

## THE VENTILATION OF HOUSES AFTER FUMIGATION WITH HYDROGEN CYANIDE

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(With 5 Figures in the Text)

IN June 1935, certain problems arose concerning the fumigation of houses with hydrogen cyanide for the destruction of bedbugs. Workmen reconditioning houses in Rochester, which had been given the customary 24 hr. aeration after fumigation with hydrogen cyanide "disks", had complained of sickness during their work. The walls, cavities and floor spaces of some of these houses had been tested by Mr Topping, the Chief Sanitary Inspector of Rochester, who, using benzidine acetate-copper acetate paper, had obtained a strong positive reaction indicative of the presence of hydrogen cyanide after 24 hr. aeration.

Further investigations by Dr J. O. Murray, the Medical Officer of Health of Rochester, and Dr Stock and Dr Monier-Williams of the Ministry of Health, indicated the necessity for carefully controlled sampling, and the matter was accordingly referred to the Bug Infestation Committee of the Medical Research Council, who authorized the investigation which is described in this report. The first part of the inquiry was carried out at Rochester and the second part at Isleworth.

It was decided that systematic tests should be made, during both the fumigation and ventilation, to study the change of concentration of fumigant in the air with time in various positions in houses. It was also decided to determine the proportion of hydrogen cyanide recoverable from plaster removed from partitions after 24 hr. airing. This information might be expected to indicate (*a*) the efficiency of hydrogen cyanide fumigation, as commonly carried out, for the destruction of bedbugs, and (*b*) the amount of ventilation necessary before reoccupation of the premises can be permitted.

One of the methods now used for applying hydrogen cyanide for house fumigation may conveniently be termed the "disk" method. Disks of papier maché, or wood-pulp, are saturated with a known weight of liquid hydrogen cyanide, usually 1 oz. per disk, and then sealed up in tins, in batches of about forty. The tin is opened by a quick-acting cutter, and the disks are distributed around the premises by workers wearing gas masks. The hydrogen cyanide quickly evaporates from the disks, most of it being in the gaseous state 15 min. after opening the tin. The disks can be collected after the fumigation, when they are almost harmless. Further information about the behaviour and properties of disks is given by Page & Gloyns (1936, p. 213*t*).

Immediately the hydrogen cyanide gas is released in the free space of the house, two processes, both diminishing the concentration, come into play: (a) Gas diffuses out of the house through cracks and pores and is lost in the open air outside. It also enters hidden spaces, such as the interior of floors, the interior of walls, etc. The hydrogen cyanide, reaching these hidden spaces, enters mainly through cracks, only a small proportion diffusing right through the woodwork or plaster. (b) Gas is absorbed on to the surface of building materials and furniture. This gas is fixed on the surface and is not available for the destruction of bugs. As the fumigation proceeds, the gas slowly penetrates into the interior of the absorbent materials and so this process of absorption continues as long as the gas is in the house. The amount of gas removed from the air, by this process, is far greater than is generally realized, and, in a reasonably airtight house, it accounts for far more loss of gas than does leakage and penetration into hidden spaces.

When all the doors and windows of the house are opened for airing, after the fumigation, most of the gas in the free space is quickly dispersed. All materials, which have absorbed hydrogen cyanide, gradually give it off again when the concentration of fumigant in the space surrounding them is greatly reduced, i.e. when airing commences. Most of the gas which has diffused into hidden spaces through cracks, etc., must also diffuse out again through these cracks. The rate of removal of gas from fumigated materials depends largely on the ease with which the gas being given off is removed by airing. This effect is well seen in a space surrounded by very absorbent material placed in a position in which there is no ready access to the open air; thus, the airing of a space in the middle of a pile of clothes in a small cupboard is very slow indeed.

On reoccupation of a house after airing, if doors and windows are left open, there is very little danger of accumulation of gas. If, however, the rooms are closed up before all absorbed gas is removed by airing, there is a possibility that enough hydrogen cyanide will be desorbed from the floor, walls, furniture, etc., to build up a dangerous concentration. It is desirable, as will be explained later, that the concentration in all hidden spaces should be below the amount which can be tolerated by man for many hours, before reoccupation is permitted.

A survey of the literature, dealing with the concentration of hydrogen cyanide endurable by man over long periods, was made, and it was found that this value had never been accurately determined. A comparison of all the available data led us to decide that a concentration of 0.03 oz./1000 cu. ft., 0.0026 % by vol., of hydrogen cyanide was endurable by man for many hours. Accordingly, this figure has been accepted as a safe minimum in this work. Experiments are now in progress to test it.

METHODS USED FOR DETERMINING THE CONCENTRATION  
OF HYDROGEN CYANIDE

As will be described later, the benzidine acetate-copper acetate paper method was found unsuitable for the accurate determination of concentration of gas, which was the object of these experiments, and the apparatus described below was used.

A flask *A*, Fig. 1 *a*, is fitted with a two-hole rubber bung *B*. This carries a constricted glass tube *C*, shown sealed off in the figure, and a capillary tube *D*. A piece of quill tubing *D'* is fused to *D* and is closed at the top by a thin end *E*.

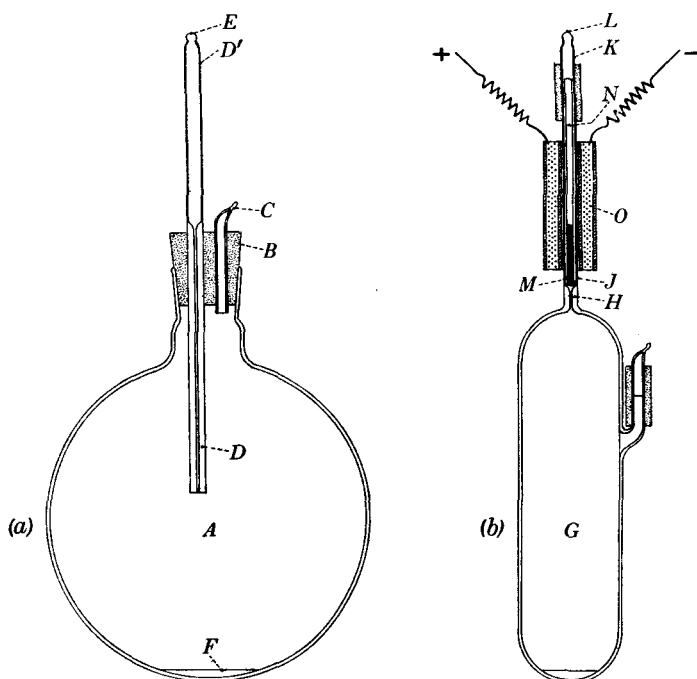


Fig. 1.

The flask contains a measured volume of a standard solution of sodium hydroxide, shown at *F*. The side tube, *C*, is connected to a vacuum pump. The pressure in the flask is reduced to 20 mm. of mercury and then the tube *C* is sealed off at the constriction, as shown. The flask is placed in the space in which is it desired to measure the concentration of hydrogen cyanide, and the thin end, *E*, is broken. Air passes into the flask until the pressure becomes atmospheric, when the capillary tube *D* prevents any more gas entering by diffusion. The cyanide is determined iodometrically. A blank experiment is made with the absorbent from a flask which has been opened in an atmosphere known to be free of hydrogen cyanide. To withdraw a sample from a hidden

space, such as that under a floor, the tube *D* is connected by rubber tubing with another capillary tube leading into the hidden space.

This method of withdrawing samples is suitable for use only during the period of airing, since men cannot enter the house during fumigation without disturbing the concentration of hydrogen cyanide. Therefore, the apparatus used during fumigation is a modification in which the thin end, *E*, is broken electrically by operation from outside the house.

The evacuated flask *G*, Fig. 1 *b*, is of 150 c.c. capacity. It carries a capillary tube *H* fused to a piece of quill tubing *J*. This is connected to the short tube *K*, which is closed at the top by a thin end *L*, and this in turn, is connected to a stainless steel capillary tube inserted in the space to be sampled. *M* is a piece of stainless steel rod and *N* a piece of tinned brass rod. *O* is a solenoid, the terminals of which are connected to a battery outside the house. On passing a current through the solenoid, the steel rod, *M*, is drawn up into it and pushes the rod, *N*, sharply against the thin glass end, thus breaking it and admitting the gas. These flasks are mounted in groups of three in metal boxes, and the leads are brought out through a standard four-core cable. All the sampling flasks are placed in position before the start of the fumigation and, when required, a sample may be taken by making the appropriate connexions to the battery. Generally, two boxes are used for each space, thus securing six samples during the fumigation period. For sampling from the free space a vessel of 15 c.c. capacity is employed.

Each of the graphs, referred to later in this paper, is the result of ten or more samples. A fuller description of the apparatus is given by Page (1935). The methods of analysis used are dealt with by Lubatti (1935). Sampling from small spaces is discussed by Page and Lubatti (1937).

#### DESCRIPTION OF THE EXPERIMENTS AT ROCHESTER

Four experiments were made:

- (1) Fumigation of an unfurnished house in summer.
- (2) Fumigation of a furnished house in summer.
- (3) Fumigation of an unfurnished house in winter.
- (4) Fumigation of a furnished house in winter.

Furnished houses, having in them a quantity of absorbent material, such as wooden furniture, bedding and upholstery, are more likely to retain dangerous quantities of hydrogen cyanide than are unfurnished houses. Further, absorption should be more rapid and desorption slower in winter than in summer. Since this must be tested experimentally, the winter experiments should duplicate, as closely as possible, those carried out in summer.

Dr Murray, the Medical Officer of Health of Rochester, kindly arranged for houses to be placed at our disposal for the experiments. They were typical examples of houses on new housing estates. The furnished house was a small terrace house and the unfurnished one was semi-detached and rather larger.

*Summer experiments*

*Unfurnished house, J.* This was a semi-detached house (see plan, Fig. 2), with 11 in. cavity external walls of sand-faced brick, considerably weathered and porous. The upper part was rough-cast. The party wall between the houses was 9 in. brickwork. The main internal walls were  $4\frac{1}{2}$  in. brickwork and the other internal walls 3 in. brickwork. The mortar appeared to be rather poor lime mortar with a struck joint, or, if pointed, then in poor condition. Internally the walls seemed to be coated with plaster finished with "Sirapite". The floor to the scullery, coal and food store is of concrete, floated off with sand and cement. The remaining floors are of 1 in. tongued and grooved boards nailed to joists. There is a layer of concrete over the site. The floors at the ground-level were well ventilated, but the upper floors and the cavity in the external walls were not ventilated. The stairs were finished with a lath and plaster soffit, where exposed. In the hall, the space under the four bottom stairs was boarded in, leaving a dead space. The ceilings were of lath and plaster. On the landing there were two cupboards with hollow walls of lath and plaster on studding. The roof was of tiles hung on battens.

The ground floor of the house, which had a capacity of 3670 cu. ft., received a dose of 40 oz. of hydrogen cyanide, corresponding to a nominal concentration of 11 oz./1000 cu. ft. (about 0.95 % by vol.); the first floor had a capacity of 3460 cu. ft., and received a dose of 80 oz. of hydrogen cyanide, giving a nominal concentration of 23 oz./1000 cu. ft. (about 2 % by vol.).

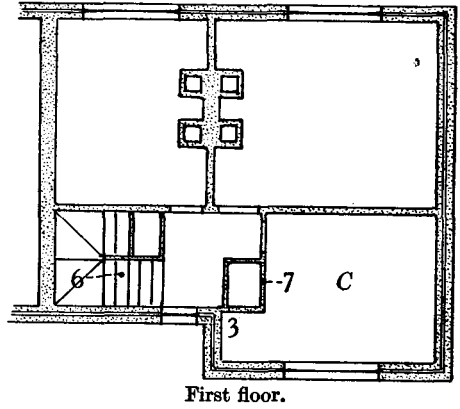
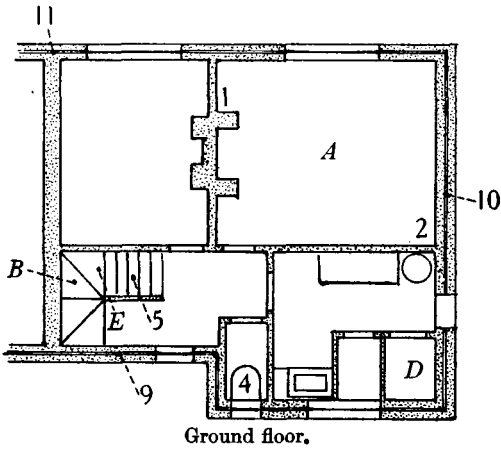
*Furnished house, K.* This was a middle house in a block of six (see plan, Fig. 2). The construction was similar to that of the unfurnished house, except in the following particulars. The external walls were of "Stock" bricks in good condition. Ventilation of the boarded floors at ground-level was provided, from back to front, through pipes laid through the cement scullery floor. The space under the four bottom stairs was bricked up, forming a dead space at the end of the coal store, which communicates with the scullery. In the living room there was a wooden cupboard between the chimney breast and the external wall. In bedroom 1 there was a cupboard of lath and plaster over the entrance hall. Each story of this house had a capacity of 2700 cu. ft., the lower story receiving a dose of 40 oz. of hydrogen cyanide, giving a nominal concentration of 15 oz./1000 cu. ft. (about 1.3 % by vol.) and the upper story receiving a dose of 80 oz. of hydrogen cyanide, giving a nominal concentration of 30 oz./1000 cu. ft. (about 2.6 % by vol.).

The temperature throughout these experiments was 65–70° F. during the day time—an ordinary summer temperature.

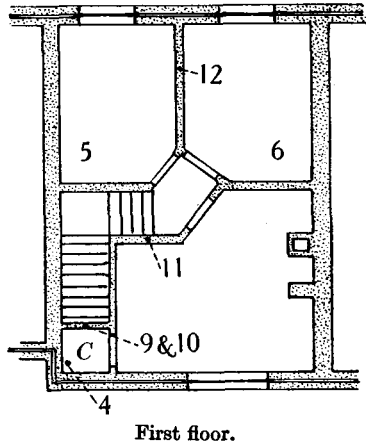
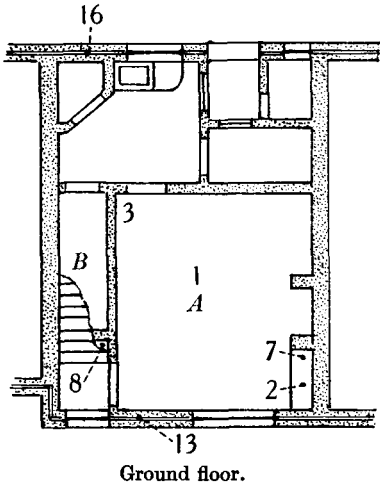
*Winter experiments*

Two houses were again kindly made available for us at Rochester, Kent. The furnished house was the identical house, K, which was used in the summer experiments. The results from this house obtained in the winter are strictly

House J.



House K.



House L.

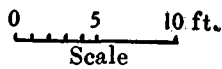
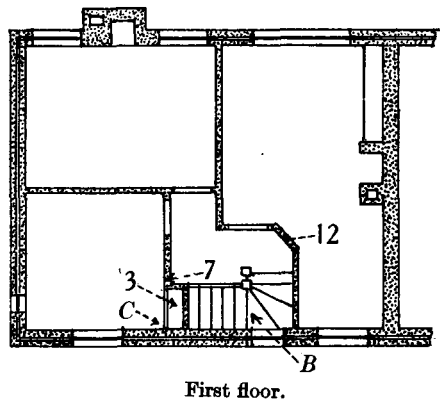
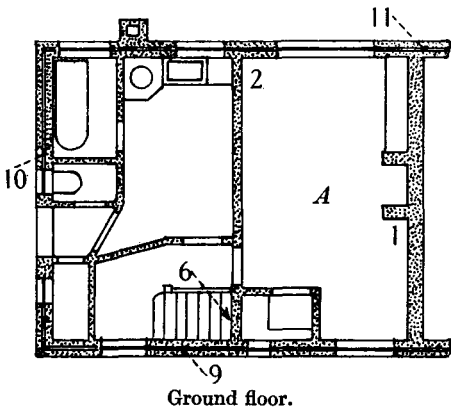


Fig. 2.

comparable with those obtained in the summer. The unfurnished house, L (see plan, Fig. 2), was of a similar type to that fumigated in the summer but was not exactly the same. The doses, nominal concentrations, and times of exposure were the same as in the summer experiments.

The temperature throughout was fairly low, keeping within the range 35–40° F.

#### DESCRIPTION OF THE EXPERIMENTS AT ISLEWORTH

These experiments were performed to determine whether, under summer or winter conditions, the effect of heating, to assist desorption, was important in tending to build up the concentration after airing.

After 24 hr. airing, windows and doors were closed and fires lit, and the changes of concentration determined.

Four experiments were made:

- (1) Fumigation of a furnished house in summer.
- (2) Fumigation of a furnished house in summer, fires being lit after airing.
- (3) Fumigation of a furnished house in winter.
- (4) Fumigation of a furnished house in winter, fires being lit after airing.

Dr Nash, the Medical Officer of Health of Heston and Isleworth, and Mr Fletcher, the Estate Manager, kindly arranged for houses to be placed at our disposal. These also were typical of houses on new housing estates. Each was an end house of a block of four.

#### *Summer experiments*

*Houses M and N.* The unwarmed house, M (see plan, Fig. 3), was the right-hand end house of the block; the warmed house, N, was the left-hand end house and was, therefore, the mirror image of it. The external walls were 9 in. brickwork, "Stocks". The party walls between the houses were 9 in. brickwork, "Flettons". The internal walls on the ground floor were of 4½ in. brickwork, "Flettons", and on the first floor were of 3 in. breeze blocks. All walls were finished internally with "Sirapite". The floors in the living rooms were of boards laid in pitch on concrete; in the kitchens, sculleries, etc., they were of concrete faced with sand and cement; and on the first floor were of tongued and grooved boards nailed to joists. The skirtings were of portland cement and sand; the picture rails consisted of iron rods built into the walls. There was a lath and plaster soffit under the stairs, and the ceilings also were of lath and plaster. The roof covering was of tiles hung on battens.

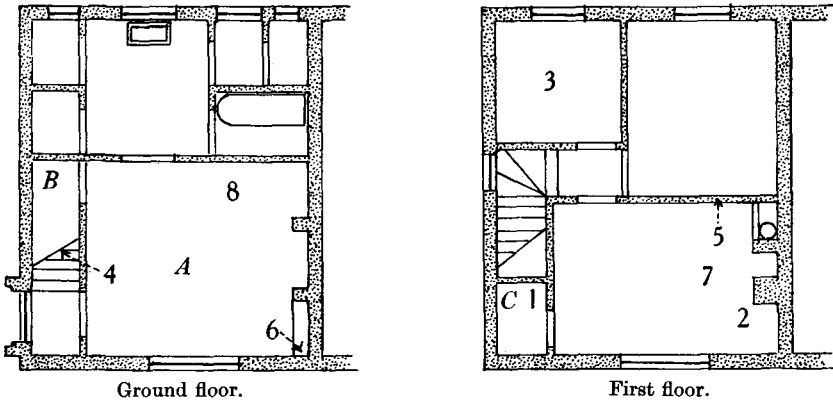
The living room of each of the houses M and N was warmed by a cooking range which also heated a saddle boiler connected with a hot-water storage cylinder in bedroom 1. This bedroom was also heated by an open fire. The only source of heat available for the other bedrooms was an oil stove.

The capacity of each of the stories of the houses M and N (see plan) was 3170 cu. ft. The lower story of each house received a dose of 40 oz. of hydrogen cyanide, giving a nominal concentration of 12.5 oz./1000 cu. ft. about (1.08 %

by vol.) and the upper story a dose of 80 oz. of hydrogen cyanide, giving a nominal concentration of 25 oz./1000 cu. ft., about 2.15 % by vol.

The outside temperature varied between 62.5 and 76.5° F. in the day time, falling as low as 56° F. at night. The rise of temperature produced by lighting fires amounted to 5.5° F. in the living room and 7° F. in the bedroom. These

House M and N.



House O and P.

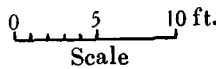
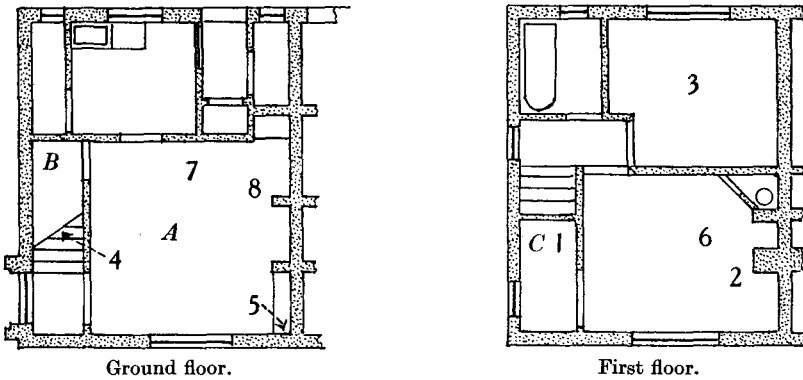


Fig. 3.

changes occurred in about 2-3 hr. Subsequent fluctuations of temperature were unimportant since they had no effect on the gas concentrations.

*Winter experiments*

*Houses O and P.* The unwarmed house, O (see plan, Fig. 3), was the left-hand end house of a block of four houses, the warmed house, P, was the right-hand end house and was, therefore, the mirror image of O. The construction and general design was similar to, but not identical with, the houses M and N



used in the summer experiments. There were two bedrooms and a bathroom on the first floor, instead of three bedrooms on the first floor and a bathroom on the ground floor. The living room was warmed by an open fire which also heated a saddle boiler connected with a hot-water storage cylinder in the living room. Each bedroom was heated by a gas fire.

The capacity of the upper story of each of the houses O and P (see plan) was 2500 cu. ft. It received a dose of 64 oz. of hydrogen cyanide, giving a nominal concentration of 25.6 oz./1000 cu. ft. (about 2.21 % by vol.). The capacity of the lower story was 2300 cu. ft. It received a dose of 32 oz. of hydrogen cyanide, giving a nominal concentration of 13.9 oz./1000 cu. ft. (about 1.2 % by vol.).

The outside temperature varied only between 41 and 43° F. The rise of temperature produced by lighting fires was greater than in the summer experiments, being 13° F. in the living room and 11° F. in the bedroom after 2½ hr. heating.

## RESULTS

The results of measurements of gas concentrations are summarized in Tables I-IV. A useful method of comparison for the period of fumigation, is to construct curves of the change of concentration with time. These will be found to approximate to one of four types which appear in Fig. 4. The ordinates represent the concentration of hydrogen cyanide in oz./1000 cu. ft. and the abscissae the time in hours from the start of the fumigation. A dotted ordinate is erected to indicate the end of fumigation.

In the tables, the type of curve for each space is shown, together with the value of the maximum concentration attained and the time at which it occurs, the concentration at the end of the fumigation, and the period of airing required for the concentration to fall to 0.03 oz./1000 cu. ft. (0.0026 % by vol.). This information gives a fairly adequate idea of the concentration during fumigation and airing.

### *Behaviour during fumigation*

*Free spaces to which the hydrogen cyanide is applied directly.* These are the rooms, stairway and passages. Generally, the maximum concentration is about 10-14 oz./1000 cu. ft. (about 0.9-1.2 % by vol.), whilst the concentration at the end of the fumigation has been found to be between 1 and 8 oz./1000 cu. ft., 0.09 and 0.7 % by vol. Typical curves are those shown in Fig. 4, type I.

*Smaller free spaces, to which no hydrogen cyanide is applied directly.* Fig. 4, type II, shows the variation of concentration in smaller free spaces, such as cupboards, etc., to which the hydrogen cyanide is conveyed by diffusion and convection from the main free spaces. The curve is similar to that obtained for the main free spaces, except that the maximum concentration attained is lower and occurs later.

*Dead spaces in lath and plaster partitions.* A curve of type III is frequently obtained by sampling from the space in the middle of lath and plaster par-

titions. This space is usually well protected from draughts, and therefore from sudden changes of concentration. When the skirting and floorboards fit badly the curve may approximate to type II.

*In piles of absorbent material.* A heap of clothes in a cupboard forms such a pile. A curve of type IV is nearly always obtained, the concentration rising slowly to a maximum at the end of the fumigation and decreasing very slowly and regularly throughout airing.

*In mattresses and upholstery.* The structure of the material greatly influences penetration. The actual value of the concentration, as well as the type of curve obtained, varies from one point to another in proximity to it. Generally, the material has a fairly open structure, the penetration is great and the type of curve approximates to that obtained in a free space, viz. type I.

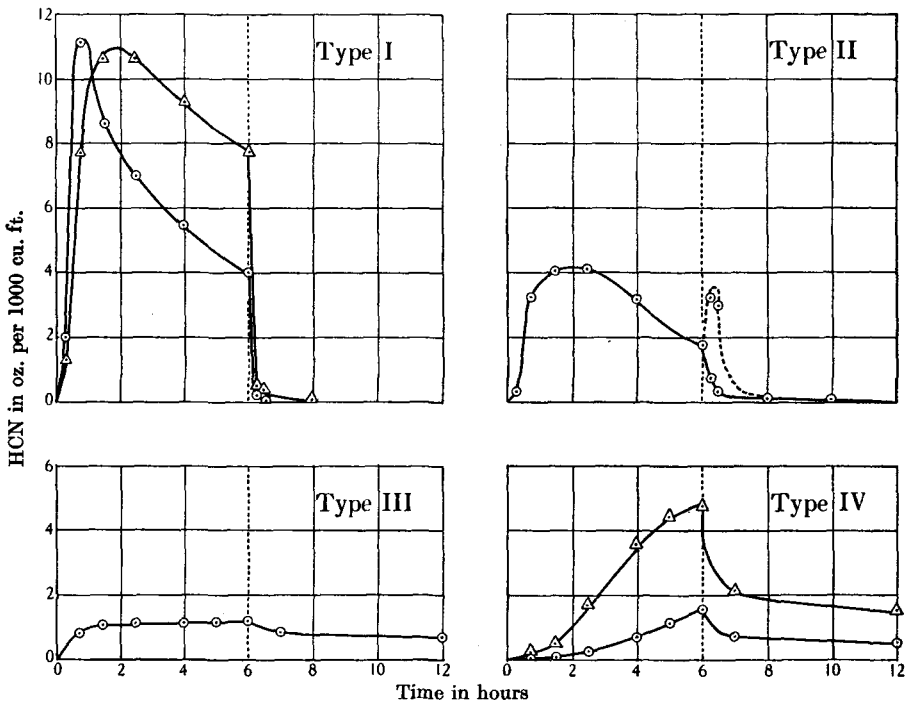


Fig. 4.

*Dead spaces under floors, etc.* (1) Unventilated floor spaces occur between the ceiling of the lower story and the floorboards of the upper story. The form of the time-concentration curve depends chiefly on the closeness of the flooring. If the joints of the floorboards are tight the maximum is very low and is considerably delayed, the curve approximating to type II or type IV. If the joints are very open, the maximum is much greater and occurs earlier, the curve approximating to that for the free space in the upper story, type I,

with which space it is, more or less, in communication. The rate of airing depends chiefly on the size of the cracks between the boards. The time taken to reduce the concentration to a safe value may be as long as 40 hr.

(2) Ventilated floor spaces are usually found under the floors of the lower story. The results obtained vary considerably. In some spaces the concentration varies irregularly, whilst in others it is found to follow one of the types of curve already described. Frequently the shape of the curve seems to be determined by small air currents moving at the time of sampling. In general, the gas concentration is small, seldom exceeding 0.5 oz./1000 cu. ft. (about 0.04 % by vol.). The time required for airing seldom exceeds 14 hr.

In both kinds of dead space under floors, a rise of concentration often occurs immediately after opening up. The maximum is usually reached in  $\frac{1}{2}$  hr.; the value of the total rise is about  $\frac{1}{2}$ –1 oz./1000 cu. ft. (about 0.04–0.09 % by vol.). Presumably this is due to draughts of air containing relatively high concentrations of gas derived from the free spaces. This rise of concentration is indicated by a broken line in the curve type II.

*Outer cavity walls.* Samples were drawn from outer cavity walls, but it was found that only a small quantity of gas penetrated these spaces, and the curves obtained varied considerably. Airing was very rapid.

In Tables I and II, F indicates the furnished house and U indicates the unfurnished house. In Tables III and IV, W indicates the warmed houses in which the windows were closed and fires lit after 24 hr. airing, whilst C indicates the cold houses in which the windows were closed after 24 hr. airing but the fires were not lit.

The results of determining the proportion of hydrogen cyanide recoverable from samples of plaster removed from plaster partitions in the four experiments at Rochester, after 24 hr. airing, showed that no detectable amounts of fumigant were retained by the plaster for this period.

#### GENERAL CONSIDERATIONS

##### *Period of airing*

(a) *Free spaces.* Perfectly open spaces, such as the middle of the living room, air rapidly, the time for the concentration to fall to 0.03 oz./1000 cu. ft., 0.0026 % by vol., varied in these experiments between  $\frac{1}{4}$  and 2 hr. Other free spaces, such as cupboards without windows which communicate with a room by only one doorway, often air much more slowly. The longest period required in the experiments at Rochester for such a space was 4 hr., and at Isleworth, under similar conditions, 13 hr. In the duplicate experiment at Isleworth the time required was only 1 hr. These figures refer to experiments in which all ventilators, windows and doors are left open for the first 2 hr. and all hopper windows and ventilators kept open throughout the period of airing. Closing of the hopper windows downstairs after 2 hr. ventilation may lead to abnormally slow airing, periods of 31 and 16 hr. being required respectively in the cup-

Table I. *Summer experiments at Rochester*

State of house	Position at which concentrations were measured	No.	Maximum concentration attained in		Time to reach maximum in hr.	Concentration at end of fumigation in		Period of airing to reduce concentration to 0.03 oz./1000 cu. ft. in hr.	Type of curve	Remarks
			Oz./1000 cu. ft.	% by vol.		Oz./1000 cu. ft.	% by vol.			
U	Living room—middle—free space	JA	9.0	0.78	1	0.7	0.06	1	I	
U	Stairway—halfway up—free space	JB	4.6	0.40	1	1.0	0.086	1	I	
U	Bedroom 3—middle—free space	JC	10.0	0.86	1	2.6	0.23	1	I	
F	Living room—middle—free space	KA	7.0	0.80	1	2.0	0.17	1	I	
F	Bedroom 1—in cupboard—free space	KC	14.0	1.21	1	4.0	0.35	3½	I	
F	Coal store—under stairs—free space	KB	4.0	0.35	1½	2.0	0.17	4	II	
U	Between stairs and lath and plaster soffit	J6	2.0	0.17	1	1.5	0.13	14	II	
U	Bedroom 3—in lath and plaster partition	J7	1.0	0.086	1	0.9	0.08	38	III	
F	Bedroom 1—plaster partition in cupboard, near floor	K9	0.7	0.06	5½	0.7	0.06	3½	IV	
F	Bedroom 1—plaster partition in cupboard, near ceiling	K10	0.1	0.009	6	0.1	0.009	3½	III	
F	Bedroom 1—plaster partition—by landing	K11	1.2	0.10	6	1.2	0.10	50	IV	
F	Bedroom 3—plaster partition—by bedroom 2	K12	0.6	0.05	3	0.6	0.05	50	III	
F	Living room—cupboard—in pile of clothes	K7	0.85	0.076	6	0.85	0.076	38	IV	Curve continues to rise on opening up from 0.85 to 1.1 oz./1000 cu. ft.
U	Bedroom 3—floor—corner near cupboard	J3	8.5	0.76	1	1.0	0.09	14	I	Wide cracks between floorboards
U	Bedroom 1—floor—in cupboard	K4	3.7	0.32	3½	3.0	0.26	37	II	
F	Bedroom 2—floor	K5	—	—	—	0.5	0.04	13	—	Only airing studied. Curve rises from 0.5 to 0.7 oz./1000 cu. ft. on opening up
F	Bedroom 3—floor	K6	—	—	—	0.1	0.09	37	—	Only airing studied. Curve rises from 0.1 to 1.6 oz./1000 cu. ft. on opening up
U	Living room—floor—corner by fire	J1	0.6	0.05	1	0.03	0.026	1	I	Low concentrations. Curve rises from 0.03 to 0.37 oz./1000 cu. ft. or opening up
U	Living room—floor—corner by copper	J2	0.2	0.017	6	0.2	0.017	1	IV	Concentration still 0.03 oz./1000 cu. ft. after 20 hr. of airing
F	Living room—floor—in middle	K1	0.2	0.017	6	0.2	0.017	14	—	Irregular curve
F	Living room—floor—in cupboard	K2	0.12	0.010	6	0.12	0.010	14	IV	Curve rises on opening up from 0.12 to 0.21 oz./1000 cu. ft.
F	Living room—floor—near scullery	K3	0.9	0.08	6	0.9	0.08	14	IV	
U	Under stairs—dead space—boarded in	J5	0.7	0.06	6	0.7	0.06	4	IV	
U	Under stairs—dead space—bricked up	K8	0.6	0.05	4	0.6	0.026	14	II	
F	In water closet—in pan—sealed over	J4	3.0	0.26	2	1.6	0.14	1	II	
U	External wall—in cavity—front	J9	0.02	0.0017	6	0.02	0.0017	4	—	
U	External wall—in cavity—side	J10	0.06	0.005	5	0.05	0.0043	1	—	
U	External wall—in cavity—back	J11	0.01	0.0009	5	0.01	0.0009	0	—	
F	External wall—in cavity—front	K13	0.07	0.006	3	0.02	0.0017	0	—	
F	External wall—in cavity—back	K15	0.05	0.0043	2	0.02	0.0017	0	—	

Concentrations low and irregular

Table II. *Winter experiments at Rochester*

State of house	Position at which concentrations were measured	No.	Maximum concentration attained in		Time to reach maximum	Concentration at end of fumigation in		Period of airing to reduce concentration to 0.03 oz./1000 cu. ft. in hr.	Type of curve	Remarks
			Oz./1000 cu. ft.	% by vol.		min. in hr.	Oz./1000 cu. ft.			
U	Living room—middle—free space	L A	9.5	0.82	1	2.5	0.22	1 1/2	I	
U	Bedroom 3—cupboard corner—free space	L C	10.0	0.86	1	3.0	0.26	1 1/2	I	
F	Living room—middle—free space	K A	7.5	0.65	1	2.0	0.17	1 1/2	I	
F	Bedroom 1—in cupboard—free space	K C	14.0	1.21	2	4.0	0.35	1 1/2	I	
F	Coal store—under stairs—free space	K B	1.3	0.11	2	0.5	0.043	2	II	
U	Between stairs and lath and plaster soffit	L 6	3.7	0.32	2	3.0	0.26	30	II	
U	Bedroom 3—in lath and plaster partition	L 7	2.2	0.19	2	0.9	0.08	32	II	
U	Bedroom 2—plaster partition by stairs	L 12	1.1	0.085	1	0.9	0.08	72	II	
F	Bedroom 1—plaster partition in cupboard near floor	K 9	0.26	0.022	1	0.26	0.022	30	III	
F	Bedroom 1—plaster partition in cupboard near ceiling	K 10	1.1	0.095	6	1.1	0.065	68	IV	
F	Bedroom 3—plaster partition by bedroom 2	K 12	2.4	0.21	4	2.0	0.172	62	II	
F	Living room—cupboard—in pile of clothes	K 7	1.7	0.15	6	1.7	0.15	80	IV	
U	Bedroom 3—floor—in cupboard	L 3	7.0	0.6	1 1/2	1.2	0.10	10	I	Floorboards leaky
F	Bedroom 1—floor—in cupboard	K 4	4.0	0.35	5 1/2	3.8	0.33	32	II	
F	Bedroom 2—floor	K 5	—	—	—	2.5	0.22	40	—	Only airing studied
F	Bedroom 3—floor	K 6	—	—	—	2.5	0.22	24	—	Only airing studied
F	Bedroom 1—plaster partition by landing	K 11	1.3	0.11	6	1.3	0.11	0.1 oz./1000 cu. ft. after 64 hr.	IV	
U	Living room—floor—corner by fire	L 1	1.1	0.085	2 1/2	0.3	0.026	8	II	Floorboards leaky. Slight rise on opening up
U	Living room—floor—corner by copper	L 2	0.9	0.08	2 1/2	0.35	0.030	10	II	
F	Living room—floor—in cupboard	K 2	0.3	0.026	1 1/2	0.03	0.003	4	I	Rises on opening up before falling again
F	Living room—floor—near scullery	K 3	0.03	0.003	1	0.02	0.002	0.06 oz./1000 cu. ft. after 6 hr.	III	Rises on opening up
F	Under stairs—dead space—bricked up	K 8	0.10	0.0086	6	0.10	0.0086	2	IV	
U	External wall—in cavity—front	L 9	0.25	0.02	1	0.06	0.005	20	II	Low concentrations
U	External wall—in cavity—side	L 10	0.55	0.047	6	0.50	0.043	7	IV	Low concentrations
U	External wall—in cavity—back	L 11	0.08	0.007	1	0.02	0.002	0	III	Low concentrations
F	External wall—in cavity—front	K 13	—	—	—	—	—	—	—	
F	External wall—in cavity—back	K 15	—	—	—	—	—	—	—	

Concentration did not rise above 0.03 oz./1000 cu. ft., 0.003 % by vol.

Table III. *Summer experiments at Isleworth*

Treatment of house	Position at which concentrations were measured	No.	Maximum concentration attained in		Time to reach maximum in hr.	Concentration at end of fumigation in		Period of airing to reduce concentration to 0.03 oz./1000 cu. ft. in hr.	Type of curve	Remarks
			Oz./1000 cu. ft.	% by vol.		Oz./1000 cu. ft.	% by vol.			
C	Living room—middle—free space	MA	15.0	1.29	1	0.8	0.07	1 1/2	I	See note at end of table
W	Living room—middle—free space	NA	15.0	1.29	1	0.6	0.05	1	I	
C	Bedroom 1—in cupboard—free space	MC	13.5	1.16	1	0.8	0.07	31	I	Curve rises from 0.01 to 0.05 oz./1000 cu. ft. on lightning fires
W	Bedroom 1—in cupboard—free space	NC	13.5	1.16	1	0.5	0.04	1	I	
C	Living room—in cupboard—free space	MB	14.5	1.25	1	0.8	0.07	16	I	
W	Living room—in cupboard—free space	NB	14.5	1.25	1	0.5	0.04	1	I	
C	Between stairs and lath and plaster soffit	M4	0.04	0.003	2 1/2	0.02	0.002	6	III	Concentration rises during first 3 hr. of airing
W	Between stairs and lath and plaster soffit	N4	0.09	0.008	1	0.03	0.003	22	II	Concentration rises to 0.06 oz./1000 cu. ft. after 3 hr. of airing
C	Bedroom 1—in breeze partition	M5	0	0	—	0	0	7	—	
W	Bedroom 1—in breeze partition	N5	0.04	0.003	2	0	0	0	II	Concentration continues to rise for 1 hr. after opening up, reaching 0.5 oz./1000 cu. ft.
C	Living room—cupboard—in pile of clothes	M6	0.20	0.017	6	0.20	0.017	34	IV	
W	Living room—cupboard—in pile of clothes	N6	0.44	0.038	4	0.35	0.030	11	II	
C	Living room—in upholstery of sofa	M8	3.6	0.31	6	3.6	0.31	42	IV	
W	Living room—in upholstery of sofa	N8	4.5	0.39	1	0.8	0.069	18	I	
C	Bedroom 1—in mattress	M7	6.0	0.52	1	1.4	0.12	30	I	
W	Bedroom 1—in mattress	N7	3.6	0.31	1 1/2	0.9	0.078	31	I	
C	Bedroom 1—in floor in cupboard	M1	1.5	0.13	1 1/2	0.82	0.071	29	II	
W	Bedroom 1—in floor in cupboard	N1	0.06	0.005	3	0.05	0.004	29	III	Only airing studied
C	Bedroom 1—in floor near fireplace	M2	—	—	—	0.39	0.033	14	—	Only airing studied
W	Bedroom 1—in floor near fireplace	N2	—	—	—	0.02	0.0017	5	—	Only airing studied
C	Bedroom 3—in floor	M3	—	—	—	0.40	0.034	23	—	
W	Bedroom 3—in floor	N3	—	—	—	0.16	0.014	31	—	

Note. The concentration in the free space during airing fluctuates somewhat, owing to all windows, except small hopper windows on first floor, being kept closed during the night.

Table IV. Winter experiments at Isleworth

Treatment of house	Position at which concentrations were measured	No.	Maximum concentration attained in		Time to reach maximum in hr.	Concentration at end of fumigation in		Period of airing to reduce concentration to 0.03 oz./1000 cu. ft. in hr.	Type of curve	Remarks
			Oz./1000 cu. ft.	% by vol.		Oz./1000 cu. ft.	% by vol.			
C	Living room—middle—free space	OA	12.6	1.09	1	5.7	0.49	1	I	Curve rises to 0.068 oz./1000 cu. ft. during airing on closing big windows after 2 hr. airing. Curve rises again from 0.005 to 0.018 oz./1000 cu. ft. on lighting fires
W	Living room—middle—free space	PA	12.1	1.04	1½	7.6	0.66	2	I	
C	Bedroom 1—in cupboard—free space	OC	12.5	1.08	1	6.0	0.52	1	I	
W	Bedroom 1—in cupboard—free space	PC	13.5	1.16	1½	8.0	0.69	14	I	
C	Living room—in cupboard—free space	OB	11.4	0.98	1	5.4	0.47	8	I	Low concentrations Curve rises from 0.20 to 0.26 oz./1000 cu. ft. on lighting fires
W	Living room—in cupboard—free space	PB	11.0	0.95	2	7.7	0.66	14	I	
C	Between stairs and lath and plaster soffit	OA	0.48	0.04	6	0.48	0.04	65	IV	
W	Between stairs and lath and plaster soffit	P4	0.06	0.005	2½	0.03	0.003	0	II	
C	Living room—cupboard—in pile of clothes	O5	1.55	0.13	6	1.55	0.13	130	IV	
W	Living room—cupboard—in pile of clothes	P5	4.70	0.41	6	4.70	0.41	80	IV	Curve rises slightly on lighting fires to 0.035 oz./1000 cu. ft. for ¼ hr.
C	Living room—in upholstery of sofa	O7	8.2	0.71	3	5.7	0.49	23	I	
W	Living room—in upholstery of sofa	P7	8.0	0.69	6	8.0	0.69	41	IV	
W	Living room—in upholstery of armchair	P8	9.5	0.82	2½	6.8	0.59	16	I	
C	Bedroom 1—in mattress	O6	0.5	0.04	6	0.5	0.04	60	III	Curve rises from 0.12 to 0.17 oz./1000 cu. ft. on lighting fires
W	Bedroom 1—in mattress	P6	7.6	0.66	4	6.5	0.56	60	II	
C	Bedroom 1—in floor in cupboard	O1	0.11	0.01	1½	0.7	0.06	80	I	Curve rises slightly on opening up on opening up to 0.28 oz./1000 cu. ft. in 1 hr. Curve rises slightly on opening up Only airing studied
W	Bedroom 1—in floor in cupboard	P1	0.025	0.002	3½	0.02	0.002	4	III	
W	Bedroom 1—in floor near fireplace	O2	—	—	—	0.028	0.0024	21	—	
W	Bedroom 1—in floor near fireplace	P2	—	—	—	0.092	0.0079	1½	—	Only airing studied Only airing studied Only airing studied
C	Bedroom 2—in floor	O3	—	—	—	0.46	0.04	60	—	
W	Bedroom 2—in floor	P3	—	—	—	0.02	0.002	0	—	

boards in the bedroom and living room of house M at Isleworth (see Table III). On the other hand, the initial airing may be so rapid that closing the windows after 2 hr. does not cause the concentration to rise above 0.03 oz./1000 cu. ft., 0.0026 % by vol. (cf. house N at Isleworth, Table III). It is clear that considerable differences will be found from time to time in the rate of airing in these cupboards or in similar spaces.

(b) *Ventilated dead spaces.* In the experiments these spaces were represented by the floor spaces of the lower story of houses J, K and L. The concentrations were generally low and irregular, depending on the wind, cracks between boards, etc. The maximum time observed for airing, to the threshold concentration, was 14 hr.

(c) *Enclosed dead spaces.* Airing of unventilated floor spaces and cavities in lath and plaster partitions is, in general, much slower than that of free spaces, and is slower in winter than in summer. In some of the spaces the concentration never rises above 0.03 oz./1000 cu. ft., 0.0026 % by vol. The slowest airing observed was that of a plaster partition, K11, in the winter experiments at Rochester (see Table II), in which the concentration was still 0.1 oz./1000 cu. ft., 0.086 % by vol., after 64 hr. airing. The average time required to reduce the concentration to the threshold value both in floor spaces and in plaster partitions is 24 hr., except in the winter experiments at Rochester when the time taken, for the partitions, was 50 hr. The volume of these spaces is of course extremely small. The maximum concentration in these enclosed dead spaces occurred in house K in the winter experiments at Rochester, point K11 Table II, and amounted to 0.33 oz./1000 cu. ft., 0.029 % by vol., after 24 hr. airing. The total volume of the dead spaces was about 430 cu. ft. If all the hydrogen cyanide in these spaces had suddenly been released into the free space in the upper story, the maximum concentration which could have been attained was of the order of 0.04 oz./1000 cu. ft., 0.0035 % by vol.

It seems safe therefore to conclude that, under the conditions of these experiments, there was no risk of ill-effects arising from residual hydrogen cyanide in the air after 2 hr. airing with all doors and windows open, and a further 22 hr. with all the hopper windows and ventilators open. This applies to both summer and winter experiments.

*The effect of lighting fires and the effect of wind.* The effect of lighting fires in a closed furnished house after 24 hr. airing was very slight. It was most noticeable in the bedroom, and resulted in the concentration in the free space building up slightly above the threshold value for a short period in one house, N, at Isleworth (sampling point NC, Table III).

The mode of heating is of some importance. The greater the draught produced, the less noticeable is the temporary rise of concentration which is liable to be brought about by the rise of temperature. An open coal-fire, living room, house P, probably produces the strongest draught, followed by a gas-fire, bedrooms, house P, followed by a hot-water tank or heater, bedroom, house N.



The open fire in the bedroom of house N was very small and inefficient. The effect of lighting fires is only slightly more pronounced in winter than in summer.

The speed and direction of the wind varied from one experiment to another, but, within the limits obtaining in these experiments, appeared not to have any great effect on the rate of airing of enclosed dead spaces. This is to be expected, since a very slow movement of air will suffice to ventilate the exposed surfaces of floors, partitions, etc., in which case the rate of airing is governed by the rate of penetration through the bounding material and the rate of desorption from it.

(d) *Clothes, mattresses and upholstery.* One of the most interesting and important results of these experiments was the persistence of dangerous concentrations of hydrogen cyanide in piles of clothing, in upholstery and in mattresses. In the piles of clothing the minimum period of airing varied between 11 and 130 hr., in the upholstery between 16 and 42 hr., and in the mattresses between 30 and 60 hr. From these experiments it appears that a longer period of airing is usually required in winter than in summer.

Mattresses, and to a lesser extent upholstery, are liable to be warmed by the human body and may then liberate fresh quantities of hydrogen cyanide even after these prolonged periods of airing. For this to be dangerous a sleeper would probably have to turn with his face towards the mattress. The kind of increase of concentration that may be expected is shown in Table IV, nos. P 8 and P 6. It is very undesirable that bedding and clothing should be fumigated in houses. It should be treated in some other manner, e.g. by fumigation in a chamber which may be heated during airing so as to assist desorption. Great care should be taken not to leave piles of cushions undisturbed during airing, and upholstered furniture generally should be placed in the best positions for airing.

(e) *Airing of adjoining houses.* Tests in the bedrooms of the house adjoining the unfurnished house during the winter fumigation at Rochester revealed the presence of quite considerable amounts of hydrogen cyanide in the free space. Samples withdrawn from under the floorboards, near the party wall separating the two houses, contained large amounts of hydrogen cyanide, as much as 1.04 oz./1000 cu. ft., about 0.09% by vol., being recorded. All the upstairs windows were opened and a few of the floorboards taken up and it was found that the concentration was quickly reduced everywhere to a safe value. Leakage from one house to another was due to holes in the brickwork in the party walls. These occurred chiefly around the points at which wooden joists entered the wall, and frequently holes one or two inches wide were found. Weak places in walls also result from failure to make good after removal of scaffolding. In the summer experiment at Isleworth, a similar leakage of gas took place, a concentration of 1.1 oz./1000 cu. ft., 0.095% by vol., being attained in the floor space of a bedroom in the neighbouring house. The joists in these houses run parallel to the party walls and there were no cracks between floorboards. These conditions confined the leakage, substantially, to the space

between the party wall and the joist nearest to it. Penetration through the party wall can also be effected through rough brickwork, filling in holes used to support scaffolding.

It is desirable that blocks of houses rather than single terrace, or semi-detached, houses should be fumigated, for the following reasons: (a) safety, (b) avoidance of leakage of hydrogen cyanide, (c) efficacy. It should, however, be noted that very simple precautions, such as the lifting of a few floorboards, will generally ensure adequate escape of gas from adjoining properties. If it is very difficult to raise the floorboards as, for example, if they are tongued and grooved, adequate ventilation may be provided, in some cases, by easing the skirting boards. It is only in very exceptional circumstances, and only then if the test with benzidine acetate paper shows the presence of hydrogen cyanide, that the adjoining house will not be fit for reoccupation within a few hours of the end of the fumigation, provided that the bedding and clothing is removed from the adjoining rooms before the fumigation.

It should be pointed out that no reliance can be placed on windows being kept open on reoccupation. During the winter experiment at Rochester, owing to the leakage of gas from the house being fumigated to that next door, the windows of the bedroom into which the gas was leaking were opened and the door was locked. In spite of being warned, the tenants, on their return, closed the windows of the room which they were occupying and, as soon as they were allowed to enter, closed the windows of the bedroom.

(f) *Airing of plaster.* It has already been stated that plaster does not normally retain appreciable quantities of hydrogen cyanide after 24 hr. airing. Presumably the surface of every particle to which the gas can penetrate is covered, not with a layer of lime, but with a layer of chalk formed previously from the carbon dioxide of the air. This carbon dioxide would not be displaced by hydrogen cyanide. Evidently the physical absorption also is not very pronounced after 24 hr. airing. Since no hydrogen cyanide is recoverable from the plaster, it seems very unlikely that men should become ill when washing down plastered walls. A maximum value for the concentration of hydrogen cyanide in the dead space of a lath and plaster partition, after 24 hr. airing, is about 0.3 oz./1000 cu. ft., 0.026 % by vol. Assuming that only two quarts of water are used to wash a wall of 82 sq. ft. and that the whole of the hydrogen cyanide from the dead space dissolves in the water, then the concentration of hydrogen cyanide in equilibrium with this solution is only 0.02 oz./1000 cu. ft., 0.0017 % by vol. It is inconceivable that this concentration, which is itself below the threshold value, could be built up in a room, even in close proximity to the wetted wall.

It may be pointed out that the majority of people can detect a slightly objectionable odour, reminiscent of hydrogen cyanide, a day or two after the concentration in a room has fallen below a measurable value. The psychological effect of this may account for certain cases of illness, which are attributed to the direct action of residual hydrogen cyanide.

*Efficacy of the fumigations*

These experiments confirm, in general, the efficacy of hydrogen cyanide as a fumigant against bedbugs. The concentration of hydrogen cyanide which is lethal to bugs exposed for 6 hr. at 15–20° C. is not accurately known but it seems, from work carried out at the Imperial College of Science and Technology by Dr Bovington, that a concentration of about 1 oz./1000 c.c. or 0.086% by vol., is required. Table V is a list of the spaces, the maximum concentration in which was below this figure.

Table V

Type of space	No.	Table
Enclosed floor spaces:		
Bedroom 1, in cupboard	N1	III
Bedroom 1, in cupboard	O1	IV
Bedroom 1, in cupboard	P1	IV
Dead space under stairs:		
Between stairs and plaster soffit	M4	III
Between stairs and plaster soffit	N4	III
Between stairs and plaster soffit	O4	IV
Between stairs and plaster soffit	P4	IV
Dead space, bricked up	K8	II
Plaster partitions:		
Bedroom 1, in cupboard, near floor	K9	I
Bedroom 1, in cupboard, near ceiling	K10	I
Bedroom 3, by bedroom 2	K12	I
Clothes and bedding:		
In pile of clothes in living room	K7	I
In pile of clothes in living room	M6	III
In pile of clothes in living room	N6	III
In mattress in bedroom 1	O6	IV
All ventilated floor spaces	—	I & II
All cavity walls	—	I & II

Some of these spaces, such as cavities in external walls, are unlikely to be infested, whilst in some others, such as the pile of clothes, airing is so effective that the effective period of fumigation may be more than 6 hr. Since, in these hidden spaces, the concentration at the end of 6 hr. is rising, or at least remaining steady at a useful value, the fumigation would be rendered even more efficacious if the period of exposure were prolonged. In these experiments the roof space was sealed off from the rest of the house and very little gas leaked into it. It is, however, doubtful if this space could have been properly fumigated unless the tiles had been laid on close boarding or set in cement. Cracks are often found in the roof space and these may reinfest the living quarters.

## RECOMMENDATIONS

*(a) Fumigation*

1. Care should be taken to ensure that cupboards, drawers, boxes, etc., receive an adequate initial dose of fumigant. If disks are used great care should be taken to see that they are all collected after the fumigation.

2. Where it is considered that the roof space cannot be fumigated with hydrogen cyanide but is likely to be infested, it should be treated in some other manner.

3. A longer period of exposure than 6 hr. is advantageous, particularly in promoting the penetration of lethal concentrations of fumigant into hidden spaces.

4. Access to unventilated floor spaces and, to some extent, to plaster partitions, should be obtained by lifting one or two floorboards close to the walls in the upstairs rooms, or by easing skirting boards. This precaution should ensure that the concentration beneath the floor reaches a value not materially less than that in the main free space in the room. The easing of one or two floorboards only is required.

#### (b) *Ventilation*

1. All windows should be kept open for 24 hr. unless this leads to the entry of rain or snow.

2. A ventilation period of 24 hr. is generally sufficient for an empty house of normal construction. A longer period may be required for a furnished house or for a house which (a) is damp, (b) contains an unusual proportion of dead space, (c) contains rooms without windows providing adequate communication with the open air.

#### (c) *Precautions*

1. Fumigation of clothing and particularly of bedding in a house, as a regular practice, is definitely undesirable.

2. Upholstered furniture should be placed in such a position as best to facilitate airing. Cushions, etc. should be spread out singly on furniture which is not upholstered.

3. The customary tests with benzidine acetate-copper acetate should be made following the procedure detailed below. A blue colour, in all air spaces, indicating a concentration of 0.01 oz./1000 cu. ft., 0.0009% by vol., or less, gives a margin of safety.

4. If the house contains a considerable quantity of absorbent material or if the fabric is likely to be unusually absorptive, e.g. if partitions of insulating boards are employed, or if the construction of the house, or any other circumstances, suggest that a period of 24 hr. airing may not be sufficiently long, all doors and windows should be closed after performing the tests with benzidine acetate-copper acetate, and these tests should be repeated after the house has remained closed for 2 hr. This will allow absorbed gas to be given off and to build up a concentration in the air spaces. If this is still not greater than 0.01 oz./1000 cu. ft., 0.0009% by vol., reoccupation may be permitted.

5. During the period of ventilation, all windows and other openings should be so secured as to prevent the entry into the house of any unauthorized person. In addition, the premises should be kept under observation, continually, by a responsible person.

6. Houses, other than detached houses, should preferably be fumigated in blocks. Failing this, however, in the houses adjoining those being fumigated, a few floorboards should be removed in the upstairs rooms next to the fumigated house, and the windows of these rooms should be opened. In some instances it may be sufficient to ease the skirting boards instead of raising the floorboards. Bedding and clothing should be removed to the far side of the house. All rooms and cupboards, the roof space and the floor spaces in adjoining houses should be tested frequently during the fumigation and ventilation.

7. The precautions recommended to be taken in adjoining houses are based on experiments carried out upon a particular type of house and may not be sufficient in all cases. Peculiarities of construction, or other factors, may necessitate the adoption of special precautions.

*The benzidine acetate-copper acetate test*

This widely used test gives only a rough measure of the concentration of hydrogen cyanide.

As the results of experiments, it is recommended that the test be performed in the following way.

*Preparation of the solution of benzidine acetate.* Benzidine acetate should be purchased in small quantities at a time from a reliable firm of manufacturing chemists. It may be stored for a short period in an amber bottle with a well-fitting glass stopper. It should be light in colour, good commercial specimens generally being pale grey. It loses acetic acid on keeping and the solubility is diminished. It should contain, originally, equimolecular proportions of benzidine and of acetic acid. A method for testing the purity of a sample is given by Page and Gloyns (1936, p. 209T). In this paper a simple method of preparation from A.R. benzidine and A.R. glacial acetic acid is also described. A more convenient method, which can be relied on to give a pure crystalline product, is to dissolve 1.84 g. of benzidine, A.R. in about 40 c.c. of benzene at a temperature of about 70° C., and to add 0.6 c.c. of glacial acetic acid, A.R. The solution is then cooled, with stirring, and filtered. The crystals of benzidine acetate are collected and dried on filter paper.

Using good quality benzidine acetate, which is fresh, or has been stored only for a short period, a solution saturated at 20° C. is prepared by weighing 1 g. of benzidine acetate and warming to 50° C. with 100 c.c. of distilled water. The solution should be kept at about this temperature for 10 min. and the material stirred with a glass rod in order to ensure that the benzidine acetate has been thoroughly wetted. The solution is then cooled to 20° C. and stirred occasionally. Whilst at this temperature it is filtered through a small fluted filter paper or through a disk in a Büchner funnel. This filtrate is diluted with half its volume of water. The resulting solution is called *solution A*. It is best to prepare a fresh saturated solution of benzidine acetate every day, although solution A has been found, on occasions to keep well, in an amber bottle, for 1 week.

*Preparation of the solution of copper acetate.* A.R. copper acetate, finely ground, should be used. 0.3 g. are weighed out and dissolved in 100 c.c. of distilled water by shaking. This is called *solution B*. If stored in a glass bottle with a well-fitting glass stopper it will keep well for several weeks. If it becomes distinctly cloudy it should be replaced by a freshly prepared solution.

*Preparation of the solution to be used for testing.* Three volumes of solution A are mixed with one volume of solution B, giving the test solution. This solution should be prepared in small quantities at a time, immediately before use. It becomes unreliable after 1 hr.

*Apparatus. (a) Paper strips.* These should be cut from sheets of Whatman's filter paper no. 20 or any paper of exactly similar quality. They should be rectangular in shape and should measure  $4\frac{1}{2}$  by  $\frac{3}{4}$  in.

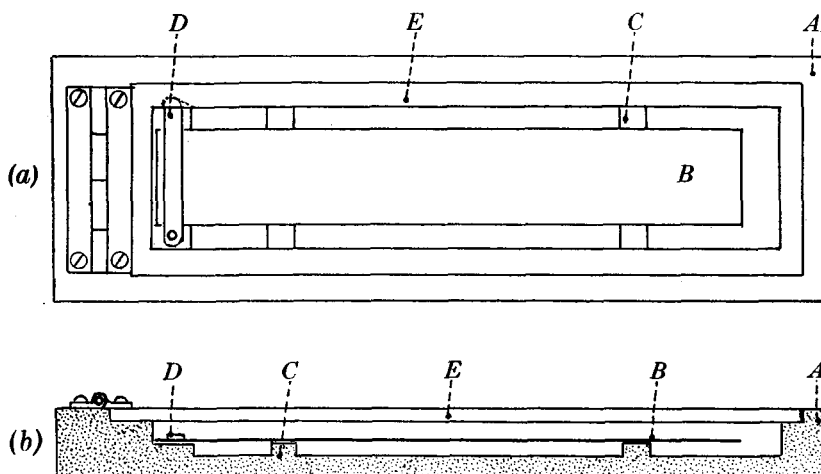


Fig. 5.

(b) *Blotting paper.* A sheet of good quality clean white blotting paper is required. This should be folded so as to permit of each filter paper strip being dried between two clean dry surfaces of blotting paper. The wet strip is placed in the folded blotting paper and pressed evenly once.

(c) *Testing case.* This is shown diagrammatically in Fig. 5a in plan and 5b in section. It consists of a flat moulded case A, measuring 2 by 6 in. The prepared strip B is laid over the supports C and held at the drier end by the spring clip D. The case is then closed by the glass window E. The case is then taken into the space to be tested. The window is opened and the watch (see para. (e)) is started simultaneously. The case is held with the window open and moved so as to allow the strip to wave freely in the atmosphere. At the end of 15 sec. the window is closed, the colour of the strip is compared immediately with the set of standard colours and the corresponding concentration is noted.

(d) *Set of standard colours.* A set of colours, Fig. 6, corresponding to the following concentrations is required:

0.005	0.01	0.02	0.03	0.04	0.1	0.2	oz./1000 cu. ft.
0.0004	0.0009	0.0017	0.0026	0.0035	0.0086	0.017	% by vol.

These standard colours should be kept clean and dry and should not be unnecessarily exposed to light.

(e) *Stop-watch or watch with seconds hand.* When one man is carrying out the test, the watch should be set going and placed in some position where it can be seen easily, as, for example, on a table, chair or ledge. This leaves both hands free, if required, for opening and closing the glass window and for waving the strip. When not using a stop-watch the window should be opened just as the seconds hand passes the 60 mark and should be closed again as it passes the 15 mark.

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