EVERGREEN POINT BRIDGE TOLL BOOTH VENTILATION STUDY

4.1

A Study

Prepared for the

WASHINGTON STATE HIGHWAY COMMISSION

DEPARTMENT OF HIGHWAYS

by

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THE STUDY AND CONTROL OF CARBON MONOXIDE EXPOSURES AT TOLL BOOTHS

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ABSTRACT

At the request of the Washington Department of Highways a comprehensive study was conducted of the exposures of toll collectors to carbon monoxide at the Evergreen Point Bridge spanning Lake Washington between Seattle and Bellevue.

The first phase of the study consisted of designing, installing and operating an automatic, continuous carbon monoxide monitoring system to establish typical air quality patterns in and around the toll booths.

The second phase consisted of developing a prototype toll booth positive ventilation system. Air, which is introduced through a vertical diffuser situated at one wall of the booth, travels horizontally across the booth and out the door. Parametric studies of sources and rates of ventilation air, diffuser design and other toll booth modifications were conducted in the laboratory. Subsequently these modifications were installed and investigated at an operating booth at the toll plaza. Concentrations of carbon monoxide in the collectors breathing zone were reduced to acceptable levels. Methodologies and results of these studies are described, and design recommendations for the control system are offered.

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1.0 INTRODUCTION AND BACKGROUND

The Evergreen Point Floating Bridge Toll Plaza, like other toll facilities, has problems of accumulating abnormally high concentrations of carbon monoxide (CO). These unusually high concentrations result from automotive exhaust when the automotive engine is operating at its most inefficient mode; decelerating from highway speed to a stop at the toll booth, idling at the plaza, and accelerating from the toll booth back to highway speeds. During this period, the auto is emitting up to 30,000 ppm carbon monoxide which at times raises the level in the toll booth above the 50 ppm Washington State Industrial Standard with peak values above 250 ppm.

In June of 1971 the University of Washington entered into an agreement with the Washington State Department of Highways in which the University would develop and install a system to monitor the carbon monoxide at the toll plaza. This agreement was extended in December 1971 to include the development and testing of a system that would lower the carbon monoxide concentration in the toll booths so that it would not exceed the State Industrial Standard for carbon monoxide of 50 ppm.

Prior to this agreement, carbon monoxide measurements had been made, and a breathing zone ventilation system developed. However, it was felt that additional methods of carbon monoxide dilution should be investigated. One system of booth pressurization is being used in New York however, data on the effectiveness of removing carbon monoxide is not available.

2.0 PLAN OF STUDY

The entire project was conducted in two main phases. The first phase was to establish a carbon monoxide monitoring system to continuously determine the CO concentration in selected booths that would represent the overall levels at the plaza. By continuing this monitoring from September until January a pattern was established to represent a pattern of annual averages.

The second phase was to develop an economical and acceptable method of lowering the carbon monoxide levels in the operator breathing zone so that it would not exceed the 50 ppm State Industrial Standard.

This second phase would entail investigating the already developed breathing zone system, and the development of a booth ventilating system that would be economical and acceptable to the operators of the toll booths. The use of chemicals to remove the CO was investigated but found to be impractical when using large quantities of air. A model ventilating system was developed in the laboratory, and tested in lane 5. Its performance was acceptable to both the operators and management personnel at the plaza.

3.0 MONITORING SYSTEM

To obtain data on the concentration of carbon monoxide (CO) in the toll booths, a continuous monitoring system was developed. This system has two functions: the first, to record the CO levels in a selected group of booths and outside locations that would establish the overall parameters needed to design a control system; second, to operate as a permanent monitoring system in the booths thereby assuring that the control system is operating properly.

3.1 Description

The monitoring system operates on the principle of drawing air from a toll booth at a rate of 1 cfm and diverting a portion of the air (12 liters/minute) to the carbon monoxide analyzer. Each sample point was sequentially selected by a switching arrangement and solenoid valves. The analyzer displays data on CO levels to a chart recorder for permanent record. To determine when a potentially dangerous CO level exists in a particular booth, the level is compared with a preset maximum established level and if that level in the booth exceeds the preset level, a signal is sent to the Administration Building where corrective measures can be initiated.

The overall sampling system is shown in Figure 1 and described below:

(1) The air monitoring equipment located in a vacated booth in lane 2.

(2) The location of the sampling probes in toll booths 2, 4, 5 and 7 starting from the right and continuing to the left.

(3) The location of the roof sample probes used to obtain a source of clean air.

(4) The location of the sample probes on the south property fence to obtain a source of clean air.

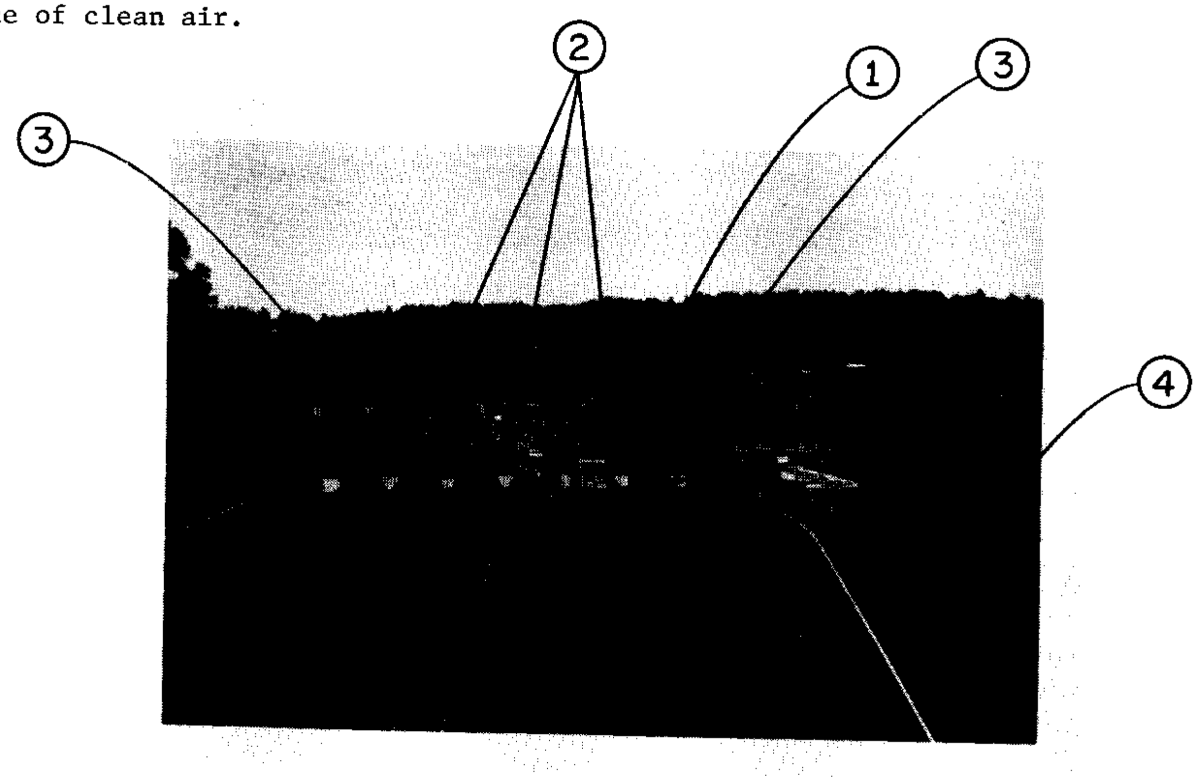

Figure 1. Location of air monitoring stations

Figure 2 shows the monitoring equipment located in the vacant booth in lane 2 and Figure 3 the schematic diagram of the system. The components of the system (numbers) and its operation are described as follows: Air from various sample station in the plaza is drawn through the 3/4" plastic pipe (1) by means of a vacuum pump (not shown). A portion of the air is removed by a small vacuum pump (3) and delivered to the flow meters (4) where 12 liters/minute is sent to the infrared detector (5). The amount of carbon monoxide is determined in the analyzer (6) and the amount is sent to the comparator (7) and recorded on the chart recorder (8). The booth to be sampled is selected by the stream selector (9) and operates a solenoid valve located at the sample point. Occasional calibration of the analyzer is required and this is accomplished by drawing gas with no carbon monoxide (zero gas) (10) though the flowmeter (4) at 12 liter/minute, and the analyzer (6) is adjusted for zero. "Standard" gas (11) with 40 ppm carbon monoxide is drawn through the flow meter (4) and the analyzer (6) is adjusted for 40 ppm as shown in the operation manual. A detailed parts list using the numbers shown in the schematic diagram is shown in the Appendix.

3.2 Stream Selector and Level Comparator

The solid state stream selector and level comparator especially designed for this project is shown in Figure 4.

The stream selector (1) is an electronically controlled timing device with variable sample time range from 1/2 minute to 16 minutes (2) that sequentially switches to a different channel. The channels to be sampled are turned on by a switch (3) where 110 volts is sequentially applied to the corresponding plug on the back of the selector and activates the solenoid valve at the sample probe. Also, the selector turns on the corresponding channel in the level comparator (4), where the level of carbon monoxide from this channel is compared against the

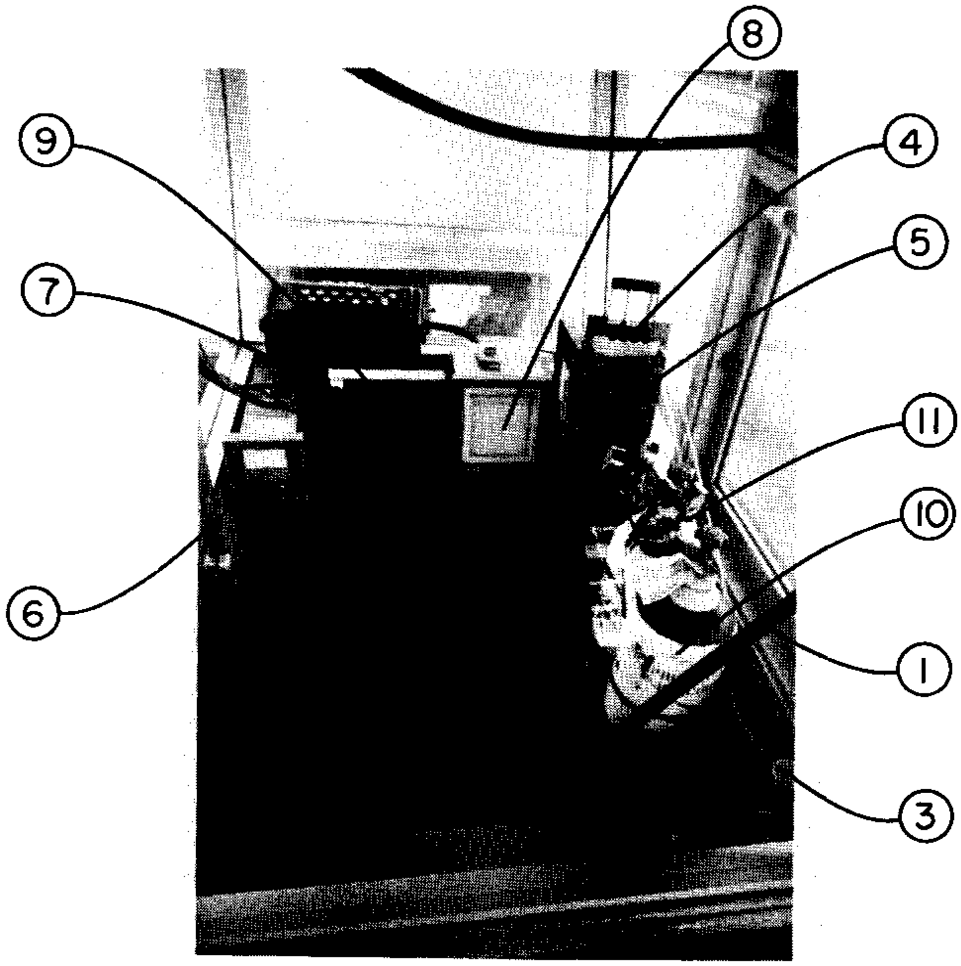

Figure 2. Monitoring equipment

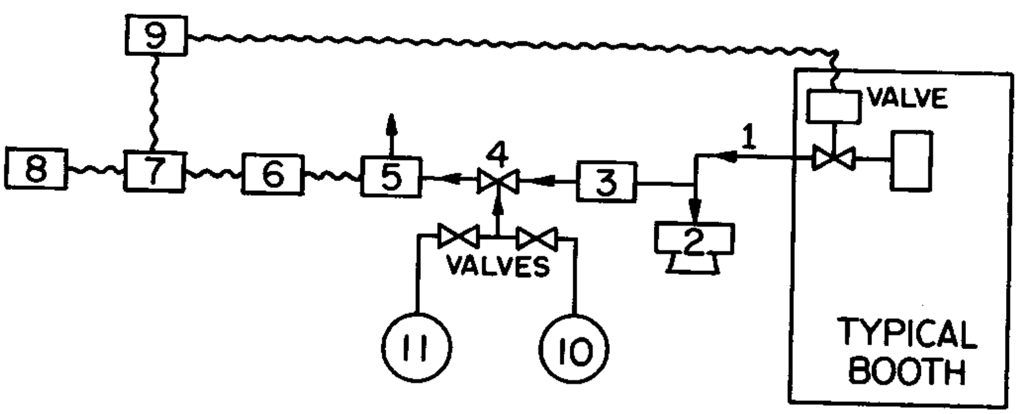

Figure 3. Schematic diagram of monitor system

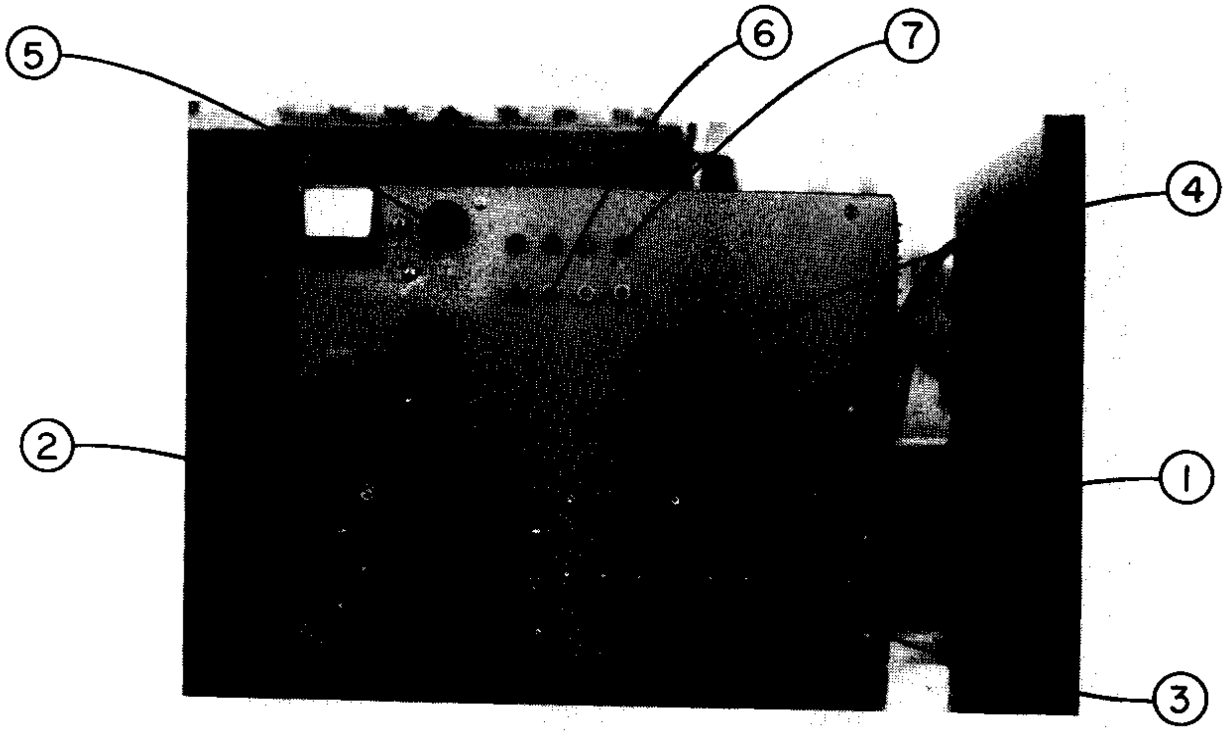

Figure 4. Stream selector and comparator

level preset by the standard level adjusted (5). The preset CO levels for the channel are adjusted with knob (6). When the level of signal equal or exceeds the preset level for one or more cycles, the indicator light (7) is tuned on at the comparator and in the Administration Building.

To obtain a reference mark, that is used to locate points on the chart recorder, a solenoid switch was attached across a selector channel. This solenoid switch grounds the contacts to the chart recorder and obtains a zero reading while on that particular channel.

Electrical schematics for both the selector and level comparator are found in the Appendix.

3.3 Booth Sampling

Figure 5 illustrates the toll booth sampling arrangement. At each booth, a solenoid valve (1) opens and allows air to be drawn through a 47 mm glass filter sample probe (2), located near the operator's face. This location obtains a representative sample of the carbon monoxide in the operator's breathing zone.

3.4 Operation

To obtain a reasonable sample the selector timer was set at a one minute interval. The stations sampled were lane 2, lane 4, lane 5, lane 7, north roof, "mark", south roof. The "mark" is a one minute blank sample that puts a zero line on the chart paper so that different lanes can be distinguished. Distinguishing each booth is easily accomplished with a 6 inch per minute chart speed.

Figure 5. Booth sampling probe

As a frequent value for carbon monoxide at the plaza is above 100 parts per million (ppm) the 250 ppm full scale deflection was selected for the analyzer.

3.5 Monitoring Program

Figures 6, 7, 8, 9 represent typical 24 hour CO values at the plaza. Note how the CO values follow the traffic patterns, with the lanes 5, 7 and north roof having high readings during the morning rush hour (west bound to Seattle). Lanes 2, 4 and south roof have higher values during the evening (east bound traffic from Seattle). The average traffic through the toll facility is 45,000 cars/day. Figure 7 shows the CO pattern on a Saturday, and was specially selected to note the odd patterns caused by football traffic going and coming from the game in Seattle.

It is most important to note that the CO levels seldom go below 50 ppm between 6:30 am and 8:30 pm which is all of first shift and most of second shift. Third receives values of over 50 ppm only during occasional traffic peaks.

The two roof sample probes were located 20 feet above the roof surface, and the probe at the south fence was located 20 feet above the ground. Values at the roof stations were normally between 5-10 ppm with one value recorded at 30 ppm with no apparent cause.

3.6 Results of Monitoring Program

The results of the sampling program indicate that levels of carbon monoxide in the sampled toll booths consistently exceeded the 50 ppm Standard during the hours of 0700 and 2200 on weekdays and at peak traffic hours on weekends. The values range from high peak value of 250 ppm when car exhaust is emitted directly

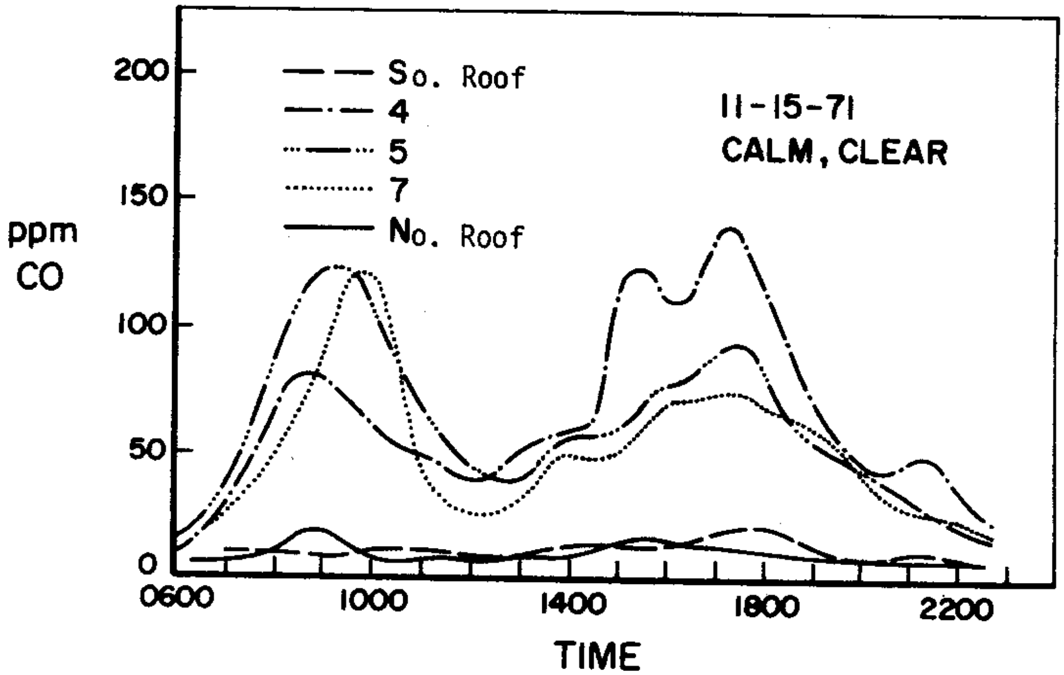

Figure 6. Carbon Monoxide levels

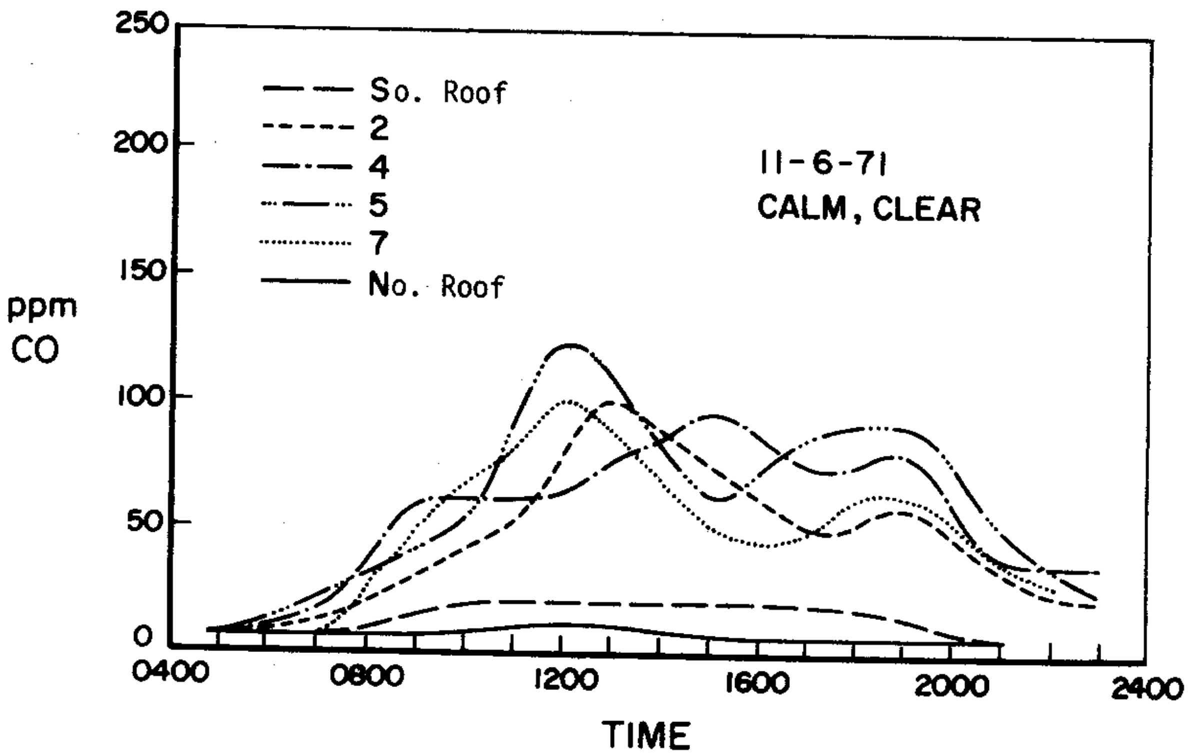

Figure 7. Carbon monoxide levels

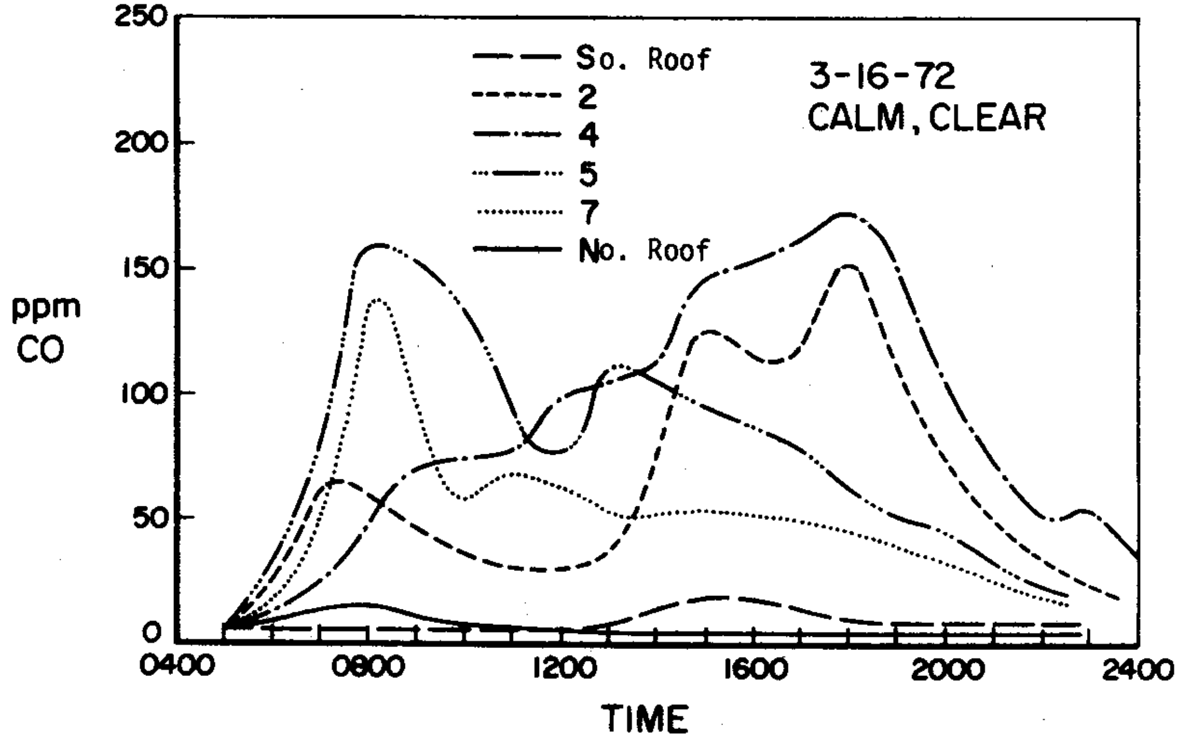

Figure 8. Carbon monoxide levels

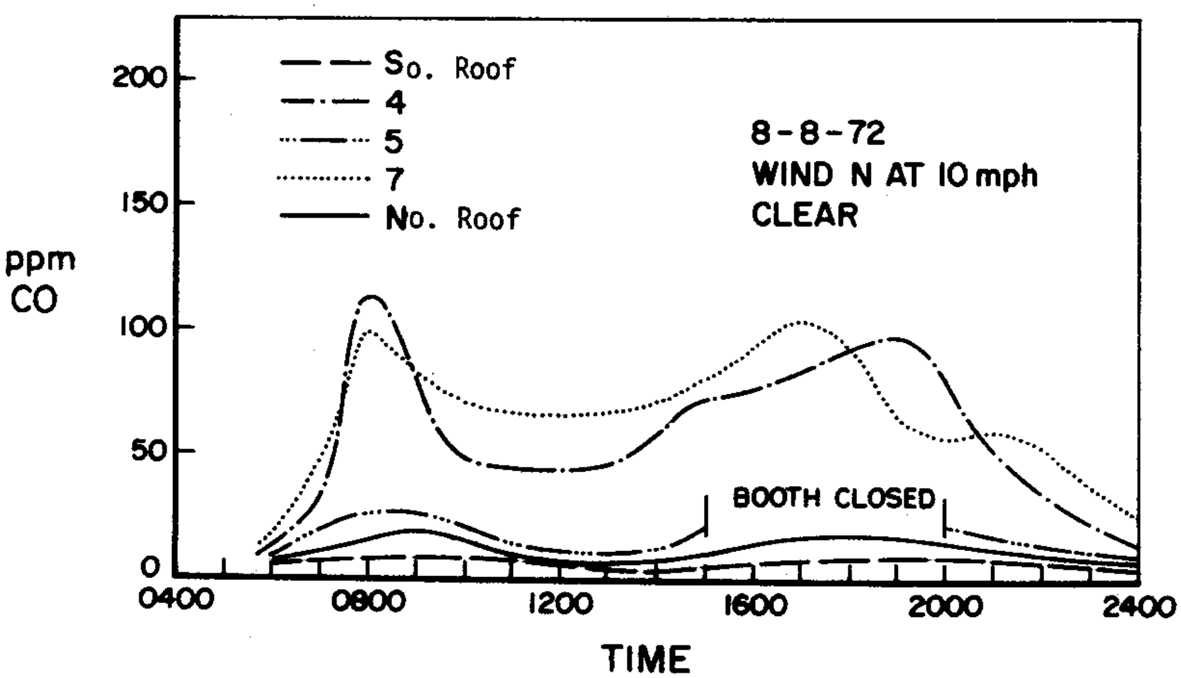

Figure 9. Carbon monoxide levels

into the booth, to ambient levels of 7 ppm during early morning hours (2300-0630).

Therefore, it is necessary to provide an atmosphere of less than 50 ppm CO to the operators breathing zone during the entire first and second shifts and the early part of the 3rd shift.

The clean air sample probes located on the north and south corner of the roof above the plaza indicate that quantities of clean air less than 1000 cfm could be obtained from either location. Quantities above 1000 cfm should be obtained from the south property line fence where air with CO concentrations below 10 ppm is consistently found, and the possibility of drawing contaminated air in the fan intake is substantially reduced.

4.0 FACE VENTILATING SYSTEM

In March of 1970, the University of Washington, Department of Environmental Health, developed two types of breathing zone ventilating systems. The first of these systems was a commercially available hard hat with a face shield, and a curtain of air (from a clean air source) was passed down across the operator's face. The second was a chest type where a plastic shield extended up past the operator's face, and air was forced up through the system across the face.

Both the chest type or hat type system, if used by the operator, would provide adequate protection from high levels of CO.

4.1 Design

Each face mask would require from 10-12 cfm of air with a total of 100 cfm of air for the entire system. Fresh air for such a system could be obtained from either the south or north roof edge at from 16-20 feet above the roof. Air would be delivered to the booth through a 4" duct system with a turbine type blower. At each booth, a low pressure drop filter, air heater, and a humidifier would be used for individual comfort.

Figure 10 shows a sketch of the system.

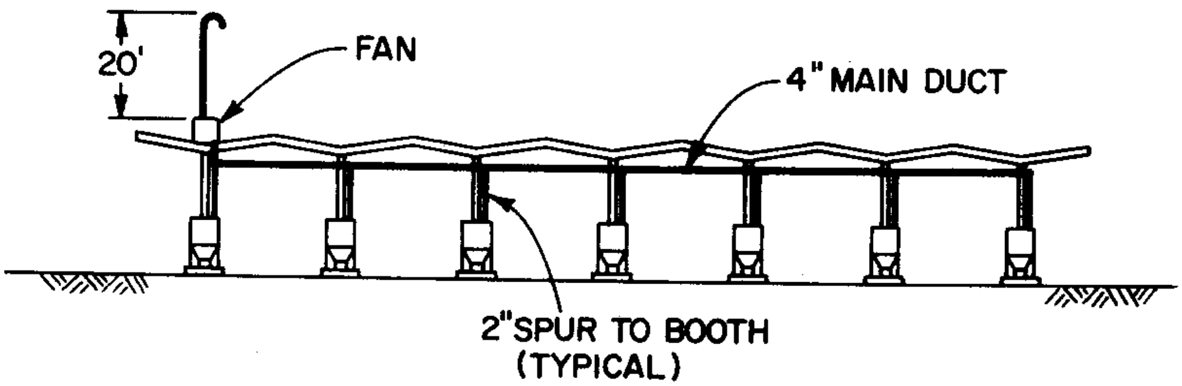

Figure 10. Face mask air distribution system

Figures 10a and 10b show the face ventilation unit.

5.0 BOOTH VENTILATION

Booth ventilation systems, although expensive to operate and difficult to design, do provide the operator with a curtain of air containing low concentrations of carbon monoxide, without having some sort of personal protective device. However, if not properly designed a ventilating system can cause excessive drafts which might be more uncomfortable to the operator than a breathing device. A properly designed system, as shown in Figure 11, must have the following characteristics; the velocity of the air past the operator must not exceed 30-40 ft. per minute thereby eliminating drafts and also, must go out all openings at a velocity greater than 80 ft. per minute to eliminate excessive carbon monoxide from entering the booth.

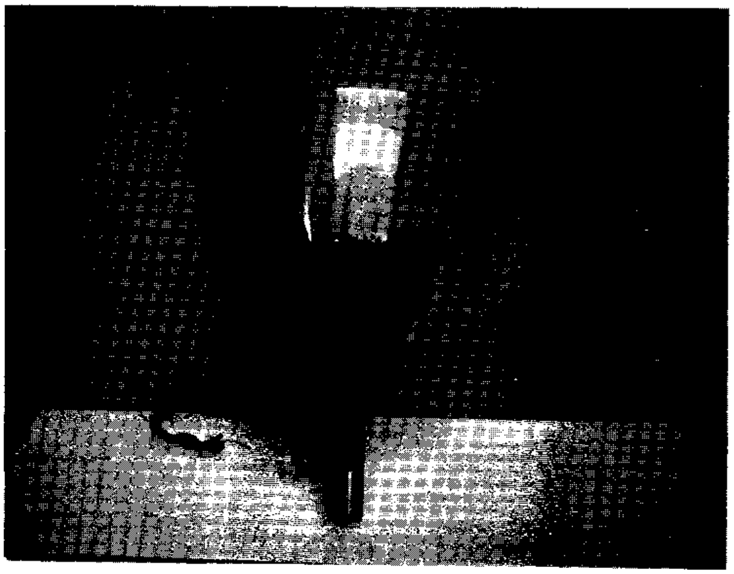

Figure 10a. Face ventilation mask

Figure 10b. Face ventilation mask

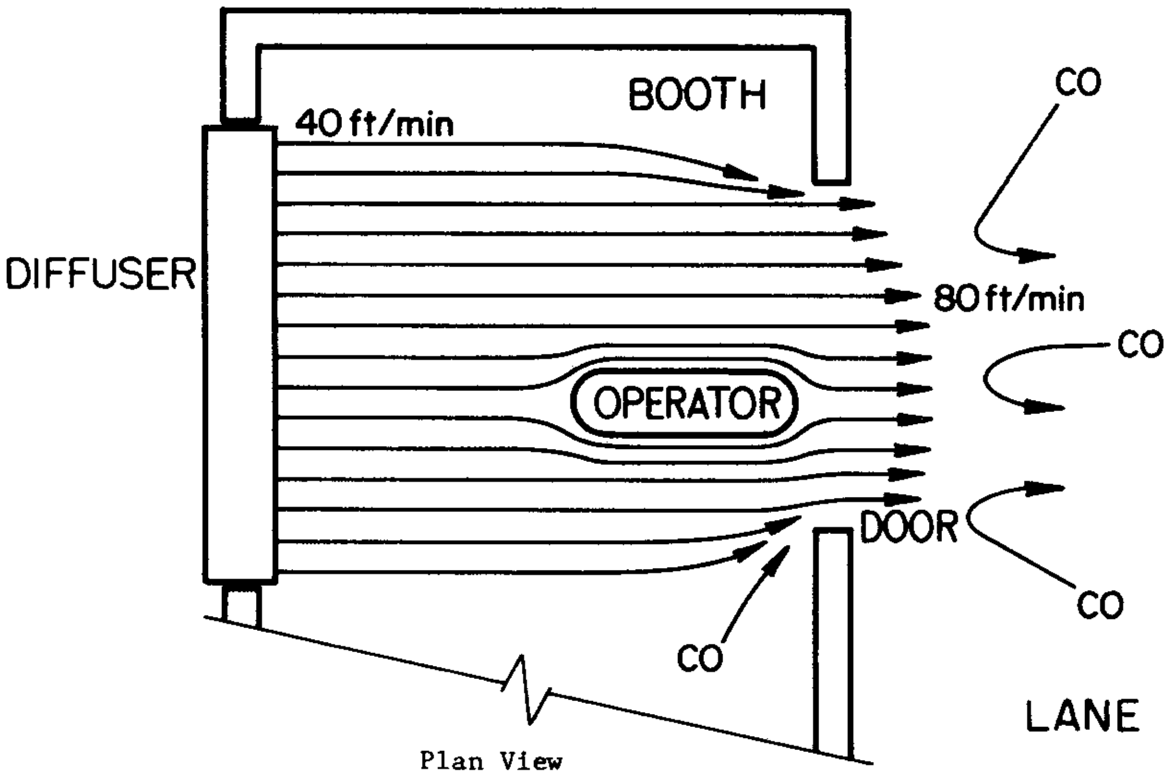

Figure 11. Booth ventilation principle

5.1 Model System Design

Two main factors were considered in designing the booth ventilating system. First, the diffuser must induce a constant and uniform draft-free flow of air and second, the diffuser must be placed in a location that will produce a uniform flow of air out of the door.

Commercially available diffusers failed to meet the needs of this particular problem in that air was not emitted uniformly over the diffuser surface. Therefore, a diffuser had to be specially designed for this application. With the help of Dr. Ritchie, Department of Civil Engineering, various internal configurations were tried, and the unit that was selected is shown in Figures 12 and 13. A detailed drawing of the unit is shown in the Appendix.

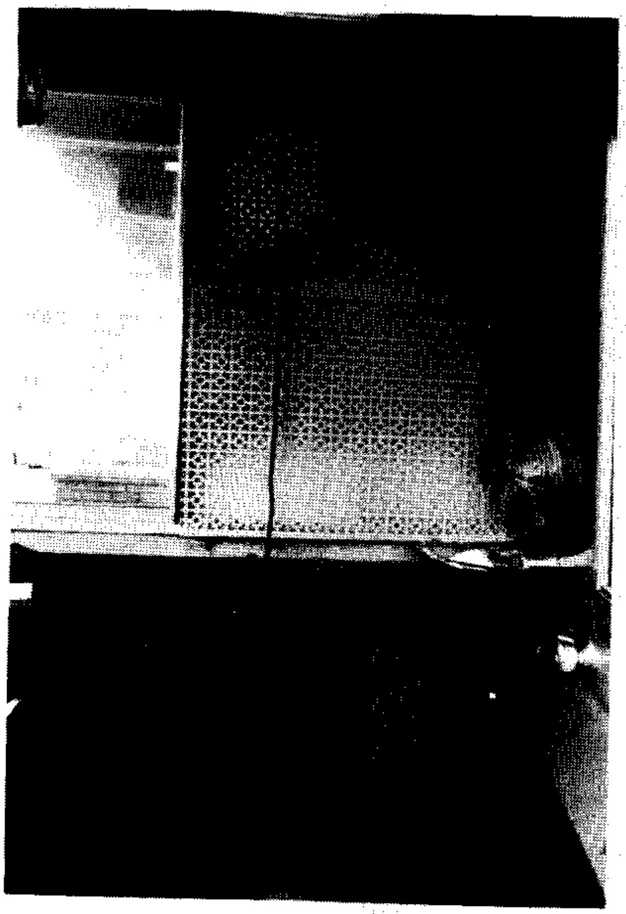

Figure 12. Air diffuser installed in lane 5

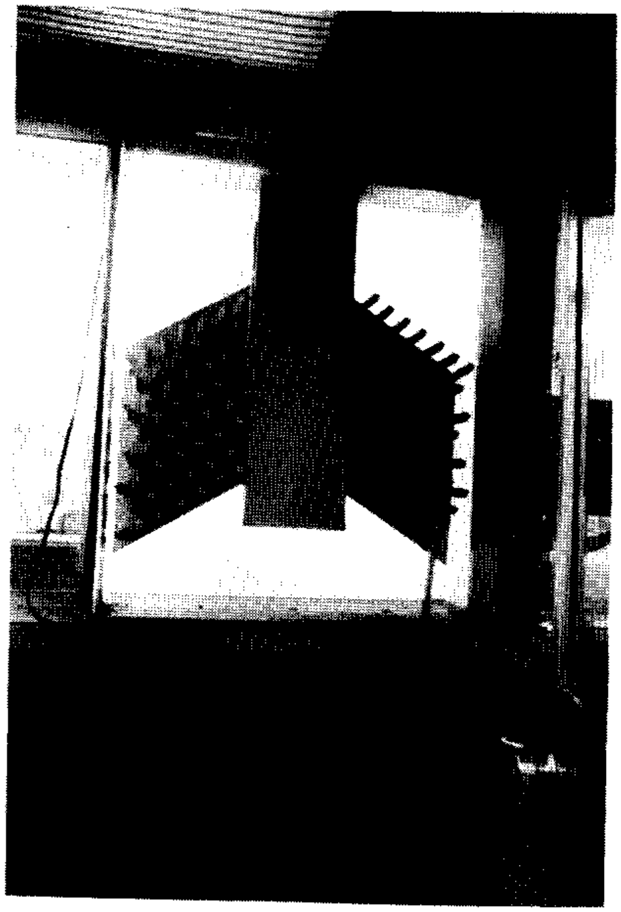

Figure 13. Air diffuser with cover removed

The diffuser operates as follows: Air enters the diffuser from a 1" slot on either side of a 4 1/2" x 10" metal duct, and the velocity of the air is reduced by means of the peg arrangement in the middle of the diffuser. A 40% covered grill backed by a 2" fiberglass filter provides enough resistance to even the flow of air coming out of the diffuser. The velocity profile at the diffusers with 500 cfm of air and the velocity taken 3 inches from the unit, has a uniform velocity profile of 45 ft/minute ± 10 ft. per minute over the entire surface. To test the diffuser and determine its location in the booth, it appeared more practical to build a model booth than disrupt operations at the toll plaza. The diffuser was placed in various locations within the model booth with varying results. The best location was directly across from the open door where an even air flow out the door was obtained.

Using a dutch door, with the bottom section closed, velocity readings were taken at the doorway opening, while the operator was standing in the doorway, and 600 cfm of air entering the booth. These readings showed a constant outflow of air that varied from 80 ft. per minute at the bottom of the opening to 125 ft. per minute at the breathing zone and top of the door.

At times, the toll booth operator is required to lean out of the door to reach the automobile in the lane. When this occurs, he is exposed to winds containing high concentrations of CO. These winds are produced from three sources: The first is the mass of air being pushed ahead and carried along with the car. The second source is generated by certain models of automobiles and trucks that have the exhaust pipe on the driver's side of the car. When the car accelerates out of the plaza the exhaust gasses enter the booth, and if the lower portion of the door is open they enter the booth or race up the door if it is closed. And third are velocity winds blowing through the plaza that could force polluted air into the booth.

To compensate for these effects, deflectors were added to the door to reduce the velocity of these winds, thereby enabling the air coming from the booth to carry the gas away. To compensate for the air moving with the car, a plastic deflector was placed on the front edge of the door as shown in Item (1) Figure 14. To reduce the velocity of the tailpipe gasses up the front of the door, two

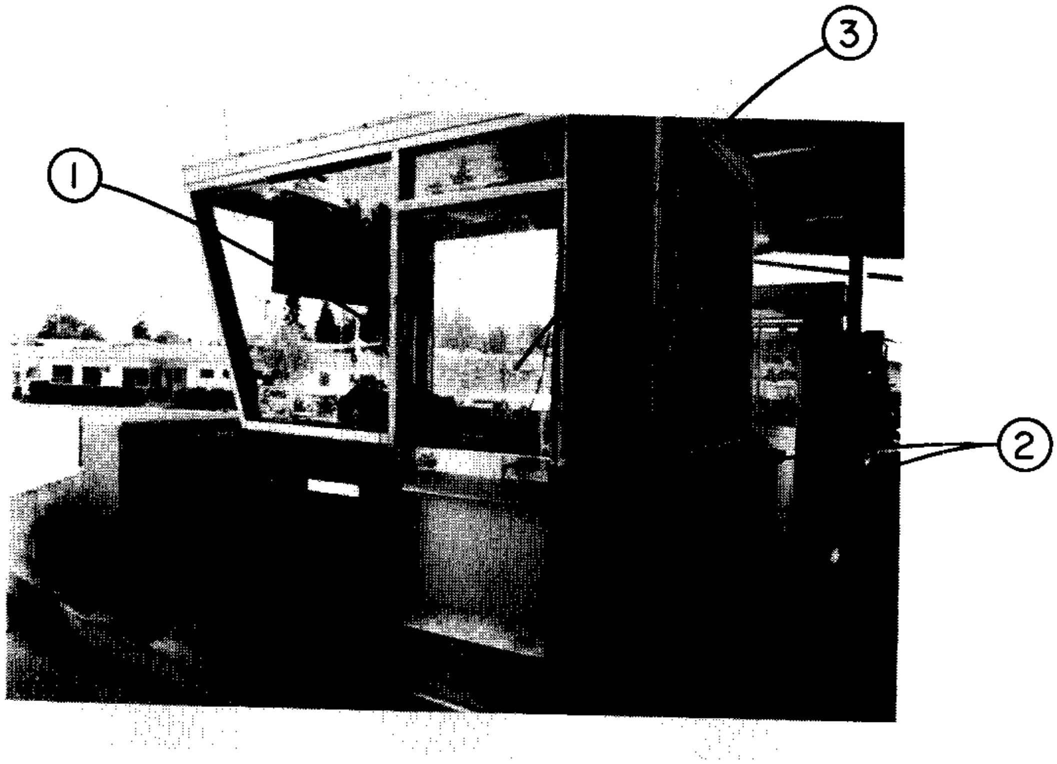

Figure 14. Wind deflectors on toll booth

deflectors were added to the lower panel as shown in Item 2. Wind approaching from the rear of the booth is reduced by a rear deflector Item 3. These deflectors also extend the effective clean air zone by channeling the clean air out into the traffic lane. However, these deflectors by themselves will not lower the CO concentration to below 50 ppm as the ambient levels are above this value. Details of these deflectors are located in the Appendix.

To obtain the necessary 80 to 150 feet per minute velocity of air leaving the booth, it is necessary to leave the lower portion of the dutch door closed. This also eliminates the high concentration of exhaust gasses that are emitted from cars with the tailpipe on the driver's side from entering the booth. This requirement presents some problems for operators who are too short since the door hit them in the lower rib area. The ideal situation is for the top of the door to be at the top of the hip bone or below. A stand was designed which provides the height necessary and which remains up against the door when not in use. Although not entirely satisfactory from the standpoint of worker's convenience, this stand did provide the added height necessary to keep the door closed during testing. A better arrangement would be to lower the existing bottom part of the door 6" to meet the requirements.

After the diffuser and its location within the booth were established, the unit was moved to the toll plaza. Figures 15 and 16 show the system installed at the booth. Air was obtained 16 ft. above the north roof, filtered and blown through the diffuser. The duct was insulated to eliminate heating due to solar radiation, and a radiant heater was istalled to warm the operator rather than heat the incoming air on cold days. The regular booth circulating fan was used to move the air within the booth for cooling as the velocity from the diffuser is too low for this effect.

5.2 Operation Characteristics

Tests were conducted over a 6 week period with various air volumes and door restriction patterns. The north roof sample probe was moved to the inlet of the ventilating system to record the CO in the inlet air. The results of these tests are shown in Figures 17 through 22.

Figure 17 shows the carbon monoxide levels with 500 cfm entering the diffuser, the lower portion of the door closed, with the top of the unrestricted in size. The levels varied from 10 to 20 ppm during the test. However, a 55 ppm reading was observed when the bottom of the door was open for a few minutes.

Figure 18 shows the same door configuration with a varying airflow of 600 and 500 cfm. It will be noted that the 600 cfm ventilating rate lowered the

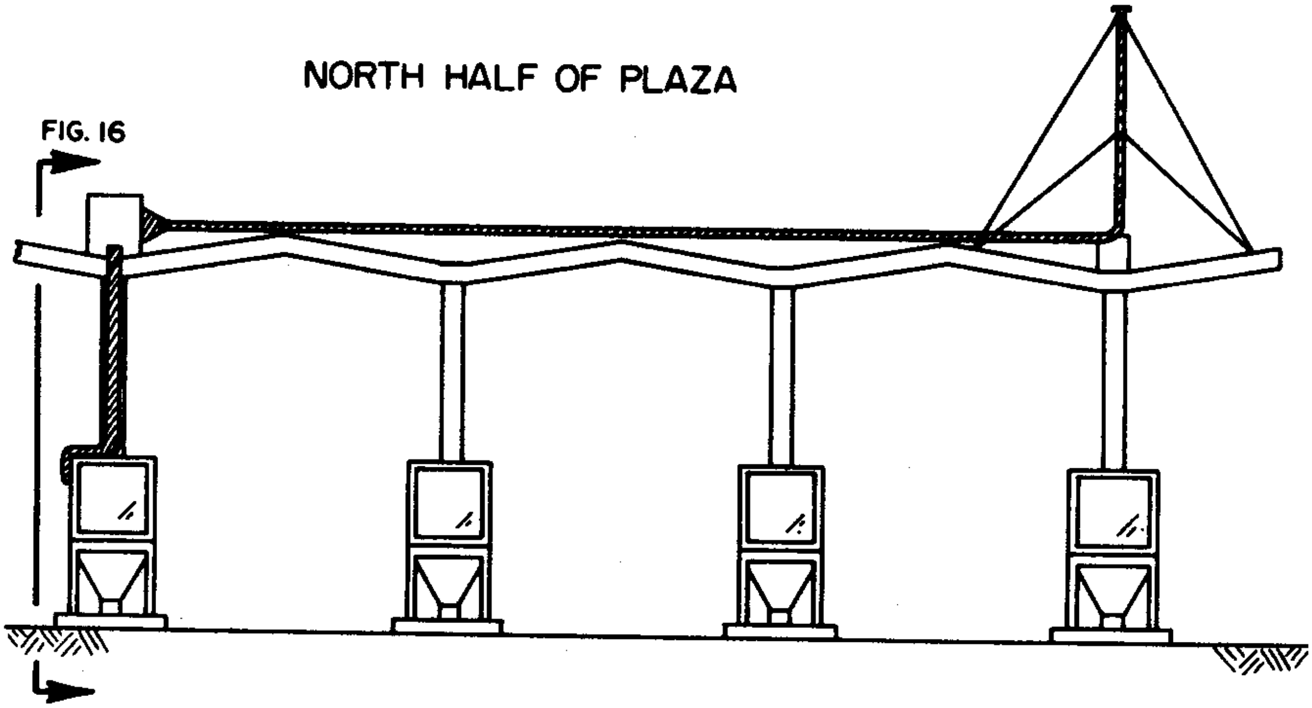

Figure 15. Prototype ventilating system

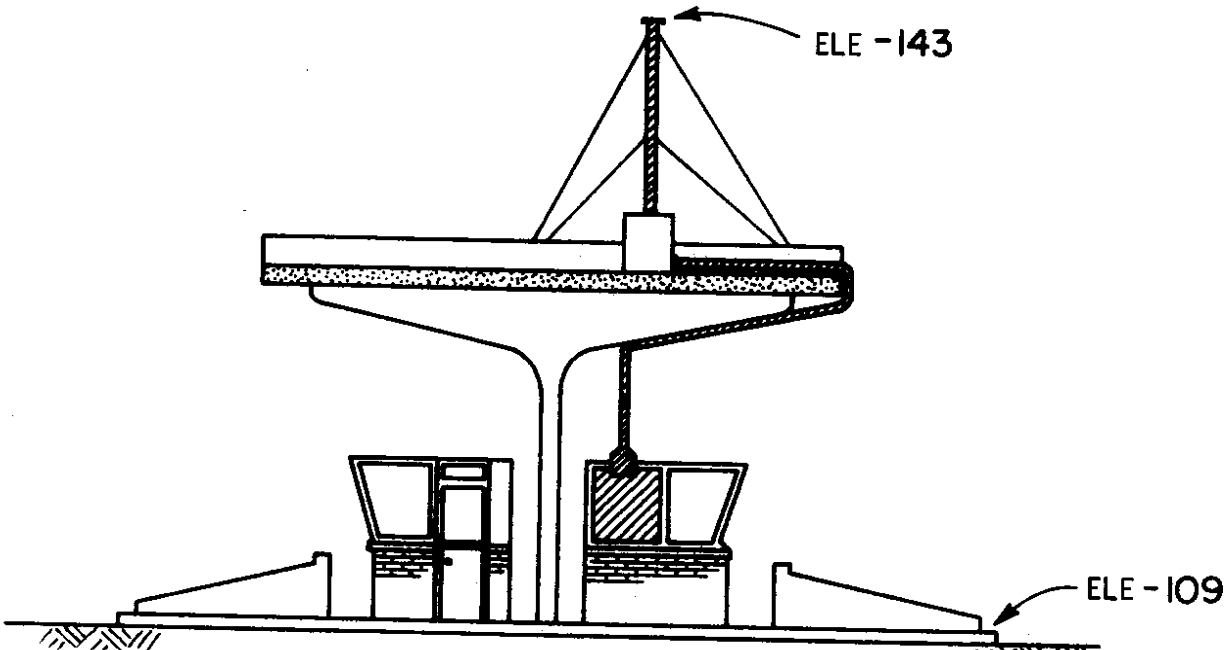

Figure 16. Section view prototype ventilating system

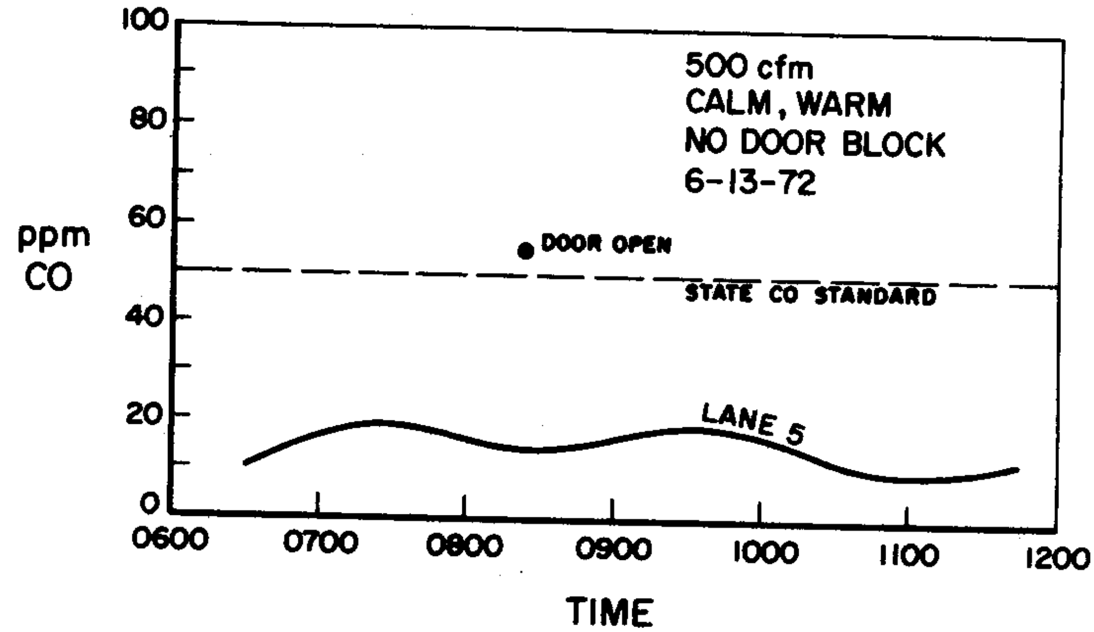

Figure 17. Ventilating system tests

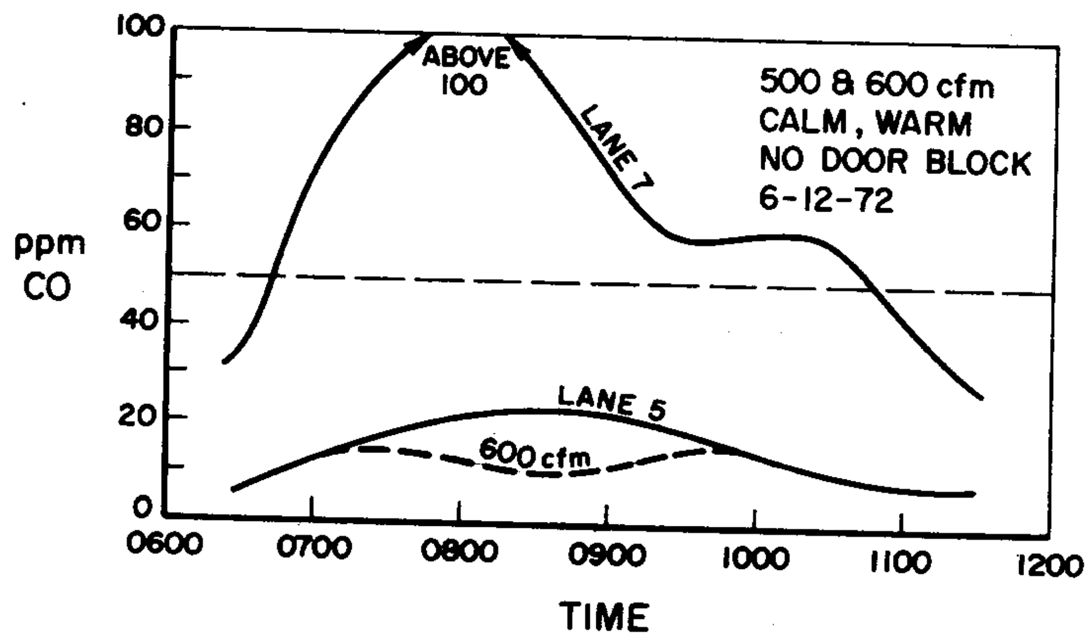

Figure 18. Ventilating system tests

booth concentration to inlet air values of less than 10 ppm. To show a comparable booth, the corresponding values for lane 7 with no ventilation system, and the bottom of the dutch door closed were also plotted on this curve. The ventilation system shows a 30% to 90% reduction in CO gas entering the operator's breathing zone.

Figure 19 shows the same unrestricted top door configuration and 400 and 500 cfm of air. At the 400 cfm rate, all CO reduction is lost, as the air velocity leaving the booth is not sufficient to stop the incoming air.

Figure 20 shows both the lower and upper portions of the door open between 0700 and 0900. These values ranged from 50 to 70 ppm, and although they are lower than without ventilation air, they are not acceptable.

Figure 21 shows the top half of the dutch door with a restricted configuration in which 9" on the side and 9" on the top were blocked off with vinyl plastic flexible enough to be moved by the operator. When 300 cfm inlet air was blown in the booth, the CO level in the breathing zone was between 5 ppm and 10 ppm, the same as the inlet air.

Figure 22 shows the 300 cfm air flow with the restricted door opening, and again comparing those readings with lane 7 that has no ventilation system.

5.3 Results of Model Booth Tests

The tests show that various door configurations and different air flow rates can be used to obtain satisfactory results. The limiting factor is the operating cost. This operating cost includes the heat required to maintain 60° - 65°F air temperature, and the fan operating costs. Using these parameters, the 300 cfm with a restricted door design is more favorable than 600 cfm design. Heating the air presents some design problems. The air can either be preheated at the fan located at the south fence with final heating at the booth, or heated at the

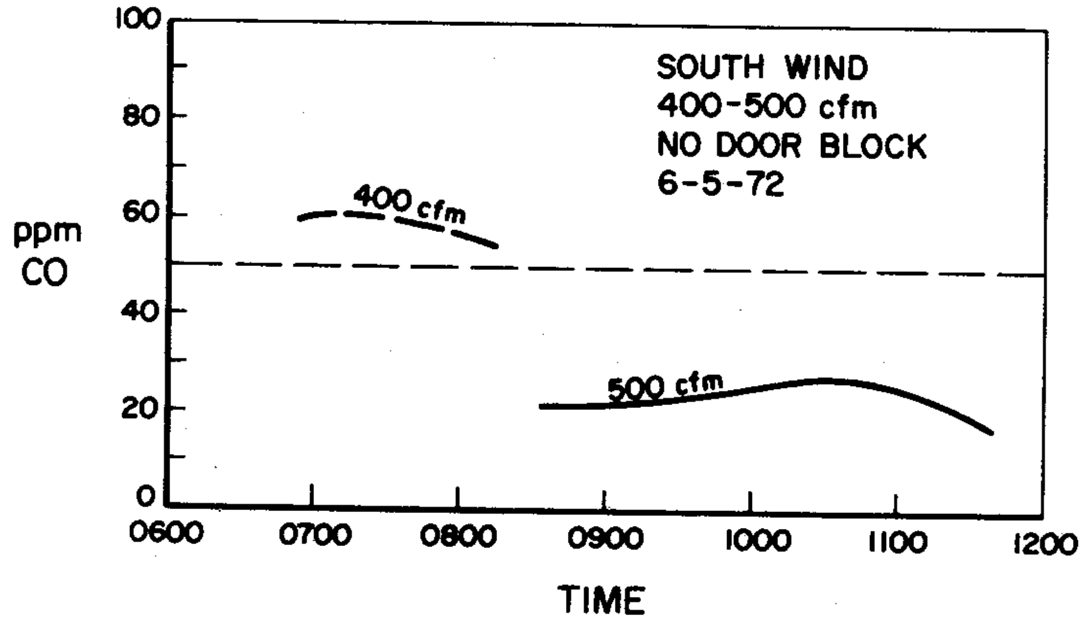

Figure 19. Ventilating system tests

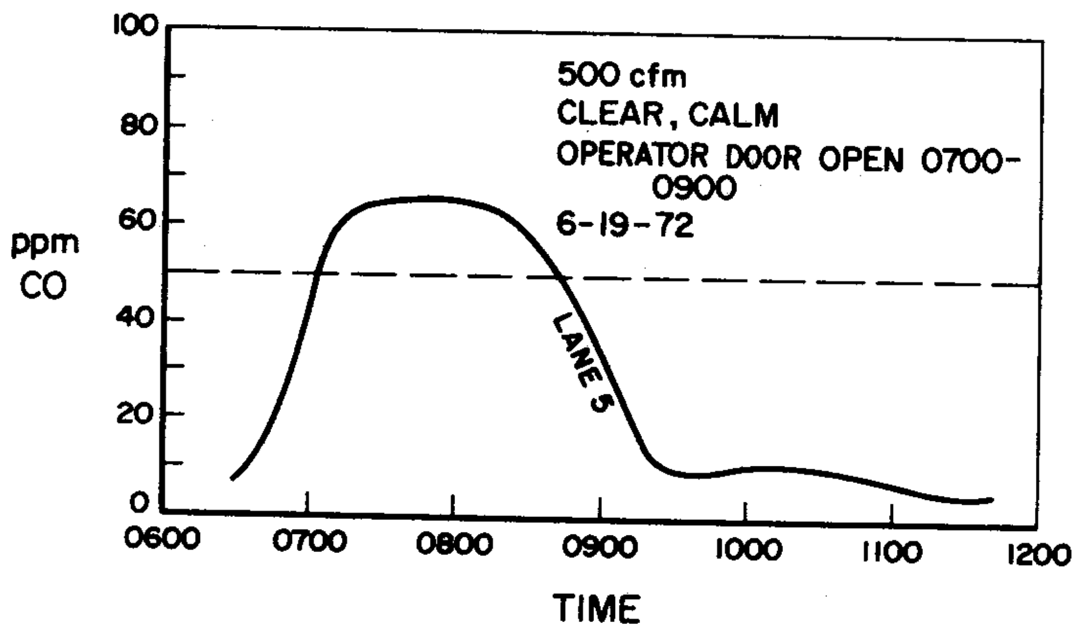

Figure 20. Ventilating system tests

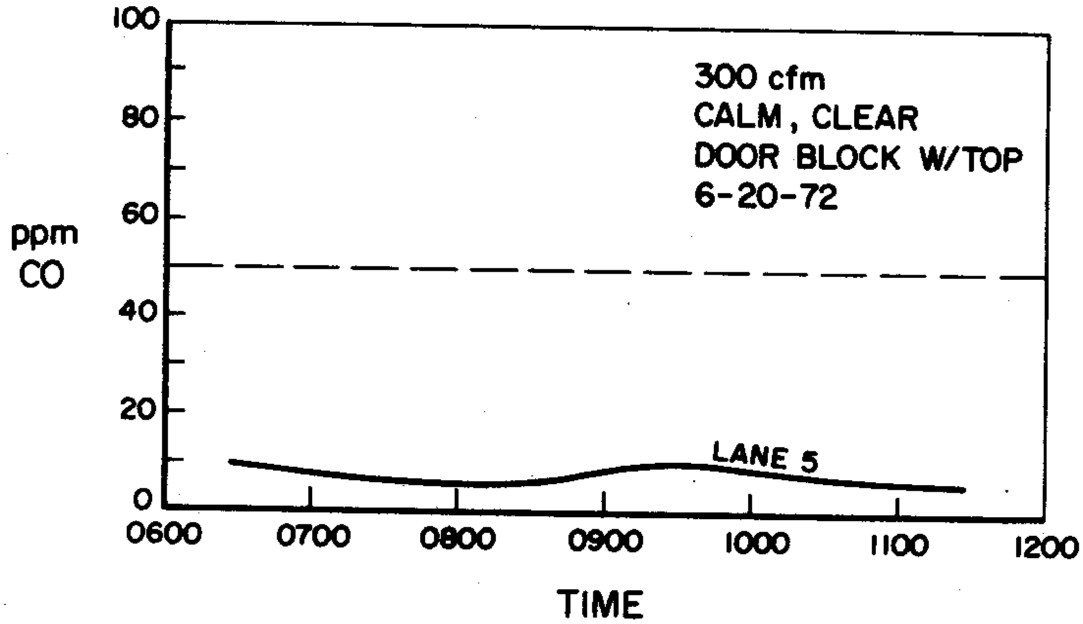

Figure 21. Ventilating system test

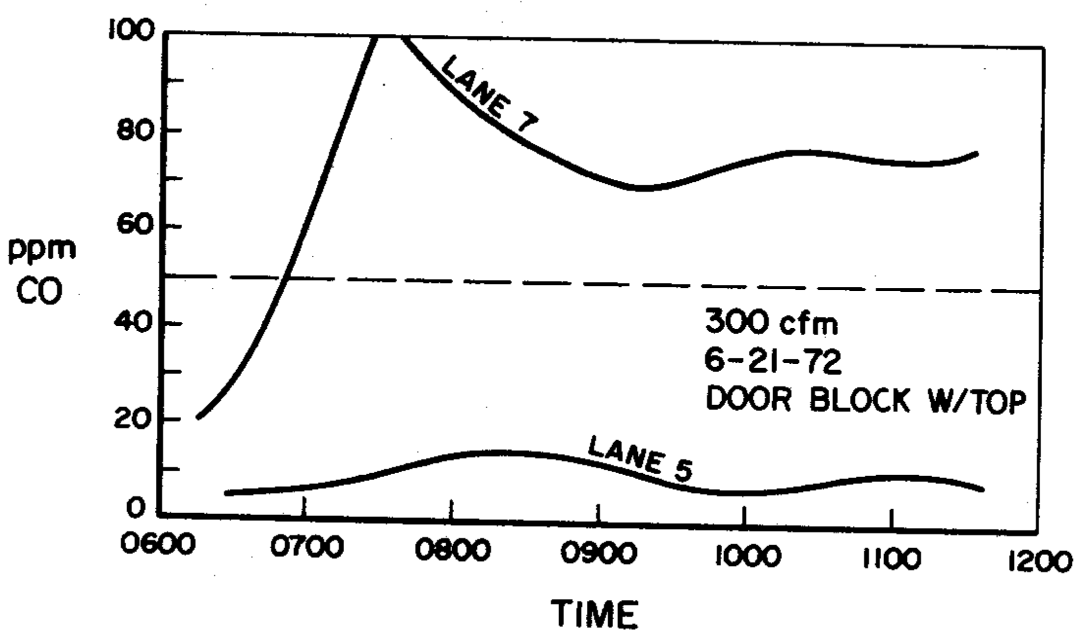

Figure 22. Ventilating system test

booth in a single stage.

Air heating at the booth does appear to be more practical as central heating at the fan would require a minimum air flow that would require additional units operating on 3rd shift, and the added expense of insulating the air ducts. Adding the heat at the booth would be more expensive from the standpoint of added heater costs and electrical installation costs but would provide temperature control at the booths. Therefore, heating the air at the booth would be more desirable.

Figure 23 shows the proposed system.

5.4 Personal Reactions

During the testing the following operator reactions were obtained:

Unfavorable

- During the 600 cfm testing, 3 operators complained of drafts on the back of their neck.
- One operator said she could not work with her door closed due to a bad back.
- 2 operators used the door stand but were not 100% satisfied. Lowering the door would probably reduce this comment.

Favorable

- One operator noted that his eyes were not blood shot when he got home.
- 8 operators said they feel better when they were in lane 5.
- 2 operators said that they did not have the headaches during the shift.
- Overall the operators like the booth ventilating system.

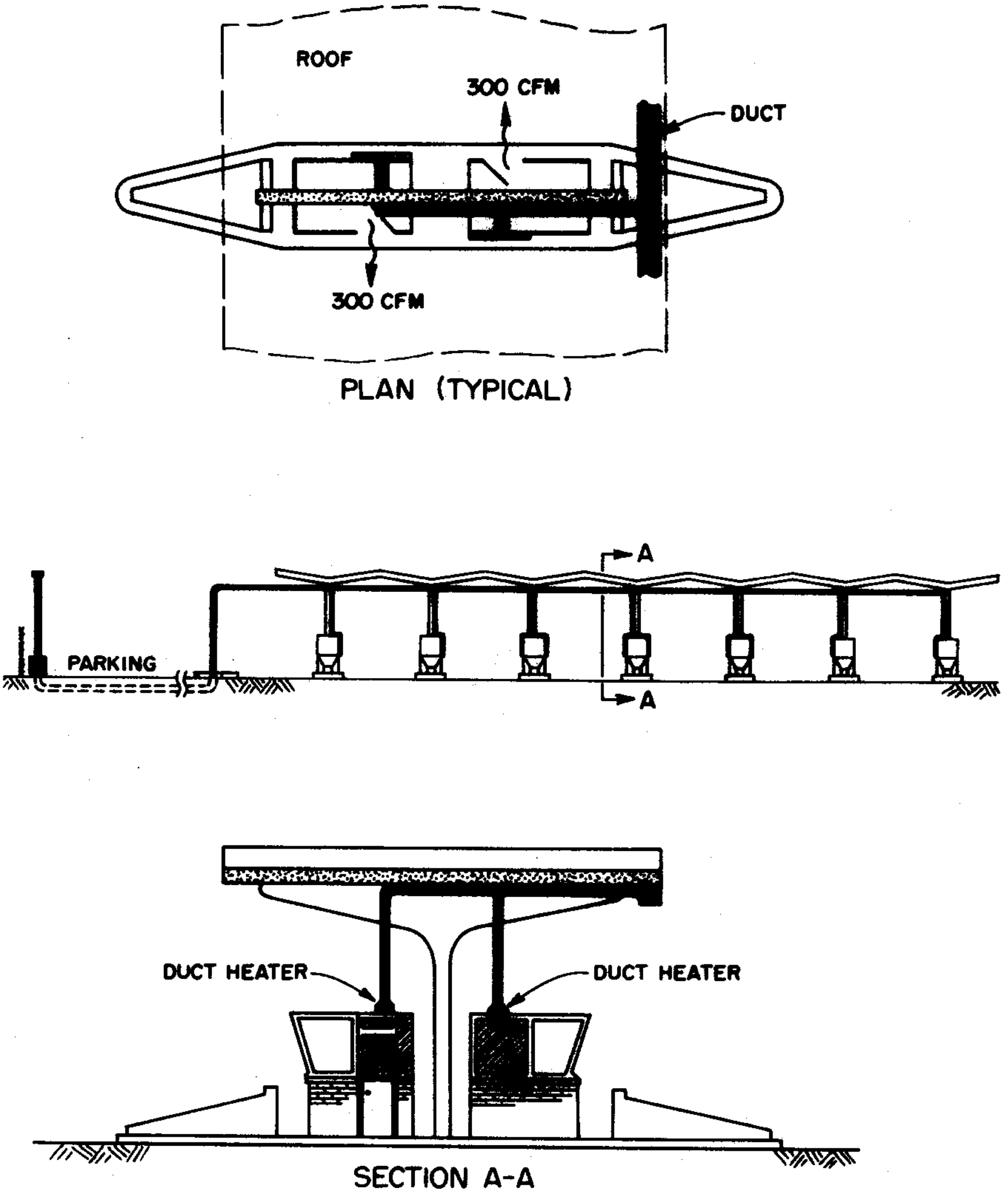

Figure 23. Proposed ventilating system

6.0 SUMMARY

Monitoring System

The monitoring system was installed in 4 booths for a representative sampling of the breathing air. In addition, probes were used to monitor the air above the north roof, south roof, and the south property fence. The monitoring program showed that the CO levels remain above the 50 ppm standard between the hours of 7:00 am and 11:00 pm with peak values above 250 ppm. Readings were higher than average in lanes where the traffic is heavier (lanes 3 to 7), and were higher when the lower portion of the door was open allowing exhaust gasses to blow directly into the unventilated booth where dilution to ambient levels could take 10 minutes or more.

6.1 Ventilating System

There are two main methods of providing low CO level air to the breathing zone of the toll booth operator. The first is a face mask system and the second is a ventilating system, both of which must keep the levels below 50 ppm.

The face mask system in which air is blown across the operator's face will meet the necessary requirement of less than 50 ppm air in the breathing zone. It is also economical to install and operate. However, it does restrict the comfort and free movement of the operator, and he can either operate the unit or leave it off.

The booth ventilation system employs the principle that relatively clean air of low velocity is pumped into the booth, past the operator and out the door with sufficient velocity that CO cannot enter the booth. CO values of 10 ppm can be obtained by either putting air into the booth @ 600 cfm with the bottom half of the door closed and the top open, or at 300 cfm with the bottom portion closed and the top restricted 40% by means of a flexible vinyl deflector.

In any type of booth ventilation system best results are achieved with door, front, and rear wind operators. The most convenient height for the lower portion of the door is at the top of the operator's hip bone. For a short operator this can be achieved by using a stand or cutting off the door.

Since the air is blown directly on the operator, it should be heated to at least 65°. This can be done with a central system or an individual system. In either case the air should be filtered with a 98% collection efficiency for dust particles in the 5-10 micron size range. This can be achieved with a Farr type J-12 filter or equivalent.

7.0 RECOMMENDATION

It is recommended that a booth ventilating system be installed in lanes 1, 2, 3, 4, 4R, 5, 5R, 6, 7, 8 using the 300 cfm per booth ventilation rate.

The fresh air supply should be obtained from the south fence, where less than 10 ppm air exists under all weather conditions, filtered and piped to the booth as shown in figure 23. Deflector should be placed on the door and arrangements made to either lower the door or provide platforms as shown in Figure 14. The air should be heated at the booth for better control.

Monitoring should be continued to insure operation of the entire system, and could be extended to all 10 booths if desired but not necessary.

8.0 APPENDIX

Equipment Maintenance

In general the equipment was found to be very reliable and trouble-free. However, occasional checks should be made to insure proper operation. These checks should be made at least every other day and consist of the following:

1. Note the strip chart for a drift or increase in the levels. This is caused by a leak in the system.
2. Turn the power switch on the selector to off. This turns all the valves off and the vacuum on the pump should read above 17" of mercury.
3. Check the oil level on the pump and add if necessary.

At least once every two weeks, the unit should be calibrated as outlined in the operation manual.

The chart paper will last for 6 days between changes.

APPENDIX

Parts List

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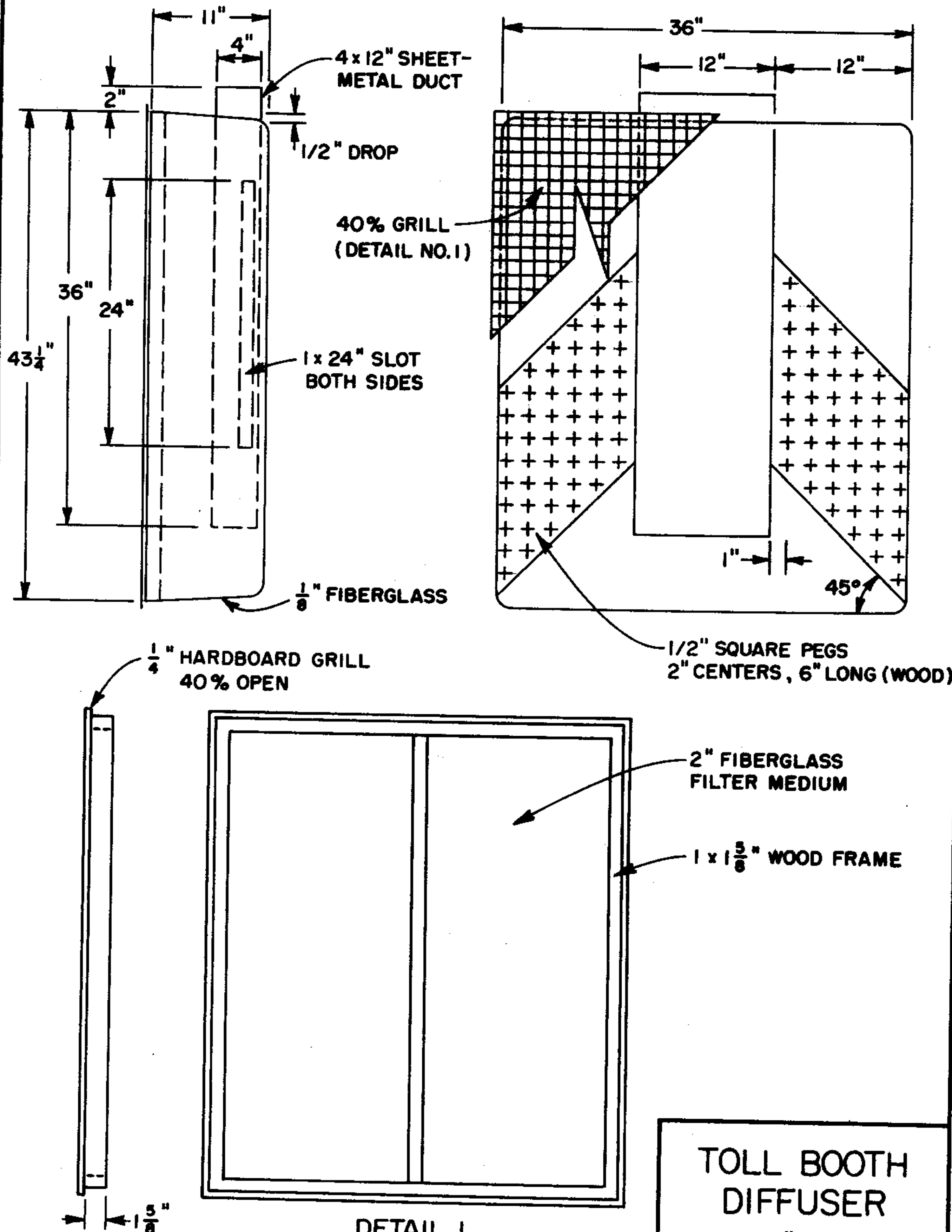
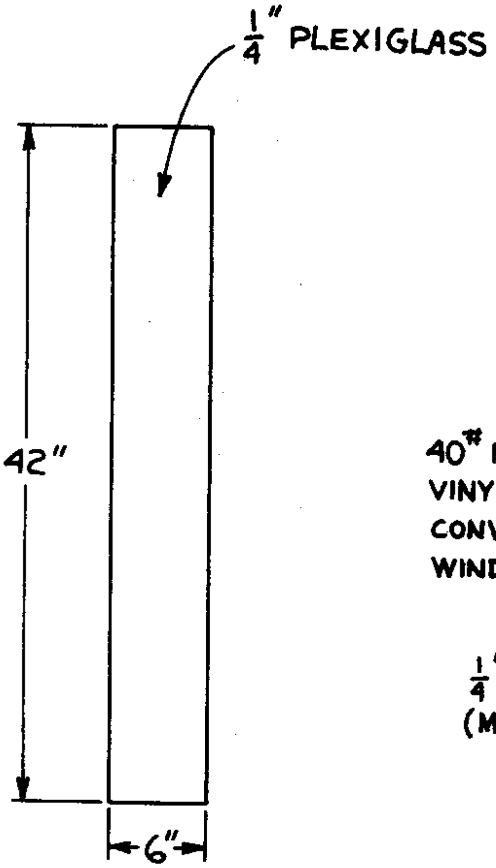
1. 3/4" plastic pipe
2. 1/4 HP - 4 cfm rotary vain vacuum pump
3. Tompson model 107CA11-443 pump w/Mohnier Br. model 202-1000-2 filter
4. 0-2.4 L/min, and 0-4.8 L/min flow meter
5. Model 315B Beckman infrared analyzer
6. " " " " "
7. Level comparator, U. of Washington
8. Leeds & Northrup model S
   Speedomax - H recorder
9. Stream selector, U. of Washington
10. Standard 50 ppm CO in balanced nitrogen
11. Zero gas balanced nitrogen

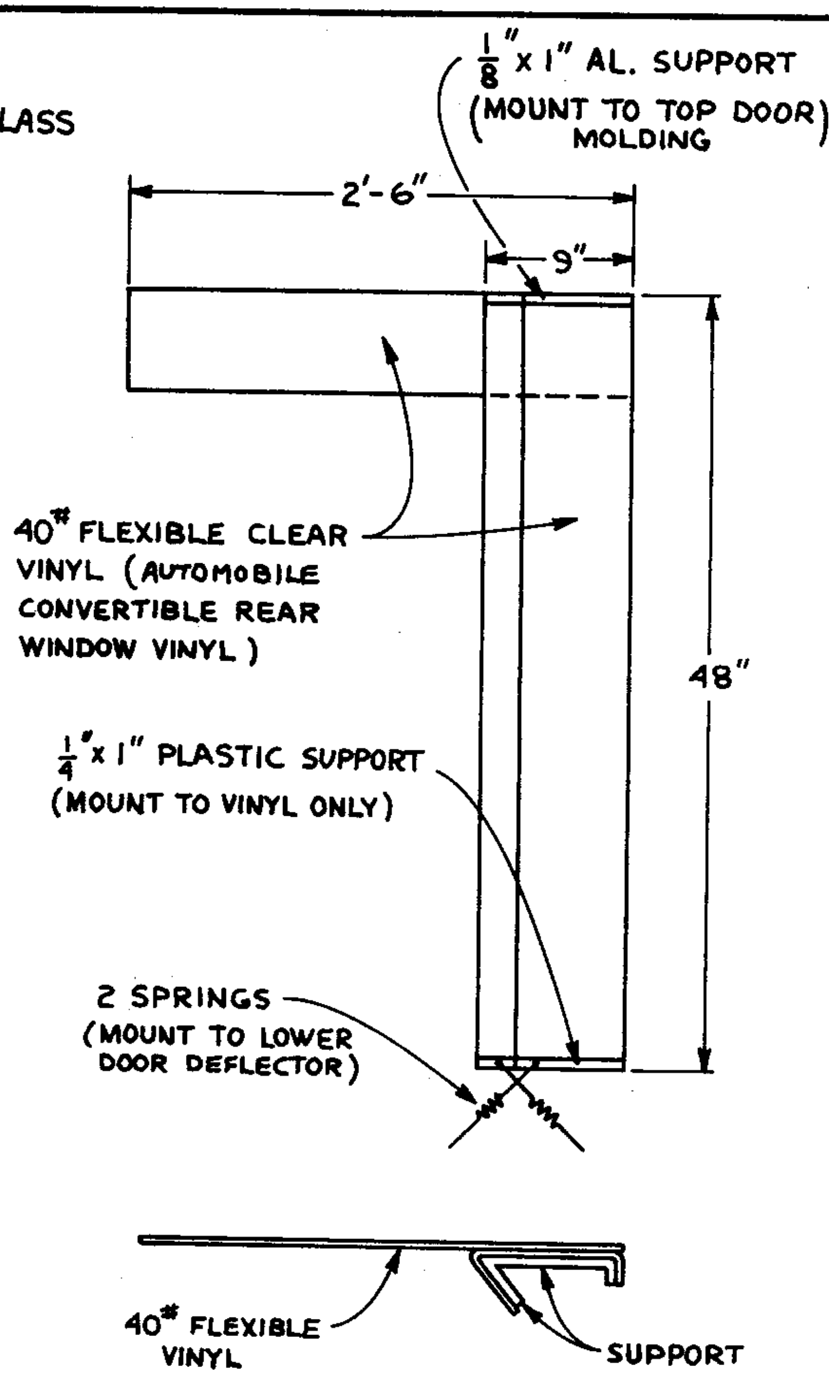


TOLL BOOTH DIFFUSER

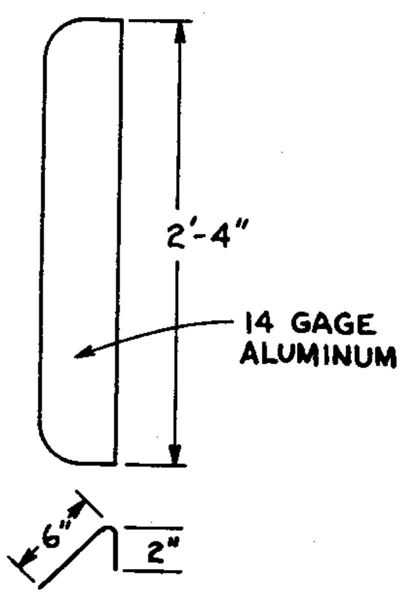
SCALE: 1" = 1'-0"



FRONT DEFLECTOR
(MOUNT TO MOLDING ON FRONT OF DOOR)

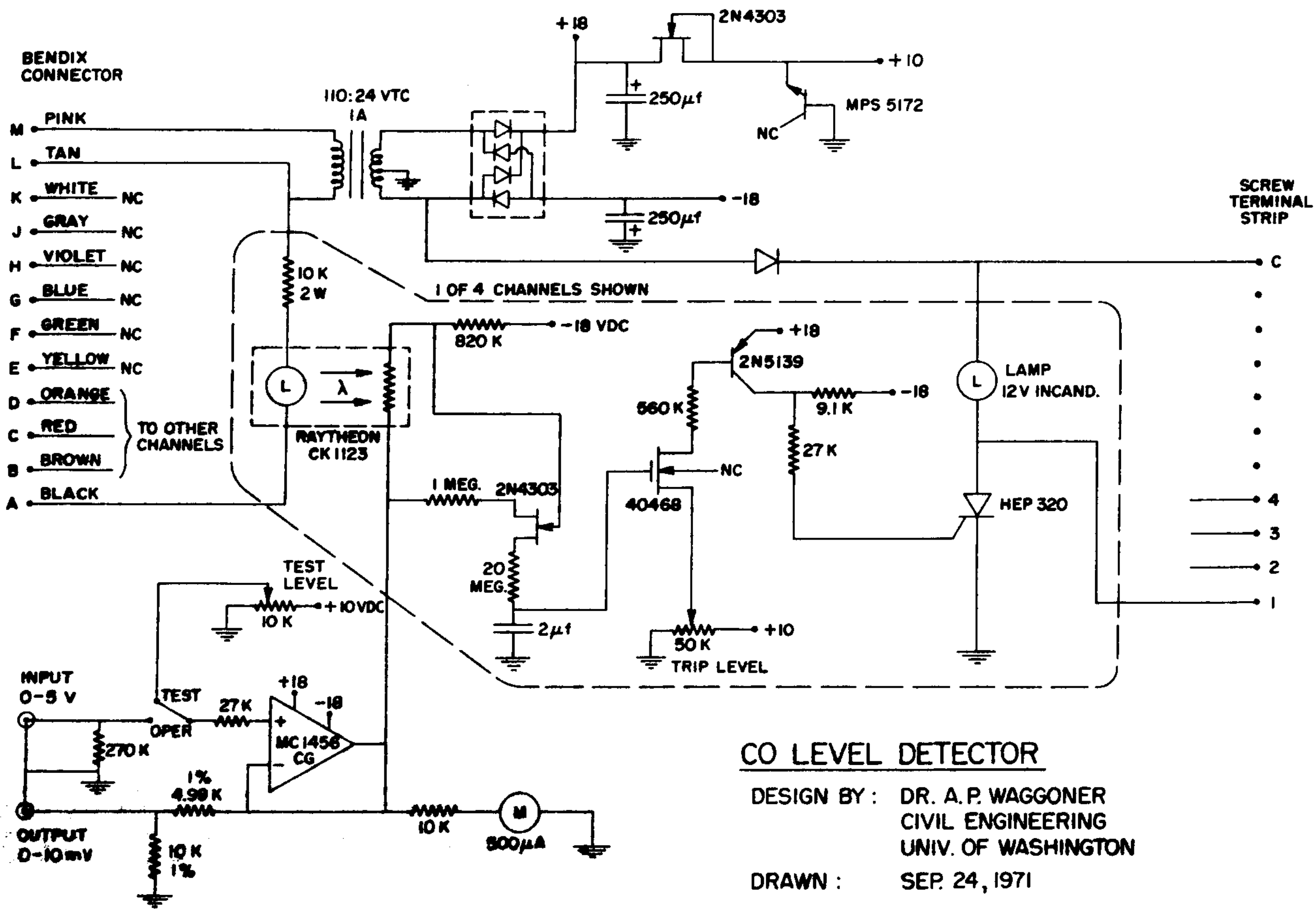


REAR DEFLECTOR & DOOR RESTRICTION



DOOR DEFLECTOR
(2 REQUIRED)

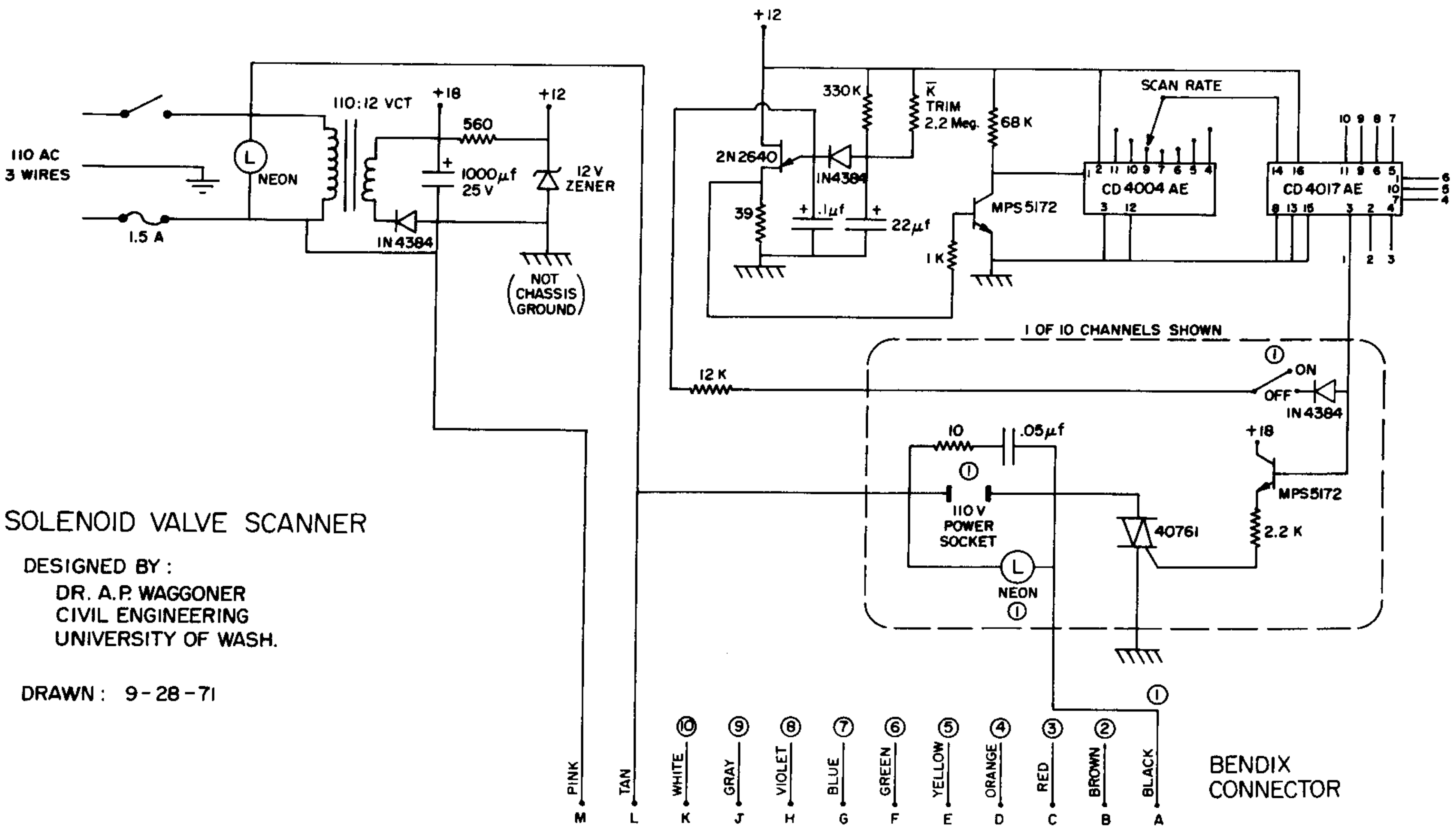
WIND DEFLECTOR DETAILS



CO LEVEL DETECTOR

DESIGN BY : DR. A. P. WAGGONER
CIVIL ENGINEERING
UNIV. OF WASHINGTON

DRAWN : SEP. 24, 1971



SOLENOID VALVE SCANNER

DESIGNED BY :

DR. A.P. WAGGONER
CIVIL ENGINEERING
UNIVERSITY OF WASH.

DRAWN : 9-28-71