INSTRUCTIONS FOR MANIPULATING THE PETERSON & PALMQUIST APPARATUS FOR THE DETERMINATION OF CO2 IN AIR AS MODIFIED BY

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of the

New York State Labor Department.

GENERAL INSTRUCTIONS:

When not in use see that

(1) Left-hand top manometer stopcock is open

(2) Air intake stopcock is open

(3) Stopcock from pipette to manometer is open

All other stopcocks are closed.

All stopcocks should be kept well greased with petroleum jelly, or they will be set firmly by the caustic potash.

The caustic potash should be changed once a month. The potash should on no account be allowed to get beyond its own stopcock. If it does, the apparatus must be entirely cleaned, carefully neutralize the measuring pipette with dilute sulphuric acid before proceeding.

The mercury in measuring pipette should be covered with a little 1/30 sulphuric acid.

Any dust or dirt getting into the capillary tubes should be carefully removed by means of soft cord.

The air intake should be at all times plugged with a little glass wool to prevent access of dust.

The mercury and caustic potash reservoirs should not be tightly stoppered while making determinations.

At all times before making readings either on manometer tube, potash level, or mercury column, the capillary tubes should be lightly and carefully tapped, and air should be blown through the water bath to equalize the temperature.

PREPARATION OF APPARATUS:

(1) Put drop of kerosene in manometer tube. This may be colored. Bloodroot is a good coloring material.

(2) Fill mercury reservoir to such a level that when it is hung on upper hook mercury will rise a little above top of 25 ccm. bulb of air pipette.

(3) Place a small drop of dilute sulphuric acid (1 to 30) on top of mercury surface in pipette, for purpose of keeping air moist.

(4) Fill caustic potash reservoir to such a level that surface in Orsat tube rises 1/4 inch or so above neck to the adjustable wire marker. Stopcock from air tube to Orsat tube should be closed while this is being done, and at all times, except when absorption is taking place.

MAKING TEST:

(1) Adjust kerosene bubble, i.e., see that it is intact and near 0 in manometer.

(2) Open left-hand manometer stopcock so that the air in the compensating tube can come as near as possible to same pressure as sample in the air pipette, so that there will be no great jumping of the kerosene drop when reading of manometer is desired.

(3) Adjust caustic potash surface, tapping the tube and blowing air through the bath in Orsat tube to wire marker, getting a sharp

reading. Caustic potash stopcock should be closed until ready for absorption.

(4) Drive out air from pipette by raising mercury surface in pipette, the stopcock between the pipette and atmosphere being open and that between the pipette and manometer being closed.

(5) Take in sample of air by allowing mercury surface in air pipette to 0 and shut off mercury. Shut off air intake stopcock.

(6) Open stopcock between air pipette and manometer and adjust mercury surface to 0 by slow motion screw, tapping tube and blowing air through bath as before. All stopcocks to outside air being closed. Read manometer.

(7) Shut stopcocks from air pipette to manometer.

(8) Open stopcock between caustic potash Orsat tube and air pipette and send air over into caustic potash two or three times by raising and lowering mercury, great care being taken not to lower mercury surface sufficiently to allow caustic potash to jump over into the air pipette.

(9) Bring caustic potash surface back to wire marker, (same position as before starting absorption). As before, great care must be taken in doing this not to allow caustic potash to jump over into the air pipette. Bring it almost to the wire, then shut off main mercury stopcock and adjust level by slow motion screw after having tapped tube and blown air through water bath.

(10) Shut off stopcock between caustic potash Orsat tube and air pipette.

(11) Open stopcock between air pipette and manometer tube, and adjust bubble in manometer tube to original reading by slow motion screw on mercury. Blow air through the water bath.

(12) Read height of mercury on scale at bottom of air pipette showing parts in ten thousandths of CO2 which was in original air sample. This CO2 has been absorbed by the potash.

KIT FOR ROGERS APPARATUS:

1 Small bottle kerosene
1 Small bottle of 1/30 Sulphuric Acid
1 Bundle fine wire
1 " coarse wire
1 " white twine
1 Pair tweezers
1 Glass siphon
1 Length of pressure tubing
1 Bulb and tube for stirring water bath
1 Tube Litmus paper
1 Bottle 250 cc. 1:1 Sulphuric Acid
2 Medicine droppers
1 Screw driver
1 Rubber stopper for mercury reservoir
1 Tube of petroleum jelly
1 Litre 33-1/3% caustic potash

INFILTRATION DATA SHEET

Test No._____

Room_____ Building_____

Date_____

Description of day_____

_____

First Sample at _____

Second Sample at_____

Third Sample at _____

Fourth Sample at _____

Fifth Sample at_____

Reaction started_____

Reaction closed_____

WIND VELOCITIES

Experimenter's Report U.S.W.B. Report

Angle of Wind with Building_____

Time	Outside D.B.	Outside W.B.	Inside D.B.	Inside W.B.
(1)				
(2)				
(3)				
(4)				
(5)				

CO2 ANALYSES

Bottle No.	First Sample F. R.	First Sample Check	Second Sample F.R.	Second Sample Check	Third Sample F.R.	Third Sample Check	Average	Corrected Average
1								
2								
3								
4								
5								
Outside								

Q_1 =

Q_2 =

Q_3 =

Q_4 =

Average infiltration per hour =

Average infiltration per ft. window crack =

Q-1

T H E S I S

Infiltration of Air in Buildings .

Submitted for degree in Electrical Engineering

BY

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--- INFILTRATION OF AIR IN BUILDINGS ---

It is the object of this investigation to determine the quantity of air that is infiltrated through the various exterior walls and around windows for different types of window and wall construction, under various conditions. A complete study must of necessity be extended to include a large number of existing buildings, so that the coefficient finally derived will apply to those types of construction commonly found in practice. Natural interchange of air through the interstices in the walls and around windows is due largely to the pressure of the wind on the outside surface. This interchange would naturally be a maximum when the wind velocity is maximum and perpendicular to the surface of the wall, and it is a minimum when the wind velocity is minimum and parallel to the surface. The leakage of air through the walls and window cracks will therefore vary between these two extremes according to the value of these factors.

In determining the infiltration factors for various constructions, the total quantity of air is considered to be composed of two components, first, the quantity of air leakage per square foot of exposed wall surface, and secondly, the quantity of air leakage per linear foot of window crack. Both of these quantities will be determined for various comstructions and wind velocities in the tests to follow. It is quite likely that the quantity of air passing directly through the wall is extremely small, and

if this is found to be so, the first component will be neglected.

To make the tests, carbon dioxide gas is generated in the room to be tested until there will be about 20 parts of CO_2 per 10,000 parts of air. The Carbon dioxide is generated by the chemical action of hydrochloric acid upon sodium bicarbonate. Samples of the air in the room are then taken, five being taken at one hour intervals. These samples are analyzed for their CO_2 content by means of the Peterson-Palmquist machine. A diagram and description of this machine will be given later. As the air in the room containing a high CO_2 content becomes diluted by outdoor air of law CO_2 content, the average CO_2 content in the room will decrease from hour to hour. The rate of decrease of the CO_2 in the room is directly dependent upon the leakage of air into the room through the walls and window cracks. The air infiltration is then calculated by means of a formula which is given later. At the same time the wind velocities are determined by taking five hourly readings of the anemometer, which is placed opposite the room at a sufficient distance to avoid any counter air currents caused by the wind striking the wall of the building.

The method of taking these samples, as proposed by the American Society of Heating & Ventilating Engineers, is that the experimenter remain in room during the period of the test. He takes the samples in liter bottles completely filled, including all rubber connections, with a saturated solution of salt water. The bottle is placed on a ringstand with its discharge connection emptying into a reservior below. A rubber tube with a nozzle at the end, sufficiently long

to reach to all parts of the room, is connected to the bottle. When the experimenter is ready to take a sample he opens the clamp cocks on the intake and discharge connections. As the water slowly runs out of the discharge connection the experimenter walks around the room with the nozzle, allowing the air of the room to displace the water in the bottle. In this way an average sample of the air in the room is obtained.

In this method of taking samples there is a possible source of error. This is in the CO_2 exhaled by the experimenter. This is taken care of in the formula proposed by the American Society of Mechanical and Ventilating Engineers in the form of a constant. It can be readily seen, however, that the quantity of CO_2 exhaled by a person depends upon his physical build and manner of breathing, therefore there is a possibility of the constant not fitting the existing conditions. This constant given by the A.S.H.& V.E. formulae is .6 cu. ft. of CO_2 per hour for each occupant in the room. Burton-Opitz in their physiology, give, as the average figures for a man at rest, the amount breathed in and out in ordinary quiet breathing as about 500 C.c. and 15 breaths per minute making 7.5 litres per minute and 450 litres per hour. This expired air has 4.06 volumn percent of CO_2 , or .62 cu. ft. per hour. Richards & Woods book on "Water & Food" give a much higher figure, estimated by Pettenkofer for the amount of CO_2 given off. This value they give varies from .76 cu. ft. to 1.52 cu. ft. CO_2 per hour, according to the degree of exertion. It can be seen from this that an element of error is possible. Again there is danger

of the experimenter contaminating the sample he is taking. Another form of inconvenience in this method is that the experimenter must be confined in the room during the entire period of the test.

Another method of taking samples was proposed by Prof. C.A. Perkins of the University of Tennessee. In this method the samples were taken out-side the room, thus eliminating the possible source of error caused by the CO_2 exhaled by the experimenter and the inconvenience of his confinement. This method is illustrated by a diagram which appears later. The sample was taken in a bottle as before. This bottle was placed on a ringstand outside the door of the room to be tested and a small flexible rubber tube is connected to the bottle and laid under the door into the room. A funnel is placed in the end of the tube and this is hung on a ringstand near an electric fan, which is placed on the floor of the room. In the preceeding method an average sample of the air in the room was obtained by the experimenter who walked around the room with the nozzle into which the air is drawn. In Dr. Perkin's method it was proposed to mix the air in the room by an electric fan, which constantly stirred it during the entire period of the test. It was thought that in this manner a sample taken in any part of the room should prove to be an average of the whole, providing that there were no dead corners in the room. Experiments, which will be described later, were donducted to see if all parts of the room were reached by the fan, and they proved to be satisfactory. Experiments were also conducted to see if a sample taken in any part of the room should prove to be an average of the whole, and these

also

also proved to be satisfactory.

The bottle and tube leading into the room were completely filled with a saturated solution of salt water. The tube was adjustible to different bottles and a predetermined quantity of water was required to fill it. When the experimenter is ready to take a sample the clamp-cocks on the intake and discharge connections are opened and the air in the room is sucked through the tube into the bottle displacing the water.

This method of taking samples was followed in the following tests:

Preliminary Tests

Before adopting the above described method, several obstacles had to be overcome. (1) To keep a record of the humidity inside the room to be tested. (2) To take a sample from the room which will represent the CO_2 content in the entire room.

The first may be taken care of by using a recording hair hygrometer, which will be described later.

To determine if sampling could be done from the outside of the room it was necessary to make several experiments. The air in the room and the CO_2 must be thoroughly mixed. Experiments were conducted using a fan to stir the air in several rooms. The rooms tested were the Electricians room, which contains a large amount of fixtures and furniture; Prof. Hamilton's old office, which was empty; Dr. Perkins office which contained two tables; a desk and some book cases. The fan was tried in different parts of the room and in different positions, lying on its back and sitting on the floor. It was found best to have the fan

lying on its back and near the center of the room, being careful that in any case it will not point toward the windows. In every case with the fan in this position, it found by using an anemometer and candle flame that the air was being stirred in every part of the room.

Tests were made in three rooms by liberating CO_2 to find if the CO_2 was thoroughly mixed.

Test I - Prof. Hamilton's Office

Size - Small room approximately 12' x 12' x 15'.

Results.

Where sample was taken	CO_2 (parts per 10000)	Check
off table in center of room	15.30	15.4
	15.20	15.4
On floor near fan	13.0	13.2
	12.4	12.6
Off window casing	14.0	14.2
	13.3	13.4

Test 2 - Dr. Perkin's Office

Size - Approximately 12' x 12' x 20'.

Contents: Desk, two tables, book cases, chairs.
Fan placed in center of room on its back.
Samples taken three minutes after generation of CO_2 ceased.

Results.

Where sample was taken:	CO_2 (parts per 10000)	Check
in front of fan-	31.6	31.8
	31.3	31.4
	31.6	31.6
Under table	31.0	31.2
	30.0	30.6
	30.5	30.7
Near door in hall	32.5	32.3
	32.4	32.2

Test 3 - Dr. Perkins Lecture Room

This room contained several chairs and a table. It was thought best to use two fans in this room as it is considerably larger than the other rooms tested. It is rectangular in shape. The fans were placed a few feet from the corners on a diagonal of the room. Samples were taken five minutes after ganeration of CO_2 was complete.

Results.

Where sample was taken:	CO_2 (Parts per 10000)	Check
North wall between windows	22.2	22.3
	26.7	26.5
	24.0	24.2
Southeast corner	26.0	26.5
	25.4	25.8
	26.0	26.2
West Wall	31.6	31.7
	31.8	31.8

To take a sample from the room under the door, the apparatus shown in the illustration is used. The air is collected over a solution of Na Cl. This is to prevent absorption of CO_2 by the water. By knowing the amount of Na Cl solution it takes to fill the sample bottle, tube and funnel, the exact amount of solution may be forced over into the funnel without overflowing into the room. To take the sample, suction must be applied to the receiving bottle for the Na Cl solution until the tube and funnel have been emptied, then the solution will syphon out without more suction.

By experiment it was found best to use a small tube (1/8" Dia) for this, as the column of water would not ~~buck~~ as readily as with a larger tube. Experiments were made with a

quarter inch tube and it would not work satisfactorily. It was difficult to get the solution over into the funnel, and in bringing it back all the solution could not be drawn out. The small tube draws the air in almost as fast as the large tube after the water has been removed.

To calculate the amount of Hcl necessary to generate the CO_2:

$NaHCO_3 + HCl = CO_2 + H_2O + Na\ Cl$
Wt. CO_2 per cu. ft. = 51.0 grams
Molecular weight of $NaHCO_3$ = 84
$\frac{51 \times 84}{44}$ = 97.4 grams $NaHCO_3$ per cu. ft. CO_2
Molecular weight Hcl = 36.5
$\frac{51 \times 36.5}{44}$ = 42.4 grams of 100% Hcl per cu. ft. CO_2

The amount of acid required will depent upon the strength of the solution.

Assume volume of room tested to be 4000 cu. ft. To generate 20 parts CO_2 per 10000 parts of air.

$\frac{4000 \times 20}{10000}$ = 8 cu. ft. CO_2 required

8 x 97.4 = 780 grams $NaHCO_3$ required. (For a solution 100% Hcl)
8 x 42.4 = 340 grams Hcl

$CO_2 = \frac{C \times R}{10000}$

Where C = content room Cu. ft.
R = parts CO_2 10000 of air
CO_2 = parts of gas that must be added to bring the room to the required content.

The determination of the CO_2 content in the samples were made with the Peterson-Palmquist CO_2 machine. It might be well to describe here the operation of the machine. An illustration is given showing the different parts of the machine.

To make a test of a sample.

The rubber tube from the air sample bottle (H) is connected to the bottle as shown.(This tube should have a pinch cock on it) The burette is filled with mercury by raising the level bulb (D) the air being forced out then the stopcock (P). When the mercury is brought up to the mark the stopcock (P) is closed also stopcock(Q). The stopcock (O) is opened and the mercury lowered, filling the burette with the sample. The mercury is brought a little below zero and the stopcock (O) closed. The burette is opened to the atmosphere for an instant to allow the excessive pressure to come down to atmospheric. Then the stopcocks are closed and it is opened to the monometer, which contains a drop of petrolium. The mercury is brought to zero, and the reading on the monometer taken as the zero or starting point. Fine adjustment of the mercury level is obtained by the screw (F). The stopcock (Q) to the monometer is then closed, and the stopcock (R) to the KOH pipette is opened, and the air forced over, and held there for about two minutes. The sample is then brought back, the K OH solution being brought back up to the mark at which it stood at the beginning. The stopcock (R) is closed, and the manometer is opened to the sample. The drop of liquid is brought to the zero or starting point by adjusting the mercury level. Then a reading is taken on the capillary tube which gives the CO_2 content direct in percent. This operation is repeated again as a check on the first, and should read the same, if not it is repeated again.

The following example shows that the error due to humidity is so small that it may be neglected.

The volume of water taken up by 1 cu. ft. of air when saturated at 82° F = 0.038.

Assume a case where the air is so dry that the humidity is 40%. Then the water vapour will be .40 x .038 = .0152 cu. ft.

The air sample is always saturated when in the burette of the CO_2 machine, a drop of water being kept over the mercury for that purpose.

If the air is taken in at .40% humidity then in 1 cu. ft. of air there will be .0152 cu. ft. water vapour when taken in and .038 when saturated in the burette. The change in volumn is .038 - .0152 = .0228 cu. ft. The percent increase in volume = $\frac{.0228}{1}$ = 2.28%. Increase due to water vapour, 97.72% air as taken in.

Assume CO_2 absorption shows 1.80%. Then to find the correct per cent of CO

Let X = corrected %

$$\frac{X}{100} = \frac{1.80}{97.72} \qquad X = 1.83\ \%.$$

Then the error is 0.03%.

An accurate check on sample will vary as much as .05%. Therefore this error may be neglected.

To calculate the quantity of air infiltrated.

S = Total cu.ft. CO_2 generated in room from any source.
$(CO_2)_1$ = CO_2 in outside air in parts per 10000.
$(CO_2)_4$ = CO_2 in room at beginning of hour parts per 10000.
$(CO_2)_5$ = CO_2 in room at end of hour in pts. 10000.
Q_1 = Cu. ft. air entering per hour.
Q_2 = cu. ft. air leaving room per hour.
C Cu. ft. of room capacity.
In calculating the room capacity the valumn of furniture, etc. should be estimated and subtracted.

$\frac{(CO_2)_1 Q_1}{10000}$ = Cu. ft. CO_2 entering per hour.

$\frac{(CO_2)_4 C}{10000}$ = Cu. ft. of CO_2 in room at start of hour

$\frac{(CO_2)_5 C}{10000}$ = Cu. ft. in room at end of hour

$\left(\frac{(CO_2)_4 + (CO_2)_5}{2}\right) \frac{Q_2}{10000}$ = Cu. ft. CO_2 leaving room per hour.

$Q_1 = Q_2$

Therefore $\frac{C(CO_2)_4}{10000} + \frac{Q_1(CO_2)_1}{10000} + S = \frac{C(CO_2)_5}{10000} + \frac{Q_1}{10000} \left[\frac{(CO_2)_5 + (CO_2)_4}{2}\right]$

$C(CO_2)_4 + Q_1(CO_2)_1 + 10000 \times S = C(CO_2)_5 + Q_1 \left[\frac{(CO_2)_5 + (CO_2)_4}{2}\right]$

$C\left[(CO_2)_4 - (CO_2)_5\right] + 10000 \times S = Q_1 \left[\frac{(CO_2)_5 + (CO_2)_4 - 2(CO_2)_1}{2}\right]$

Therefore $Q_1 = \frac{2C\left[(CO_2)_4 - (CO_2)_5\right] + 20000 \times S}{(CO_2)_5 + (CO_2)_4 - 2(CO_2)_1}$

Example to show the error which may occur due to different estimates for (S) the amount of CO_2 in cu.ft. given off by the occupants in the room.

Value for S as proposed by R. S. H. & V. E. Journal is .6 X N (N number of occupants) cu. ft.

Different authorities differ as to the amount of CO_2 exhaled by a human.

Take an example using

$S = .6 \times N$. $N = 2$ Then $S = 1.2$.

$C = 4000$
$(CO_2)_4 = 20$
$(CO_2)_1 = 4$
$(CO_2)_5 = 15$

$$Q_1 = \frac{2 \times 4000 [20 - 15] + 20000 \times 1.2}{15 + 20 - 2 \times 4}$$

$$Q_1 = \frac{64000}{27} = 2370.3 \text{ Cu. ft. per hr.}$$

Richards and Woodman's book on "Air, Water & Food" gives a higher value (Use .76 x N for S . S =1.52)

$$Q_1' = \frac{40000 + 30400}{27}$$

$Q_1' = 2607.7$

This shows a difference of 237.7 cu. ft. which would be a change of 10.02% from the first determination in infiltration per hour.

In case there are no occupants in the room S may be omited. In this case the formulae will be as follows:

$$Q_1 = \frac{2 C [(CO_2)_4 - (CO_2)_5]}{(CO_2)_5 + (CO_2)_4 - 2(CO_2)_1}$$

Construction of Hygrometer

It has been found by experiment that the human hair elongates and contracts in direct proportion to the moisture in the air. The hair hygrometer consists essentially of a human hair fixed at one end, and the other fastened to a pointer to which a pen is attached. A spring is also fastened to the pointer to balance the tension of the hair. To make the hygrometer recording a dial or disc moved by clockwork is constructed so that it moves under the pen, a figure illustration is given of this. On the dial is placed a sheet of recording paper and by this a record may be kept of the humidity in the room to be tested.

Calibration of the Hygrometer

A record was kept by the instrument over a period of several hours. The humidity was taken at intervals of time throughout the test by using the wet and dry bulb thermometer method. The dial on the clock had a sheet of circular lined paper on which the record was kept. Measurements were made on this in inches corresponding to the change noted by the sling psycrometer. From this we were able to calilrate the scale for the hygrometer.

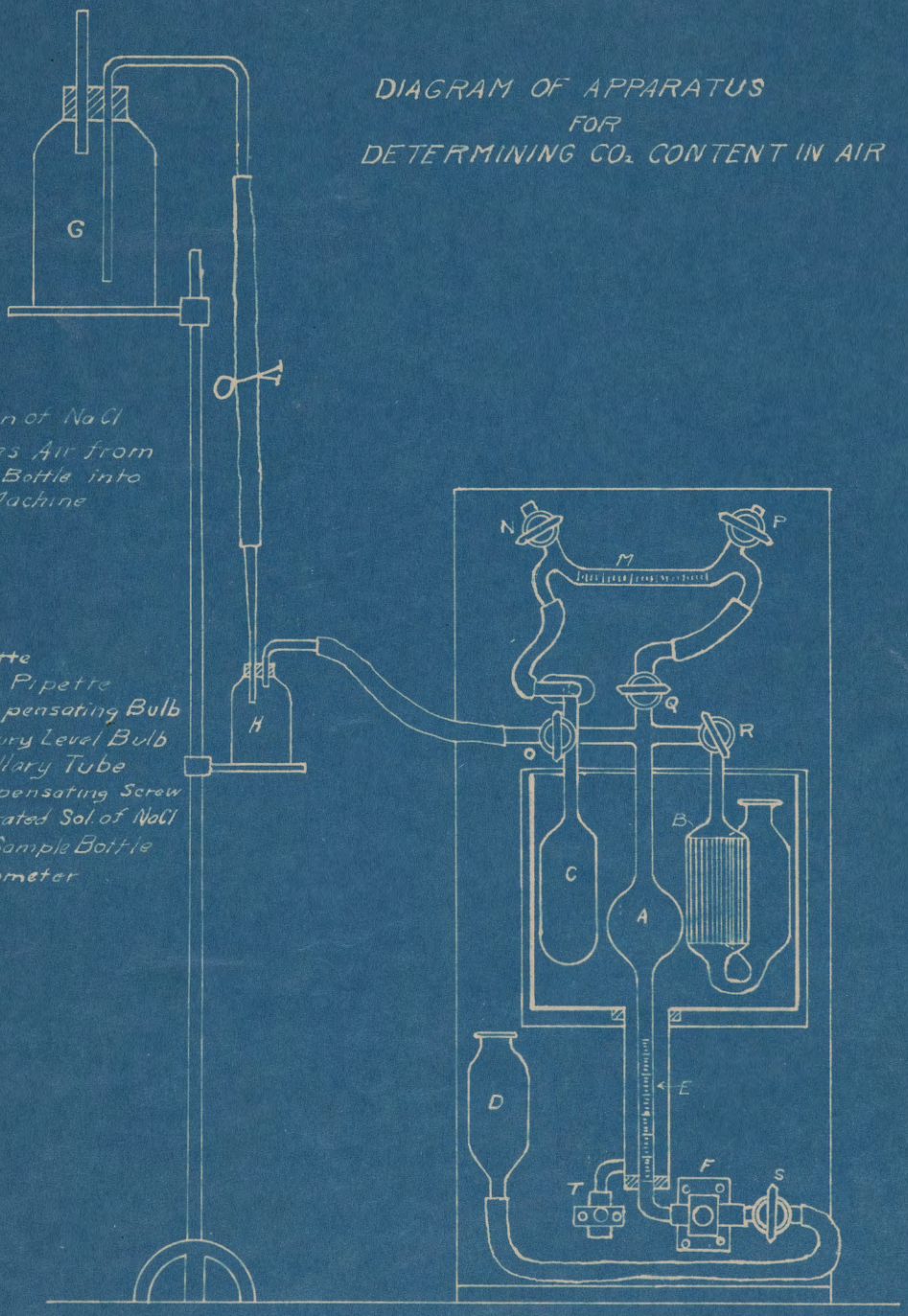
Time	°C Wet Bulb	Dry Bulb °C	°F	Humidity	Diffrn. Humidity from Maximum	Movement of Pointer from Maximum inches	0.1" = % Hum.
11:15	22.1	29.1	84.3	.55	.20	0.65	.155
11:30	21.2	28.0	82.4	.55	.10	0.65	.155
11:45	21.6	28.7	83.6	.546	.04	0.63	.168
1:30	22.6	29.7	85.6	.57	.08	0.48	.16
2:00	22.6	29.7	85.6	.57	.08	0.48	.16
2:30	22.6	29.5	85.1	.57	.08	0.48	.16
3:30	22.7	27.5	81.4	.65	.00	0.00	
4:00	22.7	27.4	81.3	.645	.005	0.00	
8:30	24.0	27.8	82.0	.838	.338	.25	15.5
						Av.	15.8

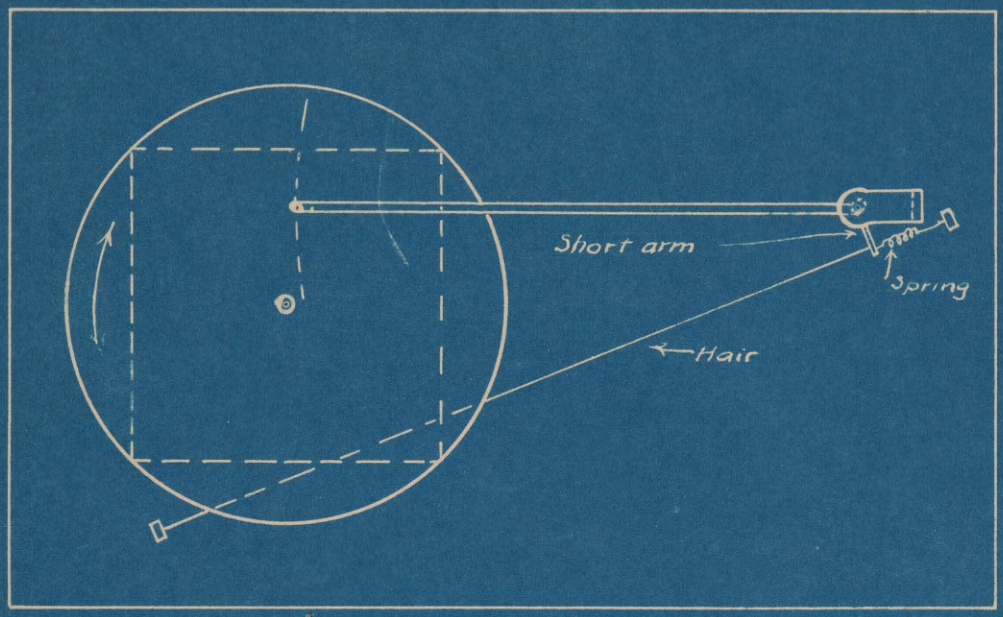
0.1" 15.8% Humidity change.

Anemometer

The Anemometer used in this investigation is shown in a following diagram. It consists essentially of an anemometer wheel, recording dial and vane. It was mounted on a pivoted center shaft on ball bearings as shown in diagram, so as to freely adjust itself to the direction of the wind. Wind readings from this instrument are taken hourly and also ~~for~~ the total for the period of the test. The average velocity of the wind in miles per hour is then calculated.

DIAGRAM OF APPARATUS FOR DETERMINING CO_2 CONTENT IN AIR





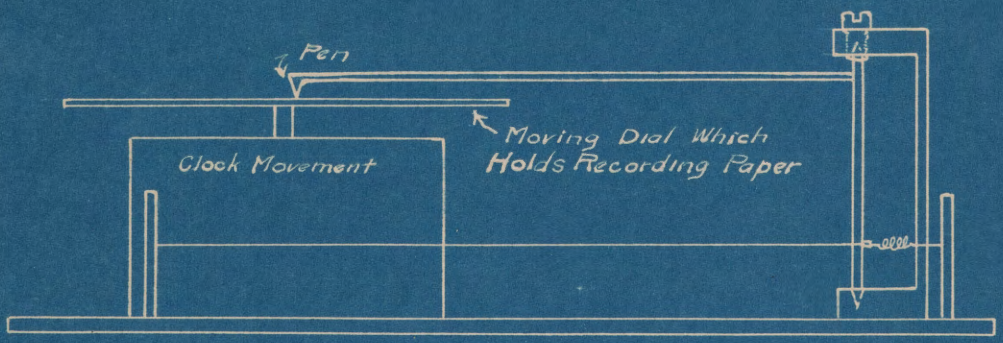


DIAGRAM OF RECORDING HAIR HYGROMETER

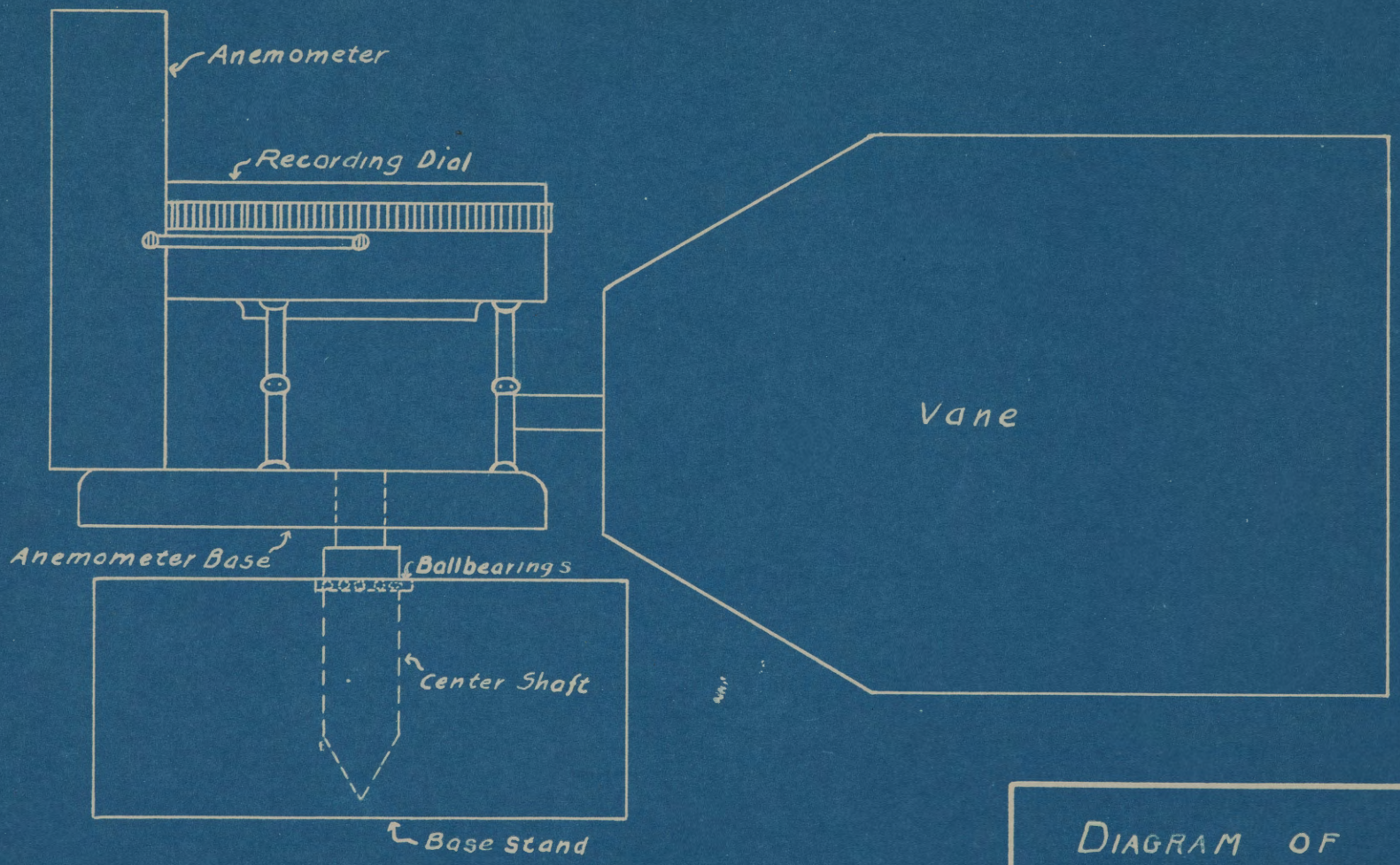
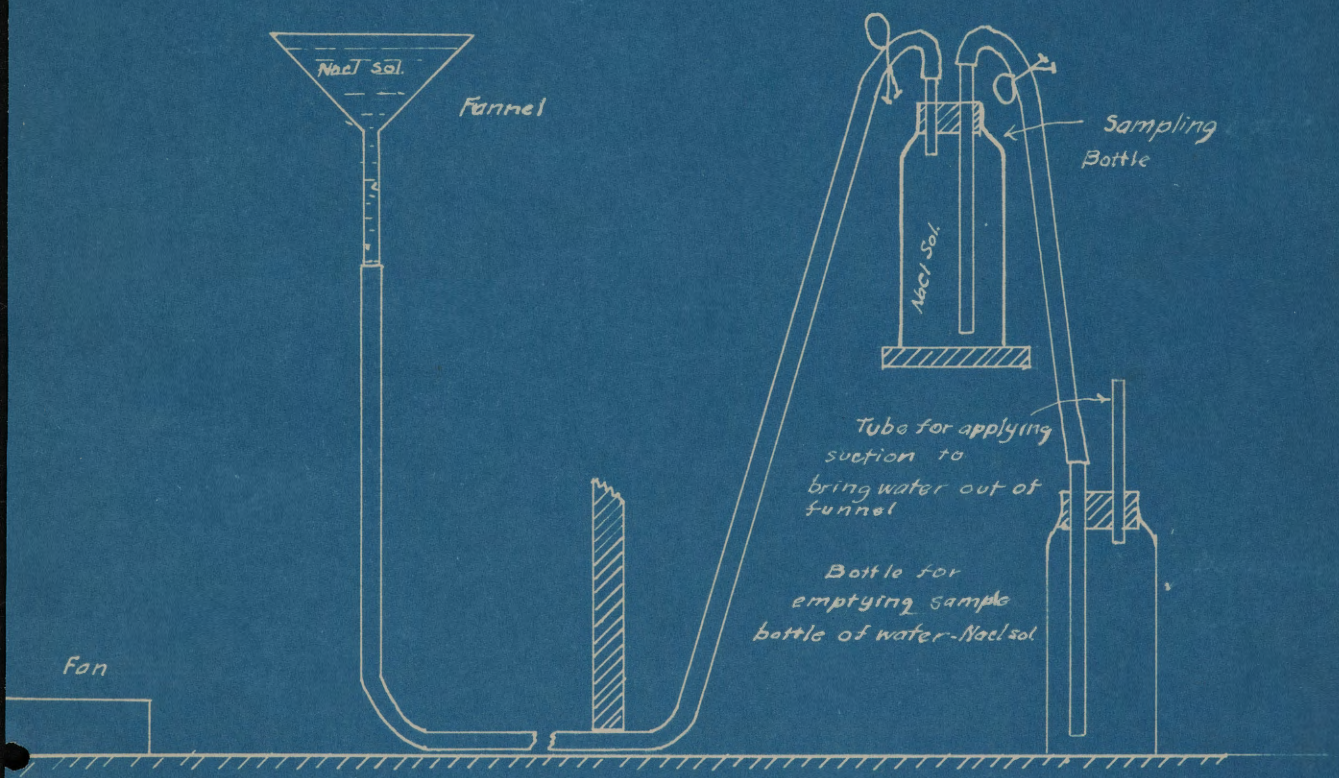


DIAGRAM OF
ANEMOMETER & VANE



Method of taking air sample from room under door