The reuse of discarded plastic water bottles as an insulating material for external walls in buildings

E Mousakhani¹, A Simons², D Harris, M Yavarkhani, and A Anvari

¹MBC Graduate, BSCI, Auburn University, US
²Assistant Professor, BSCI, Auburn University, US

Email: ellisap@auburn.edu

Abstract. The thermal conductivity of exterior wall insulation affects the overall energy consumption of a given building. Fiberglass insulation is often used for this application. This research investigated the feasibility of replacing typical fiberglass insulation with used empty Polyethylene Terephthalate (PET) bottles. In addition to potential cost savings, replacing fiberglass insulation with PET bottles on a large scale could help alleviate the environmental impact of sending these bottles to landfills. A small 8-inch by 8-inch wall section constructed with sheet metal and drywall was used for testing, maintaining a 3-inch airspace for proposed insulation. Thermal resistance was measured with the airspace packed with empty water bottles and comparisons were made to the same wall sections void of any water bottles. Testing was conducted both with and without a ½-inch foam board present for comparison. Kapton heaters and temperature sensors were used for the simulation. Preliminary testing showed promise for the proposed application. The effectiveness of the plastic water bottles at providing insulation properties increased with decreasing voltage in both test setups (both with and without the foam board) and was most effective when the foam board was present. Further research is needed to determine how the use of PET bottles for exterior wall insulation can be implemented on a larger scale and how R-values can be improved.

1. Introduction and background

Large amounts of waste are generated throughout the world on a daily basis with the amount of disposable products rising rapidly each year. In particular, there has been a fast growth in production of plastic materials in recent years. Plastic production has increased from 1.5 million metric tons in 1950 to 368 million metric tons in 2019 [1]. In the case of Polyethylene Terephthalate (PET) bottles specifically, global production reached 485 billion PET bottles in 2016, forecasting to touch 583.3 billion bottles in 2021 [2]. Although recycling rates of PET bottles have increased in many countries [3], plastic production has greatly outpaced recycling efforts. It is presumed that many unrecycled PET bottles will be damped at the environment, which will consequently lead environmental and health issues.

Several studies have examined using waste materials in new building construction. One study demonstrated that environmental concerns prompt many of us to seek environmentally friendly alternatives, as we explore green alternatives, and seek to respect our ecology by utilizing plastic bottles as a building material [4]. Many times, further processing is needed for waste material to be properly recycled. The research lists three types of recycling technology, including reuse production, mechanical...
recycling, and chemical recycling [5]. While recycling technology is necessary for many applications, some studies propose that recycling technology may not always be economically valuable [6].

Much research has been devoted to the use of recycled materials in various construction applications, both with and without the use of recycling technology. One study tested the usage of lower grade recycled PET bottles, using a mechanical recycling method, to produce a so-called PET brick [7]. A product called Heatlok Soya serves as spray foam insulation is created from plastic bottles and soy beans by first converting the bottles into liquid and the soy beans into oil [8]. Other studies have evaluated the use of PET bottles to replace concrete block. One study found that concrete block containing PET bottles could structurally and thermally be utilized as a building unit, replacing traditional concrete blocks [6]. Another study found that concrete block packed with empty water bottles showed a 57% increase in compressive strength compared to hollow block of the same size [9]. These studies combine to show promising and practical usefulness of an increasingly abundant waste product.

Most buildings require insulation materials be used for all external walls. The usual approach is to use batt, foam, or other insulation in the air space between the inner wall material (typically drywall) and exterior wall sheathing (typically plywood or foam board). These two surface materials are attached to the internal studs (made of lumber or steel). The spacing between the studs create air pockets that span across the studs at the thickness of the studs (i.e. 2 to 4 inches) and extend the entire floor to ceiling height. The air space this geometry forms is a significant portion of the overall surface area between the inner surface and the external wall surface. This air space offers very little resistance to heat flow and is typically insulated using a fiberglass insulation. The study presented herein sought to evaluate the usefulness of discarded water bottles (PET bottles) as an insulation material for exterior wall applications.

2. Research objective and methodology
The objective of this research was to gauge the effectiveness of using empty plastic water bottles as insulation material for exterior building walls. This objective was accomplished by comparing the increased thermal resistance of a test wall packed with empty water bottles in relation to an empty air space under the same conditions. A simple composite wall section for testing was fabricated whereby a 3-inch wide inner air space was sandwiched between two 3/8-inch drywall panels. The testing section also allowed for a ½ inch section of foam board to be placed between the airspace and the drywall panel facing the laboratory ambient air. The section was 8-inches by 8-inches square and was constructed using a L-channels fabricated from sheet metal and fastened by rivets. The composite wall test section is shown in Figure 1 below.

Figure 1: Composite wall test section with foam board
One of the drywall panels was exposed to the laboratory air while the other drywall panel was insulated and had thin film Kapton heaters attached on its external face. The entire test section was then instrumented with RTD temperature sensors on the two external drywall faces. The entire test section was then insulated from the external laboratory environment except for the exterior face opposite of the heaters. The testing approach was to apply heat to the inner insulated face thereby forcing all the heat to have to travel through the stack, including the airspace, and onto the external side of the exposed drywall face. The heat would be removed by natural convection off of the exposed face and into the laboratory air. Once the test section was thermally settled (usually 24+ hours), the temperatures of the inner and outer drywall faces were recorded versus the amount of heat applied by the Kapton heaters. The ratio of the temperature difference over that of the heat being applied provided a direct measurement of thermal resistance. Several power levels were tested for both conditions of an empty inner airspace and an airspace packed with empty water bottles. This comparison was done for both arrangements of having the foam board in place and without the foam board present. Therefore, there are four arrangements that were tested as follows:

- Arrangement A – Packed airspace with the foam board present
- Arrangement B – Empty airspace with the foam board present
- Arrangement C – Packed airspace with no foam board
- Arrangement D – Empty airspace with no foam board

Figure 2 below shows the testing setup with insulation, power source, and sensors.

3. Results and discussion
The four arrangements (A-D) described above were tested over three separate power levels. Two arrangements (A&B) included foam board in the wall section stack up while two other arrangements (C&D) did not include the foam board. Measurements and comparisons were made between these arrangement pairs when the air space was filled (A&C) and un-filled (B&D) with the empty water bottles. These arrangements and the results are shown in Table 1 below.
Table 1: Test results

| Foam Bottles | Volt | Amps | Power | Flux | RTD1 | RTD2 | AT | U | DU | R | R* |
|--------------|------|------|-------|------|------|------|----|---|----|----|----|
| **Arrangement A** | | | | | | | | | | | |
| Test 1 | 9.69 | 0.006 | 0.058 | 1.408 | 110.23 | 26.6 | 108.22 | 21.4 | 5.22 | 0.011 | 0.27 | 89.80 | 3.71 |
| Test 2 | 13.00 | 0.009 | 0.117 | 2.833 | 111.79 | 30.6 | 108.35 | 21.7 | 8.94 | 0.013 | 0.32 | 76.37 | 3.15 |
| Test 3 | 20.00 | 0.140 | 2.800 | 67.80 | 116.45 | 42.7 | 108.79 | 22.8 | 19.80 | 0.141 | 3.41 | 7.11 | 0.29 |
| **Arrangement B** | | | | | | | | | | | |
| Test 4 | 9.69 | 0.006 | 0.058 | 1.409 | 110.05 | 26.1 | 108.38 | 21.6 | 4.47 | 0.013 | 0.32 | 76.84 | 3.17 |
| Test 5 | 13.00 | 0.009 | 0.117 | 2.833 | 111.40 | 29.6 | 108.48 | 21.8 | 7.79 | 0.015 | 0.36 | 66.60 | 2.75 |
| Test 6 | 20.00 | 0.140 | 2.800 | 67.80 | 115.71 | 40.8 | 108.83 | 22.9 | 17.87 | 0.157 | 3.79 | 6.38 | 0.26 |
| **Arrangement C** | | | | | | | | | | | |
| Test 7 | 9.70 | 0.006 | 0.058 | 1.409 | 109.90 | 25.7 | 108.43 | 21.9 | 3.82 | 0.015 | 0.37 | 65.60 | 2.71 |
| Test 8 | 13.00 | 0.009 | 0.117 | 2.833 | 111.24 | 29.2 | 108.87 | 23.0 | 6.16 | 0.019 | 0.46 | 52.61 | 2.17 |
| Test 9 | 20.00 | 0.140 | 2.800 | 67.80 | 114.53 | 37.7 | 109.59 | 24.9 | 12.83 | 0.218 | 5.28 | 4.58 | 0.19 |
| **Arrangement D** | | | | | | | | | | | |
| Test 10 | 9.70 | 0.006 | 0.058 | 1.409 | 109.66 | 25.1 | 108.40 | 21.8 | 3.27 | 0.018 | 0.43 | 56.23 | 2.32 |

Table 1 provides the three different Voltages used and associated Ampere in each stage. From the values given here, the amount of provided Power (W) (Power = Volt x Amps) and Heat Flux (W/m²) (Heat Flux = Power / Area) have been calculated based on the known sample area (8" x 8" or 0.2023 m x 0.2023 m). The next column states Resistance of RTD (ohm or Ω) and Temperature (°C) over the inner and outer drywall faces. The right side of Table 1 shows the Temperature Difference over inner vs outer face (ΔT). Thermal Conductivity (U) is the inverse of R and indicates how well the element conducts heat or the rate of transfer of heat (in watts) through one square meter of a sample. Finally, R-value (or Thermal Resistance) is calculated by Temperature Difference times Area per Heat Transfer flow rate (or Heat Flux).

During testing, an IR Camera was used to capture a thermal infra-red image of the face exposed to the laboratory air. These images were taken at the completion of each thermal soak, lasting 24 – 48 hours, and included all 12 tests (3 tests for each of the 4 testing arrangements). Figure 3 (a)-(l) show these IR images at the end of thermal soak (thermal equilibrium). The thermal images shown in Figure 3 help to visually illustrate the numerical findings included in Table 1.
While the experimental results, including calculated values, are included in Table 1 above, the authors sought to determine the insulation value gained from the addition of water bottles on a numerical and a percentage basis. Table 2 below provides the percent increase in R-value for each test setup (with and without foam board) at each of the 3 experimental voltages.

| Voltage | △R (C-D) (with Foam Board) | % Increase in R | △R (A-B) (without Foam Board) | % Increase in R |
|---------|-----------------------------|-----------------|------------------------------|-----------------|
| 9.70    | 0.54                        | 17.0%           | 0.39                         | 16.8%           |
| 13.00   | 0.40                        | 14.5%           | 0.21                         | 10.7%           |
| 20.00   | 0.03                        | 11.5%           | 0.01                         | 5.6%            |

As shown in Table 2, the plastic water bottles provided greater insulation value (R-value) at lower voltages (i.e. lower temperatures). Additionally, the increase in R-value with the addition of plastic water bottles was greater when foam board was present in the testing setup. Generally, the effectiveness of the plastic water bottles at providing insulation properties decreased with increasing voltage in both setups, but even more so when the foam board was not present. The greatest increase in R-value (0.54 or 17%) was found with the foam board present at 9.7 Volts while the smallest increase in R-value (0.01 or 5.6%) was found at 20 Volts in the absence of foam board. It is evident that the foam board and water bottles worked together to provide greater and more sustained insulation properties.

4. Conclusions and recommendations

Results of this study indicate that discarded plastic water bottles can contribute to insulation value for exterior building walls, thus providing construction cost savings and reducing environmental waste. Each test setup (with and without ½ inch foam board insulation) exhibited an increase in R-value with the addition of empty plastic water bottles at each test voltage (9.7 Volts, 13 Volts, and 20 Volts). The effectiveness of the plastic water bottles at providing insulation properties increased with decreasing voltage in both test setups. Additionally, the water bottles were more effective at providing insulation properties (i.e. greater R-value) when the ½ inch foam board was present in the sample. The greatest increase in R-value (0.54 or 17%) was found with the foam board present at 9.7 Volts while the smallest increase in R-value (0.01 or 5.6%) was found at 20 Volts when the foam board was not present.

This study is limited to the test setup utilized, including size and makeup of the test specimen and specific voltages utilized. Future research should examine larger air spaces (allowing room for a larger amount of water bottles) and alternative insulating materials which may be used in conjunction with discarded PET bottles to reduce cost while contributing to sustainability. Further research should also determine how the use of PET bottles for exterior wall insulation can be implemented on a larger scale and other ways in which R-values can be improved.
5. References

[1] Statista 2021 Production of plastics worldwide from 1950 to 2019 (in million metric tons) https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/

[2] Tiso I 2021 Global PET bottle production 2004-2021 https://www.statista.com/statistics/723191/production-of-polyethylene-terephthalate-bottles-worldwide/#statisticContainer

[3] Welle F 2011 Twenty years of PET bottle to bottle recycling-An overview Resources, Conservation and Recycling 55 865-875 https://www-sciencedirect-com.spot.lib.auburn.edu/science/article/pii/S0921344911000656?via%3Dihub

[4] Writer C 2011 Best of eco-friendly homes built with recycled material https://greendiary.com/2011-eco-friendly-homes-built-recycled-material.html

[5] Hamad K, Kaseem M, and Deri F 2013 Recycling of waste from polymer materials: An overview of the recent works. Polymer Degradation and Stability 98 2801–2812 https://doi.org/10.1016/j.polymdegradstab.2013.09.025

[6] Mansour A and Ali S 2015 Reusing waste plastic bottles as an alternative sustainable building material. Energy for Sustainable Development 24 79–85 https://doi.org/10.1016/j.esd.2014.11.001

[7] Nováková K, Šeps K, and Achten H 2017 Experimental development of a plastic bottle usable as a construction building block created out of polyethylene terephthalate: Testing PET(b)rick 1.0 Journal of Building Engineering 12 239–247 https://doi.org/10.1016/j.jobe.2017.05.015

[8] Greer S 2007 New priorities prompt innovation in materials Toronto Star https://eds-b-ebscohost-com.spot.lib.auburn.edu/eds/detail/detail?vid=9&sid=b5190063-30ca-4d70-85c2-abced7bf6de8%40sessionmgr102&bdata=JnNpdGU9ZWRzLWxpdmUmc2NvcGU9c2l0ZQ%3d%3d#AN=6FP3166209003&db=pwh

[9] Safina S and Alkalbani A 2016 Use of recycled plastic water bottles in concrete blocks. Creative ConstructionConferencehttps://www-sciencedirect-com.spot.lib.auburn.edu/science/article/pii/S1877705816339534?via%3Dihub