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Remote sensing for detection of termite infestations—Proof of Concept

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ABSTRACT

This paper reports the results of a search to discover the most cost effective and robust method of detecting *Reticulitermes flavipes* infestations in structural members of remote bridges, homes and other wooden structures and transmitting these results to internet cloud storage thus obviating routine travel to these structures for periodic visual inspections. Duplicate stainless steel tanks were constructed for housing *R. flavipes* colonies and commodity size dimension lumber members. Overall, results indicated that the simplest and cheapest independent variables to measure and send were: temperature (ºC), relative humidity (% RH); dew point (DPºC) and wood moisture content (WPE %) using off-the-shelf commercially available sensor systems. Above ground termite bait stations were determined to be the best method of housing the various sensors to permit ease of subsequent baiting if any termite activity was detected. We conclude that it is feasible and cost effective to monitor valuable wooden structures, like historic covered bridges, against termite infestation and potential structural damage.

Keywords: *Reticulitermes flavipes*, remote sensing, acoustic emission (AE), moisture, gases

This study is part of the Research, Technology and Education portion of the **National Historic Covered Bridge Preservation** (NHCBP) Program administered by the Federal Highway Administration. The NHCBP program includes preservation, rehabilitation and restoration of covered bridges that are listed or are eligible for listing on the National Register of Historic Places; research for better means of restoring, and protecting these bridges; development of educational aids; and technology transfer to disseminate information on covered bridges in order to preserve the Nation's cultural heritage.

This study is conducted under a joint agreement between the Federal Highway Administration – Turner Fairbank Highway Research Center, and the Forest Service – Forest Products Laboratory.

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Forest Products Laboratory Program Manager – Michael A. Ritter, P.E.

1. INTRODUCTION

United States residents spend an estimated $5 billion annually to control termites and repair termite damage: (www.termites.com). Other estimates go as high as $11 billion U.S. dollars annually with another $11 billion for global termite control and remediation (Rust and Su 2012). These numbers are increasing annually, as global climate changes raise worldwide temperatures opening new habitats to termite invasion (Peterson 2010). In many cases termites are not detected until severe structural damage has already been done (Ahmed and French 2008; Arango et al. 2014; Esenther 1969). One factor that might dramatically reduce costs of damage and remediation is early detection combined with remote sensing. The Forest Products Laboratory (FPL) has been investigating remote sensing methods that shorten the time between discovery of termite infestation of buildings and transportation structures and thus elimination of colonies prior to structural damage. A variety of different technologies might be employed for detection, especially in remote areas that make it difficult or impossible to visit for periodic on-site annual inspections. Technologies considered included: a wireless smart probe (Oliver-Villanueva and Abiam-Perez 2013), WiSP acoustic probe (http://www.ecu.edu.au/news/latest-news/2012/08/acoustic-termite-detection: last accessed 04 March 2015), geophonic sound detection (Mankin and Benshemesh 2006), acoustic emission (AE) by accelerometers and radar (Fujii et al. 1999; 2001; Yanase et al. 2003a; 2003b; 2014) and temperature, gas and relative humidity (Mauceri et al. 2010; Yanase et al. 2003b) Key elements of the ideal detection system would be: low cost, simplicity, reliability and the ability to convert the system quickly and easily to termite elimination by baiting following detection (Garcia et al. 2007; Green et al. 2013; Myles 2012; 2013; Osbrink et al. 2011).

The objective of our study was to survey and test a variety of termite detection systems under laboratory conditions in order to evaluate their usefulness in remote locations on covered bridges, buildings or other vulnerable wooden structures in termite prone areas (Phares et al. 2010).

2. EXPERIMENTAL METHODS

2.1 Construction of stainless steel termite tanks

Two identical stainless steel tanks (0.92(w) x 1.5(l) x 0.61(h) meters) were fabricated at FPL and placed into a cement block room in the sub-basement at the laboratory (Fig. 1).

Figure 1: Tanks for testing *R. flavipes* invading pine beams.

2.2 Observations on acoustic emission (AE) and released gases

Acoustic emission vibrations were recorded in the stainless steel tanks using the AED-2010L (Acoustic Emissions Consulting). The low frequency Model SP-1 probe provides an acoustic range of detection from 1-50 kHz. (see Fig 2. A & B). The AED-2010 allows the operator to hear the "pops" which indicate termite activity. The amplified AE signal was output and captured using high speed DAQ for computer graphing and analysis. Four locations were monitored and a direct correlation between radar detection of termites and acoustic emissions was confirmed (Yanase 2003b).

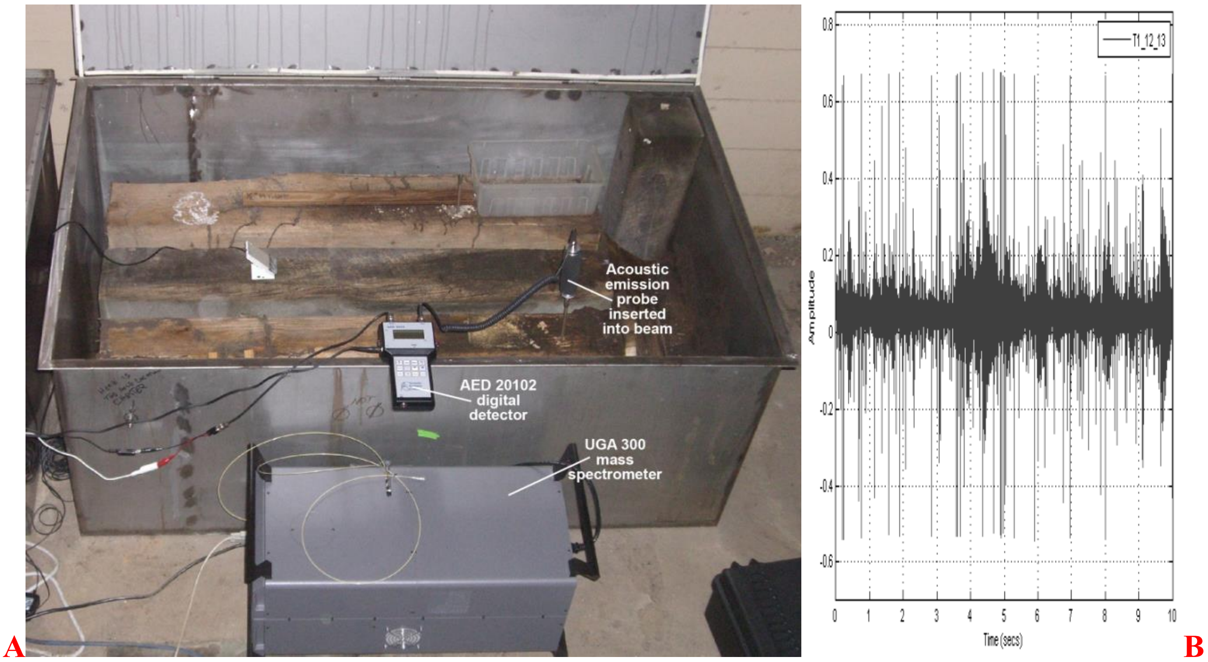

Figure 2: Termite tank (A) for testing acoustic emissions signals to establish an AE fingerprint (B) of *R. flavipes* invading red and Southern pine members.

In addition, gas analysis of air inside the termite tanks was performed using a Stanford Research Systems UGA300 Quadrapole Mass Spectrometer (Fig. 2). The mass spectrometer sampled a small amount of gas from a port on each tank, ionized it, then measured the mass to charge ratio of the ions present. This produced a mass spectrum of all of the gases present in the system (a graph of mass to charge ratio vs. relative abundance). With careful calibration, the partial pressures of the gases present in the system were then calculated from the mass spectrum using a least squares algorithm. In this set of experiments the machine was calibrated using room air. This is appropriate because the major gases of interest are present in room air, and measurements showed deviations from room air. To quantitatively measure gases like methane or hydrogen, which are not present in large amounts in room air, a separate calibration gas would be required. The results of these initial experiments showed that there was a significant amount of CO_2 (+6.28%) being produced inside of the tanks and a corresponding amount of O_2 (-4.81%) being consumed. This is consistent with the results expected from termite metabolism. However, it was not certain that all the changes were the result of termite activity, or if other biological decay activity was playing a role in altering the gas composition of the stainless steel tanks (Yanase et al. 2003b).

2.3 Collecting and maintaining termites

Reticulitermes flavipes (Kollar) were captured in corregated cardboard in Janesville, Wisconsin and transferred to stainless tank #1 housing 3 different specimen sizes of untreated red or Southern pine beams, each 1.2m in length at three different dimensions to mimic structural bridge members in the field. Captured termites were released with commercial sand and soil from the colony sites into both tanks. Using trap and release methods, it was estimated that there were 8,000-10,000 workers in each tank. Colonies quickly adapted to the sealed tanks and the relative humidity remained over 99% RH over the course of testing as measured by moisture meters. Termite detection was evaluated once the termites migrated from the cardboard and began feeding on the wood specimens.

2.4 Observations using wireless temperature and relative humidity sensors

For remote sensing the Omnisense system was used. Wireless battery operated-sensors monitored relative humidity and temperature in the chamber. The sensors wake up periodically and relay data to a base station connected to the internet cloud. That base station communicates through the internet with the cloud storage maintained by Onminsense. Our system used local University of Wisconsin-Madison internet resources with a firewall, but for fully remote applications it is possible to use a cellular phone to maintain an internet connection [https://www.omnisense.com/]. Batteries last approximately one year.

3. RESULTS AND DISCUSSION

3.1 Measurements of acoustic emissions (AE)

For approximately one calendar year, continuous readings of acoustic emissions were monitored from stainless tanks 1 and 2. Methods to increase and refine the AE signal produced by the termites during wood consumption were explored. The best AE response resulted from the combined use of AED-2010L and piezoelectric probe-sensor Model SP-1L (Figs. 3-4) from Acoustic Emissions Consulting (AEC) with the pre-amp built into the probe. Although detection of termites using AE was successful in this study, we determined that the cost, complexity and sensitivity of the system were not well-suited for the rigors of remote field monitoring. Head-banging in *R. flavipes* was not detected, but has been previously shown to be a long distance distress and warning signal made by rapidly banging mandibles in Formosan soldier termites (Fink et al. 2006). The focus was gradually shifted to less expensive and more robust detection methods (Maurceri et al. 2010). The graph shown in Fig. 3 is a record of "hits" over time. A "hit" occurs when the amplitude of the AE signal rises above a set threshold defined in the AEC device. A comparison of the two AE readings in Figure 4 illustrates that termites can be readily detected by AE hits. We were unable to devise any simple system to transmit AE signals to the internet cloud.

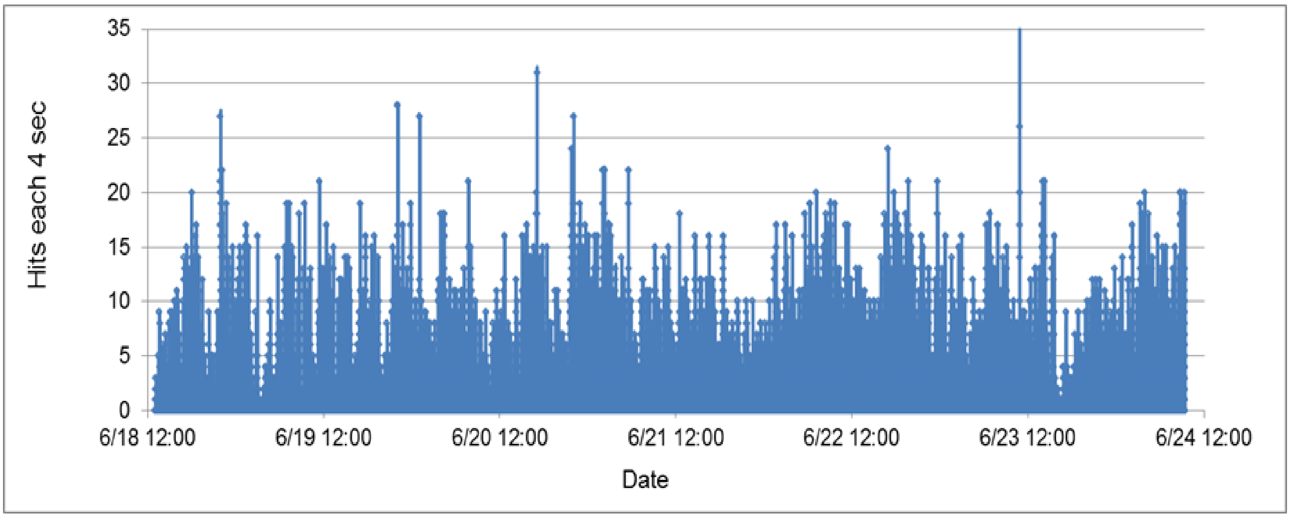

Figure 3: Termite activity every 4 seconds for one week using both workers and soldiers. We tested only a very small block of wood to have better control over the number and castes of termites exposed to the wood. Note: Head-banging of *R. flavipes* soldiers was not detected.

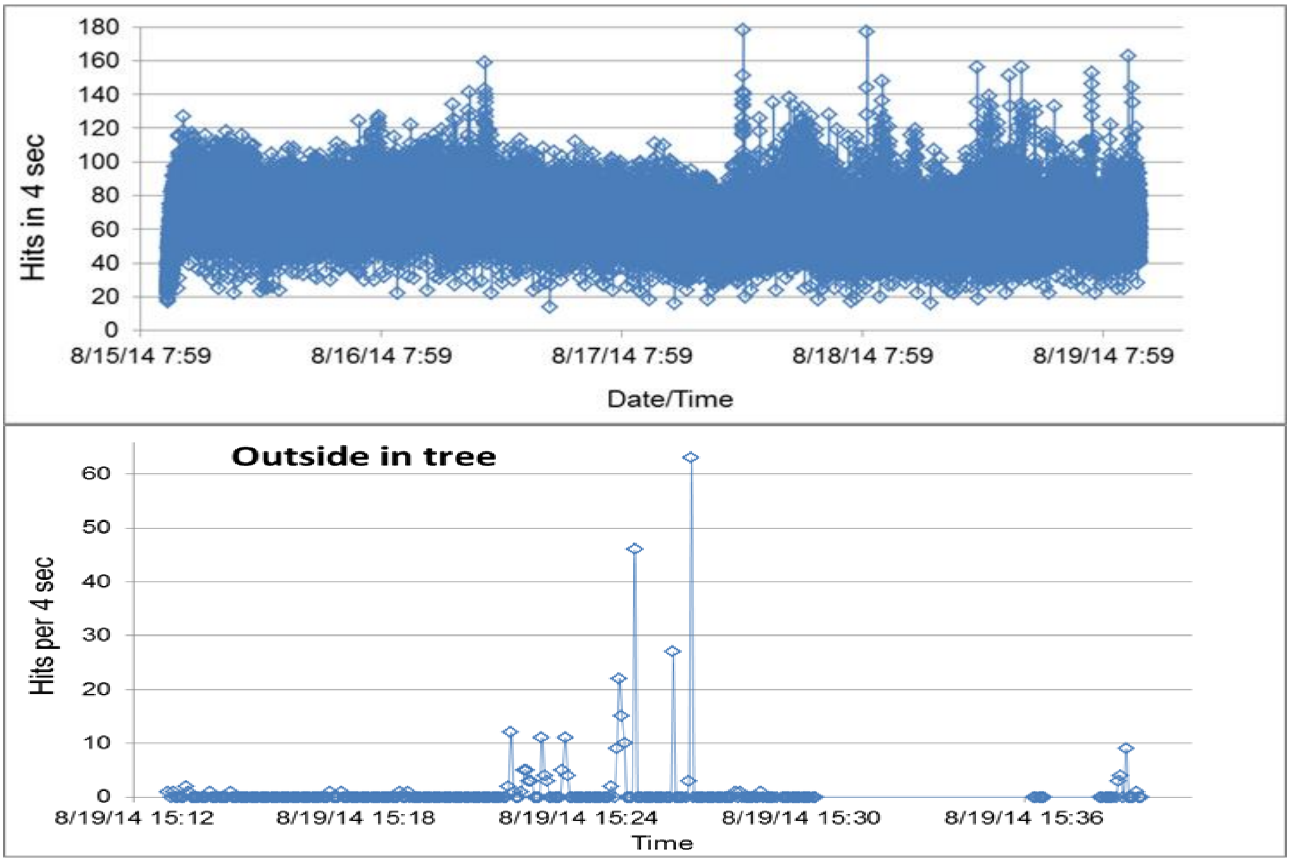

Figure 4: AE hits with the detector hooked to a beam inside in indoor termite tank vs. outside FPL in a tree. The differences in signal frequency and number of hits/sec are striking and would be easy to distinguish in real time and in-situ situations as long as the site remained as quiet as the tree at the start of AE detection. [The spikes in the lower graph were user induced to test the sensitivity of scraping the tree bark]

3.2 Omnisense Remote sensors detect temperature, relative humidity and wood moisture content.

The OmniSense Facility Monitoring System (FMS) provides a user friendly interface to the OmniSense Database Server (ODS). Two above ground bait stations were installed on the top of the lid on stainless steel tank #1 and an access hole drilled thru each to connect with the termite colony below. A remote sensor was added to each bait station (Fig. 5). A typical termite installation or tank will generate about ~700 sensor data points per day. The ODS checks each data point against user settable alarm thresholds, and permanently stores the data point and its context including the sensor ID, Network ID, and time it occurred. The website combines sensor data points into tables and graphs. Increased humidity in Biochamber 2000L following invasion in the stations by *R. flavipes* from the main tank was observed (Fig. 6). The data captured by the wireless sensor relays information to a base station that is connected to the internet. Periodically the sensor "wakes up" and sends data to the base station which then relays the data to the internet cloud storage maintained by Omnisense so that it is available on their Web site (Sandberg et al. 2011).

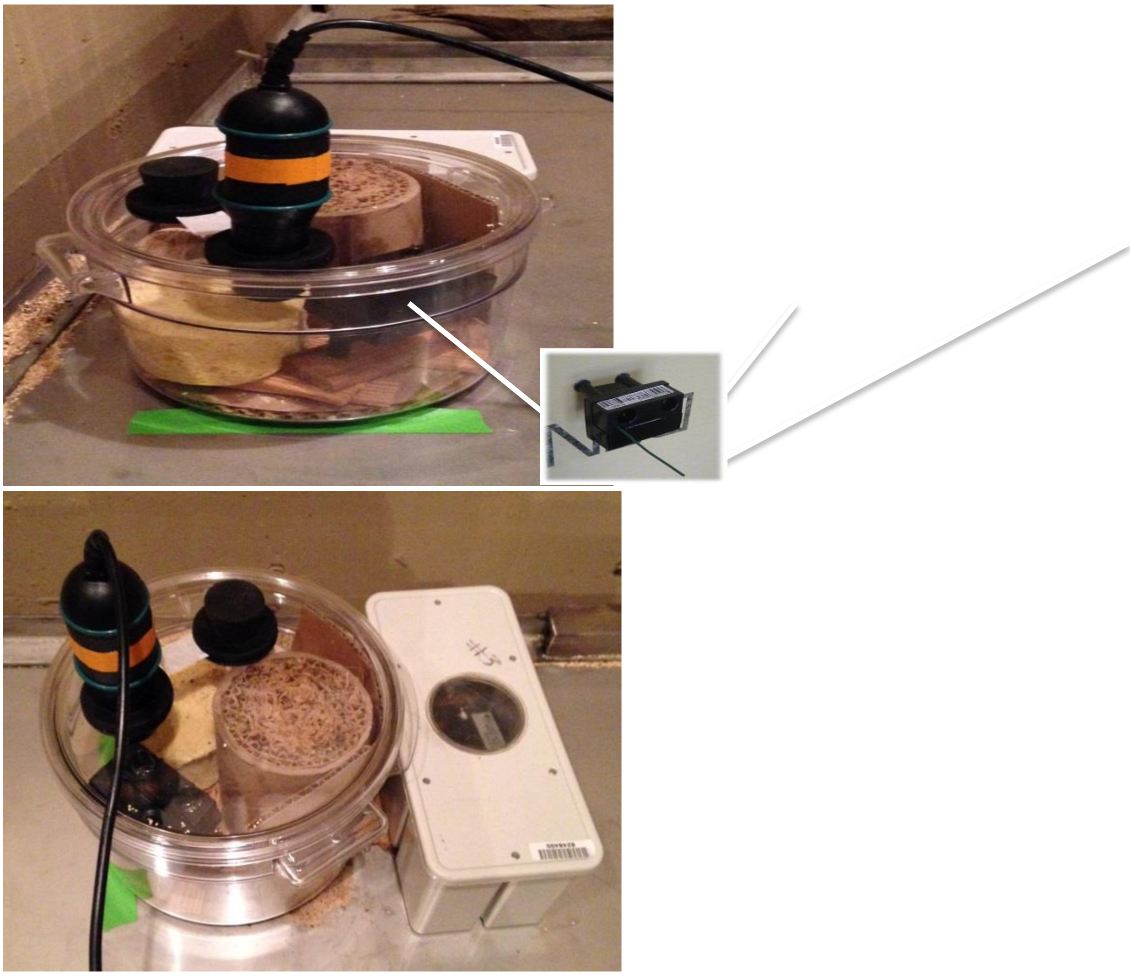

Figure 5: Two external, above ground termite bait stations each contain the Omnisense Remote Wi-Fi sensor (inset), which tracks relative humidity [% RH], temperature, and DP % 24 hours a day as the parent termite tank adds these bait stations into the colony domain and begin to consume the substrates. Data can be downloaded from Internet and graphed as shown by % RH, T C^0 and WME % shown below in Figs. 6, 7 & 8.

Over the period from 2/7 to 2/13/2015 Omnisense detectors showed varying changes in % RH in the two above ground (AG) termite stations (Fig. 6). The round clear 2L plastic AG-station (blue line) and the rectangular grey AG-station (orange line) differ in that the latter has only been invaded by termites for less than one week. Figures 7 and 8 illustrate the dramatic changes in temperature and WME % detectible in the presence of invading termites into the above ground bait stations. WME % is the same as wood moisture content of the wood bridging the two pins of the Omnisense sensor.
In addition, the Omnisense sensors (S-16 and S-900) have the capacity to be screwed directly to the structural wooden members to measure WME % continuously if warranted, which could provide advanced warning for both decay and termite attack.

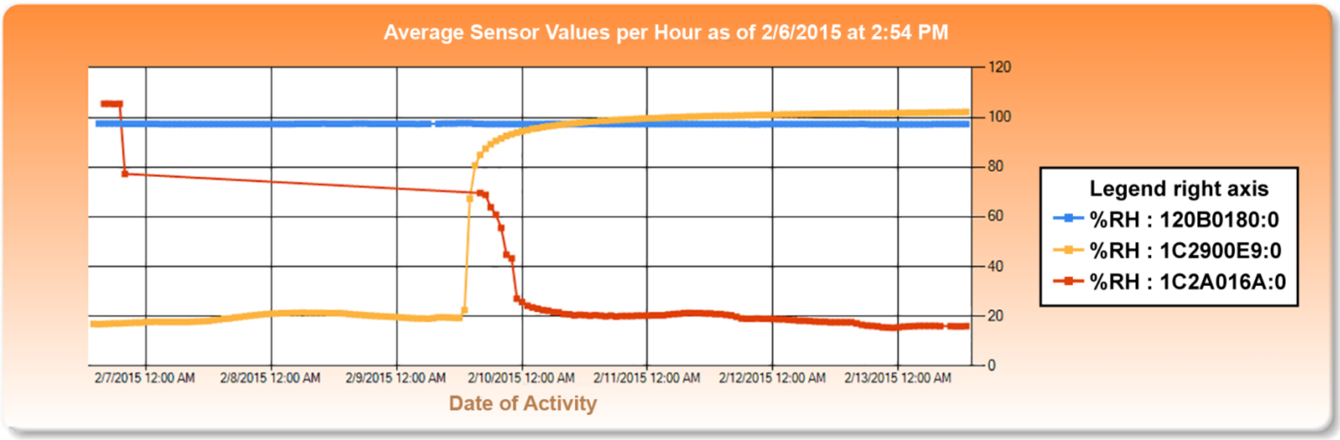

Figure 6: Changes in relative humidity in the two external above ground bait stations shown above in Fig 5. The red line (IC2A) illustrates the low humidity exterior to the stainless tanks on 2/13. The yellow line is sensor 120B in the clear Biochamber and the blue line is sensor IC29 in the grey plastic above ground Exterra station--% RH =~100%.

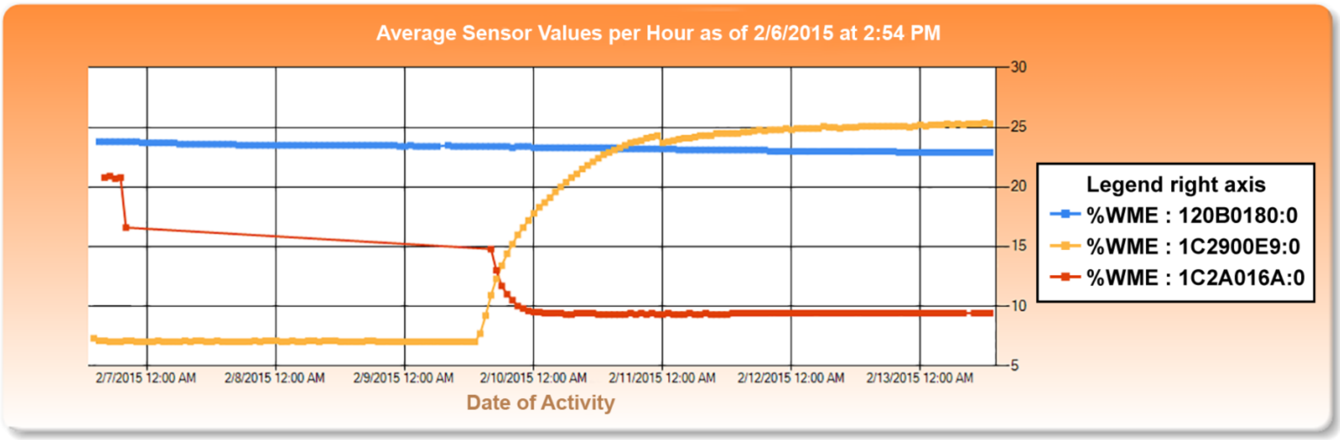

Figure 7: Wood Moisture Equivalent of the plywood insert on the Omnisense remote sensors which shows circa 24-25% on the infested above ground stations and less than 10% on the control room sensor 1C2A.

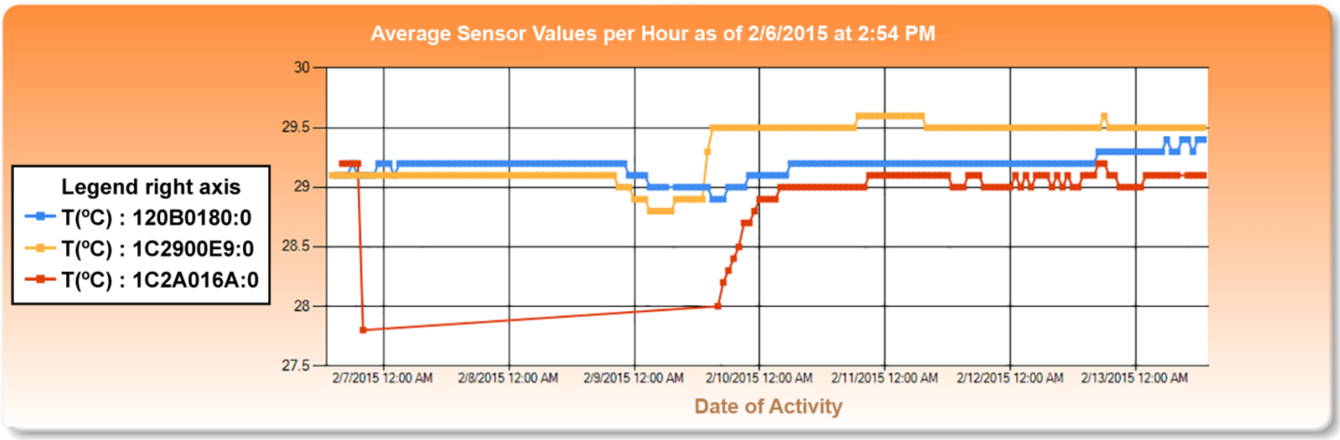

Figure 8: Data compiled from Internet data shows similar temperature of the 3 remote sensors: yellow line = Biochamber 2L; blue line = grey AGS in Fig. 5 and the red line = room temperature nearly equal.

4. CONCLUSIONS

Although the AE system readily detected termite activity using the AED-2010L and piezoelectric probe-sensor Model SP-1, we decided that this technology, while good for on-site inspection was unnecessarily cumbersome, complex and expensive for remote detection of termites, and also less than ideal due to the very high sensitivity of the system and potential for false AE readings from wind, weather and traffic false external signals. For these reasons it was decided that off-the-shelf technology with built in Wi-Fi sensor system and nationwide reporting access via internet cloud would be preferable in the long run. As can be seen in the graphs above termite bait stations quickly rise from 19 to 100% RH after colonization by *R. flavipes.* After three months of testing the Omnisense system it was determined to be preferable to use in place of AE technology. Wood moisture content (WME %) also gave good separation of readings from room conditions and bait stations after infestation, and more than doubled after termite invasion of the bait stations. We conclude that these parameters and sensors represent the best fit for early remote detection and elimination of termites in wooden structures.

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