Temperature Performance of the Energy Research Laboratory

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INTRODUCTION

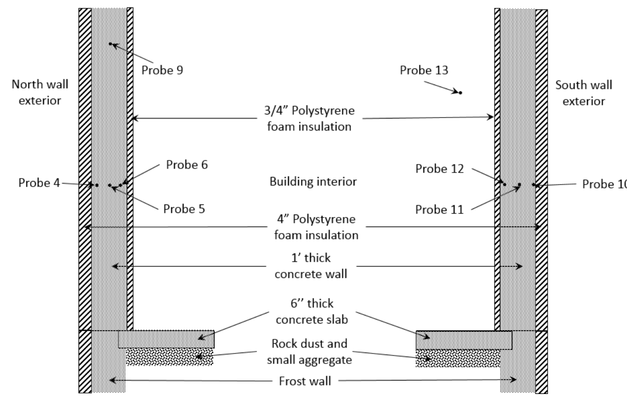
The Energy Research Group at Hampden-Sydney College has been monitoring temperatures at various locations throughout the newly constructed Energy Research Laboratory (ERL). The main idea behind these measurements is to empirically prove large thermal mass buildings are economical to heat and cool. For this paper we measured some temperatures of interest in the building without adding any heat or cooling to the building until it was absolutely necessary to prevent mold from developing in the building. The building was not occupied during this period of time and access to it was limited to a bare minimum so our measurements were indicative of the building and not its use. During the measurement time fresh air was brought into the building using a heat recovery ventilator so our measurements would reflect normal building operating conditions.

Principal Approaches

The main features that differentiate the ERL from conventional construction is that its walls are composed of one foot thick concrete sandwiched between inner and outer sheets of polystyrene and there are no roof or soffit vents. This combination provides a large thermal mass and a well-controlled mechanism for transferring air from inside to outside the building. See previous publication s[1, 2] for more details of the buildings construction. The data for this paper came from Onset HOBO UX120, 4-channel data logger to record[3] temperatures at ten-minute intervals. The seven of the eight sensors were located inside the concrete walls at different depths and the eighth measured the ambient temperature of the building interior. The following lists the locations of the thermocouples used in this experiment. Four of the measurements were made inside the north facing wall and three measurements came from the southern 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 1 shows a cross section of the building's interior along with the locations of the temperature probes.



Our goals for this experimental analysis were two-fold: first, to identify trends and relationships in the indoor and outdoor temperature of the ERL, and second, to create models that would predict these values.

In the first part of the experiment, data from the installed probes during the past year (2015-2016) was gathered into spreadsheets for the north and south walls, specifically. 20 time periods, partitioning the data from 2/3 – 12/18 were identified in the data as appearing to have some significance or correlation. Correlation coefficients were calculated for each sensor, for both the other probes and the outside temperature.

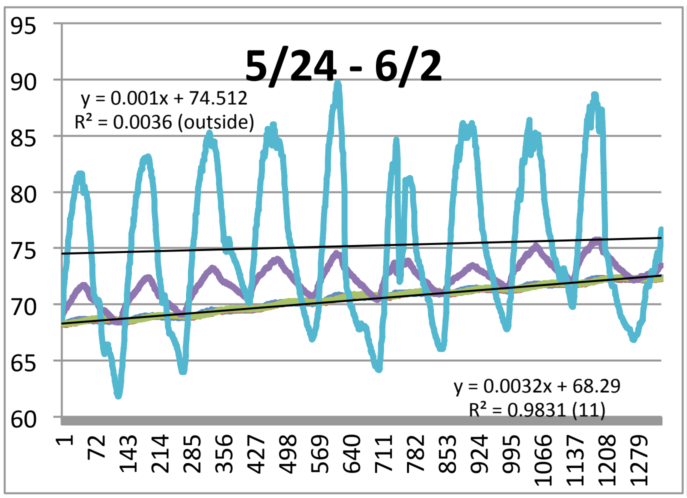
In order to check for the possibility of values caused by measurement error or other unusual circumstances, outliers were identified by identifying data values outside of 1.5*IQL, where IQL is the interquartile range.

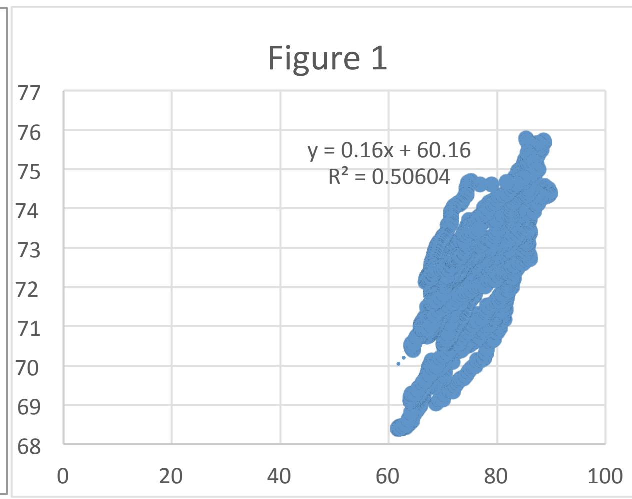
Regression lines for the change in temperature inside of ERL over the change in temperature outside ERL for each time period with a correlation coefficient to the outside of greater than 0.6 were created via regression on graphs of outside temperature vs inside temperature. An average and a weighted average by correlation coefficient was created.

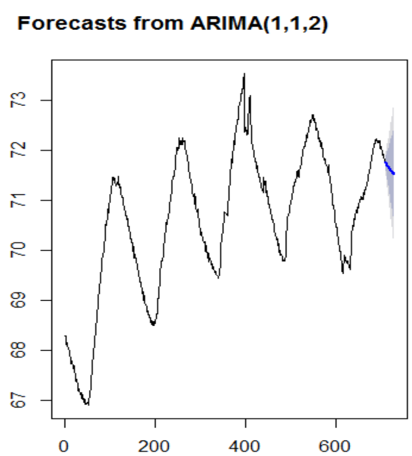
An ARIMA model was created for the indoor temperature of the ERL in R via use of tools from the ‘forecast’ package. Partial autocorrelation factors were examined after calculation of the model.

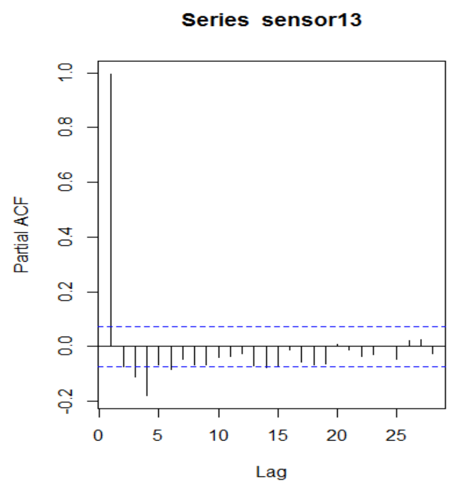
In addition, a piecewise linear model was created using values for $\frac{\Delta(inside\ temp)}{\Delta(outside\ temp)}$ found when the outside temperature was approximately a constant value different from the inside temperature for several different temperature deviations:

Present Knowledge









Graphs from left to right:

Row 1: Graph 1 – *An example of data collected in from the various probes.*

Row 1: Graph 1 – *An example of the regression performed on the inside and outside wall data.*

Row 2: Graph 1 – *Example of the ARIMA predictions for some of the temperature data.*

Row 2: Graph 2 – *The PACFs calculated from the sample data.*

DISCUSSION

Out of 20 time periods, 7 were identified for which the sensors had a low correlation with the outside temperature. Specifically, the periods from 2/12-2/21, 3/8-3/26, 3/26-3/31, 4/1-4/24, 6/29-7/29, 7/29 – 8/12, 8/12 – 9/20, 9/22 – 12/18 had correlation coefficients below 0.6.

Only one section of outliers were identified, and this was identified to be the time period where the batteries in the sensors were changed. This does help confirm that the method used to identify the outliers was able to catch significant outliers. weighted average by correlation coefficient was created.

An ARIMA model was created for the indoor temperature of the ERL in R via use of tools from the 'forecast' package. Partial ACF's were examined after calculation of the model.

In addition to the time series model, the piecewise linear model was developed by utilizing the value of 0.163 for the average change in inside temperature with respect to outside temperature. An attempt to calculate this value for specific values of the inside and outside temperature only succeeded in confirming a value 0.314 for $\frac{\Delta(inside\ temp)}{\Delta(outside\ temp)}$ for when the outside temperature is approximately 10 degrees higher than the inside temperature and 0.187 when the outside temperature is approximately 3.5 degrees higher than the inside.

An ARIMA model was created for the data, and examination of the graph of the remaining partial ACF's appeared to show only white noise. The order of the model of best fit was calculated to be p (the number of autoregressive terms) = 1, d (the number of nonseasonal differences needed for linearity of the model) = 1, q (the number of lagged forecast errors in the prediction equation) = 2.

CONCLUSION

The temperature data gathered over the span of a year from ERL provided valuable insights into the thermal behavior of ERL. This data will be used to further ERL's goals of characterizing the thermal effect of the materials used in its construction.

ACKNOWLEDGEMENTS

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