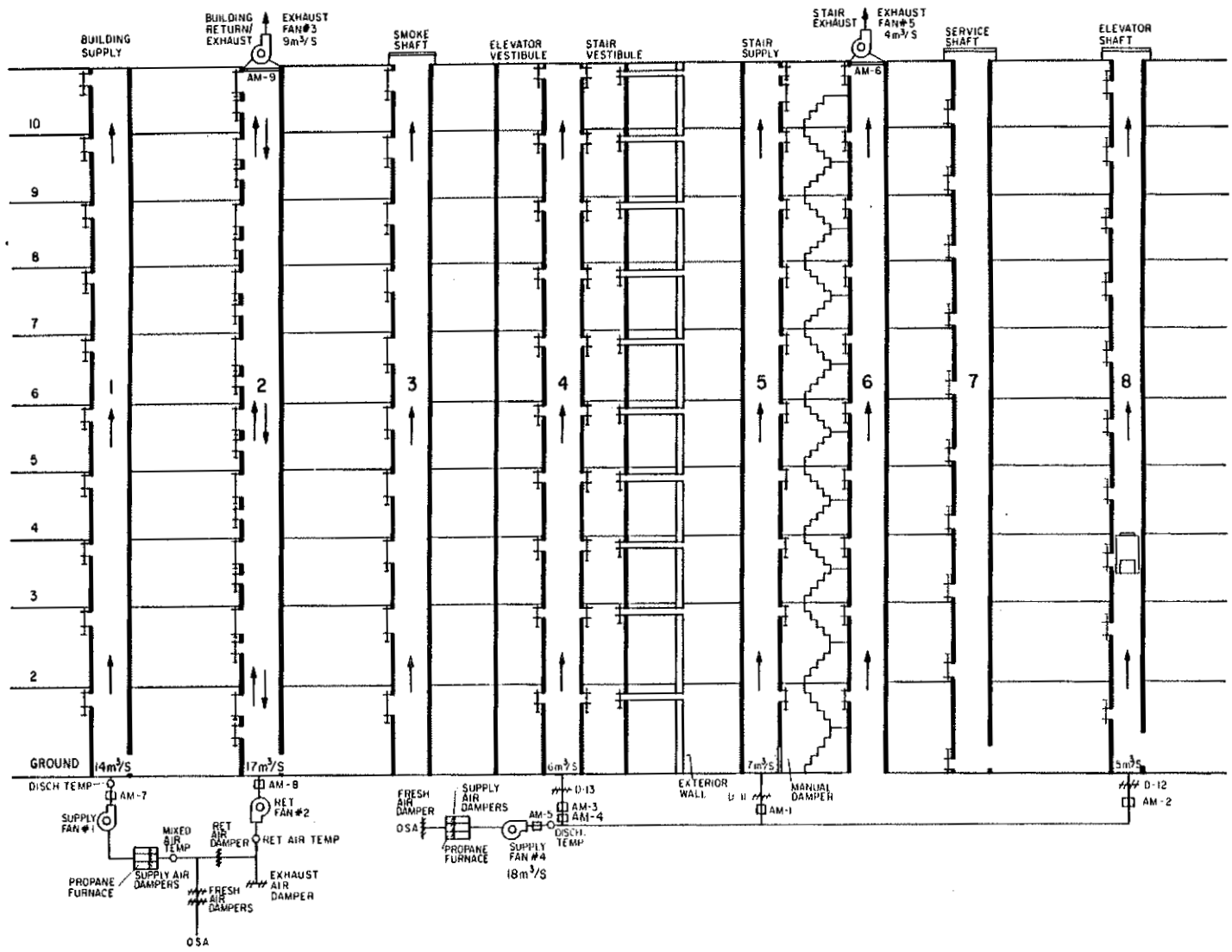


FIGURE 8 SCHEMATIC DIAGRAM OF THE TOWER'S AIR FLOW SYSTEMS.

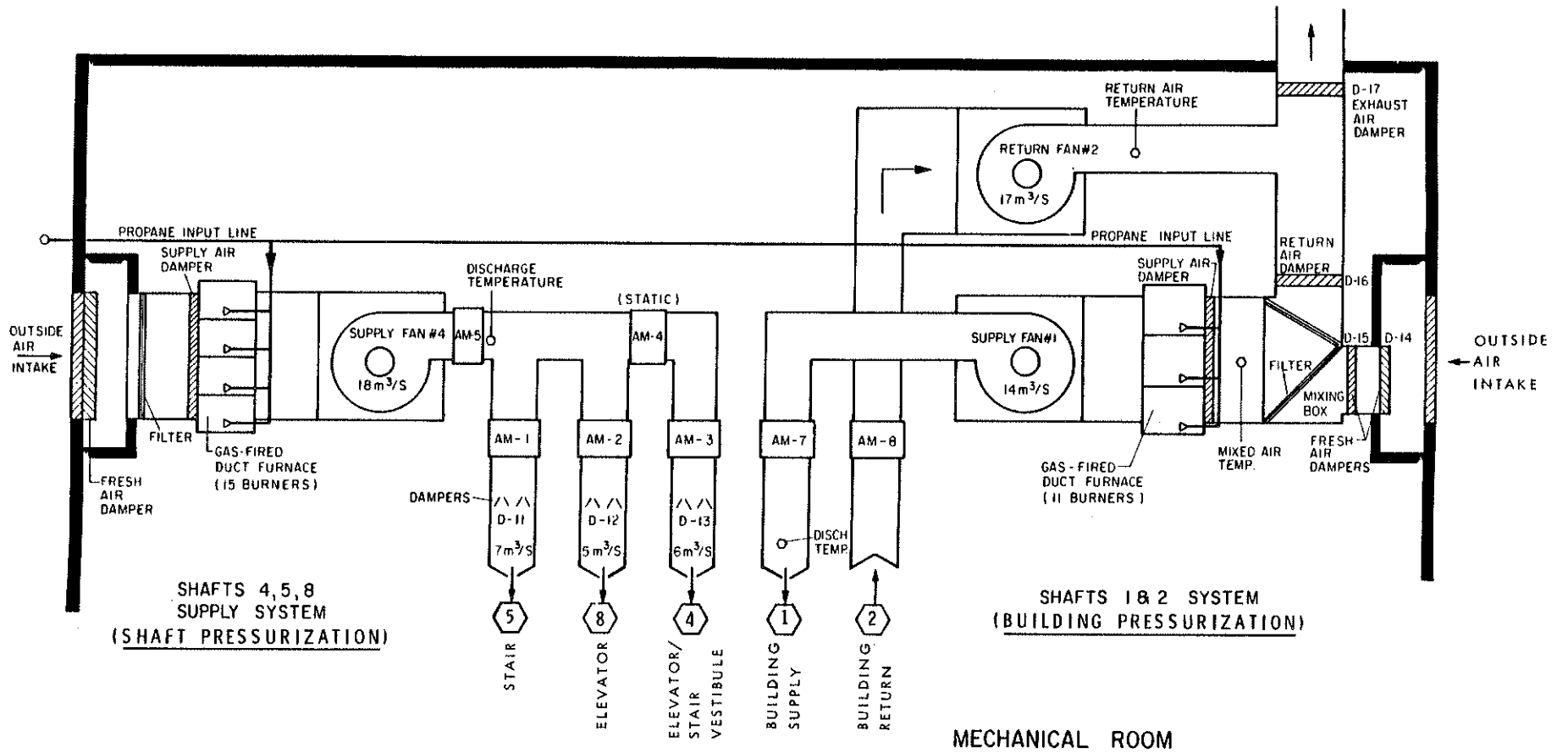


FIGURE 9

LAYOUT OF AIR HANDLING EQUIPMENT IN THE TOWER'S MECHANICAL ROOM.

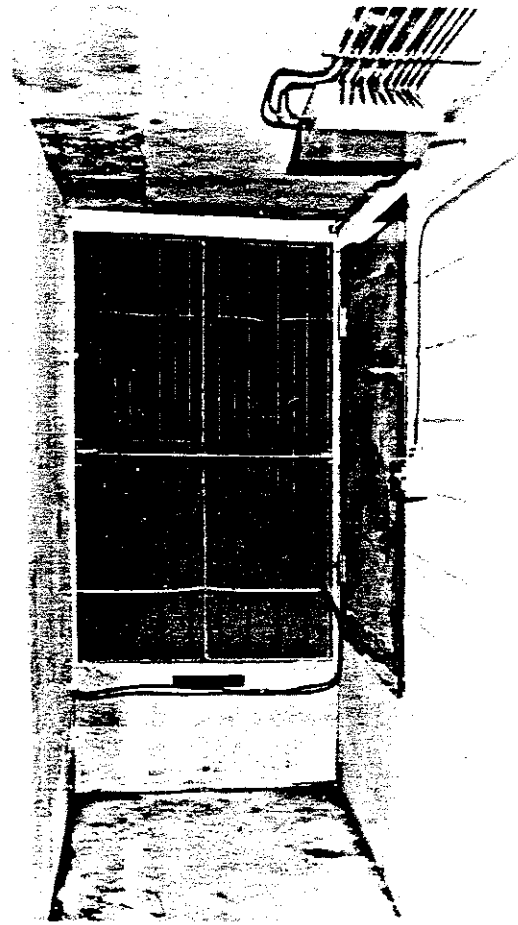


FIGURE 10  
VIEW OF TYPICAL AIR FLOW MEASURING STATION,  
AM-5 OF SUPPLY FAN No.4

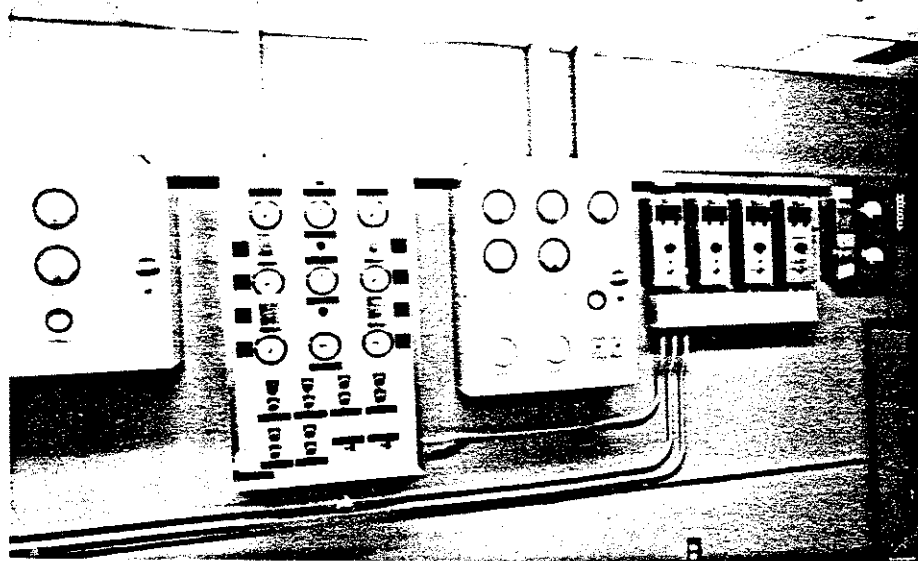


FIGURE 11  
VIEW OF AIR HANDLING OPERATION CONTROL  
(fan control)

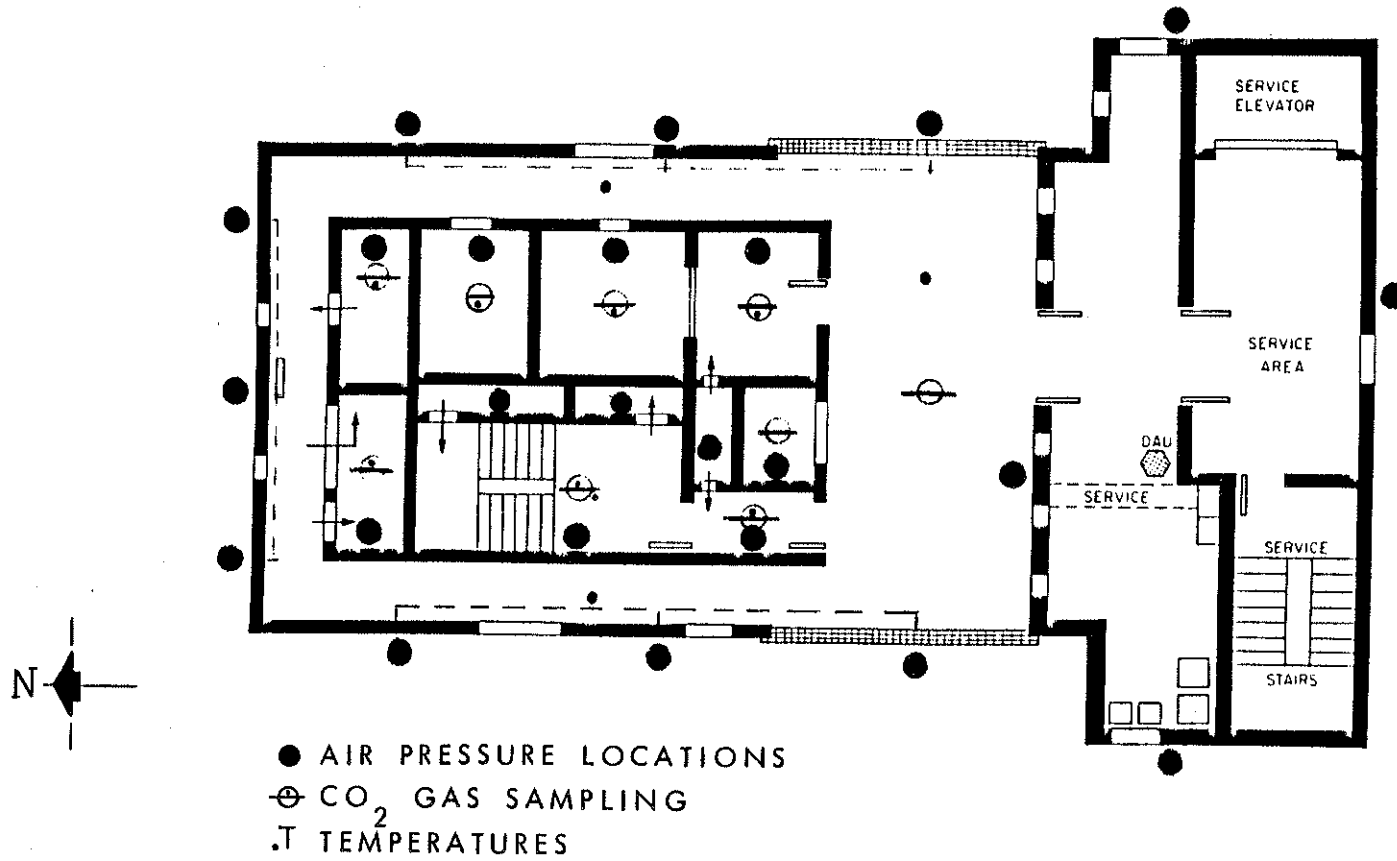
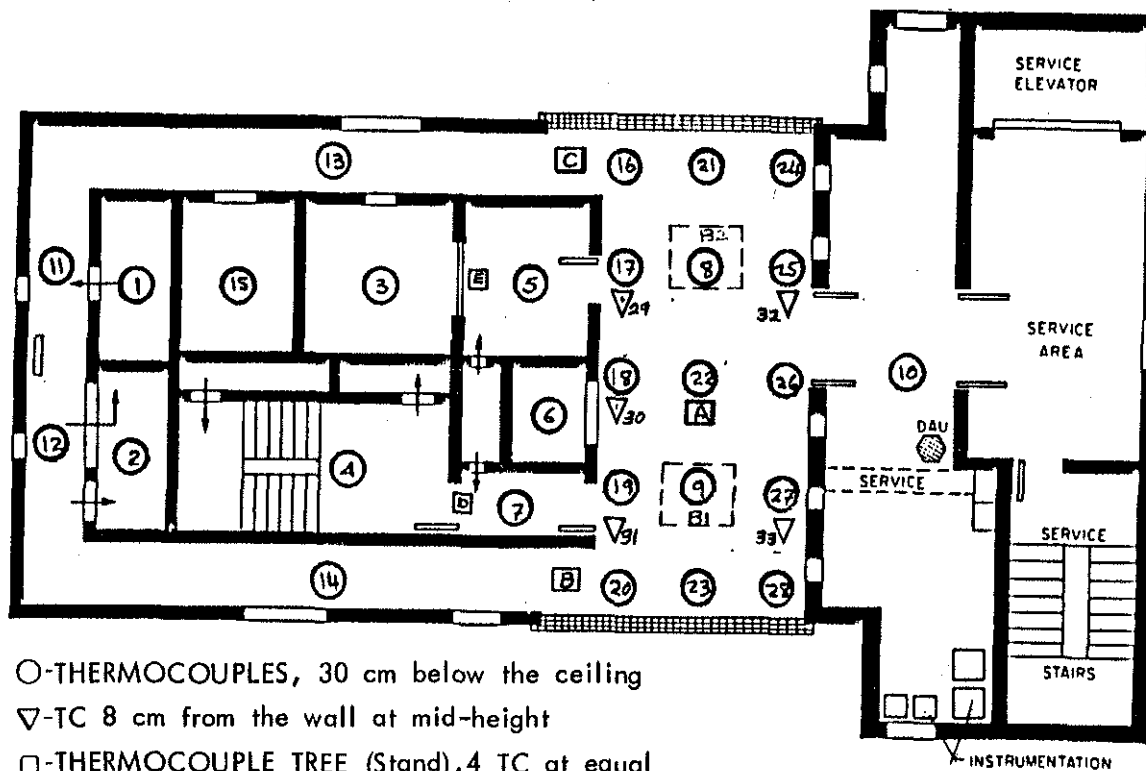


FIGURE 12

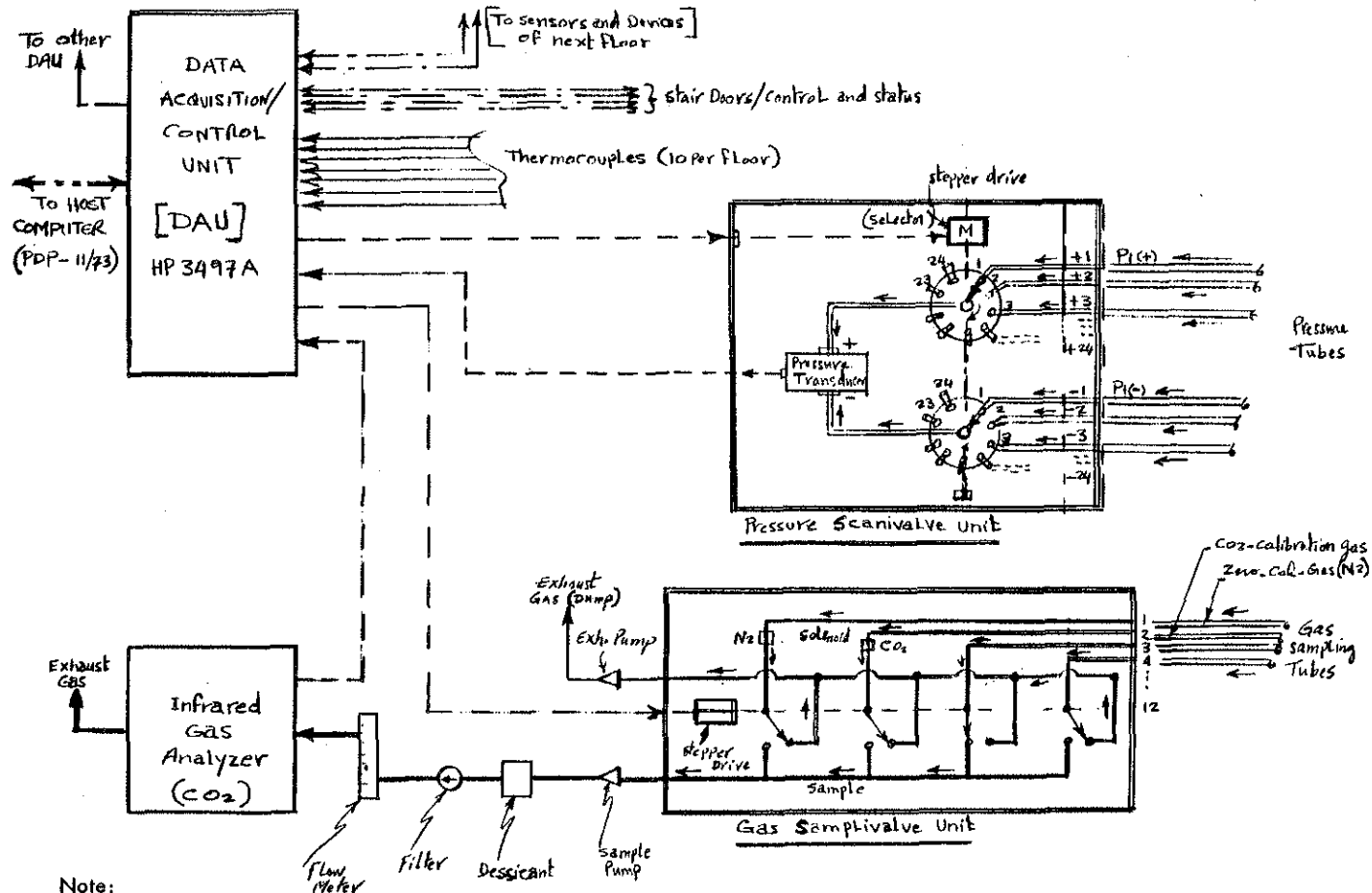
LOCATIONS OF PRESSURE TAPS, THERMOCOUPLES AND GAS SAMPLING  
Typical Floor



- THERMOCOUPLES, 30 cm below the ceiling
- ▽-TC 8 cm from the wall at mid-height
- THERMOCOUPLE TREE (Stand), 4 TC at equal height on stands A, B, and C, and D&E has 5 TC each.
- ▭ Location of the GAS BURNER SETS (refer to section 7.0 for details).

FIGURE 13

THERMOCOUPLE LOCATIONS ON THE 2nd FLOOR. (gas burners)



**Note:**

- One data acquisition unit control and monitor devices of two floors
- Additional CO gas sampling on fire floor
- Additional pressure scanivalve on fire floor and control room

**FIGURE 14**

**SCHEMATIC REPRESENTATION OF THE INSTRUMENTATION FOR A TYPICAL FLOOR. (Fire Tower)**



FIGURE 15  
INSTRUMENTATION ARRANGEMENT IN THE  
SERVICE ROOM OF THE 2nd FLOOR

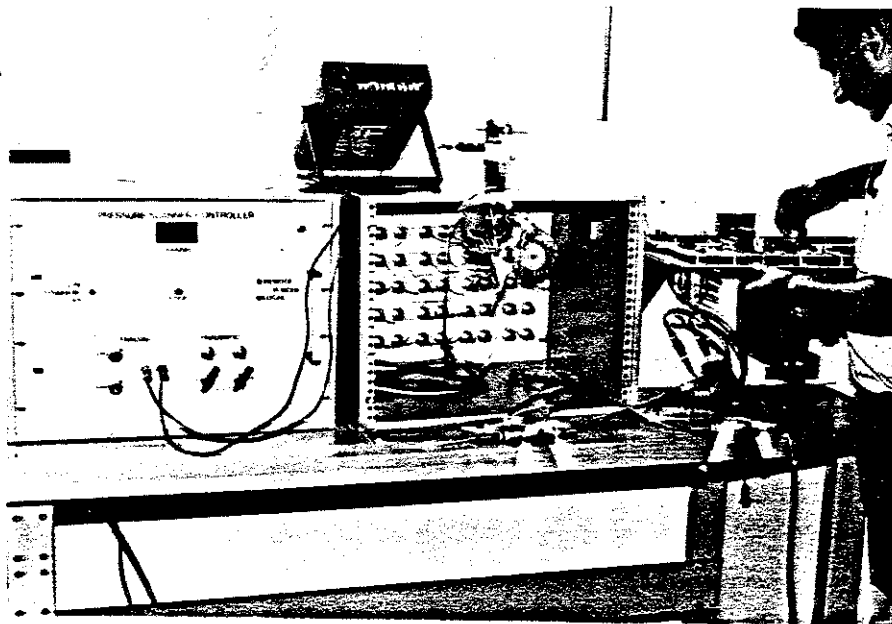


FIGURE 16  
FRONT AND BACK VIEWS OF THE PRESSURE  
SCANIVALVE UNIT (two units are shown)

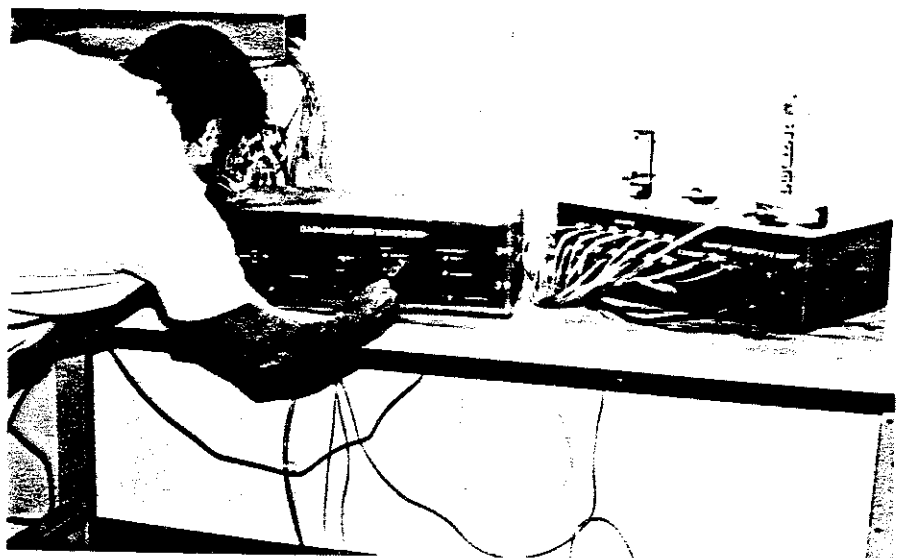


FIGURE 17  
FRONT AND BACK VIEWS OF THE GAS  
SAMPLIVALVE UNIT (two units are shown)

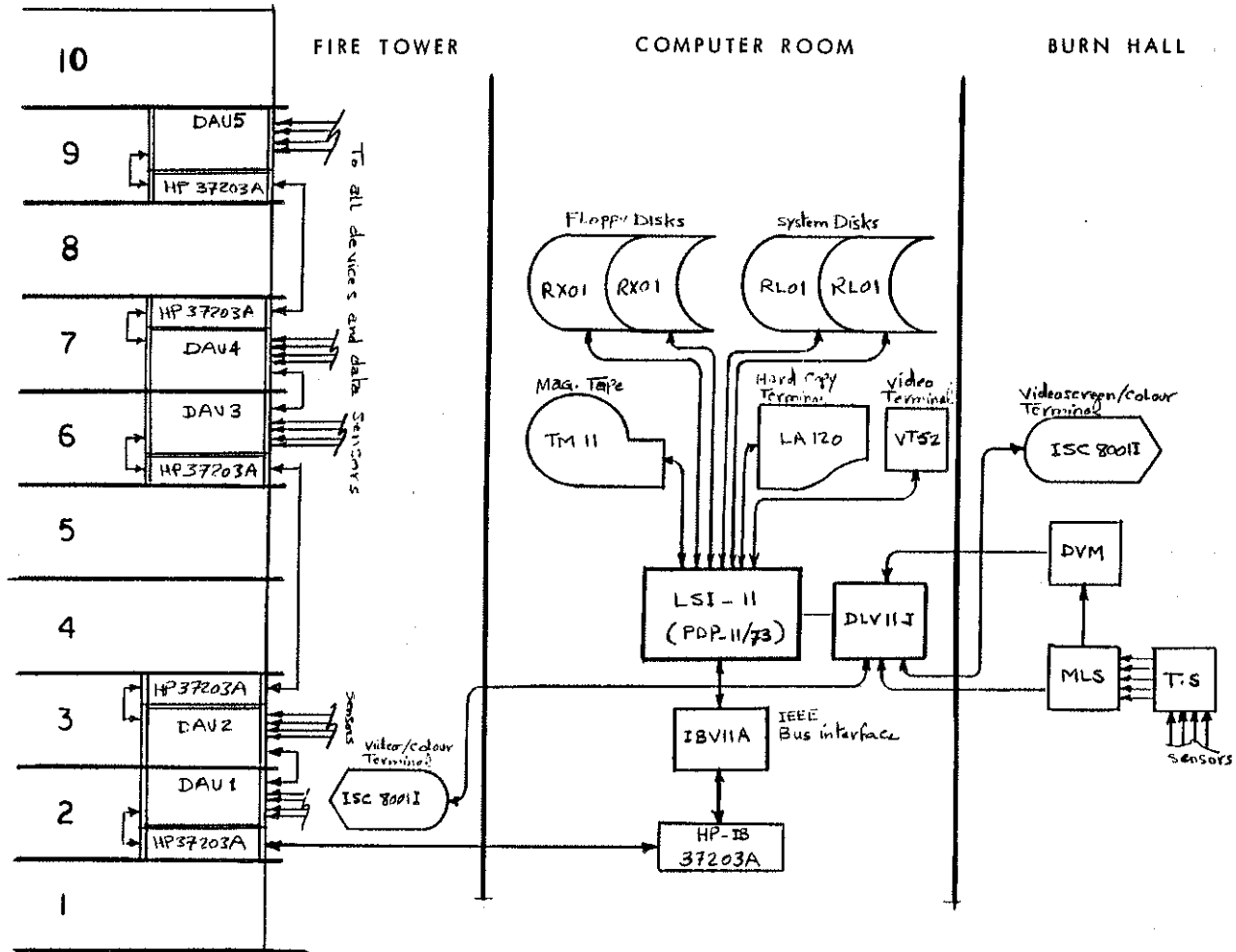
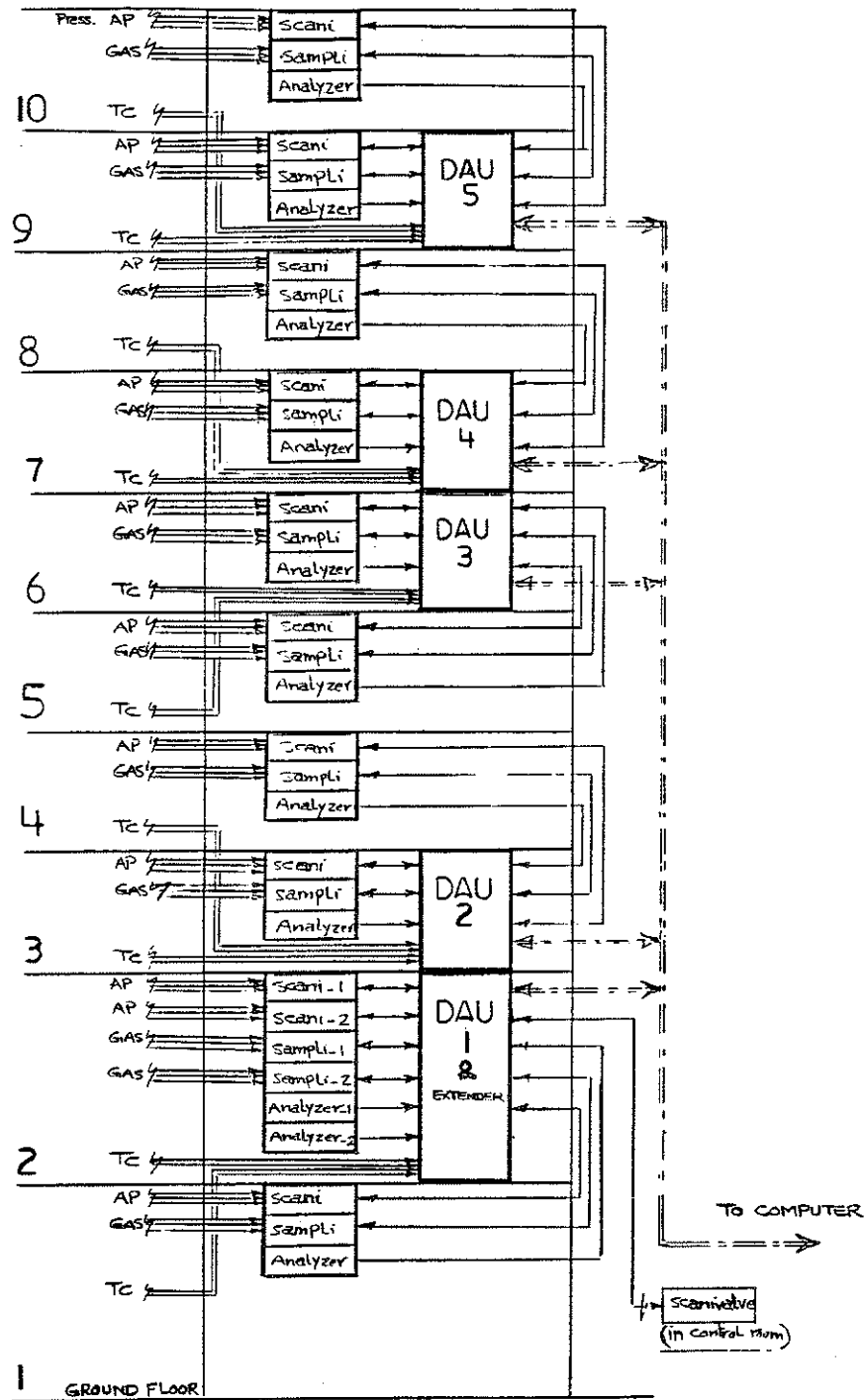


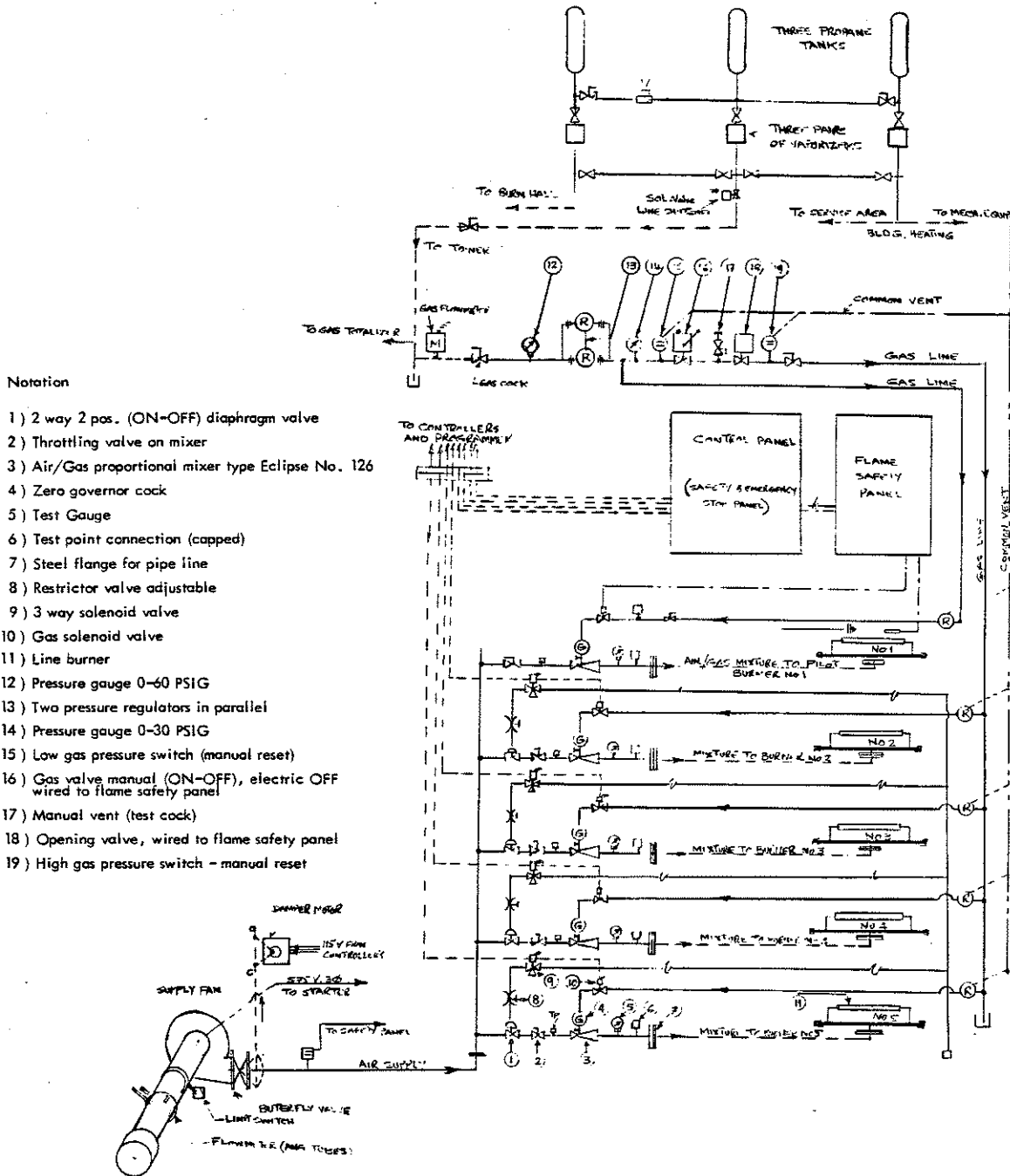
FIGURE 18

SCHEMATIC REPRESENTATION OF THE MINICOMPUTER-BASED DATA ACQUISITION AND CONTROL SYSTEM



(Note: see Fig-14 for door control)

FIGURE 19  
HARDWARE CONFIGURATION OF THE TOWER'S  
DATA ACQUISITION AND CONTROL SYSTEM



**FIGURE 20**  
**SCHEMATIC REPRESENTATION OF GAS BURNERS SYSTEM**

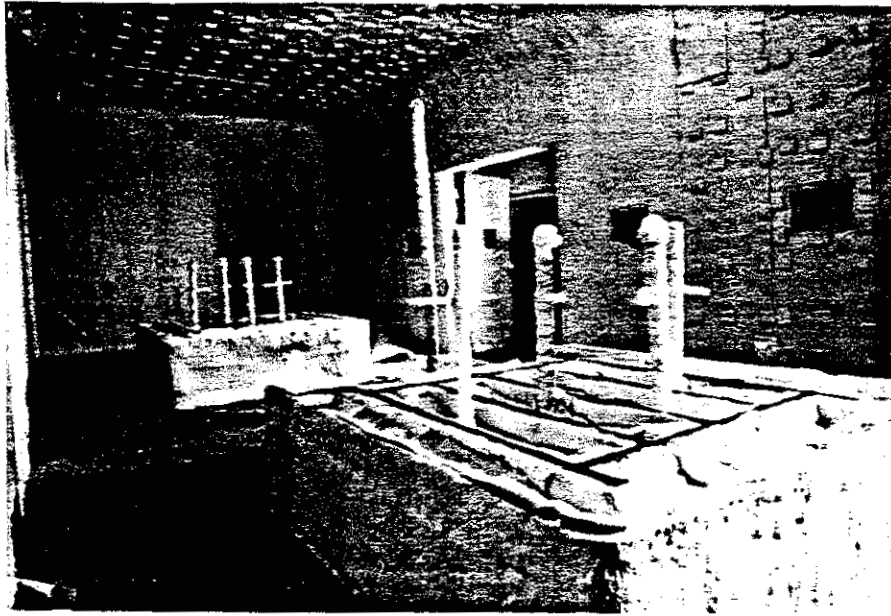


FIGURE 21  
INSTALLATION OF TWO SETS OF PROPANE  
FIRED GAS BURNERS - FIRE FLOOR (2nd floor)

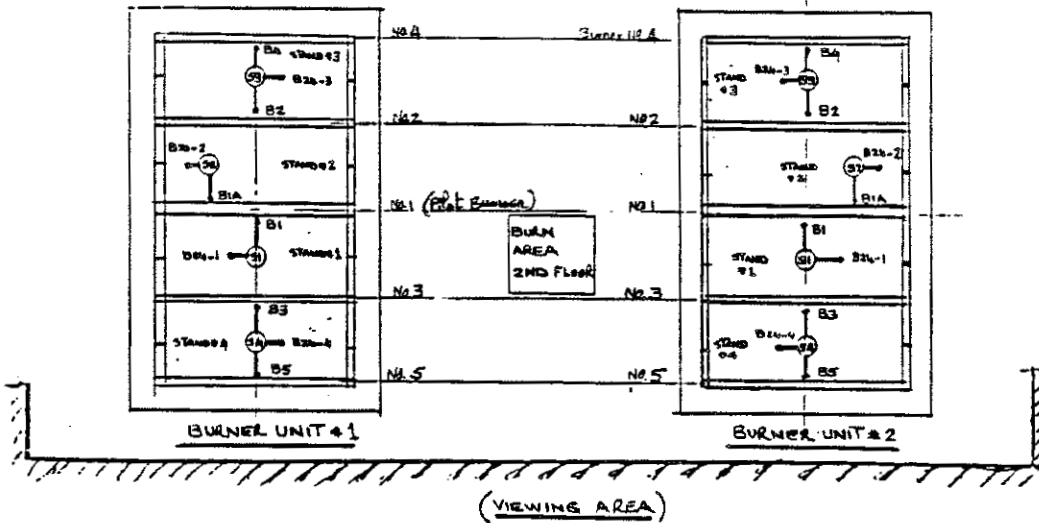


FIGURE 22  
THERMOCOUPLE LOCATIONS ON GAS BURNERS  
(Plan View)

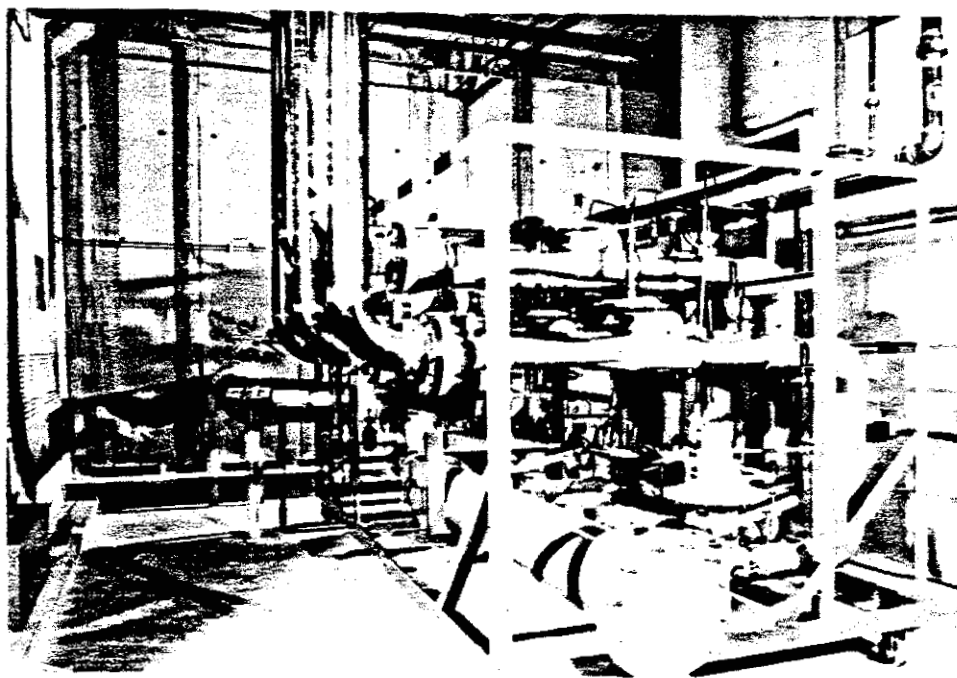


FIGURE 23  
GAS BURNER TRAIN-STAND No.1 GROUND  
FLOOR (fire tower)

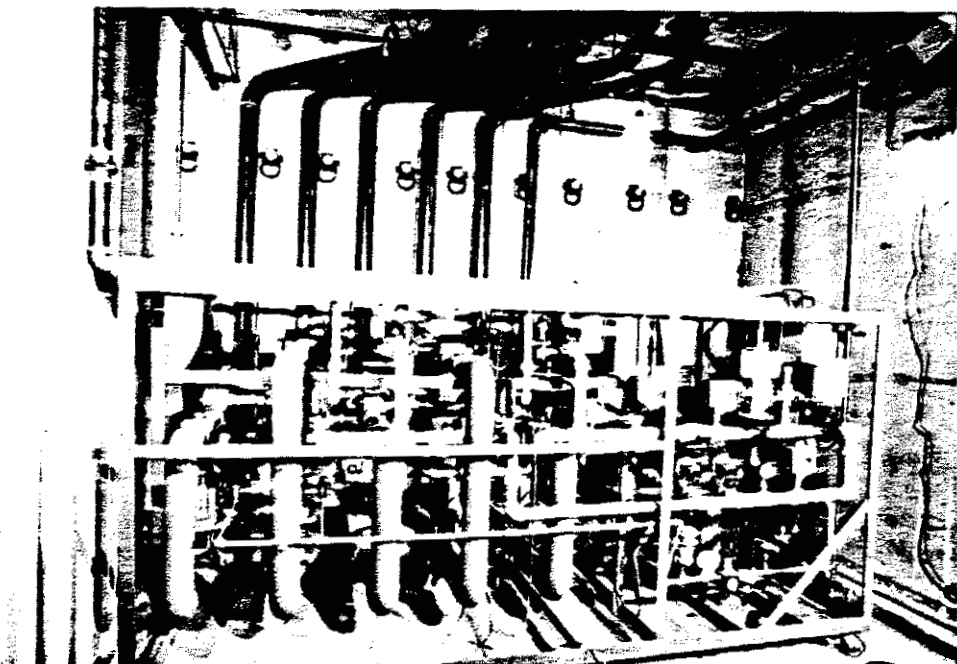


FIGURE 24  
GAS BURNER TRAIN-STAND No.2 GROUND  
FLOOR (tower)

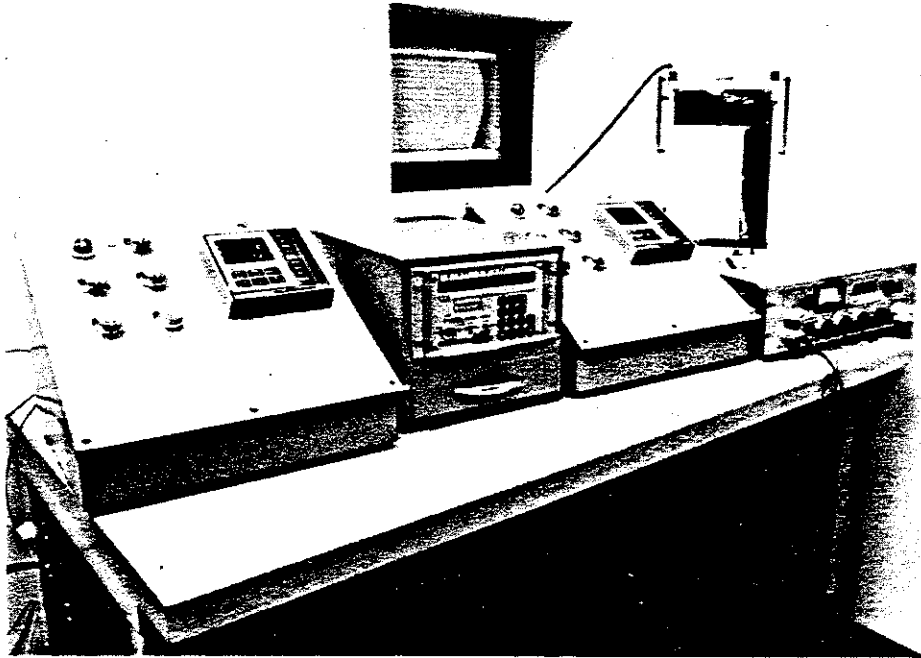


FIGURE 25  
BURNERS' SET-POINT CONTROLLERS AND  
SET-POINT PROGRAMMER

## APPENDIX

- Appendix A. Calibration of the Air Flow Measuring Systems.
- Appendix B. Instrumentation and Measuring Techniques - Detailed Description.
- Appendix C. Fire Tower Database Reference Lists - Data Acquisition and Control System.

APPENDIX A

A1 Calibration of the Airflow Measuring System

All the airflow measuring systems (AM1 to AM9) were calibrated and the calibration flow rates were described as a function of the velocity pressures which were measured with the AM systems (Figures A1, A2 and A3). The calibration was performed at the area adjacent to each measuring station using a pitot traverse method<sup>13</sup> for rectangular ducts. A pitot tube was connected to a calibrated differential pressure transducer which outputs a voltage proportional to the velocity pressure ( $V_p$ ). The readings were taken in the center of equal areas over the cross-section of the duct, and the average velocity pressure was obtained. The corresponding volume flow rate was determined using the flow equation in the following form:

$$Q = C A_d \frac{1}{N} \sum_{i=1}^N (V_p)^{0.5}$$

$$V_p = P_t - P_s$$

where

$Q$  = volume flow rate,  $m^3/s$

$A_d$  = cross-sectional areas of the duct at the measuring section,  $m^2$

$C$  = conversion constant, 1.29

$N$  = number of measuring points in a traverse

$V_p$  = time average of velocity pressure (measured at the individual points)

$P_t$  = total pressure, Pa

$P_s$  = static pressure, Pa

and the flow rate was corrected to 20°C, as standard temperature

$$Q_c = Q \left( \frac{293}{273 + T} \right)$$

where

$Q_c$  = volume flow rate corrected for temperature,  $m^3/s$

$T$  = flow temperature in the duct, °C

The systems calibration curves (flow rates vs velocity pressures) are given in Figures A1 and A2. The points of each curve (4 to 6 points) were established by changing the air flow rate over the range of system capacity. Figure A1 provides three calibration curves for the building air supply (fan #1, AM7), building return air (fan #2, AM8), and building

exhaust (fan #3, AM9). Figure A2 provides four calibration curves for the stair air supply, the elevator air supply, and the stair/elevator vestibule supply which are provided by fan #4 and measured by AM 1,2 and 3 respectively, and the fourth curve is for the stair exhaust (fan #5, AM6).

The user will be able to set the required air flow rate for a shaft by setting the corresponding value of air velocity pressure across the air measuring system (AM1 - AM9) by adjusting the fan speed. The velocity pressure reading measured by the pressure transducer (scanivalve unit) is recorded by the DACS on line, and also on a chart recorder.

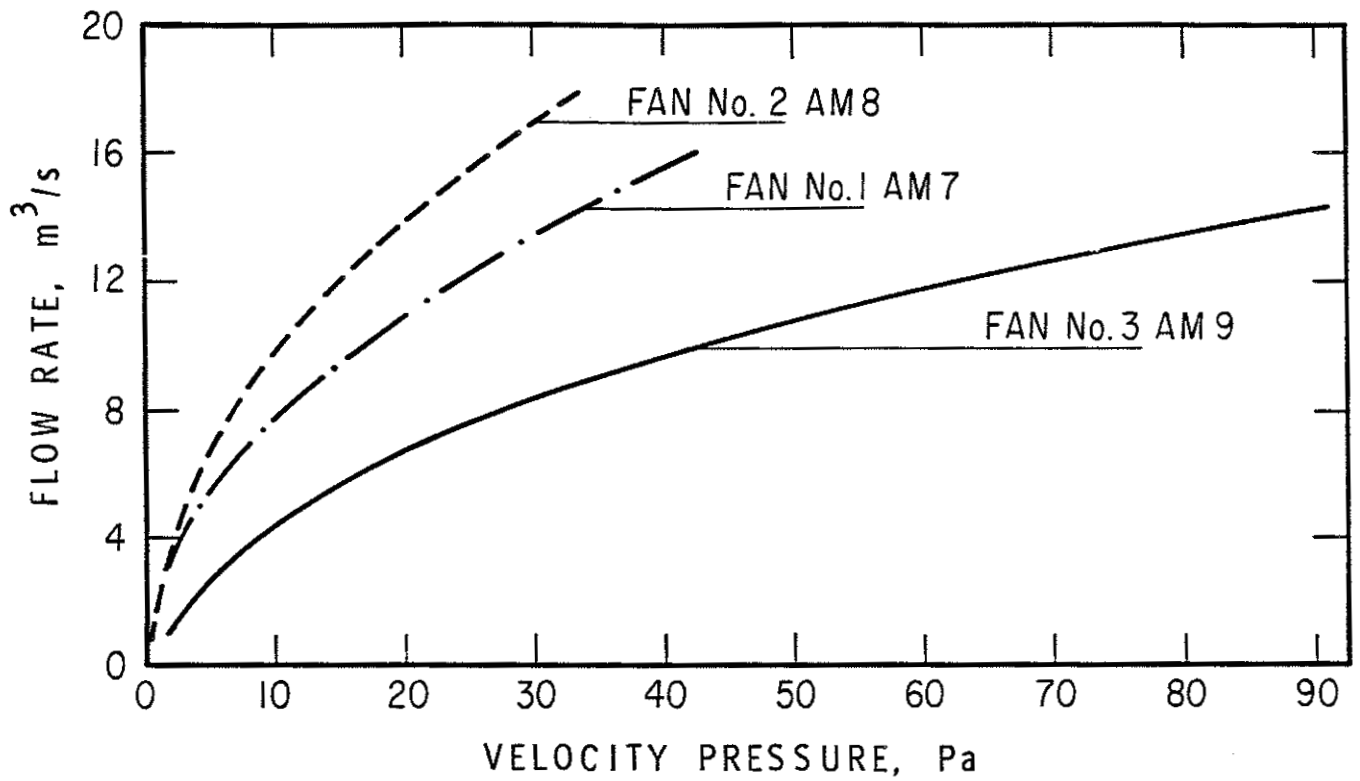


FIGURE A1

CALIBRATION CURVES FOR BUILDING AIR SUPPLY,  
BUILDING RETURN AIR, AND BUILDING EXHAUST  
(fan No. 1, 2&3, AM-7, 8, 9)

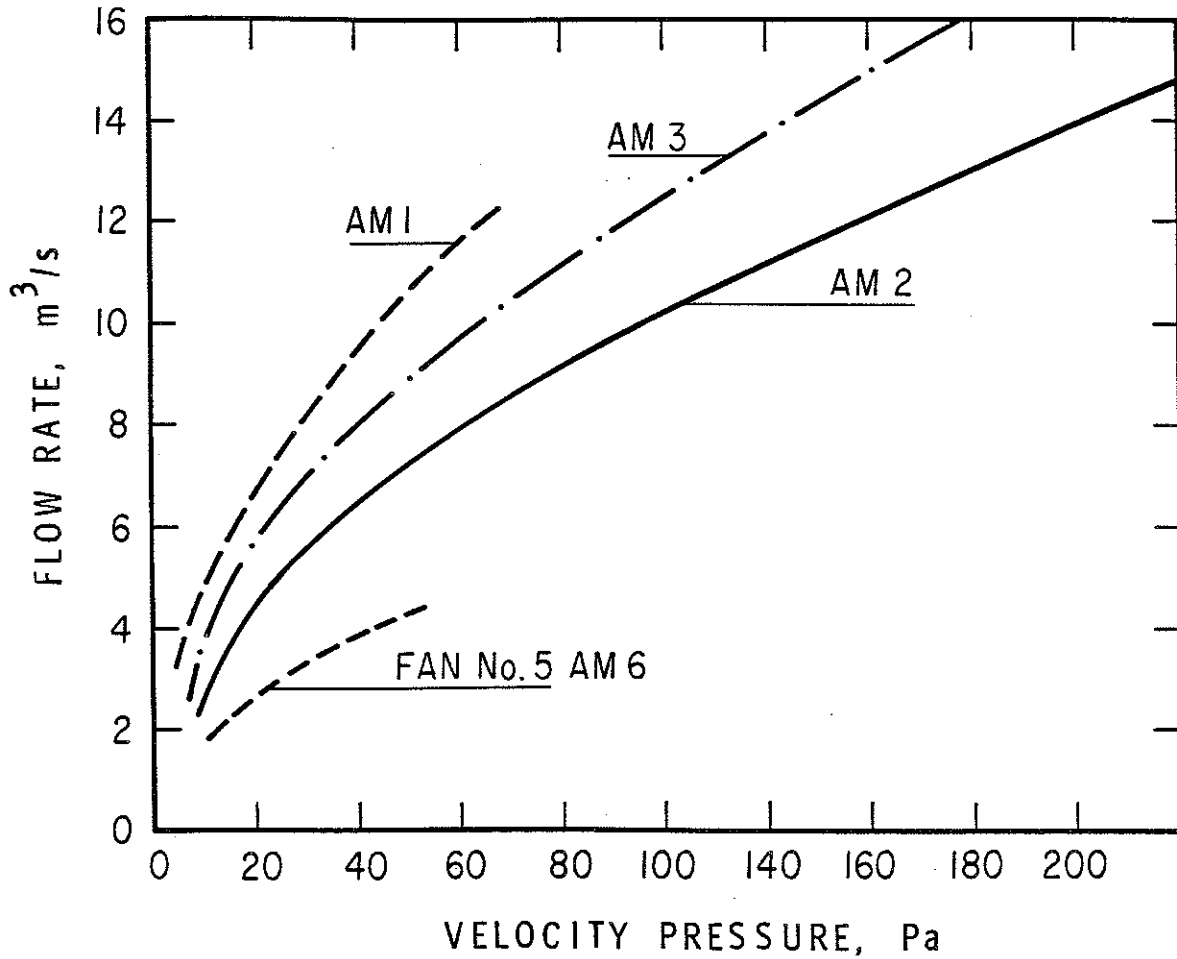


FIGURE A2

CALIBRATION CURVES FOR THE STAIR AIR SUPPLY, ELEVATOR AIR SUPPLY, AND VESTIBULE AIR SUPPLY (fan No. 4 AM-1, 2, 3). AND STAIR EXHAUST (fan No. 5, AM-6)

APPENDIX B

Instrumentation and Measuring Techniques -  
(Detailed Descriptions)

B1 Temperature Measurements

The temperatures in the experimental tower are measured using thermocouples which are located as shown in Figure 12. All thermocouples are welded, gauge #20 type K chromel-alumel with glass insulation<sup>22</sup>. The thermocouples are connected to the data acquisition unit DAU (HP3497A) through a relay multiplexer assembly with thermocouple compensation (HP44422A) module. The thermocouple compensation is used as a synthetic ice-point reference. Further details are provided in references (23),(24) and (25).

The thermocouple produces an output voltage which is a function of the temperature of the sensor. The output voltage is converted to temperature by a data conversion algorithm in the computer software program using a 3rd order polynomial (Ref. 15). A calibration test was conducted to determine the accuracy of the temperature measurement system using a calibrated voltage source (input to the DAU) to simulate the desired temperature values over the full temperature range of type K thermocouple of 0 to 1300°C (0 to 52.398 millivolts input) in 20 steps. In addition to the voltage source, an ice bath and boiling water were used for the 2 reference points of 0°C and 100°C respectively. The maximum error was 3.5°C at 150°C and in the ranges of 0°C to 100°C and 200°C to 1300°C the average error was 1.5°C. This represents the total measurement error which includes the errors from reference junction compensation, temperature difference at terminals, thermal offset, and voltage to temperature conversion error.

B2 Differential Pressure Measurements

Pressure taps of copper tubing flush mounted to the walls 6.3mm are used to sense the static pressure. A total of 18 pressure taps were installed in the outside walls and the walls of all vertical shafts on every floor as shown in Figure 12. The pressure tubes are connected to a scanivalve unit. The pressure tubes on all floors and the pneumatic lines of the scanivalves were checked for leakage.

## Pressure Scanivalve Unit

As shown in Figure 14, the scanivalve unit incorporates two synchronous scanivalve modules of 24 ports which are driven in parallel by a stepper drive. The stepper drive receives the control signals, from the DAU, and sequentially connect each of the 24 pressure inputs to the pressure transducer for differential pressure measurements. The first and second pressure ports (channel 1 and channel 2) are used for calibration of the transducer, where the readings from channel 1 indicate the full scale pressure difference of the transducer and channel 2 indicates a zero pressure difference. The sequential connections to the transducer is achieved by stepping the scanners, at a selected rate (e.g., 10 seconds per step) set by the user in the software program (see Section 6.0 on DACS). The pressure transducer used is Validyne diaphragm type variable reluctance transducer, Model DP-103-20, 0.86 Kpa, with a sensitivity of 20 mV/V and a linearity of  $\pm 0.1\%$  F.S.. A functional description of the diaphragm magnetic reluctance is provided in Reference 26. The transducer outputs voltage in response to the pressure difference across the diaphragm. The millivolt outputs are then converted to pressure difference (Pascal) using the data conversion algorithm, specified in the computer software program<sup>14</sup>. The pressure transducers were calibrated in the range of 0 to 500 Pascals (0 to 5 volts). The calibration is conducted by loading the transducer with a known input pressure (0,100,200,... 500 Pa), at the scanivalve input port, and measuring the corresponding output values. The input pressure is measured using a calibrated micro-manometer (Dwyer Microtector) with an accuracy of  $\pm 0.06$  Pa; the calibration was conducted by NRC Division of Physics using a reference mercury manometer. The output values are measured and recorded directly from the transducer at the scanivalve unit using a calibrated DVM, and also measured simultaneously by the data acquisition system. The accuracy of the pressure transducers varies from one unit to the other but is in the range of  $\pm 2\%$ . A check-out of the transducer calibration and leakage in the scanivalve is recommended prior to each new series of tests. Details on the control and operation of the scanivalves are discussed in the Section 6.0 "Data Acquisition and Control System", and in Refs. 27 and 14.

The pressure scanivalve is used for measuring a large number of pressure difference points up to 22 max. per floor at scanning rate of 10 sec per port, i.e., measurement can be taken for the same port at four minute intervals. For measurements of shorter intervals, the same pressure point can be connected to multiple ports or individual pressure transducer can be used. A close up view of the pressure scanivalve unit is shown in Figure 16.

B3 Gas Sampling Measurements

Carbon dioxide gas concentrations are sampled on every floor at 6 locations as shown in Figure 14, using a twelve port gas samplivalve unit<sup>28</sup> (Model S65 with solenoid drive) connected to an infrared gas analyzer (Beckman Model 865). An additional samplivalve unit and analyzer (Beckman Model 864) is installed on the 2nd floor for measuring the carbon monoxide gas concentration in the burn area. The CO<sub>2</sub> gas analyzers have two ranges of 0.5% and 2.5% by volume and are linearized: the 2nd floor CO<sub>2</sub> analyzer's ranges are 5% and 20%, also linearized. The CO gas analyzer has two ranges of 0 to 1000 PPM (linearized) and 0 to 5000 PPM (not linearized). The accuracy of the gas analyzers are 1% of full scale and the span drift and zero drift are ±1% of full scale (each) in a 24 hour period.

Gas Samplivalve

The gas sampling system is described by a schematic representation as shown in Figure 14. The stepping operation is controlled by the DAU at a specified rate of 30 sec. or longer to allow enough time for the current sample gas to displace the previous one in the sample cell of the analyzer. The sample gas is drawn to the analyzer at 1000 cc/min by the sample pump (type Neptune Dyna). During the sampling of one gas stream the other eleven streams which are not sampled are allowed to flow through the exhaust line of the samplivalve unit, so that each stream sampling tube is continually updated to contain a fresh sample ready for the analyzer. The sample gas flows through a drying filter with dessicant (type Chromatographic RGFB-250-200), a particle line filter (0.2 micron) to remove particulate matter, and a flow meter before entering the analyzer. A close up view of the samplivalve unit is shown in Figure 17.

Analyzer

The principle of operation of the infrared gas analyzer is based on a differential measurement of absorption of infrared energy within the analyzer. Two equal-energy infrared beams are directed through two optical cells: one being the sample cell (sample flowthrough) and the second is a sealed reference cell. Solid-state electronic circuitry continuously measures the difference between the amounts of infrared energy absorbed in the two cells. The difference is a measure of the concentration of component of interest (CO<sub>2</sub>, CO, etc.) in the sample. The calibration of the analyzer is conducted using the following standard calibration gases; the zero standard gas (dry nitrogen) for setting the zero point, and a 2.2% CO<sub>2</sub> in nitrogen for the upscale calibration point (0-2.5% CO<sub>2</sub> range) of typical

floors. For fire floor, the upscale calibration gas used are 0.45%, 4.86%, and 17.99% CO<sub>2</sub> for the CO<sub>2</sub> analyzer and 598 and 897 ppm for the CO analyzer. The zero and the upscale calibration gases are admitted into the sampling system through the first and second ports of the samplivalve respectively. Further details on the analyzer operation, linearization, and calibration processes are provided in Reference (29). The background CO<sub>2</sub> gas concentration was measured at various locations in the fire tower and found to be up to 0.04% CO<sub>2</sub> in ambient air.

#### B4 Gas Velocity Measurements Using Bidirectional Probes

Copper pressure lines are installed from the observation areas to the stair door on the second floor to permit the connections of five low-velocity bidirectional probes at various heights at the centre line of the open doorway. This type of probe was developed by Heskestad (30) for low-velocity measurements under fire conditions (Reynolds number  $40 < Re < 3800$ ). The probes used are 12.7 mm diameter with construction details based on the above reference. The basic equation is

$$\frac{(2\Delta P/\rho)^{\frac{1}{2}}}{U} = C(Re)$$

where  $\Delta P$  = measured differential pressure,

$\rho$  = gas density at the probe (obtained based on the thermocouple reading adjacent to the probe)

$U$  = the gas velocity,

$C(Re)$  = a constant which depends on the Reynolds number, (Reference 31).

Using a uniform calibration constant  $C(Re) = 1.08$  would result in a maximum error of about 7% down to a velocity of 0.304 m/sec. For lower velocities or more accuracy, the calibration data in reference (31) can be used. The probe responds equally to flow in either direction on its axis (within  $\pm 50$  degrees of the probe axis) and the pressure signal from each probe is sensed with a pressure transducer Validyne DP103-12, 0.14 kPa, - linearity of 0.1% F.S. and sensitivity of 20 mV/V).

#### B5 Wind Speed and Direction

Wind speed and direction are measured using a four bladed propeller type anemometer (Skyvane wind sensor, Model W102P, with electronic translator - by Weather Measure Corporation). The anemometer is located 8 m above the tower's main roof, and about 36 m above ground level. The propeller of the Skyvane sensor is connected to a velocity transducer whose output is fed into the wind speed portion of the electronic translator.

Wind direction is sensed by a potentiometer located at the base of the skyvane providing voltage indicative of the wind direction. The electronic package includes an analog averaging module and has an overall accuracy of  $\pm 2\%$  Full Scale (includes linearity, gain and offset errors, and noise). The wind speed calibration is accomplished at the factory by driving the propeller's shaft at a known rpm rate by means of a synchronous motor and measuring the corresponding voltage output value. The relation between wind speed and rpm is obtained by tests in a wind tunnel at various wind speeds up to 100 km/hr (full scale). The overall accuracy of the system is 5%. Further details about this system and calibration data are provided in Reference (32). Both wind speed and direction are recorded on a chart recorder located on the ground floor of the service tower.

APPENDIX C

Fire Tower Database Reference Lists,  
of all Analog Input, Digital Output and Digital Input Points -  
Data Acquisition System

SYSTEM	AREA FLOOR	POINT	DATABASE#	SLOT# ON DAU	DEVICE/ SENSOR
<u>Table C1) ANALOG INPUT POINTS (on DAU#1)</u>					
TC	F1	1	01	00	Thermocouple
		•	•	•	
		10	10	09	
TC	F2	1	11	10	
		•	•	•	
		10	20	19	
SD	F1	1	21	-	Reserved/smoke detector
		•	•	•	
		5	25	-	
SD	F2	1	26	-	
		•	•	•	
		5	30	-	
AP1	F1	1	31	20	Press. scani.
		•	•	•	
		24	54	20	" "
AP1	F2	1	55	30	" "
		•	•	•	
		24	78	30	" "
CD1	F1	1	81	21	Gas sampli.
		•	•	•	
		12	92	21	" "
CD1	F2	1	93	31	Gas sampli.
		•	•	•	
		12	104	31	" "
ONE	F1	CON	105	-	constant value (one)
ZER	F2	CON	106	-	constant value (zero)

ANALOG INPUT (table C1 cont'd)  
[DAU#1 ONLY]

SYSTEM	AREA FLOOR	POINT	DATABASE#	SLOT# ON DAU	DEVICE/SENSOR
CD2	F1(or F2)	1	107	33	[Sampli #2]
		12	118	33	
AP2	F1	1	119	22	[Scani. Cont. Room]
		24	142	22	
AP3	F1	1	143	32	[Scani#2 F2 Spare]
		24	166	32	
TC1	FF(F2)	..	..		[TC/Fire Floor Burners]
		..	..		
		..	..		
		.	.		

Table C2) DIGITAL OUTPUT POINTS

AP1	F1	STP (stepping)	1	1	Scanivalve
AP1	F2	STP "	3	3	"
CD1(GA1)	F1	STP "	5	5	"
CD1	F2	STP "	6	6	"
CD2(GA2)	F2(or F1)	STP "	7	7	Sampli#2,F2
AP2	F1	STP "	8	8	Scani.Cont.Room
AP3	F1	STP (stepping)	10	10	Scani.2nd Floor spare
-	-	-	-	-	-
Door	F1	1	13	13	DAU#1
Door	F1	2	14	14	DAU#1
Door	F2	1	15	15	DAU#1
Door	F2	2	16	16	DAU#1
Door	F3	1	17	17	DAU#1-extender
Door	F3	2	18	18	DAU#1-extender
Door	F4	1	19	19	DAU#1-extender
Door	F4	2	20	20	DAU#1-extender

DIGITAL OUTPUT POINTS (table C2 cont'd)

SYSTEM	AREA FLOOR	POINT	DATABASE#	SLOT# ON DAU	DEVICE
Door	F5	1	21	21	DAU#1-extender
Door	F5	2	22	22	DAU#1-extender
Door	F6	1	23	23	DAU#1-extender
Door	F6	2	24	24	DAU#1-extender
Door	F7	1	25	25	DAU#1-extender
Door	F7	2	26	26	DAU#1-extender
Door	F8	1	27	27	DAU#1-extender
Door	F8	2	28	28	DAU#1-extender
Door	F9	1	29	29	DAU#1-extender
Door	F9	2	30	30	DAU#1-extender
Door	F10	1	31	31	DAU#1-extender
Door	F10	2	32	32	DAU#1-extender

Table C3) DIGITAL INPUT POINTS

AP1	F1	HOM (home position)	1	1	DAU#1
AP1	F2	HOM "	2	2	DAU#1
CD1(GA1)	F1	HOM "	3	3	DAU#1
CD1	F2	HOM "	4	4	DAU#1
CD2	F1(or F2)	HOM (home position)	5	5	DAU#1
Door	F1	1	6	6	DAU#1
Door	F1	2	7	7	DAU#1
Door	F2	1	8	8	DAU#1
Door	F2	2	9	9	DAU#1
AP2	F1	HOM	10	10	DAU#1
AP3	F1	HOM	11	11	DAU#1

CODES for Appendix C

System : measuring system  
TC : thermocouples (typical on all floors)  
TC1 : additional thermocouples on the fire floor  
SD : reserved channel for smoke density or other sensors  
AP1 : air pressure scanivalve (typical on all floors)  
AP2 : air pressure scanivalve in the control room  
AP3 : air pressure scanivalve (spare unit) on the fire floor  
CD1 : gas samplivalve and analyzer (typical on all floors) for CO<sub>2</sub>  
measurement  
CD2 : gas samplivalve and analyzer for CO measurement on the fire  
floor  
ONE : constant value, (one) for the conversion algorithms  
ZER : constant value (zero) for the conversion algorithms  
area/floor : floor no. (F1 = 1st floor, F2 = 2nd floor, etc.)  
Point : identification number of the measuring points  
Database : a specified database number for a specific point (one number  
for every point)  
Slot# : the slot# (channel number) on the DAU  
AI : analog input  
DO : digital output  
DI : digital input

NOTE: The Tables and the assigned database numbers are repeated  
identically for all the 5 DAU's in the tower.

