BRITISH MUSEUM (NAT. HIST.) DEPARTMENT OF ENTOMOLOGY

DESTRUCTION OF LICE IN CLOTHING BY HOT AND COLD AIR.

By J. R. Busvine, B.Sc., Ph.D.,

Entomologist, Ministry of Health.

Introduction.

The most suitable methods of disinfesting clothing and bedding depend upon circumstances, such as the extent and importance of the pest infestation, the numbers to be treated and the facilities available. This paper describes investigations of heat and cold for killing lice which were undertaken with an eye to very different situations, *viz.*, the heat treatment of bedding in London air-raid shelters and the possible use of winter cold in Eastern Europe during post-war relief. Nevertheless, the problems have one thing in common; the inherent difficulty of heat transference through clothing and bedding.

Various articles of clothing and bedding must vary greatly in heat insulation so that it is difficult to generalise. As a rough standard, ordinary army blankets (also used in civil defence posts) were adopted and were used in both experiments with heat and with cold. The thermal insulation value of one typical blanket was very kindly determined for me by the Wool Industries Research Association at the request of Dr. T. Bedford. The measurements made are given in comparison with an all-wool blanket and with a poor quality substitute. It will be seen that the sample was intermediate between them.

Blanket	Weight oz./sq. yd.	Thickness at 5 gm/cm² pressure	Thermal Insulation Value	Approx. Thermal Conductivity
All wool...	13·3	·228 cm.	40%	8×10^5cal/cm/sec/°C.
Sample	17·2	·286 cm.	32%	14 ,, ,,
70% Waste Hessian ... / 30% Shoddy	15·5	·237 cm.	22·5%	20 ,, ,,

Destruction of Lice by Hot Air.

Laboratory Data.

The precise limits of resistance of lice and eggs to high temperature were defined by Buxton (1940) and are set out in Table I in comparison with data for certain other parasites.

The louse eggs used by Buxton were from one to five days old, since older eggs were less resistant. These young eggs appear to be rather more difficult to kill by short exposures to high temperature than the other human parasites. Accordingly they make a good test subject, for if louse eggs are destroyed, it can be assumed that other common vermin will be killed.

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TABLE I.

Resistance to high temperature of louse, bug, itch mite and a species of flea.

Exposure (Mins.)	Lethal Temperature (°C.)					
	Pediculus		*Cimex*		*Sarcoptes*	*Xenopsylla*
	Egg	Adult	Egg	Adult	Adult	Adult
5	53·5	51·5	—	—	—	—
10	52	50	—	—	49	—
30	50	47	—	—	47·5	—
60	—	46	45	44	—	39·5
Authors	Buxton (1940)		Mellanby (1935)		Mellanby and others (1942)	Mellanby (1932)

Small Scale Trials.

The object of these experiments was to measure the penetration of heat into a bundle of blankets put into hot air at a constant temperature.

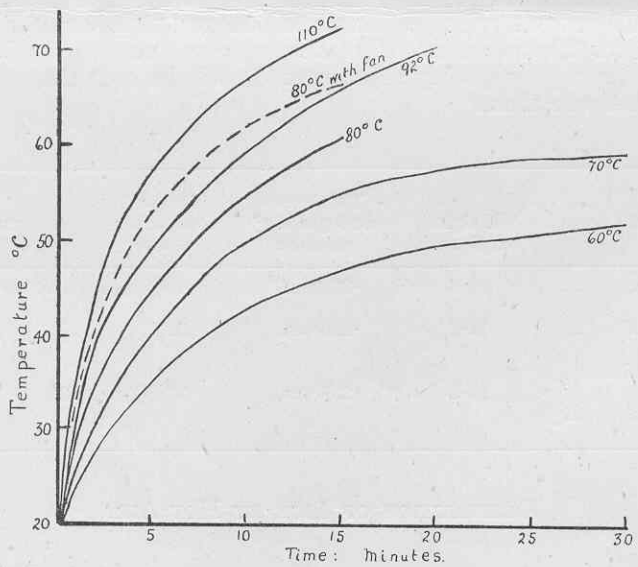

Fig. 1. Records of the thermocouples under one layer of blanket for various oven temperatures.

A piece of blanket material 1 metre square was folded four times into a wad of 16 thicknesses, and thermocouples were inserted between the top three layers. This bundle was rapidly introduced into a water-jacketed oven about 2 ft. long and $1\frac{1}{2}$ ft. internal diameter. (Measurements of the free air temperature proved that this operation caused only a slight loss of heat which was soon made good.) It was assumed that the heat penetrating the top three layers came exclusively by conduction from

the hot air and by radiation. Conduction through the bottom 13 layers was neglected. The temperature of the blanket before the experiment (*i.e.* the room temperature) was approximately 20°C. throughout.

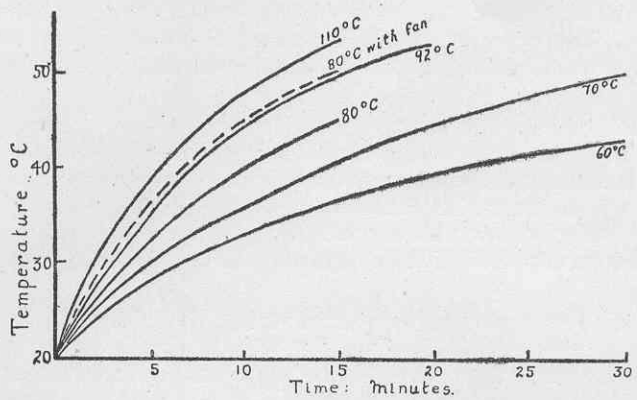

Fig. 2. Records of the thermocouples under three layers of blanket for various oven temperatures.

The records of the thermocouples under one and three layers of blanket are shown in figs. 1 and 2 for various oven temperatures. All the curves fall off logarithmically as the temperature in the blanket approaches that of the hot air. By plotting the curves against a logarithmic time scale, straight lines are obtained which can be fitted more accurately. From such lines have been calculated the times necessary to reach a rapidly lethal temperature (54°C.) under one or three layers. Adding on five minutes for a fatal exposure, the following times were estimated :—

TABLE II.

Exposures to kill lice under blankets in still hot air.

Air temperature	Lethal exposure when protected by blanket	
	1 layer	3 layers
110°C.	9½ minutes	20 minutes
92°C.	12 ,,	25 ,,
80°C.	14 ,,	35 ,,
70°C.	20 ,,	58 ,,
60°C.	50 ,,	115 ,,
80°C. with fan	11 minutes	25 minutes

In one test an electric fan was put in the oven close to the blanket wad. The turbulence of the air greatly accelerated the heat transference and reduced the necessary exposure by about 25 per cent.

Field Trials.

A. *Heated rooms without forced draught.*

With the co-operation of Dr. Macmillan, Dr. Standring and Mr. Sumner, trials were made in two hot air chambers in the Borough of Woolwich. One chamber was the

hottest room of the Turkish baths at Plumstead which can be maintained at a temperature between 70° and 80°C. This room is heated by a slow (imperceptible) current of air which passes round furnace flues, enters the room by openings round the base of the walls and returns from a port near the ceiling to be re-heated. The other chamber was a specially built disinfestation room at Sherrard Road Cleansing Station, lined with cork and heated by five electro-vapour 10 KW heaters, controlled by a thermostat. The capacity of the Plumstead chamber was approximately 500 cu. ft. and that of the Sherrard Road one was 250 cu. ft. ; both rooms were about 9 ft. high.

In each test a folded blanket was placed on the floor, another at two feet and a third at six feet from the floor. Lice and eggs in muslin bags were placed under one and three layers of the blankets and the air temperature at 4–5 feet was read at intervals. After the exposure, the bags of insects were removed, and a few hours later the lice were put into breeding boxes on the leg and the eggs into an incubator at 30°C. The kills of lice were determined within two days and the egg mortality when the controls had hatched.

The results of four experiments are summarised in Table III. Trial No. 3 at Sherrard Road was completely ineffective. The other trials were moderately successful at 6 ft. ; but even there only a partial kill of eggs was produced under three layers.

The poor results at two feet from the floor and below were due to layering of the hot air. In test 1, where the temperature of 74°C. was recorded at 5 feet, the temperature of the floor was only 40°C. rising to 50°C. a few inches up.

Owing to this poor distribution of heat, hot air chambers are rather unreliable. If they are used, the following conditions must be fulfilled :—

Only that part of the chamber which can give a free air temperature of 70°C. when fully loaded may be used. The temperature must be maintained at this level for an hour's exposure.

TABLE III.

Results of tests in heated chambers.

Site	Trial No.	Exposure	Average Temp. (4 or 5 feet)	Under blanket	Percentage kill of test insects					
					At Floor		At 2 feet		At 6 feet	
					Lice	Eggs	Lice	Eggs	Lice	Eggs
Plumstead ...	1	½ hr.	74°C.	1 layer	100	89	—	—	100	100
				3 ,,	0	11	0	0	100	94
,,	2	¾ hr.	70°C.	1 ,,	100	100	100	100	100	100
				3 ,,	0	0	0	0	100	20
Sherrard Road	3	½ hr.	62°C.	1 ,,	0	0	—	—	0	0
				3 ,,	17	0	0	0	0	8
,,	4	1 hr.	66°C.	1 ,,	0	0	0	0	100	100
				3 ,,	0	8	0	0	100	19

B. *A Trial of the "Millbank" Disinfestor.*

In view of the far greater efficiency of moving hot air, the Army adopted early in the War a portable disinfestor in which the air is circulated by a forced draught. This apparatus, which is known as the "Millbank" Disinfestor, is also used by some civilian authorities (Borough Health Departments, etc.) for treating bedding bundles of air raid shelterers.

During a routine disinfestation in the Borough of Marylebone, the opportunity was taken to test the performance of the apparatus. The disinfestor was working in the open with an outside air temperature of 10°C. An assortment of rugs, bedding and clothing was being treated. Twenty test batches of louse eggs were placed at various points among the bedding and three thermocouples were also inserted as follows :—

A. Exposed, in the centre of the chamber

B. Under two blankets, in the centre of the chamber

C. Under two blankets, near the loading entrance

All three were about half way between floor and ceiling.

The hot air was circulated for half an hour and then cut off ; the loading curtains were opened and the interior allowed to cool for 15 minutes before unloading and collection of the test louse eggs.

The temperatures (°C.) recorded during the run were as follows :—

	Minutes from start of hot air circulation									
	5	10	15	20	25	30		35	40	45
A	46	65	77	88	95	101	Heat	90	56	37
B	38	56	67	77	83	88	cut	86	64	43
C	20	37	48	52	54	55	off	54	42	36

Position C was chosen as being the most difficult part of the chamber to heat and, indeed, the temperature beneath the blankets there was 30°C. lower than at B. Nevertheless, the louse eggs at C were killed and in all other batches except three. These three were protected respectively by (*a*) a folded pillow, (*b*) a folded palliasse, (*c*) a thick folded eiderdown. (The folding was the result of hanging the bedding over rods so that two halves hung down side by side.)

The treatment successfully killed all lice eggs whether near the top or bottom of the chamber and at various points except for these three inaccessible points. It appears that the disinfestor is much more efficient than hot air chambers without air circulation, and that it can be relied upon to disinfest clothes and blankets (but not pillows or mattresses) with a half-hour exposure.

C. *A Hot-air Disinfestor attached to an Air-raid Shelter.*

The Civil Defence authorities, no less than the Army, are aware of the convenience of hot air disinfestation. For the treatment of bedding in large air raid shelters, particularly the deep shelters, a new type of disinfestor has been developed by officers of the Ministry of Home Security and the consulting engineers responsible for constructing the deep shelters. Full details will be published elsewhere but it may be briefly described as a gas-heated chamber with a circulating hot air system. It consists of a tunnel 30 feet long and about 6 ft. by 6 ft. in cross section, with doors at each end. The bedding to be disinfested is placed over rods carried on cradles which hang from an endless overhead rail running right through the chamber and completing the circuit outside.

There are ten cradles, of which five can be disinfested at a time, allowing the remainder to be unloaded and reloaded.

The temperature can be maintained steadily at any temperature up to 260°F. (127°C.).

When a set of loaded cradles have been run in, the temperature naturally falls; but, unless the materials are very damp and cold, the regulated temperature is regained in quite a short time (about 5–10 minutes).

Experimental.

The first disinfestor of this type was completed in 1943, and tested during some cold weather in November, *i.e.* under unfavourable conditions.

Small pieces of tape bearing body louse eggs and identification numbers were pinned to various parts of the bedding before exposure. Afterwards, the test eggs were collected and incubated at 30°C. to determine the percentage hatch. Among the control eggs 80–90 per cent. hatched.

Results.

In all tests the exposure was for 20 minutes after the required temperature had been reached.

Test No. 1.

Average temperature 220°*F.* (105°*C.*) (*reached in about* 5 *minutes from entry of the cradles*).

Cradle No.	Position	Percentage hatch of eggs
1	In mattress fold	80
1	In blanket fold	0
1	In blanket fold	0
3	In mattress fold	79
3	In mattress bottom	0
3	In blanket fold	0
4	In mattress fold	67
4	In blanket fold	0
5	In blanket fold	0
5	In mattress fold	43

Test No. 2.

Average temperature 260°*F.* (127°*C.*) (*reached within* 8 *minutes*).

Cradle No.	Position	Percentage hatch of eggs
1	Mattress	52
1	Blankets	0
1	Blankets	0
2	Blankets	0
2	Blankets	0
3	Mattress	50
3	Blankets	0
3	Mattress (bottom)	0

In these first two trials the results were quite definite: the only failures were louse eggs secreted between the two touching sides of mattresses hanging over rails. Accordingly in the next two trials the mattresses were each hung over two rails about 9 inches apart and inside the arch so formed, two blankets were hung on rods at a slightly lower level. This arrangement enabled the hot air to penetrate to all surfaces of the mattresses. Pillows were hung on hooks from one end of each mattress.

Test No. 3.

Average temperature 240°*F.* (115°*C.*) (*reached in about* 10 *minutes*).

Cradle No.	Position	Percentage of eggs
1	In blanket under arch (a)	0
1	In blanket under arch (a)	0
1	In blanket under arch (b)	0
1	In blanket under arch (b)	0
1	On mattress under arch (a)	0
1	On mattress under arch (b)	0
3	In eiderdown	0
3	In blankets...	0
3	In eiderdown (bottom) ...	0

Test No. 4.

Average temperature 220°*F.* (105°*C.*) (*reached in* 5 *minutes*).

Cradle No.	Position	Percentage of eggs
5	In blankets under arch (a)	0
5	In blankets under arch (a)	0
5	In mattress under arch (a)	0
5	In blankets under arch (b)	0
5	In blankets under arch (b)	0
5	In mattress under arch (b)	0
5	In mattress under arch (b)	0
5	In thick wad of blankets	75
5	In blankets...	0

These two trials prove the adequacy of this method of suspending the bedding. The only failure was in a thick wad of blankets amounting to about five or six thicknesses on either side of the eggs.

Conclusions.

It has been shown that the disinfestor is capable of disinfesting bedding with 20 minutes exposure to an air temperature of 220°F. or over, *provided* that no great thickness of material protects the vermin. To prevent this, mattresses or palliasses must be hung so that their entire surface is exposed to the circulating hot air. Blankets should be hung in such a way that there is nowhere more than two thicknesses protection from the hot air.

Destruction of Lice by Cold Air.

There exist only a few scattered data on the resistance of lice to low temperatures (Chung, 1937), but it is clear that lice are not very easily killed by cold and that artificial chilling is not a practical measure. However, typhus epidemics are quite liable to occur in winter in parts of the world where the winter temperatures are exceedingly low, and it is important to know whether these natural low temperatures can be relied upon to disinfest clothing in a reasonably short time.

Some of these areas may become devastated or famine stricken as a result of the present war, and, in post-war relief, it would be difficult to send insecticides and equipment to them since all transport would be required for food (see Mackenzie, 1942). In such cases, delousing measures not requiring special apparatus would be especially valuable.

Laboratory Experiments.

Body lice and their eggs were taken from pill box cultures which were kept against the skin of the leg during the day. They were exposed to cold air in small cages of black voile with very little specific heat. From 8 to 20 lice and 25 to 100 eggs were used for each exposure.

TABLE IV.

Resistance of lice and their eggs to low temperatures. The egg mortalities have been corrected for control deaths.

Exposure in hours	Percentage killed at different temperatures									
	−20°C.		−17·5°C.		−15°C.		−10°C.		−5°C.	
	Lice	Eggs	Lice	Eggs	Lice	Eggs	Lice	Eggs	Lice	Eggs
¼	11	23								
½	100	23	75							
¾	100	46	94							
1		50	100	17	88					
2		93	100	44	100					
4		100		82	100	64	30			
5		100		100		79	45			
7½						80	100	5	0	30
10						100	100	14		
12									25	27
15									59	
20								82	100	
24								100	100	
46										44
53										73
64										99
71										100

It was considered that a very violent change of temperature would not be likely to occur in a garment under practical conditions and, since such a sudden change might be especially harmful, the lice were chilled in two stages. From the leg (30°C.) they were sorted and placed in the cages at room temperature (about 10 minutes at 20°C.). Then the cages were placed in a refrigerator for 20 minutes at about 0°C. Finally they were exposed to the test temperature. Preliminary tests showed that recovery from this gradual chilling was more likely than from an abrupt transference.

The low temperatures required were obtained in the ice box of an ordinary refrigerator fitted with a thermostat which worked down to −20°C. The temperature fluctuated considerably as the cooling system cut on and off, but this was damped by a vacuum flask. Inside the vacuum flask the variation was not more than ±1°C.

Experiments with eggs up to three days old and eggs older than that indicated that the younger eggs were more susceptible. But the difference was not great and eggs of all ages were pooled for the general experiments.

Table IV shows the exposures which are needed to kill lice and their eggs. These results can best be shown graphically by converting to time exposure to a logarithmic scale when it will be seen that the logarithm of the exposure is a linear function of the lethal low temperature (Figs. 3, 4).

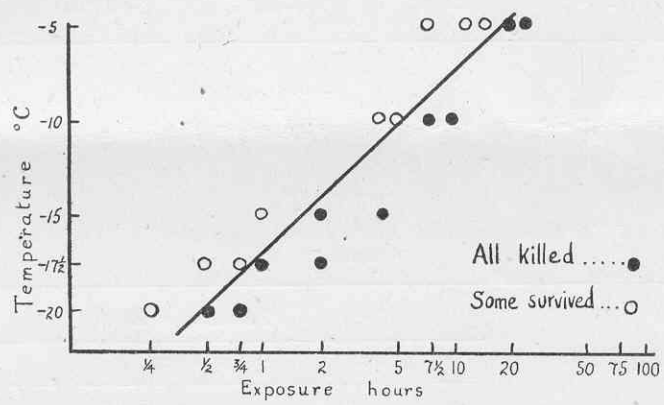

Fig. 3. Resistance of lice and their eggs to low temperatures.

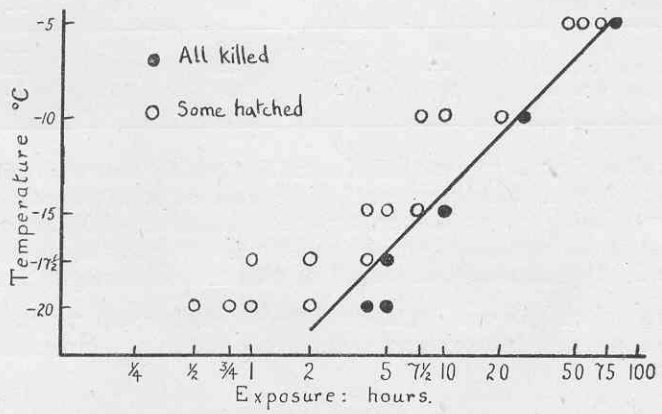

Fig. 4. Resistance of lice and their eggs to low temperatures.

Practical Trials.

Having found the low temperatures lethal to exposed lice and eggs, it was necessary to determine whether they can be killed by reasonably short exposures (less than 12 hours) when protected by a thick garment. For these practical tests, the use of a cold chamber was kindly allowed by the Director of the Road Research Station.

Lice and eggs were secreted in (*a*) a lined musquash fur coat ; (*b*) the folds of a woollen blanket ; both at room temperature before the experiment. (It was found that one thickness of the coat gave about the same protection as three layers of blanket.) The rate of fall in temperature was observed by thermocouples and a galvanometer.

Results.

In two trials in which the temperatures were recorded, the cooling proceeded as follows :—

Air temperature	Temperature inside coat or 3 folds of blanket at various times				
	½ hr.	1 hr.	2 hrs.	3 hrs.	5 hrs.
−15°C.	0°C.	−5·5°C.	−11°C.	−13°C.	−14·5°C.
−20°C.	−2°C.	−8°C.	−14°C.	−17°C.	−19·5°C.

The effect on the lice and eggs is shown in Table V.

TABLE V.

Kill of protected lice and eggs by low temperatures. (Egg mortalities adjusted for control deaths.)

Air temperature	Exposure	Percentage killed					
		2½ hrs.		5 hrs.		12 hrs.	
		Adults	Eggs	Adults	Eggs	Adults	Eggs
−15°C.	In coat	0	0	100	25	100	71
	In blanket (1 layer)	100	0	—	—	—	—
	In blanket (3 layers)	70	0	100	41	—	—
−20°C.	In coat	90	23	100	100	—	100
	In blanket (1 layer)	—	80	—	100	—	—
	In blanket (3 layers)	100	0	100	90	—	—

The results show that a complete kill of adult lice is fairly easy to attain even when they are protected by a thick garment : there were no survivals after 5 hours at −15°C. The eggs, being more resistant, survived 5 hours at −20°C. and 24 hours at −15°C. But their destruction might be a matter of rather less importance than the adults because the typhus rickettsia cannot be transmitted through them.

As a general conclusion one could be sure of delousing all types of garments (at least from adult lice) by exposing them overnight to a temperature of minus 15°C. or lower.

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