A comparison of curing rates for insulated and non-insulated concrete

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INTRODUCTION

During the spring of 2014, Hampden-Sydney College agreed to accept the generous donation of an Alumnus to construct a new building on the campus now referred to as the Energy Research Laboratory (ERL) using revolutionary materials and unconventional building practices. The purpose of the building is to provide a mechanism to stimulate faculty/student research at the college in the areas of sustainable construction and low energy consumption for heating and cooling. The sustainable construction has been accomplished by using poured concrete containing stainless steel fibers[1] for both the floor and the walls. It is believed that this building will be able to survive a direct hit from a category F5 tornado, a massive earthquake, or a large explosive blast. It is hypothesized that small energy requirements for the building will result because of the extremely large thermal mass of the concrete walls coupled with specialized foam insulation encasing the concrete.

It was understood by the company that developed the insulated concrete design (TF Systems[2]) and poured the walls of the ERL that the foam insulation resulted in higher concrete temperatures as the concrete cured compared to conventional concrete walls without any insulation. This paper describes our techniques and results for measuring the concrete curing temperature over the period of a week for both the non-insulated slab floor and the insulated walls. We found that not only did the temperature of the insulated walls become significantly hotter than the floor, but the walls also displayed a smoother rate of temperature variation as the concrete cured.

Methods

The Energy Research laboratory (ERL) at HSC has interior dimensions of 45 feet long, 26 feet wide and 12 feet high. The floor is a conventional slab floor consisting of concrete that is six inches thick poured on top of compacted earth, small sized aggregate, and rock dust. There is a six millimeter plastic vapor barrier isolating the slab from the rock dust. The slab is enclosed by a previously poured "frost wall", which supports the weight of the concrete walls. We used the Onset HOBO UX120, 4-channel data logger to record[3] temperatures at ten-minute intervals. We also made four thermocouples using the J-type materials and connected them to the data logger. Three of the thermocouples were used to measure the curing temperatures of the slab and one was used to measure the ambient air temperature. Two others were placed near both the beginning and ending of a PEX zone. Another thermocouple was attached to the wire mesh at a location that was not near the PEX. Figure 1 below shows the experimental setup before the slab was poured

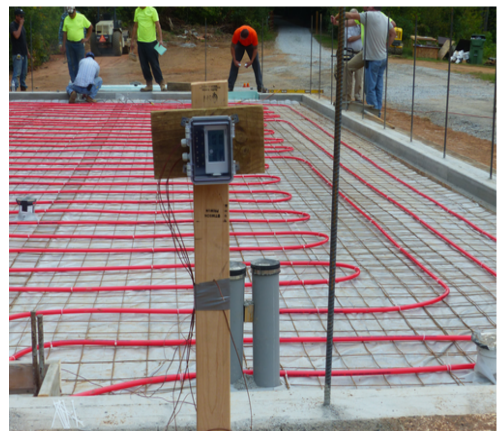

Figure 1: The experimental setup showing the temperature data logger and several thermocouples prior to pouring the concrete slab.

In this figure you can see the height of the frost walls, the Onset temperature logger positioned near the slab, and the thermocouples. The thermocouple measuring the ambient temperature was located near the gray duct tape on the post. While the concrete slab was being poured, a worker would pull the mesh up so the PEX tubing was about two inches below the top surface of the concrete once it had solidified. The pour began at about 10:30am on a sunny day and the three thermocouples were covered in concrete early in the pour. We measured those three temperatures, as well as the ambient air temperature, for eleven days as the concrete cured.

The walls were poured several weeks later to give the slab suitable time to cure. Special concrete forms developed by TF Systems were brought into the HSC building site. A knowledgeable crew of five construction works spent several days putting the forms and insulation in place. Once the forms were positioned we located seven thermocouples at various locations throughout the walls. The following lists the locations of the thermocouples used in this experiment, all of which were all located on the northern wall. The outside of the wall faces to the north and the inside of the wall faces south.

- Probe 3 was located one foot above the slab in the center of the wall
- Probes 4, 5, and 6 were attached to a fiberglass rod that traverses the wall thickness and located four feet above the slab
- Probe 4 was located 1 1/4 inches from the outside of the wall.
- Probe 5 was located in the center of the wall
- Probe 6 was located two inches from the inside of the wall
- Probe 7 was located on the PEX tubing in the center of the wall
- Probe 8 was located on a cross tie, three inches from the inside wall
- Probe 9 was located in the center of the wall, one foot from the wall top
- Probe 10 was used to measure the ambient temperature

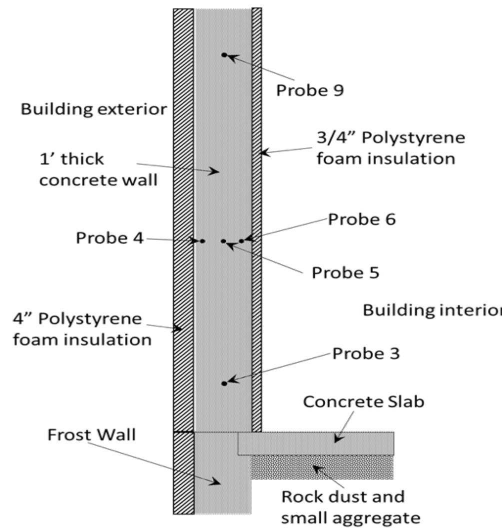

Figure 2: Cross section of the concrete wall, frost wall, and slab showing the locations of some of the temperature measuring probes.

The walls were poured with the help of a forty-foot concrete pumper truck as shown in Figure 3. The TF Systems contractor took special care when pouring the walls so the thermocouple locations were not disturbed with the flowing concrete. The pour began at 10:30 and lasted until 2:00. Once the walls were poured the thermocouples were connected to the Onset temperature loggers and the temperatures of the probes were sampled every ten minutes for approximately two weeks. The TF Systems forms were dismantled a day after the walls had been poured.

The ambient temperature probe was just a thermocouple dangling near the wall in the construction zone. Therefore, it was prone to tampering. Upon review of the data, we noticed that the temperatures recorded by that specific thermocouple were significantly inaccurate. This was likely caused by the probe shifting due to the chaotic environment it was exposed to. In order to correct these ambient temperature values, we used data from the Observatory weather station that was uploaded to Weather Underground. This required us to download the HTML files for each day that the probe was active. We wrote a **C++** program[4] to extract only the outdoor ambient temperatures from all the recorded values in the weather file. Our program then output just these values to an additional file, which was then used by Excel to plot the values.

Results

The temperature measurements for the slab are shown in Figure 3. As can be readily seen in this plot, the three temperature measurements within the slab are very similar to each other. The peak cure temperature for the slab was 115 degrees Fahrenheit, and it occurred on the day of the pour. The concrete temperature cooled as the direct sun no longer illuminated the slab. The graph shows that the slab temperatures again rose during the next day due to the ambient temperature and the sun directly illuminating the slab. This pattern continued until five days after the pour. The temperature was relatively cool for that day and it was cloudy and raining. The result was that the ambient temperature stayed relatively stable and the slab did not follow the previous pattern of being heat charged. The remainder of the curing days saw a similar, but significantly smaller thermal charging and discharging cycle.

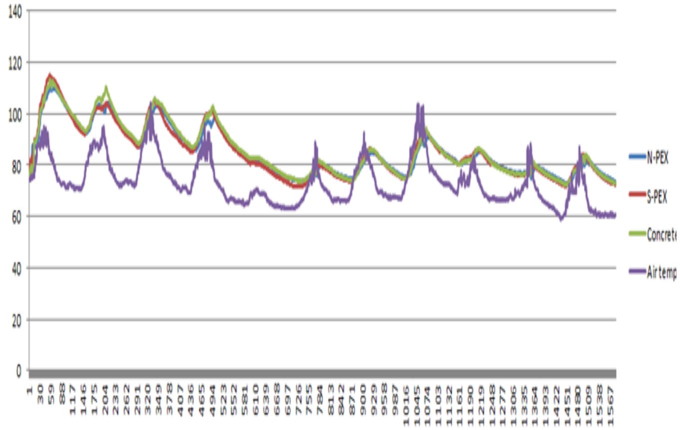

Figure 3: Uninsulated concrete slab curing temperatures as a function of time.

The temperature measurements corresponding to four of the thermocouples located in the north wall are shown in Figure 4. The peak temperature is significantly higher and the curing temperatures appear to be significantly smoother for the insulated wall compared to the non-insulated slab. The hottest the wall temperature achieved was 156.6 degrees Fahrenheit. The highest temperature was measured from the thermocouple that was closest to the outside wall of the concrete. Closely matching this temperature is from the thermocouple near the center of the wall. The thermocouple closest to the inside wall of the concrete was cooler by a few degrees but would periodically increase. The thermocouple placed closest to the floor consistently read the lowest temperature until the concrete had cured and the temperatures were indistinguishable.

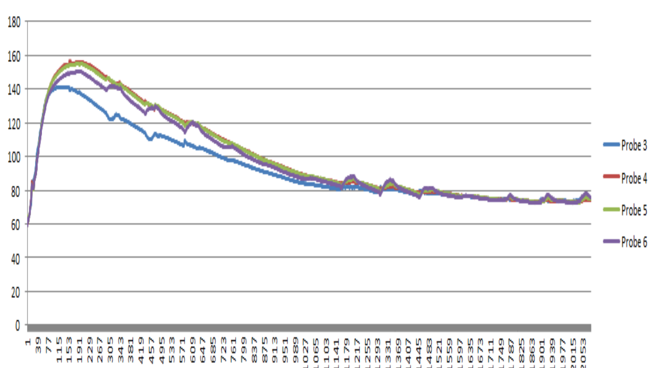

Figure 4: Insulated north wall curing temperatures as a function of time.

The temperature measurements for the remaining three thermocouples located in the north wall and the thermocouple measuring the ambient temperature are shown in Figure 5. The curves for probes 7 and 8 are very similar to the other four in Figure 4. The thermocouple located near the top of the wall (probe 9) shows the lowest recorded temperatures with a significant amount of oscillation. Finally, the thermocouple measuring the ambient temperature near the wall shows quite a few unusual and obviously incorrect measurements. The main cause of these readings likely occurred because the thermocouple was significantly disturbed by the workers taking the concrete forms off the walls. We confirmed the incorrect readings by checking the weather monitoring station located at the observatory, which is in close proximity to the construction site. We downloaded the historical temperature data for the same time the walls were curing, interpolated and resampled the measurements so that they better aligned in time with the wall samples. This curve is shown as the lowest curve in the plot in figure 5 and an expanded view is shown in figure 6.

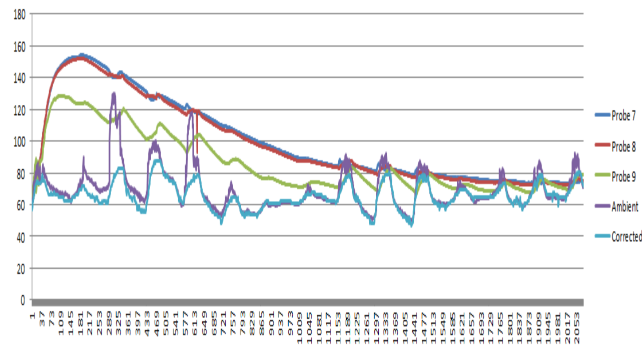

Figure 5: Insulated south wall curing temperatures as a function of time.

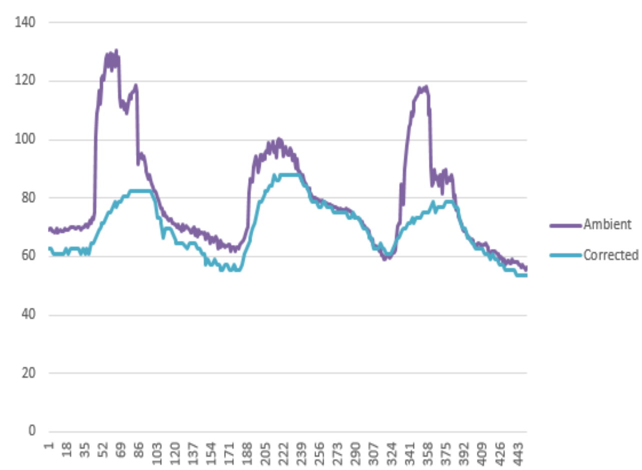

Figure 6: Expanded view of the ambient temperature as measured with a thermocouple close to the walls and floor, versus the temperature measured by the weather station at the nearby observatory.

Conclusions

Thermocouple 3 was closer to the floor, which absorbed the heat generated in the wall. Hence, this temperature was lower than the temperatures measured higher in the wall. There are still some periodic temperature variations caused by the exposure of the inside of the northern wall to the sun. The inner concrete is covered with three-quarter inch foam, so some incident radiation was absorbed. The thermocouple closest to the inside of the wall showed the most variation due to the sun. It also measured a cooler reading compared to the thermocouple located in the center of the wall and the one closest to the outside of the wall.

Thermocouples 7 and 8 recorded similar temperatures to thermocouples 4, 5, and 6.

Thermocouple 9 near the top of the wall was exposed to more effects of the sun and hence made the temperature vary more. This thermocouple is also located near an uninsulated part of the concrete, which contributed to heat loss and hence cooler temperatures than those lower in the wall.

The Energy Research Laboratory is an exceptional facility for collaborative research between faculty and student.

Acknowledgements

The authors are extremely grateful to the Pensmore Foundation for making this building possible on our campus. The crew from TF Systems deserves special recognition for the great care they took in properly placing the thermocouples in the walls prior to pouring the concrete as well as their expertise in pouring the walls.

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