PENETRATION OF ULTRA-LOW VOLUME APPLIED INSECTICIDE INTO DWELLINGS FOR DENGUE VECTOR CONTROL[1]

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ABSTRACT. Determinations on the penetration of ultra-low volume applied insecticide into dwellings was accomplished with a model house in Frederick, MD, USA, and native houses in Santo Domingo, Dominican Republic. Results from the model house tests show that aerosol droplets, with a volume median diameter of 4 μm, penetrated and remained suspended in low recesses of the building during the first 2 min after spraying. Similar results were found with tests in Santo Domingo, where man-made or natural obstructions were determined to be critical factors in aerosol penetration.

INTRODUCTION

Prevention of epidemic outbreaks of dengue, such as the dengue pandemic in the Caribbean in 1977, rely on control of *Aedes aegypti* (Linn.), the primary vector of dengue in the Western Hemisphere (Bres 1979). Efforts to eradicate this disease vector have been unsuccessful, with the Centers for Disease Control (1990) reporting confirmed dengue hemorrhagic cases from the Caribbean as recently as December 1989.

In areas of urban infestations, where *Ae. aegypti* typically rest in dark recesses in buildings, intradomiciliary residual spraying is an effective method of treatment (Giglioli 1979). However, during epidemic outbreaks, aerial ultra-low volume (ULV) adulticiding, which covers large areas in a short period of time, is the preferred method of treatment along with ground applied ULV aerosols and source reduction for an integrated attack against the vector (Giglioli 1979, Moody et al. 1979). With extradomiciliary aerosol spraying for *Ae. aegypti*, it is important to know the extent of insecticide penetration in houses to assess the effectiveness of application and the need for future applications.

The objectives of this study were: 1) determine the penetration of ULV applied insecticide aerosols into a model house at Fort Detrick, Frederick, MD, USA, and 2) compare the model home aerosol penetration with the penetration of aerially applied ULV insecticide aerosols into typical lower middle-class houses, which historically had high *Ae. aegypti* densities, in Santo Domingo, Dominican Republic.

MATERIALS AND METHODS

Ground treatments: Ultra-low volume cold aerosols of technical grade malathion (91% AI, Cythion®, American Cyanamid Co., Wayne, NJ 07470) were applied perpendicular to and 30 m upwind of a plywood model house in an open field at Fort Detrick, MD, with a truck-mounted Leco Model MD (Lowndes Engineering Co., Inc., Valdosta, GA 31601) ULV aerosol generator at a rate of 177.44 ml/min (6 fl oz/min), a blower pressure of 8 psi, travelling 8 kph. The pretreatment volume median diameter (VmD) was taken immediately prior to applications using the slide wave technique described by Beidler (1975) with determined VmDs of 16.9, 13.8 and 24.0 μm for field tests done on July, October and November, respectively. Field tests were done between 1130 and 1500 h with the meteorological conditions of 30 ± 1°C, 65 ± 5% RH in July and average of 18 ± 1°C, 53 ± 2% RH in October and November, and wind speed range of 3–9.6 kph.

The plywood model house was 3 × 3 × 1.8 m high and divided into 2 rooms. The larger room was 3 × 2 m with a door opening 1.2 × 0.76 m and a window 0.6 m^2 in one wall. A second window the same size as in the opposite wall, and no openings in the third outside wall. In the smaller room, a 3 × 1 m closet had no openings to outside, but the inside wall contained a 1.2 × 0.76 m door opening to the larger room. The structure had a 0.3 m high peaked roof, with heavy canvas flaps covering the 2 open angles of the roof on the same sides as the outside door and windows. Battery-powered spinning droplet collectors (John W. Hoch Co., Gainesville, FL 32604) with 2 teflon-coated slides per spinner

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were placed at 6 locations within the building: on each of the window sills, under a table in the larger room, on a 0.4 m stool in the closet entrance and on the rafters beside the walls containing windows. The teflon slides were removed from spinners 15 min after treatment, placed in plastic slide boxes, and returned to the laboratory, where droplets were measured and VmDs calculated by a computer program described by Boobar et al. (1986). The VmD was based on 200 droplet maximum; if fewer than 200 droplets were present all legitimate drops were counted.

Real time changes in droplet size-distribution of the malathion aerosol were determined in discrete locations of the building using a Particle Measuring Systems (PMS) Foreward Scattering Spectrometer Probe Model 100 (FSSP-100) (PMS Inc., Boulder, CO 80302) to count and size the droplets. The FSSP-100 uses a HeNe laser beam to size the droplets with the information processed and stored by the PMS Particle Data System Model 400. The FSSP-100 system has been shown to measure accurately real time droplet spectrum for a droplet range of 1–95 μm (Anonymous 1989). Locations characterized in real time were beneath a window in the larger room and in one corner of the closet.

Aerial treatments: Aerial ULV treatments of resmethrin (18% AI) (Rousell Bio Corp., Englewood Cliffs, NJ 07632) with Orchex® (Exxon Inc., Houston, TX 77052), a mineral oil, were applied in a discrete urban residential area of Santo Domingo, Dominican Republic. *Aedes aegypti* were regularly monitored in this location (Tidwell et al. 1990) and was a site for previous vector control research (Perich et al. 1990). Spray applications were made with a Micromist 900 Aztec System sprayer mounted on a twin engine Piper Aztec Model 700 airplane (Duflo Aerospray Systems, Inc., New Bremen, NY 13367) at a rate of 5.88 ml AI per ha, with a nozzle size of 8002 and a blower pressure of 45 psi for 32 nozzles and 50 psi for 50 nozzles, respectively. The airplane was flown at 241 kph, 30 m above ground level with a swath width and flight path interval of 46 m, corresponding to the approximate distance between streets. Aerial applications were made at 1140 h on October 19, 1989, with a temperature of 27.8 ± 1°C, 79 ± 5% RH and a wind speed of 3–5 kph; and 1040 h on October 20, 1989, with a temperature of 25.6 ± 1°C, 68 ± 5% RH and 8–11 kph wind speed. Wind direction on both days was approximately 85 degrees to the direction of the spray output.

Typical houses in the treatment area were one-story stucco or cement block dwellings with 2 or 3 bedrooms, a living room in the center and a backroom kitchen (Fig. 1). A 1 m high stone or cement block wall, approximately 5 m from the center of the street, was located in the front of each home. Houses had a small courtyard area behind the wall which contained various plants 0.5–2.0 m high along with 1 to 2 tropical trees ranging from 10 to 15 m high. In the rear of the houses, uncovered 55-gal (208.2 liters) metal water storage drums lined with cement and used for water storage were found to be the primary source of *Ae. aegypti* larvae (Tidwell et al. 1990).

Prior to aerial application, doors and windows of all houses in the treatment area were opened. Four battery-powered spinning droplet collectors containing 2 teflon-coated slides each, were placed in 3 selected houses within the 6-block center portion of the treatment area. At each house, the spinners were located: 1) on the perimeter wall ca. 5 m from the street center, 2) a hidden area in a closet or under a bed, 3) on a table or chest in a bedroom, and 4) on a table in the living room (Fig. 1). Slides were retrieved within 30 min after insecticide application, placed into plastic slide boxes, returned to the laboratory and VmDs calculated as previously described (Boobar et al. 1986).

RESULTS AND DISCUSSION

Ground treatment: Real-time movement of the malathion aerosol in specific sites within the test model house are shown in Table 1. On October 25, the FSSP-100 was located in the larger room with 2 open windows and an open door. Most of the malathion aerosol had either passed through the building or settled out within 90 sec after spraying, with most droplets penetrating the building having a VmD of 4 μm. Similar results were found on November 14 when the FSSP-100 was located in a corner of the closet. The closet was connected by a single doorway to the larger room. Over 700 droplets passed by one discrete point in the corner within 90 sec after spraying. This can be attributed to secondary currents and drift of the aerosol cloud. Thus a conclusion can be derived that penetration by small droplets of ULV applied insecticide into low recesses of a building results in approximately 2 min of potential insecticide exposure (vector contact).

Table 2 shows the VmD and relative droplet density of the malathion aerosol droplets deposited on spinner slides located at 6 separate locations within the model house at various heights from the ground. A consistent droplet VmD of 5 microns was found for all 3 spray applications. A slight difference in droplet VmD was noted with respect to height, with a lower VmD collected on slides located at the highest

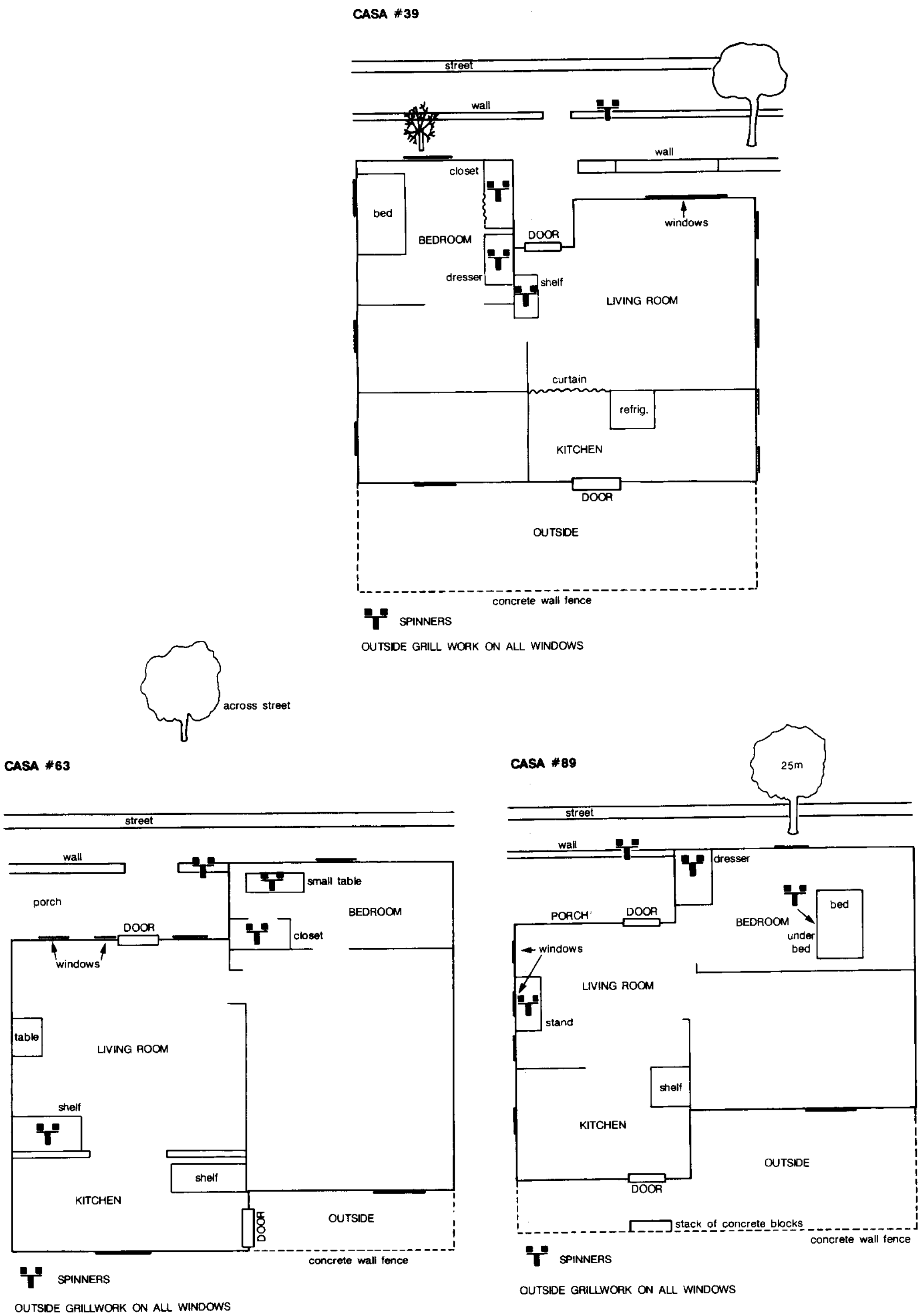

Fig. 1. Schematic drawings of the test houses used in Santo Domingo, Dominican Republic, with locations of the slide spinners.

Table 1. Real time changes in droplet number and size distribution of malathion aerosol in discrete locations inside model house[a] following ULV ground spraying.

Time after spraying (sec)	Oct 25, 1989[b] no. of droplets				Nov 14, 1989[c] no. of droplets			
	4 μm	6 μm	8 μm	10 μm	4 μm	6 μm	8 μm	10 μm
30	197	18	5	0	305	54	3	0
60	127	5	3	2	210	26	6	1
90	129	18	2	2	161	24	5	1
120	30	5	2	0	74	11	2	1
150	15	1	0	0	29	2	0	0

[a] Building located 30 m from source of aerosol dispersal.
[b] FSSP-100 positioned on floor in front of west (entrance) window; wind speed 3–5 kph.
[c] FSSP-100 positioned on closet floor, facing corner; wind speed 6.4 kph.

(2 m) elevation within the building. This is probably due to the larger droplets settling out first. Higher droplet densities were found on the side of the room opposite the prevailing wind direction. This is consistent with the principles of fluid dynamics (Yoshida et al. 1979) in which aerosol enters the building through a confined opening, and spreads out when no longer confined, resulting in a reduced velocity, then hits the opposite wall of the building causing stagnation, currents and eddies within the building and a higher concentration of the aerosol at the point of stagnation. Similar results were reported by Pant and Mathis (1973) in Thailand, when hand-held ULV generators were used to spray insecticides at the entrance of a room.

The data shown in Table 3 indicate good penetration of houses with resmethrin aerosol from ULV aerial spraying when the areas were not totally obstructed. All houses faced the prevailing wind, allowing for maximum insecticide aerosol drift into the houses. The VmDs of droplets on slides on the outside walls were about 10–20 μm higher than the droplets collected on slides located inside the home. This maybe due to larger droplets settling out first and only smaller droplets being carried by air currents into the houses.

In house number 39, the spinner slides on the bedroom dresser were covered with pollen and no insecticide droplets. This can be attributed to large flowering perennials obstructing the bedroom window. The slides in the closet showed neither pollen nor insecticide droplets, suggesting that the curtain covering the closet entrance acted as an impervious obstruction. However, aerosol deposition on the slides in the living room indicate penetration of the aerosol into the house where there was no obstruction.

House number 63, had a similar closet situation to that described in the Fort Detrick model house field test, and findings were similar. The aerosol readily penetrated a closet with no flow-through air currents as long as the closet entrance was not obstructed. Smaller and fewer droplets reached the living room spinner slides as compared with the open bedroom slides. This can be explained by the greater distance from any outside opening to the living room spinner compared with the bedroom spinner, thus allowing for more and larger droplets to reach the closer bedroom location.

Data from house number 89 indicate the importance of wind in initially moving aerosol into the building. On October 19, the breeze was only 3–5 kph and penetration of aerosol into the bedroom (which was partially obstructed by a large tree) was reduced (Table 3). However, on October 20, wind speed had increased to 8–11 kph and all slides, including the 2 impingers obscured under the bed, contained over 200 drops each.

When no obstruction (man-made (curtains) or natural (plants)) interferes with the aerosol flow, insecticide droplet penetration with a uniform VmD can be achieved in interior closets and under beds, as shown by the data from the unobstructed houses, 63 and 89, compared with obstructed house 39 (Table 1).

Small droplets found penetrating the interior closet locations in this study are similar in size to those reported (Lofgren et al. 1973) as having the greatest efficiency of impinging on the body of mosquitoes. Thus, based on the premise that the amount of insecticide required to kill a mosquito is the same regardless of particle size (La Mer et al. 1947), smaller droplets which penetrate hidden locations offer the greatest probability of killing a mosquito resting there.

We have shown that penetration by small droplets into unobstructed, limited access areas in buildings can be achieved with ULV applied insecticide aerosols. The actual deposition of insecticide onto target *Ae. aegypti* adults is achieved through either settling or impingement. The necessary impingement velocity increases as the size of the aerosol droplets decrease (Benzon 1987). This critical velocity can originate from convection currents carrying aerosol droplets or from the flight of *Ae. aegypti.*

Table 2. VmD of malathion aerosol droplets from spinner slides inside model house following ULV ground spraying.[a]

		Jul 25, 1989[b]		Oct 11, 1989[c]		Nov 14, 1989[d]	
Spinner location	Slide no.	VmD	No. drops counted	VmD	No. drops counted	VmD	No. drops counted
East window sill,	1a	8	200	4	27	8	7
0.6 m	b	8	200	4	13	6	13
Floor under table	2a	8	200	4	9	5	137
	b	7	200	4	5	8	68
West window sill,	3a	8	17[e]	4	200	5	200
0.6 m	b	5	75[e]	4	200	5	200
Stool at closet en-	4a	7	200	5	15	4	147
trance, 0.4 m	b	7	200	—[f]	—[f]	4	138
West wall rafters,	5a	—[f]	—[f]	4	36	5	118
2 m	b	6	200	7	23	4	200
East wall rafters,	6a	6	200	3	200	4	99
2 m	b	6	200	4	200	5	71

[a] VmD based on 200 droplet maximum; if fewer than 200 droplets were present, all legitimate drops were counted. Building 30 m from aerosol dispersal site.
[b] Wind from W at 6.4–8 kph.
[c] Wind from SSW at 9.6 kph entering west window at an oblique angle.
[d] Wind from E at 6.4 kph.
[e] Spinner fell off the window sill 3 min into test.
[f] Data not available due to broken slides.

Table 3. VmD of resmethrin from spinner slides in houses in Dominican Republic following ULV aerial spraying[a] (October 19–20, 1989).

		House number		
Site in house	Slide no.	39	63	89
Oct 19, 1989				
Wall outside	1a	39	32	42
	b	32	22	42
Closet	2a	—[b]	8	23[c] (33)
	b	—	18	26 (43)
Bedroom	3a	—[d]	21[e] (14)	13 (15)
	b	—	9 (24)	19 (31)
Living room	4a	11	17 (102)	21
	b	15	19	26
Oct 20, 1989				
Wall outside	1a	33	31	40
	b	33	30	46
Closet	2a	—[b]	14	26[d]
	b	—	21	27
Bedroom	3a	—[d]	20	26
	b	—	24	26
Living room	4a	15 (171)	18 (88)	28
	b	14	16 (105)	26

[a] Calculated from 200 droplets unless noted in parentheses.
[b] Closet opening obstructed with curtain.
[c] Spinner located under bed instead of closet.
[d] Slides covered with pollen from succulent obstructing window.
[e] Spinner stopped shortly after spray began.

Both of these sources of velocity would be expected to be minimal with adult *Ae. aegypti* resting in limited access areas of houses. The impingement velocity and insufficient number of spray droplets per unit area (Thompson 1973) are limiting factors in the efficacy of extradomiciliary ULV spraying against *Ae. aegypti*. Further research on the resting behavior of *Ae. aegypti* and the impact of insecticide spray application in reducing vector populations is necessary for developing effective epidemic dengue control methods.

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