Field Studies on the Use of High Temperatures to Control *Cryptotermes brevis* (Isoptera: Kalotermitidae)

by

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ABSTRACT

Nine separate commercial high temperature treatments were observed throughout the State of Hawaii. Both ambient temperatures and structural wood core temperatures were monitored in the areas most prone to slow rates of temperature increase, i.e., the largest, lowest structural lumber and timbers next to potential heat-sinks. Data were analyzed to determine the range of temperature increase rates under various conditions as well as to test the impact of those conditions on heating rates.

The mean maximum wood core and ambient temperatures were 55.1°C and 68.1°C, respectively. The longest time that it took to achieve the target wood core temperature of 49°C was 5h. The mean rate of temperature increase was 0.28°C/min, the minimum was 0.04°C/min and the maximum was 1.41°C/min. Minor and repairable property damage was observed during two high temperature treatments when ambient treatment temperatures exceeded 70°C. The rates of temperature increase observed in field applications were generally considerably lower than those used in laboratory studies of the effects of rate on the thermal tolerance of *C. brevis*. Degree of surface exposure to heated air had a significant effect on the rate of temperature increase in lumber.

INTRODUCTION

Cryptotermes brevis (Walker) is an economically important species throughout the southernmost region of the United States as well as throughout the subtropics (Gay 1969). High temperatures have recently been used to control drywood termites (Ebeling 1997). Thermal treatment provides a non-chemical alternative to conventional control methods of drill-and-treat insecticide injection and structural fumigation.

Evaluations of the use of high temperature to control drywood termites have revealed some difficulties. Lewis and Haverty (1996), utilizing a structural mock-up, evaluated the use of excessive temperatures to control the drywood termite *Incisitermes minor* (Hagan) and

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observed a lack of efficacy in wood in the substructure next to a heat sink (concrete foundation). This lack of efficacy may be attributable to an inability to achieve lethal wood temperatures or to some other phenomenon such as termite acclimation. The research performed in support of the high temperature control method (Forbes and Ebeling 1987) utilized a thermal tolerance bioassay in which test insects (*I. minor*) were placed at preset temperatures and the time until death was determined at each temperature. Other researchers (e.g., Woodrow and Grace 1995) have used similar methods in laboratory studies. More recent studies, however, have found differences between results obtained using constant temperature methods and those utilizing controlled rates of thermal increase and it has been hypothesized that slow rates of temperature increase may allow time for termite acclimation (Woodrow and Grace 1998).

Scheffrahn et al. (1997) investigated the effects of several different rates of temperature increase on the thermal tolerance of *C. brevis* and did not observe any overall effects of thermal rate on thermotolerance. However, the lowest rate of increase studied by these researchers was 0.5°C/min. Ebeling (1994) reported that 7.6 X 7.6 X 12.7cm Douglas-fir blocks required 74min to reach an internal temperature of 48.9°C when subjected to a constant temperature of 65.6°C. This change of temperature converts to an overall rate of increase of 0.34°C/min. Since Ebeling's tests were carried out under laboratory conditions and many structural timbers exceed a width of 7.6 cm and a length of 12.7cm, actual rates of temperature increase in the field are likely to be less than those previously studied.

In the present report, nine separate commercial high temperature treatments were observed throughout the State of Hawaii. Both ambient temperatures and structural wood core temperatures were monitored in the areas most prone to slow rates of temperature increase, i.e., the largest, lowest structural lumber and timbers next to potential heat-sinks. Resulting data were analyzed to determine the range of temperature increase rates under various conditions as well as to test the impact of those conditions on heating rates.

MATERIALS AND METHODS

Commercial high temperature treatments were conducted by Certified Pest Control and Fumigation, Lahaina (Maui) and Hilo (Hawaii), under license from TPE Associates Isothermic/Biothermotec Inc., Orange, CA. The minimum target regime was a wood core temperature of 49°C for 30 minutes (Forbes and Ebeling 1987). During the first four treatments, temperatures were monitored using 18 gauge type-t thermocouples attached to an Omega HH-21 single input type-t thermocouple thermometer (Omega Engineering, Inc., Stamford, CT) equipped with a six channel thermocouple switch. Both core and ambient temperatures were monitored throughout the area of treatment, particularly in areas subject to slow rates of increase, such as baseboards, large beams, sill plates, etc. Core temperature probes were installed by drilling (0.476cm [3/16"] drill-bit) to the center of the selected wooden member, placing the thermocouple in the hole and sealing the hole with duct tape. Six channels were recorded manually at 30 minute intervals.

For the remaining five high temperature control treatments, a model E-23000-30 eight channel self-contained thermistor data logger (Cole Parmer Instrument Company, Vernon Hills, IL) was used to collect core and ambient temperature data. Eight general purpose YSI series 400 thermistor probes (Cole Parmer Instrument Company, Vernon Hills, IL) were placed similarly to the thermocouples described above. Careful records were kept as to the location of monitored core and ambient temperatures as well as the dimensions of lumber used for core readings.

Linear regression (SAS Institute 1985) was applied to determine the rates of increase from ambient to 49°C with all the core temperature data that were collected. A general linear model (SAS Institute 1985) was used to test the significance of ambient treatment temperature, height off the floor, degree of exposure, and width of lumber on the rate of thermal increase in type III *F*-tests (SAS Institute 1985).

RESULTS

Nine high temperature control treatments were observed in the State of Hawaii, four on the island of Oahu, four on the island of Hawaii and one on the island of Maui.

Waikiki Shore Apartments

This first treatment observation was performed at the Waikiki Shore Apartments, Kalia Rd, Honolulu, Oahu on 5 September 1995. The owner of the condominium apartment had noted termite damage along the book shelves next to the kitchen (Fig. 1). The entire apartment was treated with high temperatures by placing propane gas blowers at the front and back lanai doorways. Thermal blankets were placed in the doorways to prevent the heated air from escaping the structure. To facilitate air circulation, three fans were placed in the apartment: one in the kitchen doorway, one in the hallway to the bathroom and the other in the living/bedroom area (Fig. 1). To monitor wood core temperatures, thermocouples were placed at floor level in 3.8 X 8.6cm studs in the living room/ bedroom closet, in the kitchen cabinets, and in the bathroom door jam. Ambient temperatures were monitored in the same general vicinity as the core probes at a height of ca. 2m above the floor (Fig. 1). The treatment commenced at 0915 hours and was concluded at 1520 hours.

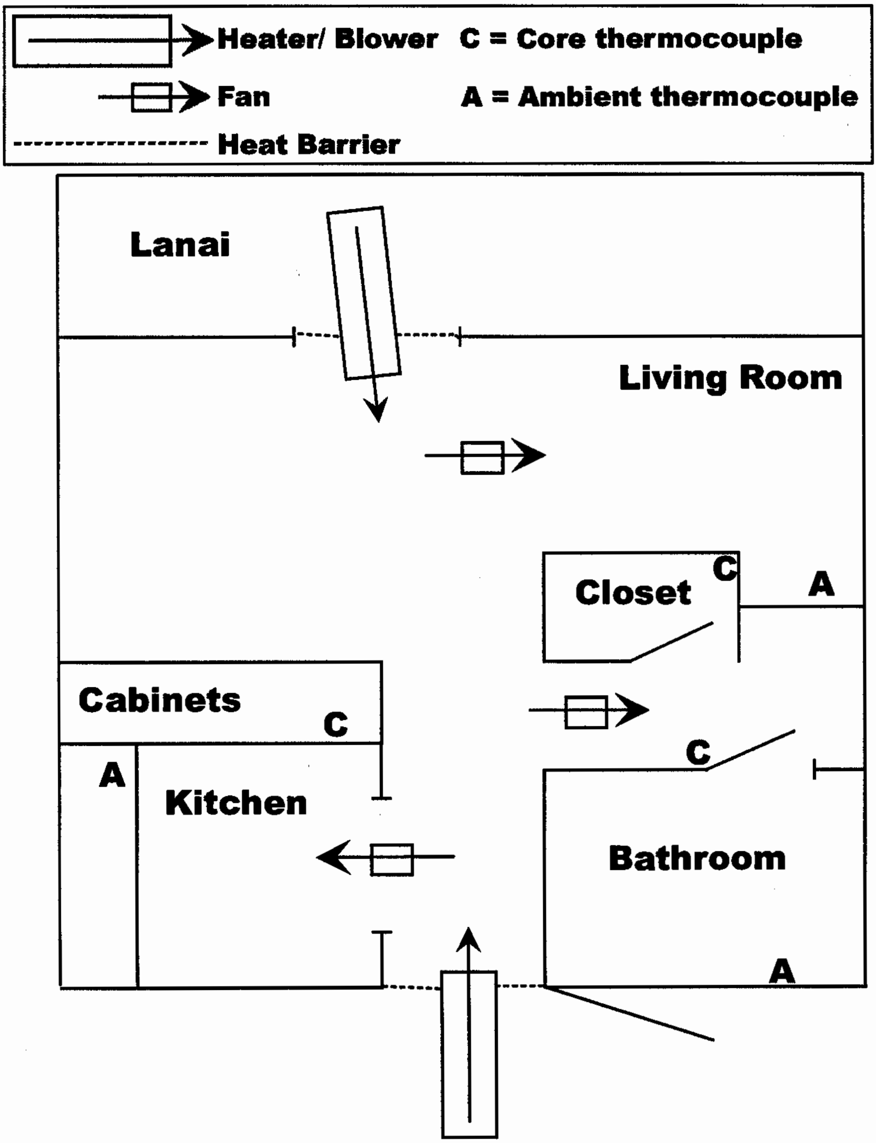

Fig. 1. Overhead drawing of the high temperature treatment at Waikiki Shore Apartments, Honolulu, Oahu, 5 September 1995.

Table 1. Summary statistics for the high temperature treatment at Waikiki Shore Apartments, Honolulu, Oahu, 5 September 1995.

Location	Height (m)[a]	C/A[b]	Wood dimension (cm)	Rate (°C/min)	Max temp[c] (°C)	Time to 49[d] (min)
Bath	0	C	3.8 X 8.6	0.065	54.3	270
Bath	2	A	—	—	71.8	—
Closet	0	C	3.8 X 8.6	0.039	54.6	180
Closet	2	A	—	—	59.4	—
Kitchen	0	C	1.9 X 3.8	0.041	52.9	240
Kitchen	2	A	—	—	62.0	—

[a]=Height from floor to probe.
[b]=Core (C) or ambient (A) probe.
[c]=Maximum temperature.
[d]=Time required to reach a core temperature of 49°C.
—= No data collected.

Rates of wood temperature increase ranged from 0.039°C/min in the closet to 0.065°C/min in the bathroom (Table 1). It took 4.5h (270 min) for the temperature to reach 49°C in the bathroom core and ca. 3h in the closet core. The slow rates of temperature increase were most likely due to the low ambient temperatures in these areas which ranged from 59.4°C in the closet to 71.8°C in the bathroom.

Hawaii Kai

The second high temperature control treatment was in a single family dwelling on Poipu Drive in Hawaii Kai, Oahu on 10 May 1995. Drywood termite damage was found in the front and rear attic sections as well as in the front office (Fig. 2). The treatment was performed in two sections, front and rear of the house. Two propane blowers were used in the front, one to heat the office and the other directed up into the attic through a duct (Fig. 3). The office doorways and attic vents were sealed with fumigation tarps (Figs. 2 and 4). In the front section, tarps were hung from the eves and secured to the ground with sand snakes (Fig. 4). In the attic sections, temperatures were monitored with core probes in 3.8 X 18.4cm ceiling joists and ambient probes placed next to the core locations (Fig. 2). In the office, core temperature was monitored within a 8.6 X 26cm beam located on top of a concrete masonry unit (CMU) wall at ceiling height (ca. 2.5m) and ambient temperature was monitored with a thermocouple secured to a bookcase at ca. 1.5m high. In the attic sections, fans were used to facilitate air circulation (Fig. 2). Heating commenced in the front section at 1000 hours and terminated at 1500 and 1600 hours for the attic and office areas, respectively. The rear attic was treated similarly to the front attic, with a propane heater directed

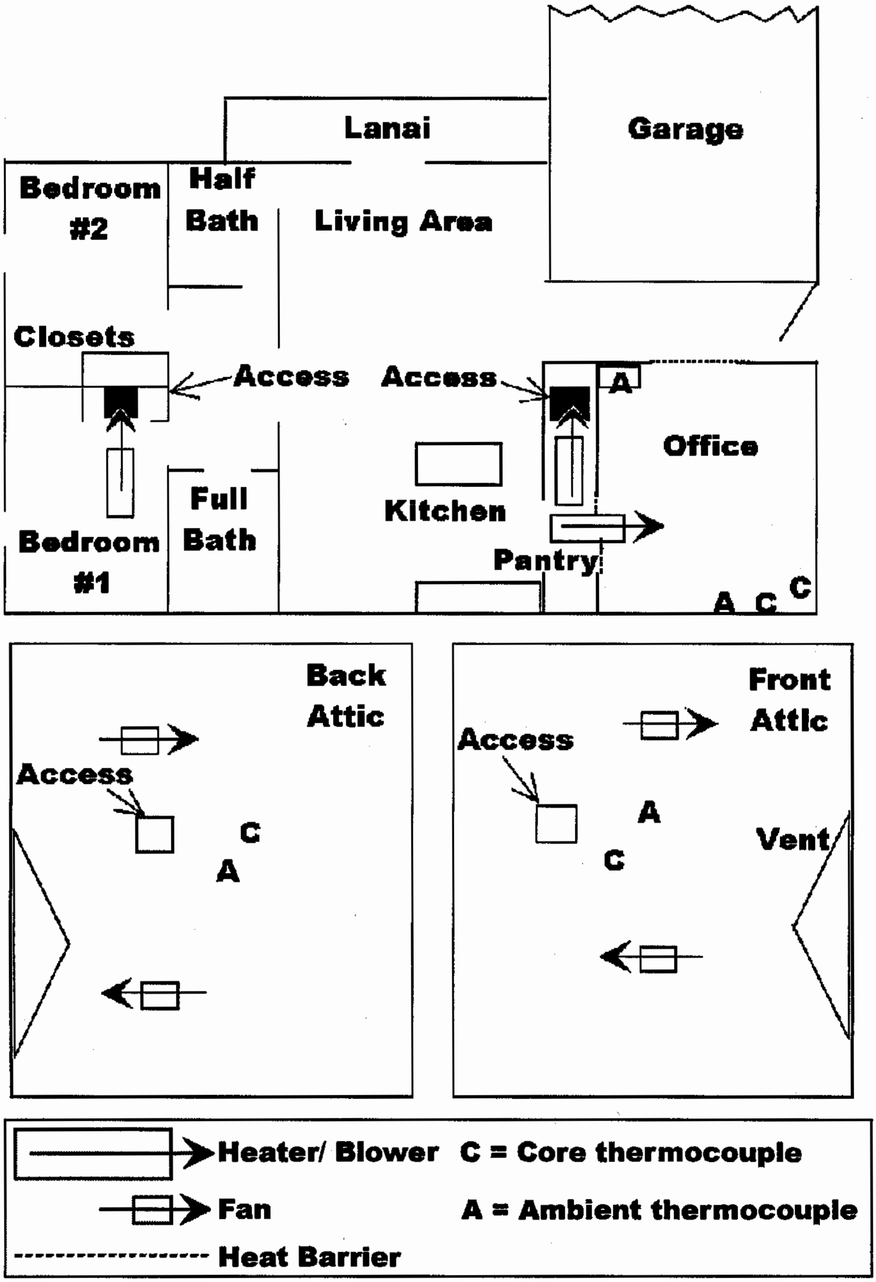

Fig. 2. Overhead drawing of the high temperature treatment at Hawaii Kai, Oahu, 10 May 1995.

Table 2. Summary statistics for the high temperature treatment at Hawaii Kai, Oahu, 10 May 1995.

Location	Height (m)[a]	C/A[b]	Wood dimension (cm)	Rate (°C/min)	Max temp[c] (°C)	Time to 49[d] (min)
Office	2.5	C	13.3 X 26.0	0.09	54.4	300
Office	1.5	A	—	—	71	—
Front Attic	0	C	3.8 X 18.4	0.13	57.6	120
Front Attic	1	A	—	—	72.9	—
Back Attic	0	C	3.8 X 8.6	0.23	58.3	90
Back Attic	1	A	—	—	65.4	—
Eve	2.5	C	3.8 X 8.6	0.23	56.3	90

[a]=Height from floor to probe.
[b]=Core (C) or ambient (A) probe.
[c]=Maximum temperature.
[d]=Time required to reach a core temperature of 49°C.
—= No data collected.

into the crawl space. Heating commenced in the back section at 1115 hours and was terminated at 1600 hours.

Ambient air temperatures were considerably higher than those observed at the previous site, with high ambient temperatures ranging from 65.4°C in the rear attic to 72.9°C in the front attic (Table 2). In the front office, the heat-sink effect of the CMU wall is obvious from the slow rates of increase (0.09°C/min) and the five hours required to reach 49°C in the 8.6 X 23.5cm beam given an adequate ambient high temperature of 71°C.

Marine Fisheries Lab

This high temperature control treatment was conducted on 11 May 1995 at the National Oceanographic and Atmospheric Administration Marine Fisheries Research Lab (Kewalo Basin), Honolulu, Oahu. The structure was a ca. 50-year-old warehouse that contained four offices and two restrooms framed in Douglas Fir 3.8 X 8.6cm studs and 3.8 X 13.3cm joists covered with unfinished 1.25cm plywood (Fig. 5). Most of the ceiling joists and plywood were heavily infested with *C. brevis*. The six rooms were treated in two sections. The front section contained three offices and the rear section contained the remaining office and the restrooms (Fig. 5). The ceiling areas of the front section were infested along with the joists, so fumigation tarps were used to cover the entire section as a unit. Three propane heaters were used to treat the front section, one partially directed into room #1 and down the hall under the tarp and the remaining two directed into rooms #2 and #3. The

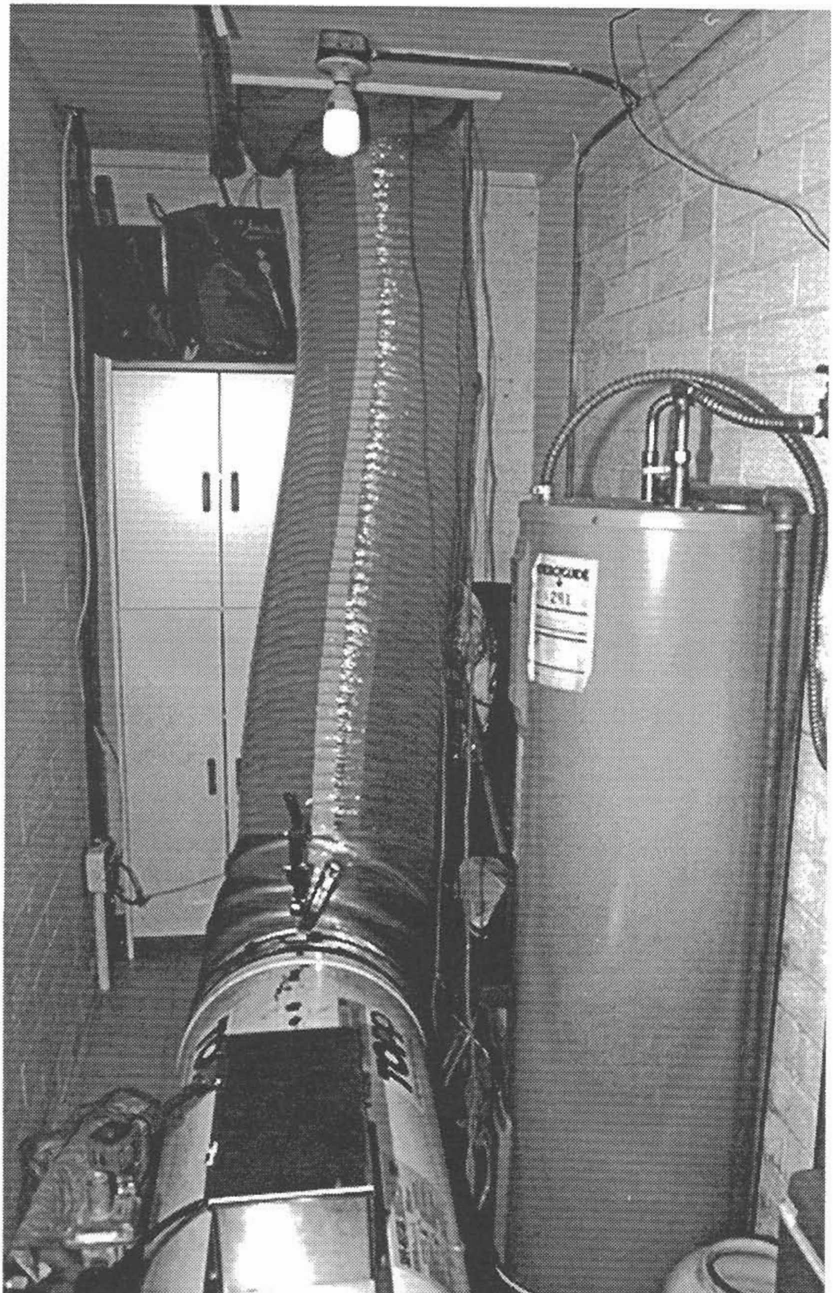

Fig. 3. Duct work used to direct heated treatment air up into the ceiling crawl space during the high temperature treatment at Hawaii Kai, Oahu, 10 May 1995.

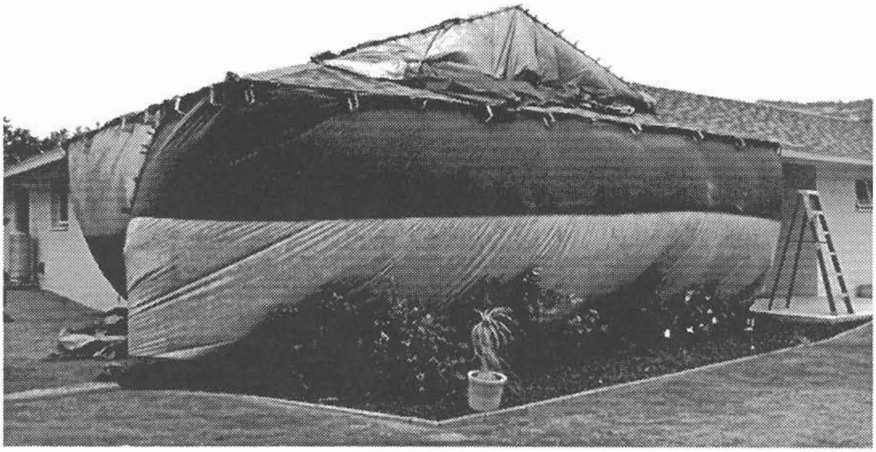

Fig. 4. Side view of the high temperature treatment done at Hawaii Kai, Oahu, 10 May 1995.

remaining rooms in section two were treated individually. Ambient air temperature was monitored at the center door jam and at ceiling height in rooms # 3 and #4 (Fig. 5). Two thermocouples were placed into 3.8 X 13.3cm ceiling joists, one in room #3 and one in room #4. Core temperatures were monitored in baseboards of rooms #1, #2, #4 and the ladies restroom. Heating commenced at 1000 hours and was terminated at 1530 hours.

Table 3. Summary statistics for the high temperature treatment at the Marine Fisheries Lab, Honolulu, Oahu, 11 May 1995.

Location	Height (m)[a]	C/A[b]	Wood dimension (cm)	Rate (°C/min)	Max temp[c] (°C)	Time to 49[d] (min)
Room #3	2.5	C	3.8 X 13.3	0.12	43.8	135
Room #3	2.5	A	—	—	51.8	—
Center door	2	A	—	—	59.6	—
Room #4	2.5	C	3.8 X 13.3	0.08	48.7	120
Room #4	2.5	A	—	—	61.7	—
Ladies	0	C	1.9 X 8.6	0.07	50.2	120
Room #4	0	C	1.9 X 8.6	0.08	48.3	120
Room #1	0	C	1.9 X 8.6	0.10	51.7	90
Room #2	0	C	1.9 X 8.6	0.04	39.2	—

[a]=Height from floor to probe.
[b]=Core (C) or ambient (A) probe.
[c]=Maximum temperature.
[d]=Time required to reach a core temperature of 49°C.
—= No data collected.

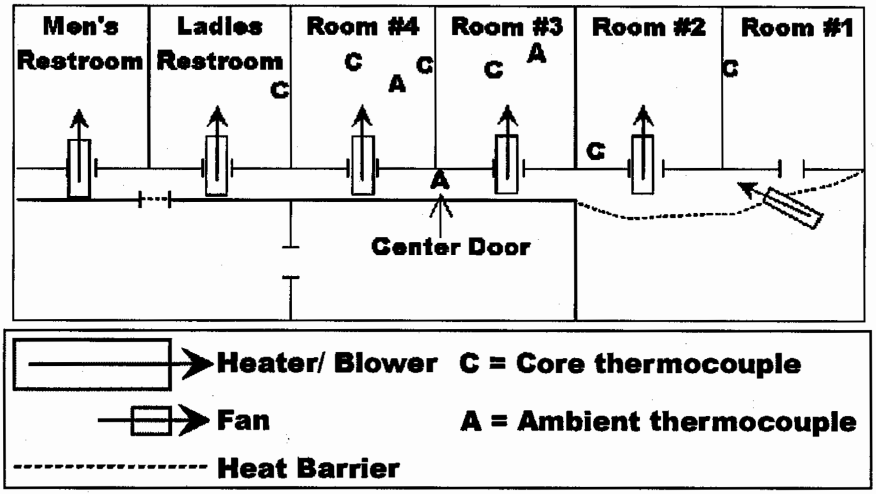

Fig. 5. Overhead drawing of the high temperature treatment at the Marine Fisheries Lab in Honolulu, Oahu, 11 May 1995.

Maximum ambient treatment air temperatures were relatively low during this treatment, ranging from 51.8 to 61.7°C (Table 3). Rates of wood thermal increase ranged from 0.04°C/min in a 1.9 X 18.4cm baseboard to 0.13°C/min in a 3.8 X 13.3cm ceiling joists.

Table 4. Summary statistics for the high temperature treatment at Island Princess Candies, Honolulu, Oahu, 13 May 1995.

Location	Height (m)[a]	C/A[b]	Wood dimension (cm)	Rate (°C/min)	Max temp[c] (°C)	Time to 49[d] (min)
201	0	C	1.9 X 8.6	0.35	51.9	60
201	2	A	—	—	72.1	—
201A	0	C	3.8 X 8.6	0.17	52.9	90
201A	2	A	—	—	68.2	—
207	0	C	1.9 X 8.6	0.05	51.3	30
207	2	A	—	—	71.6	—
205	0	C	1.9 X 8.6	0.20	54.8	30
209	0	C	3.8 X 8.6	0.12	51.7	30
203	0	C	1.9 X 8.6	0.13	52.1	90
203	2	A	—	—	66.5	—

[a]=Height from floor to probe.
[b]=Core (C) or ambient (A) probe.
[c]=Maximum temperature.
[d]=Time required to reach a core temperature of 49°C.
_ = No data collected.

Island Princess Candies

This treatment took place on 13 May 1995 at the Island Princess Candies warehouse and offices, Honolulu, Oahu. The area of treatment was a second story office complex within the industrial warehouse. Termite damage was evident in rooms 201, 201A, 203, 205, 207, 208 and 209 in door jams and moldings (Fig. 6). Only those rooms with evidence of infestation were treated. During this treatment, blowers were directed into each room individually until the suggested endpoints had been reached, then moved to the next nearest room. During the treatments, doorways were covered with thermal blankets to prevent heat loss. A single ambient and a single core thermocouple were used to monitor treatment temperatures in each room. Treatment commenced at 1015 hours in rooms 201, 201A and 205 and were concluded in rooms 203, 207 and 209 at ca. 1500 hours (Fig. 6). No data were available for room 208.

Both the highest and lowest rates of temperature increase occurred in 1.9 X 8.6cm baseboards. The lowest observed rates were 0.05°C/min in room 207, the largest room, and 0.35°C/min in room 201, a relatively small room (Table 4).

Kona Palisades Estates

This treatment was the first in a series of treatments observed on the island of Hawaii, 24 July 1995 at Kona Palisades Estates, Kailua-Kona. The treatment area was a tool shed built against the garage of a single-story house (Fig. 7). Evidence of drywood termite damage was primarily in 1.9cm (3/4") plywood shelving in the shed. A single blower was directed into one side of the shed and the area around the door was sealed with the use of fumigation tarps. A single ambient probe was placed in the opposite end of the shed at ca. 3m high and four core

Table 5. Summary statistics for the high temperature treatment at Kona Palisades Estates, Kailua-Kona, Hawaii, 24 July 1995.

Location	Height (m)[a]	C/A[b]	Wood dimension (cm)	Rate (°C/min)	Max temp[c] (°C)	Time to 49[d] (min)
Far side	1	C	1.9 (plywood)	0.70	61.2	29.3
Far side	1	C	3.8 X 8.6	0.75	63.6	30.9
Far side	3	C	3.8 X 8.6	—	72.3	14.9
Near side	1	C	8.6 X 8.6	0.41	59.0	54.4
Far side	3	A	—	—	75.9	—

[a]=Height from floor to probe.
[b]=Core (C) or ambient (A) probe.
[c]=Maximum temperature.
[d]=Time required to reach a core temperature of 49°C.
— = No data collected.

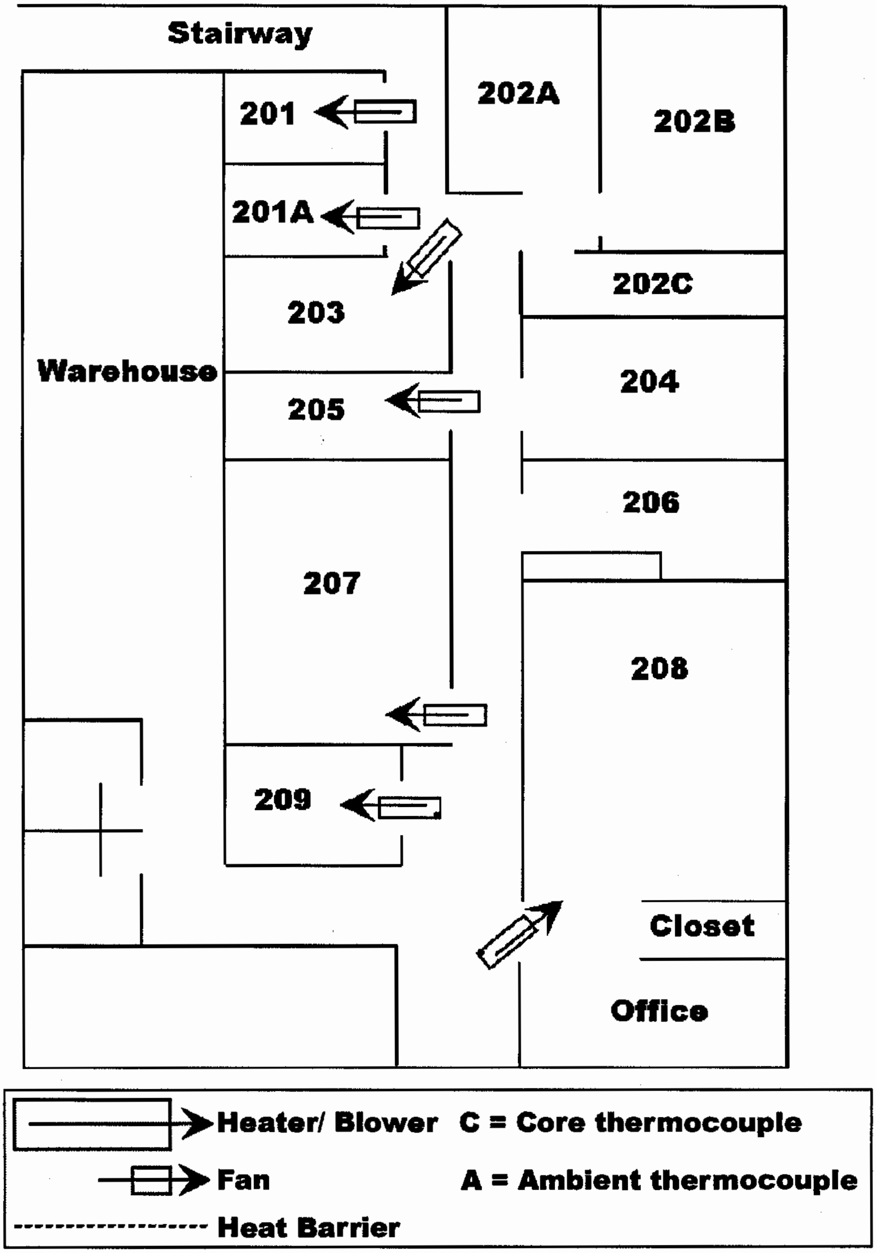

Fig. 6. Overhead drawing of the high temperature treatment at Island Princess Candies, Honolulu, Oahu, 13 May 1995.

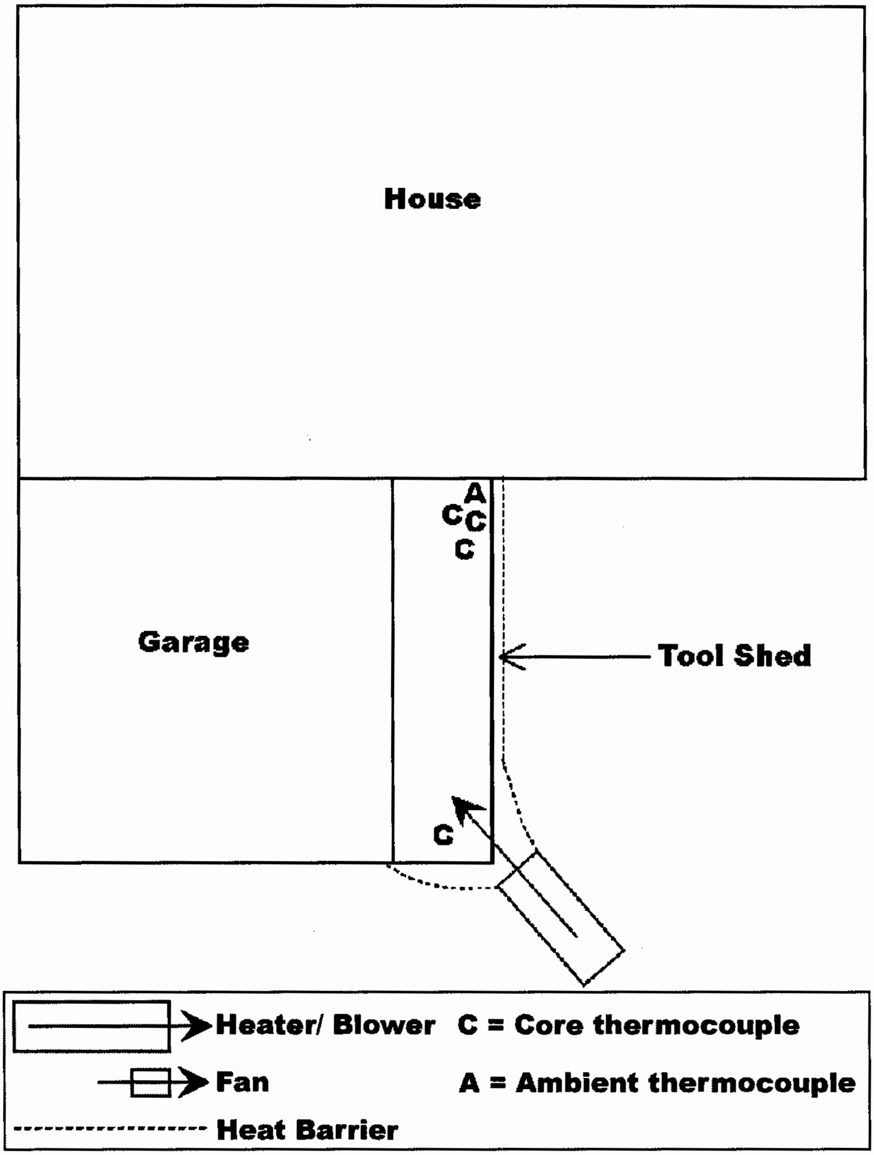

Fig. 7. Overhead drawing of the high temperature treatment at Kona Palisades Estates, Kailua-Kona, Hawaii, 24 July 1995.

locations were monitored with thermistors: one in a 8.6 X 8.6cm beam at 1m high in the treatment doorway, two in vertical 3.8 X 8.6cm lumber opposite the treatment side (one at 1m and one at 3m high) and the

Table 6. Summary statistics for the high temperature treatment at Plantation Estates, Kailua-Kona, Hawaii, 25 July 1995.

Location	Height (m)[a]	C/A[b]	Wood dimension (cm)	Rate (°C/min)	Max temp[c] (°C)	Time to 49[d] (min)
Middle support	0	C	13.3 X13.3	0.13	51.8	151.4
Side support	0	C	13.3 X13.3	0.09	66.2	222.2
Middle support	2.5	C	13.3 X13.3	0.33	44.8	55.7
Main beam	3	C	8.6 X 23.5	0.33	63.6	53
Ceiling	3	A	—	—	85.1	—
Bath	1	A	—	—	66.2	—
Ceiling joist	2.5	C	8.6 X 18.4	0.13	51.8	147.57

[a]=Height from floor to probe.
[b]=Core (C) or ambient (A) probe.
[c]=Maximum temperature.
[d]=Time required to reach a core temperature of 49°C.
— = No data collected.

remaining core-probe in the 1.9cm plywood shelving at 1m high. Heating commenced at 1012 hours and was stopped at 1140 hours .

This treatment, being relatively small, yielded rapid rates of thermal increase and required only a short time to reach 49°C (Table 5). The lowest rate of increase was 0.41°C/min in a 8.6 X 8.6cm beam and the highest was 0.70°C/min in the 1.9cm plywood shelving.

Plantation Estates

This treatment took place in a two-story home in the Plantation Estates of Kailua-Kona, Hawaii on 25 July 1995. Two blowers were used to treat the second floor, one placed vertically on the first floor directed

Table 7. Summary statistics for the high temperature treatment at Hilo Terrace Apartments, Hilo, Hawaii, 27 July 1995.

Location	Height (m)[a]	C/A[b]	Wood dimension (cm)	Rate (°C/min)	Max temp[c] (°C)	Time to 49[d] (min)
Facia	2.5	C	1.9 X 8.6	1.03	66.2	35.5
Brace	0.5	C	3.8 X 18.4	0.70	63.6	49.8
Floor	0	A	—	—	69.0	—
Beam	2.5	C	8.6 X 8.6	0.18	53.4	118.7

[a]=Height from floor to probe.
[b]=Core (C) or ambient (A) probe.
[c]=Maximum temperature.
[d]=Time required to reach a core temperature of 49°C.
— = No data collected.

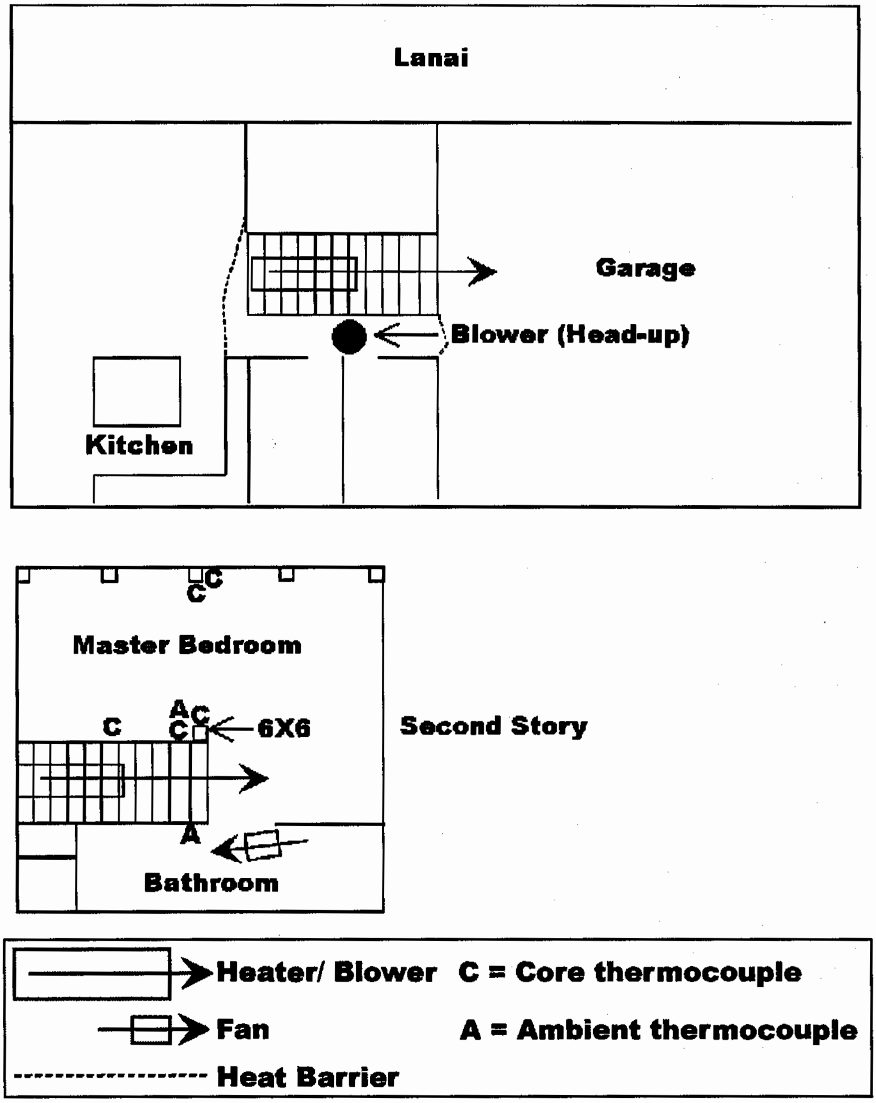

Fig. 8. Overhead drawing of the high temperature treatment at Plantation Estates, Kailua-Kona, Hawaii, 25 July 1995.

up into the loft and the other directed up the stairway to the second floor (Fig. 8). Plastic sheeting was used to seal the second floor and the stairway section from heat loss. A single fan was used to facilitate circulation on the second floor. Ambient temperature was monitored with the use of thermistor probes, one at 1m in the second story bathroom and the other in the peak of the second story. Five core

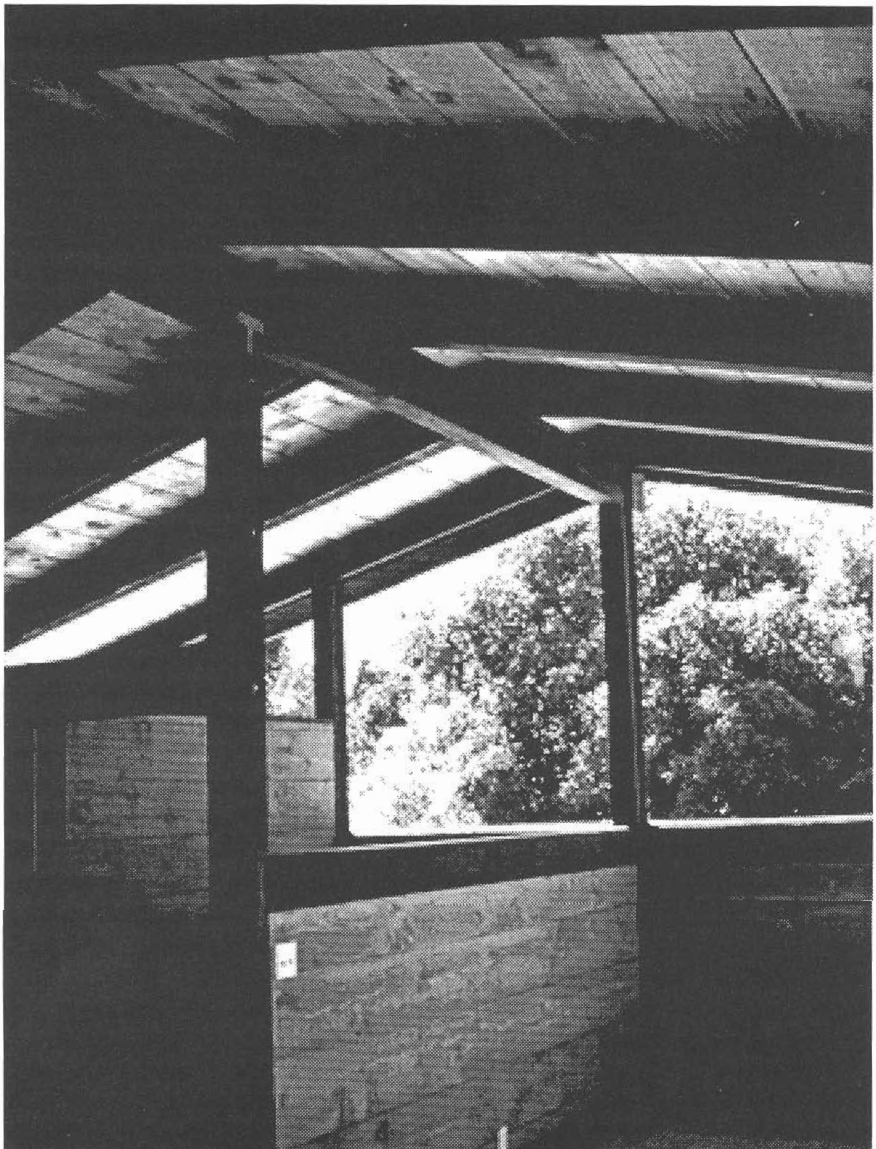

Fig. 9. Inside view of the high temperature treatment at Plantation Estates, Kailua-Kona, Hawaii, 25 July 1995.

Table 8. Summary statistics for the high temperature treatment at Punahele Estates, Kailua-Kona, Hawaii, 28 July 1995.

Location	Height (m)[a]	C/A[b]	Wood dimension (cm)	Rate (°C/min)	Max temp[c] (°C)	Time to 49[d] (min)
Cabinet	0.5	C	1.9 (plywood)	1.44	61.2	33.4
Cabinet floor	0.25	A	—	—	75.9	—

[a]=Height from floor to probe.
[b]=Core (C) or ambient (A) probe.
[c]=Maximum temperature.
[d]=Time required to reach a core temperature of 49°C.
— = No data collected.

locations were monitored: two in a 13.3 X 13.3cm beam in the side wall of the second story (one at floor level and one ca. 2.5m), two in the center 13.3 X13.3cm beam (one at floor level and the other at the junction with the main beam) and the remaining one in the 8.6 X 23.5cm main beam (Figs. 8 and 9). Heating was started at 1005 hours and was terminated at 1330 hours.

In this treatment the fans did not adequately facilitate air movement and the air stratified, with hotter air at the ceiling. The highest temperature at 1m was 66.2°C, while in the peak of the ceiling the temperature reached as high as 85.1°C (Table 6). The ambient temperatures induced relatively fast rates of thermal increase (0.33°C/min) in the large 8.6 X 23.5cm and 13.3 X 13.3cm beams at ceiling level, which reached the target temperature of 49°C in 53 and 55.7min, respectively. The floor level core monitoring locations in the same beams, on the other hand, had rates of thermal increase of 0.13 and 0.09°C/min and required at least an additional 100min to reach 49°C. During this treatment some checking (minor splitting) was observed in the 13.3 X 13.3cm beams which could have been the result of the high ambient temperatures. The slow rate of temperature increase in the 8.6 X 18.4cm ceiling joist (0.13°C/min) as compared to the two upper monitoring locations was most likely the result of heat loss to the outside air being that the joist was monitored close to the outside wall.

Hilo Terrace Apartments

This high temperature treatment took place in a two-bedroom apartment in the Hilo Terrace Apartments, Hilo, Hawaii on 27 July 1995. Fumigation tarps were used to cover the outside exposure of the lanai and a single blower was directed into the lanai from the living room (Fig. 10). Thermistors were placed at floor level to monitor ambient temperatures and were placed in a 8.6 X 8.6cm beam boxed by 2.5cm

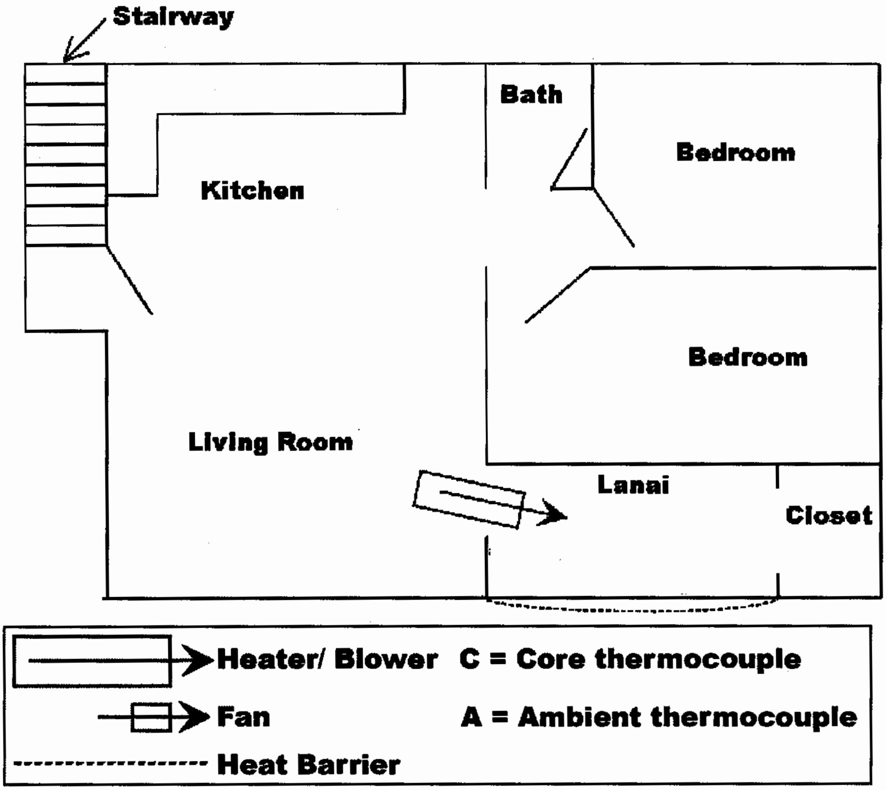

Fig. 10. Overhead drawing of the high temperature treatment at Hilo Terrace Apartments, Hilo, Hawaii, 27 July 1995.

lumber, in a 1.9 X 18.4cm facia, and in a 3.8 X 18.4cm railing to monitor wood core temperatures. The treatment commenced at 1030 hours and concluded at 1300 hours. Rates of temperature increase ranged from 0.18°C/min in a 8.6 X 8.6cm beam to 1.03°C/min in the 1.9 X 8.6cm facia that surrounded the beam (Table 7).

Punahele Estates

The last high temperature treatment observed on the island of Hawaii was on a cabinet constructed entirely out of 1.9cm (3/4in) plywood and located on the lanai of a two-bedroom condominium in the Punahele Estates, Kailua-Kona on 28 July1995. The area of the lanai containing the cabinet was isolated with the use of fumigation tarps and a single blower was placed on the lanai and directed into the isolated area (Fig. 11). Ambient temperature was monitored at ca. 10cm from the bottom of the cabinet and a single core probe was located in the bottom of the

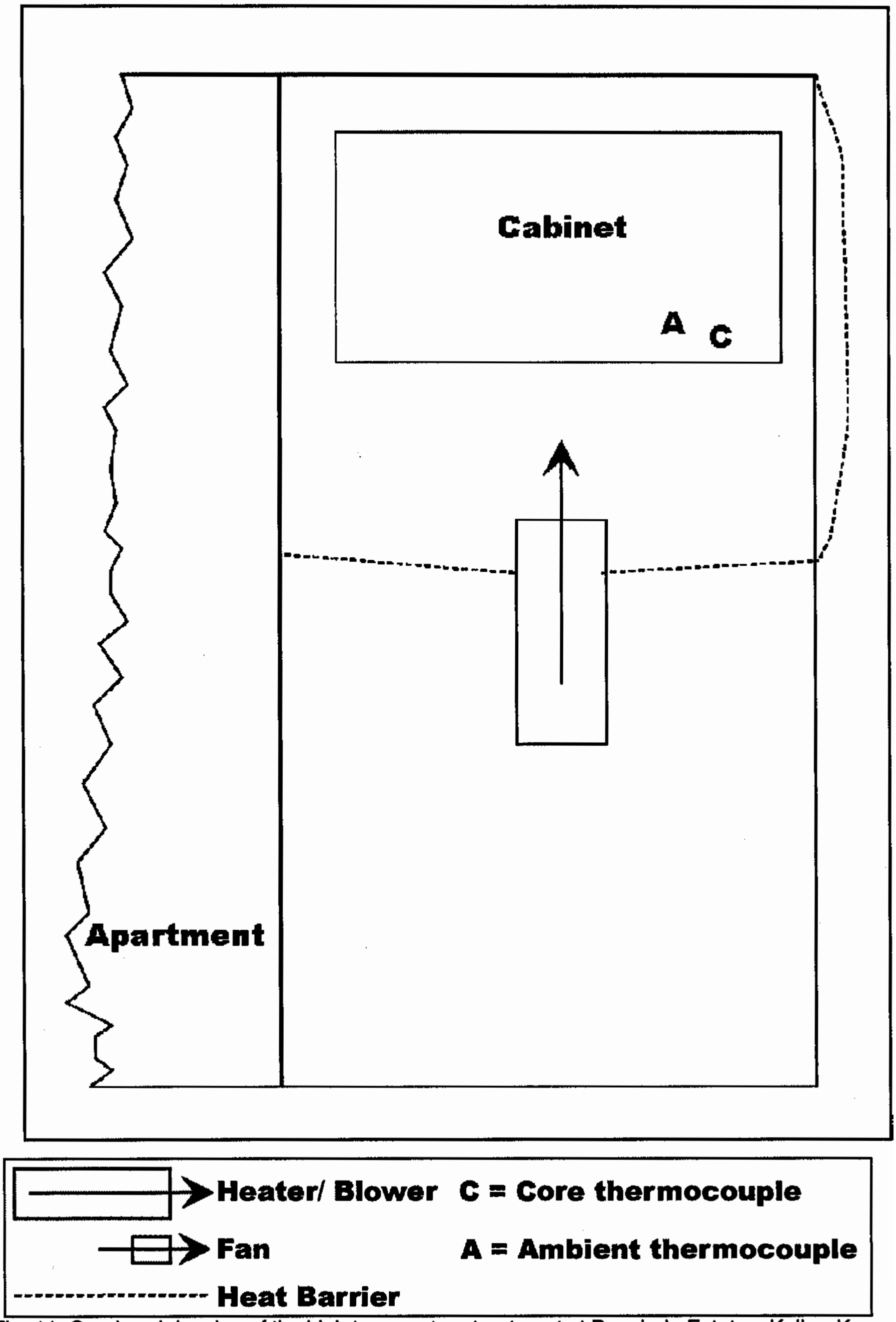

Fig. 11. Overhead drawing of the high temperature treatment at Punahele Estates, Kailua-Kona, Hawaii, 28 July 1995.

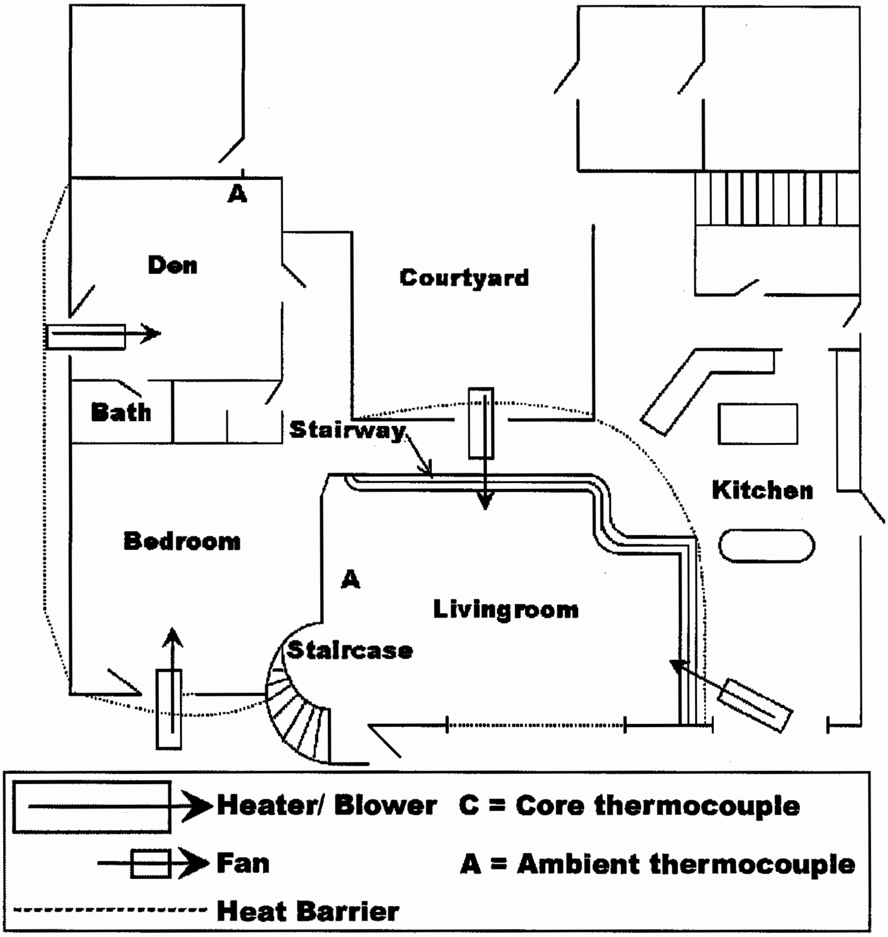

Fig. 12. Overhead drawing of the high temperature treatment at Lahaina, Maui, 11 May 1996.

cabinet in the 1.9cm plywood. The treatment started at 1010 hours and finished at 1040 hours. This treatment produced the fastest rate of temperature increase of 1.41°C/min in 1.9cm plywood and took the least amount of time, 33.4min (Table 8).

Maui

The only treatment observed on Maui was in a two-level home in Lahaina, Maui on 11 May 1996. There were a number of *C. brevis* infestations throughout the structure, most notably in the hardwood flooring. The entire structure was to be treated over a three-day period, and the researcher was granted access during the first day. The area of

Table 9. Summary statistics for temperature data collected during 8 separate high temperature termite treatments in the state of Hawaii.

Variable	N	Mean	SEM[a]	Min	Max
Rate (°C/min)	29	0.28	0.06	0.04	1.44
Max. core temp. (°C)	32	55.12	1.25	39.20	72.30
Time to 49°C (min)	29	98.00	13.70	15.00	300.00
Max. ambient temp. (°C)	18	68.12	1.80	51.80	85.10

[a] Standard error of the mean.

treatment was isolated with the use of fumigation tarps as well as plastic sheeting (Fig. 12). Ambient probes were placed 2m high in the living room and the den. The treatment started at 0935 hours and concluded at 1440 hours.

No wood core temperature data were collected at this site because of the potential damage that would have been caused by drilling into the elaborate inner detailing. Ambient temperatures reached as high as 72.1°C in the living room. During the treatment it was observed that paint was bubbling on one wall, however it was found that the damage was minor and readily repairable.

DISCUSSION

Maximum ambient air temperatures within treated structures ranged from 51.8°C to 85.1°C with a mean of 68.1°C (Table 9). The mean maximum wood core temperature was 55.12°C. The longest time taken to achieve the target wood core temperature of 49°C was 5h.

Minor and repairable property damage was observed during two high temperature treatments. For example, during the treatment on Maui, paint began bubbling on the wall when the ambient temperature reached approximately 72°C. The highest ambient temperature of 85.1°C observed during a treatment on the island of Hawaii (Table 6) resulted in some visible checking in 13.3 X 26.0cm and 13.3 X 23.5cm Douglas-fir beams.

The rates of temperature increase observed in field applications were lower than those used in laboratory studies of the effects of rate on thermal tolerance. As previously mentioned, the lowest rate studied by Scheffrahn et al. (1997) with *C. brevis* was 0.5°C/min. However, during some high temperature treatments in Hawaii, the mean rate of temperature increase was 0.276°C/min, with some rates as low as 0.04°C/min (Table 9). Further studies are needed to assess the impact of rates of temperature increase as low as those measured during commercial treatments.

During two of the high temperature control sessions, it was observed that target treatment temperatures were not achieved at some of the probe locations selected by the researcher, as opposed to the technicians (Tables 3 and 6). This does not indicate that these treatments were ineffective as the goal of the commercial technicians was to monitor temperatures in areas thought to contain drywood termites, whereas the intention of the researcher was to seek out worst case areas in the vicinity of the treatment. Thus, our research objective was to measure thermal dynamics, not treatment efficacy. Having said this, the temperature differences observed between the research and commercial monitoring sites during the field studies indicates that probe placement may be crucial, especially given that large thermal differentials are possible within an individual treatment area. Given the fact that conventional drywood termite detection using physical evidence is far from definitive (Scheffrahn et al. 1993), we suggest that thermal monitoring should be located in worst case areas regardless of the outward evidence of infestation.

Recommended temperatures were achieved in the largest structural members during high temperature control sessions; some of them proximate to potential heat sinks. During the Hawaii Kai session, temperatures were monitored in a 8.6 X 26cm beam on top of a CMU wall (Fig. 2), and during the Plantation Estate session, temperatures were monitored in a 8.6 X 18.4cm ceiling joist that had outside exposure (Fig. 8). In both cases, the rates of temperature increase were quite low (0.09°C/min and 0.13°C/min, respectively); nonetheless, the target of 49°C was met, although requiring as long as 5h (300 min) for the Hawaii Kai treatment (Table 2).

In statistical tests, the only significant factor was degree of lumber exposure ($p<0.005$), which had an effect on the rate of temperature increase. The mean rate of increase for single-sided exposures was 0.19°C/min, while when heated from both sides the mean was twice as high at 0.38°C/min.

These observations demonstrate that the original suggested treatment temperature of 49°C (Ebeling 1994) is readily achievable in worse-case areas within a reasonable amount of time. However, the current practice of placing core temperature probes in specific areas of suspected infestation may be risky considering that large thermal gradients are possible, even within a given treatment area, and current drywood termite detection methods are not perfect. Additionally, minor and repairable property damage is possible if excessive ambient temperatures are utilized during high temperature control sessions. Thus, the efficacy of this non-chemical termite control method can be assured by placing thermocouples in worse case areas and maintaining adequate ambient treatment temperatures to achieve the recommended thermal endpoints while not exceeding safe limits.

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