Quantitative Heat Transfer for Low-Slope Roof Membranes

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INTRODUCTION

Current energy and hygrothermal modeling programs account for the three forms of heat transfer for the roof membrane: conduction, convection, and radiation. However, their output is typically limited to just membrane temperature or energy consumption.

This article will discuss the basic components of heat transfer as they relate to a low-slope roof membrane and show the assembly of a theoretical temperature model for an in-service roof. Using this model, it is possible to calculate and plot the quantities of heat energy exchanged by the roof membrane in real time.

In order to run the model, field data for an in-service roof were needed. Field data from a test bed project conducted by the Midwest Roofing Contractors Association (MRCA) in Manhattan, Kansas, were used for this purpose. This project used six unique roof membranes installed on a common roof slope/exposure, over the same insulation configuration, and over the same occupied space below. A high-speed data acquisition system (DAQ) was used to collect weather, atmospheric radiation, and membrane temperature data. In addition to the field data, the physical properties of the six instrumented membranes were measured in a laboratory for use in the model.

By combining the theoretical model, field data, and laboratory data, the heat transfer for the low-slope roof membranes can be calculated in real time. Then, by reporting the transient membrane heat transfer, we can gain an improved insight into the thermal behavior of roof membranes and their impact on their surrounding environment.

ROOF MEMBRANE THERMAL MODEL

The basic components of a low-slope roof membrane temperature model are terms for heat transfer via conduction, convection, and radiation. These terms and the subsequent theoretical model can generally be assembled from the treatments within a traditional heat transfer text.[1] Several other studies have examined this type of model for the building envelope.[2-4] These efforts varied from basic programs to a complex finite element approach. Whether the simple or complex methods were used, the heat transfer portions all contain the same elements of conduction, radiation, and convection.

The fundamental concept of a roof membrane temperature model is to start with an initial condition, track all energy entering or leaving the membrane over time, and then use the change in energy to calculate the temperature change. This idea follows from the law of conservation of energy; therefore, any net change in heat energy will result in a temperature change.

For the purposes of this paper, we will treat the roof membrane, typically only 0.060 in. thick, as a continuous surface that has a uniform temperature throughout. This assumption simplifies the heat transfer model to a one-dimensional lumped capacitance model. In such a model, we are not concerned with how the heat energy flows or is distributed within the roof membrane. We are only concerned with quantities of energy that come and go from the top and bottom surfaces (roof membrane) over time. This reduces the problem to a summation of the three sources of heat flux, as shown in *Equation 1*. This equation forms the basis of the model development that follows.

$$q''_{Net} = q''_{Conduction} + q''_{Radiation} + q''_{Convection}$$

Where:
q'' = Heat flux in W/m^2

Equation 1 – Basic form roof membrane thermal model.

Conduction

To calculate the rate of heat energy conduction through the roof system, we utilize a general-form equation shown in *Equation 2*. We can simplify *Equation 2* by replacing the thermal conductivity (k) and roof system thickness (L) with the thermal resistance (R). This simplification leads to *Equation 3* used in the model.

$$q''_{Conduction} = \frac{k\,(T_I - T_S)}{L}$$

Where:
k = Thermal conductivity (W/m·K)
T_I = Interior temperature (K)
T_S = Roof surface temperature (K)
L = Roof system thickness (m)

Equation 2 – Basic form for conduction rate.

Radiation

The radiation term refers to the electromagnetic energy exchanged at the exterior surface of the roof membrane with its surroundings. This energy exchange results from incident radiation absorbed and radiation emitted by the roof membrane. Calculation of the net radiation exchange requires accounting for all sources of irradiance and emission. The sources of radiation that must be accounted for include incident solar radiation, incident long-wave radiation, and emitted long-wave radiation.

The incident solar radiation is the incoming global solar irradiance. A percentage of the incident solar radiation is reflected away by the roof membrane. The net solar radiation absorbed by the roof membrane is the solar irradiance less the reflected portion.

The global long wave irradiance term in the model results from infrared energy emitted from terrestrial and atmospheric sources. A percentage of the incident long-wave radiation is reflected away by the roof membrane. To the author's knowledge, the long-wave reflectivity of roof membranes has not been published. However, an assumption is made by Rose[3] that the long-wave reflectivity is related to the gray-body emissivity. Rose suggests that the long-wave infrared wavelengths that a material readily emits are also sensitive to absorbance. In effect, the long-wave reflectivity is taken as the difference between one and the roof membrane's emissivity. The net long-wave radiation absorbed is the long-wave irradiance subtracted from the reflected portion.

$$q''_{Conduction} = \frac{T_I - T_S}{R}$$

Where:
R = Thermal resistance in $m^2 \cdot K/W$

Equation 3 – Model form of conduction rate.

$$E_{Roof} = \varepsilon \sigma T^4$$

Where:
E_{Roof} = Emitted energy from the roof membrane in W/m^2
ε = Roof membrane emissivity (%)
σ = Stefan-Boltzmann constant (5.6704×10^{-8} $W/m^2 \cdot K^4$)

Equation 4 – The Stefan-Boltzmann equation for real bodies.

$$q''_{Radiation} = (1 - \propto_{Solar})G_{Solar} + (1 - \propto_{Roof})G_{Long} - E_{Roof}$$

Where:
$\propto_{Solar}$ = Solar reflectance of roof membrane (%)
G_{Solar} = Global incident solar irradiation (W/m^2)
$\propto_{Roof}$ = Long-wave reflectance of roof membrane (%)
G_{Long} = Global atmospheric irradiation (W/m^2)

Equation 5 – Net radiative exchange for the roof membrane.

$$q''_{Radiation} = (1 - \propto_{Solar})G_{Solar} + (1 - (1 - \epsilon)G_{Long} - \varepsilon\sigma {T_S}^4$$

Equation 6 – Net radiative exchange for the roof membrane.

$$q''_{Radiation} = (1 - \propto_{Solar})G_{Solar} + \epsilon G_{Long} - \varepsilon\sigma T_S^4$$

Equation 7 – Net radiative exchange for the roof membrane.

All matter above absolute zero emits long-wave radiation as described by the Stefan-Boltzmann Law. The roof membranes under study are not black bodies (i.e., perfect radiators of energy). Therefore, they are gray bodies that have an emissivity. The rate of energy radiated by the roof membranes in the long-wave infrared is shown in *Equation 4*.

Collecting the three sources of radiative energy exchange on the roof membrane, we arrive at *Equation 5* (and then, with substitutions in *Equation 6* and simplification in *Equation 7*).

Convection

The convection term describes the heat transfer rate of energy brought into or taken away from the roof membrane by exterior fluid movement. For building science purposes, we generally are concerned only with the exterior air as the fluid. The air movement comes in two forms. The first air movement type is wind or forced convection. Wind forces air over the roof surface, bringing with it air of ambient temperature to exchange energy with the roof membrane. The second form of air movement, involving air buoyancy, is more complex. It is commonly referred to as natural convection.

Equation 8 shows the basic form of the convective energy transfer rate. This form of the equation is typically referred to as Newtonian cooling.[1] The temperature components of this equation are self-explanatory. The convection heat transfer coefficient term is not.

$$q''_{Convection} = h_{Convection}(T_S - T_A)$$

Where:

$h_{Convection}$ = Convection heat transfer coefficient (W/m²·K)

T_S = Roof surface temperature in degrees (K)

T_A = Ambient air temperature in degrees (K)

Equation 8 – Basic form of convective heat transfer.

The convective coefficient is one that accounts for the effects of both the forced and the natural convection. In previous roof membrane temperature studies, the convection term was typically simplified[2-4] to only a constant, or it utilized the closed-form textbook solution for a flat plate. The exact reason for this is not known. However, these assumptions made in other studies may result from the wide variations in reported convective heat transfer coefficients from multiple studies.[5-7] It appears every building may have its own unique coefficient.

Compiled Roof Temperature Model

Combining the conduction, convection, and radiation terms will produce a theoretical heat transfer model for the roof surface in W/m². The compiled roof temperature model is shown in *Equation 9*.

Equation 9 is the heat flux equation, quantifying an energy exchange rate in J/s·m². This is not yet a temperature model. In order to get a result in the temperature domain, we must convert using the specific heat capacity (J/g· K), the mass per square meter of each specific roof membrane (g/m²), and a time period(s). This will give a predicted temperature change—positive or negative. *Equation 10* shows the roof temperature model. The only remaining unknown in *Equation 10* is the convective coefficient for the building studied. The value of the convective coefficient ($h_{convective}$) is discussed in the next section.

Determination of Convective Coefficient

Using the assumption that each building's coefficient is unique, it is necessary for accuracy to determine the convective coefficient for the building under study. The determination of the convective coefficient is not a trivial matter. There are four common methods for determining the convective heat transfer coefficient for a real building:

- Utilize a published value by others.
- Conduct a computerized fluid dynamics (CFD) model of the building.
- Conduct a field experiment to measure the heat transfer.
- Utilize field data from the building in question to interpolate one.

A thorough discussion of developing a building-specific convective coefficient is beyond the scope of this article. That being said, utilizing a number published by others should be considered a last choice, for accuracy. Conducting a CFD simulation is an excellent choice if and only if the researcher has both the resources and knowledge to conduct one. Conducting a field experiment such as Jiantao[5] is another good choice. In the case of the MRCA project data used for this study, the volume and quality of the data made interpolation the best choice in determination of the convective coefficient.

From the literature,[5-8] it is known that the convective coefficient is dependent on the wind speed. At zero wind speed, the roof experiences natural convection. When the wind speed is greater than zero, the roof is

$$q''_{Net} = \frac{T_I - T_S}{R} + (1 - \propto_{Solar})G_{Solar} + \epsilon G_{Long} - \varepsilon\sigma T_S^4 + h_{Convection}(T_S - T_A)$$

Equation 9 – Compiled heat flux model.

$$\Delta T = \frac{\left(\frac{T_I - T_S}{R} + (1 - \propto_{Solar})G_{Solar} + \epsilon G_{Long} - \varepsilon\sigma T_S^4 + h_{Convection}(T_S - T_A)\right)\Delta t}{CU}$$

Where:

ΔT = Change in temperature during time period (K)

Δt = Time period (s)

C = Specific heat capacity (J/g·K)

U = Unit mass of roof membrane (g/m²)

Equation 10 – Roof temperature model.

subject to combined natural and forced convection. Therefore, it is necessary to plot the results from the convective coefficient calculation against the wind speed that produced that value. The results of over 150,000 model samples are plotted in *Figure 1*.

In order to confirm the reasonableness of the convective coefficient arrived at in *Figure 1*, that coefficient was plotted with other convective coefficients from other published studies.[5,8] The results of this plotting are shown in *Figure 2*. As previously stated, it is assumed that every roof will have a convective coefficient unique to

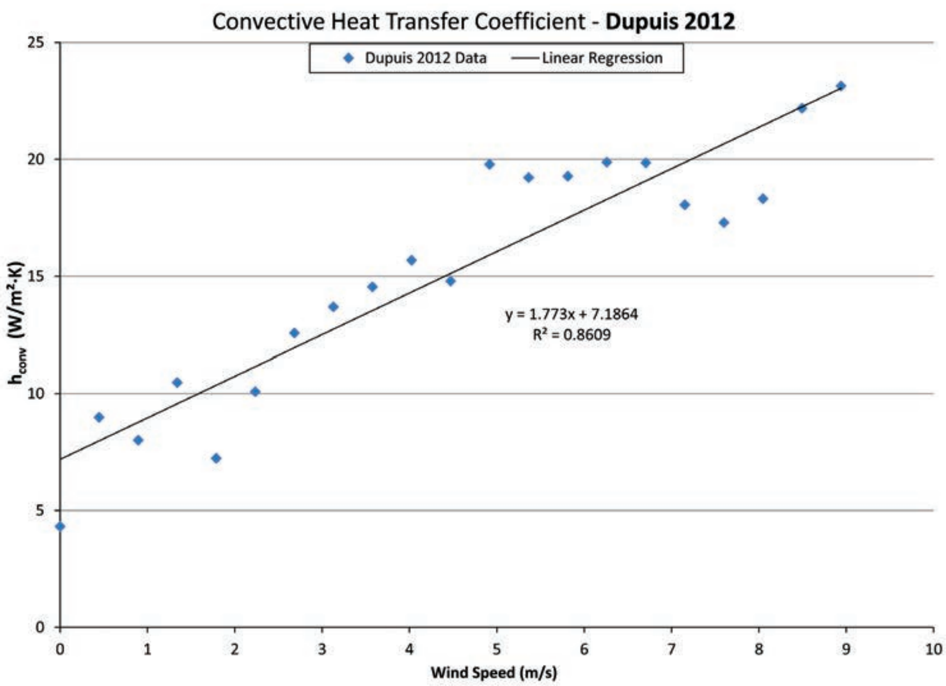

Figure 1 – Data for the calculated convective coefficient.

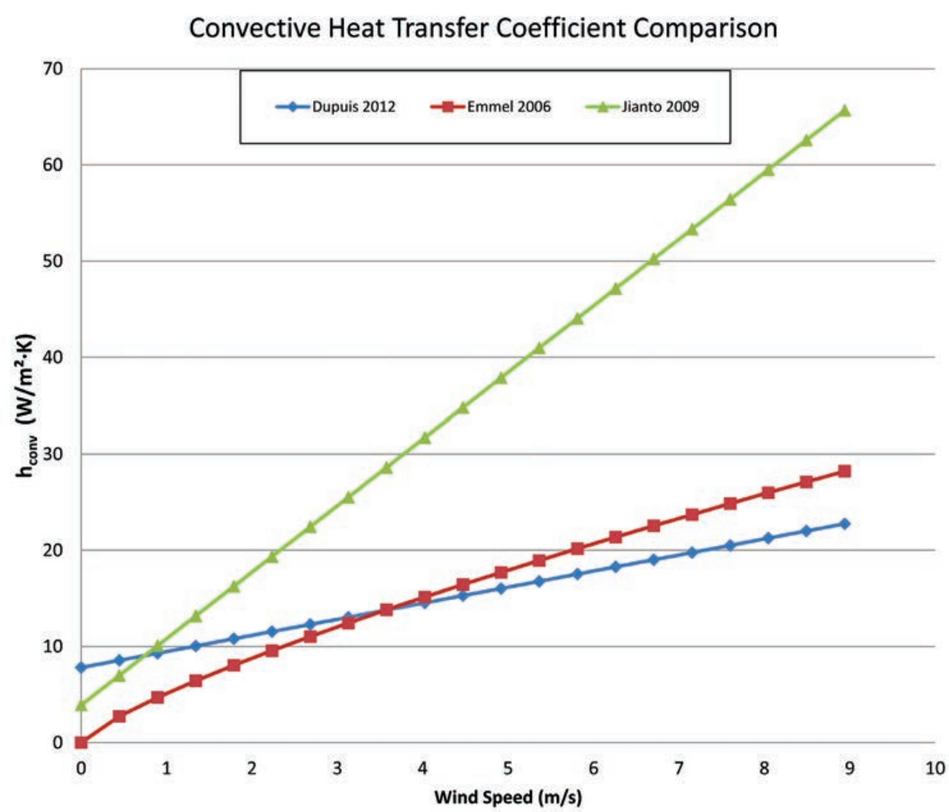

Figure 2 – Comparison of different convective coefficients for low-slope roofs.

$$T = T_s + \frac{\left(\frac{T_I - T_S}{R} + (1 - \alpha_{Solar})G_{Solar} + \epsilon G_{Long} - \varepsilon\sigma T_S^4 + (1.18W + 7.19)(T_S - T_A)\right)\Delta t}{CU}$$

Where:
T = Roof membrane temperature at the end of time step (K)
W = Wind speed (m/s)

Equation 11 – Roof temperature model.

factors such as (but not limited to) slope, orientation to the wind, surface roughness, height above ground, and upwind distance from ground-level obstructions. Given this assumption, the result in *Figure 2* demonstrates that the convective coefficient arrived at for this model appears reasonable and valid.

Final Form of Roof Temperature Model

Using the convective coefficient determined in the previous section, the final form of the roof temperature model is presented in *Equation 11*. *Equation 10* was solved for the temperature differential caused by the addition or removal of energy during the time step (Δt). In *Equation 11*, the additional step of solving for the final temperature (T) at the end of the time step is made. The roof membrane temperature at the beginning of the time step (TS) is changed by the result of *Equation 10* to arrive at the final temperature (T) in *Equation 11*.

Membrane Study Label	Manufacturer	Membrane	Unit Weight (g/m^2)
White EPDM	Firestone	Eco White – 60 Mil	2096.117
White TPO A	Firestone	Ultra-Ply 60 Mil	1501.961
White Modbit	Derbigum	Derbibrite	3559.033
Black EPDM	Carlisle Syntec	Sure-Seal - 60 Mil	1848.507
White TPO B	Carlisle Syntec	Sure-Weld 60 Mil	1501.961
Grey PVC	Sarnafil	G-410 60 Mil	1730.937

Table 1 – Unit weights of the roof membranes.

Membrane	Solar Reflectivity
White EPDM	0.690
White TPO A	0.699
White Modbit	0.759
Black EPDM	0.067
White TPO B	0.724
Grey PVC	0.455

Table 2 – Solar reflectivity of the roof membranes.

Membrane	Emissivity
White EPDM	0.86
White TPO A	0.83
White Modbit	0.83
Black EPDM	0.84
White TPO B	0.86
Grey PVC	0.85

Table 3 – Thermal emissivity for the roof membranes.

ROOF MEMBRANE PROPERTIES

Several of the variables in *Equation 11* need to be determined by laboratory measurement or published values. These variables are unit weight (U), solar reflectance ($\propto_{Solar}$), roof membrane-specific heat capacity (C), roof membrane emissivity (ε), and thermal resistance (R).

Unit Weight

The unit weight for a membrane is simply obtained by utilizing a material sample of the subject membrane. Four samples of each membrane were prepared, massed, and then averaged. The results are reported in *Table 1*.

Reflectivity

One of the radiative properties needed for temperature modeling is the insolation reflectivity or, more simply, the solar reflectivity. The solar reflectivity is expressed as a decimal percentage of the total incoming solar energy that is reflected away from a surface.

The measurement of solar reflectivity of roof membranes is typically conducted with a solar spectrum reflectometer such as the Devices and Services Company model SSR. Manufacturers will almost exclusively list the aged reflectivity values for their membranes as tested under the Cool Roof Rating Council (CRRC) standard CRRC-1. This standard is a prescriptive aging process under ASTM G7 before conducting solar reflectivity testing under ASTM C1549. It has been shown that while the CRRC-1 methodology for aged values gives a reasonable aged reflectivity number, the local roof conditions have a large influence on measured field values.[9] Therefore, for this study, a recently calibrated SSR reflectometer was utilized to measure the in-situ reflectivity. The reflectivities for the membranes modeled in this study are reported in *Table 2*.

Emissivity

Emissivity refers to the efficiency as a decimal percentage of Plankian-type radiative emission from a real body compared to a black body at the same temperature.

An examination of relevant literature finds that no measurements of in-situ roof membrane emissivity according to ASTM C1371 or ASTM E408 have been published. In addition, a portable field emissometer was not available for this study, so in-situ emissivity measurements of the roof membranes in Manhattan, Kansas, were not possible.

The CRRC publishes data for aged values for reflectivity and emissivity. The values published in the CRRC data assume roof membranes to be Lambertian emitters, meaning they emit energy in all directions equally. This assumption is currently being discussed in the roofing industry. However, for this study, the published emissivity values from the CRRC are assumed correct. The emissivity values for the appropriate membranes were located in the CRRC directory and are reported in *Table 3*.

Specific Heat Capacity

Specific heat, also known as specific-heat capacity, is the amount of heat energy required to change the temperature of a unit mass by a degree. This property is possibly the most fundamental one for modeling temperature change in roof membranes. Unfortunately, this property is never published by manufacturers. The only literature found to report this material property was by Clear.[6] Clear's study reports a heat capacity of a granulated polymer-modified bitumen cap sheet to be 1.51 J/g·K.

Utilizing a TA Instruments Q100 Differential Scanning Calorimeter (DSC) in the Soft Materials Laboratory at the

	Specific Heat Capacity (J/g·K)		
Membrane	**Combined**	**Endothermic**	**Exothermic**
White EPDM	1.24	1.16	1.32
Modified Bitumen	1.23	1.12	1.34
Black EPDM	1.40	1.32	1.48
PVC	1.13	1.05	1.21
TPO	1.78	1.63	1.92

Table 4 – Specific heat capacity of the roof membranes.

University of Wisconsin at Madison's College of Engineering, specific heat capacities for the roof membranes being modeled were measured. The membranes were characterized with isothermals at 110°C and -10°C to produce a smooth reading between 0°C and 100°C. The membranes were tested under a nitrogen atmosphere. The heating and cooling rates for the testing were 10°C/min.

Samples were obtained for all the roof membranes except "TPO A." Therefore, "TPO B" served as the representative sample for the TPO class of membranes in this study. The samples tested were full cross-sections of the membranes—outside surface to outside surface. This means any constituent part of the membrane was tested as well, including any reinforcement. Each membrane tested had a replicate. The results of replicates were included in an arithmetic average for each membrane or membrane class.

Roof System Thermal Resistance

In order to calculate the heat flux through the roof into the building interior, the thermal resistance of the roof system needs to be determined.

The laboratory measurement of thermal resistance has been a controversial topic within the building envelope community since at least the 1980s. Of particular concern is how to prepare and measure insulation, and then at what temperature to measure the thermal resistance. As of this writing, this issue has yet to be resolved with any finality.

For the purposes of this study, a definitive source of accepted knowledge and data is used to determine the roof system thermal resistance. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) publishes the *ASHRAE Handbook – Fundamentals*.[10] This book contains commonly accepted values for thermal conductivity for building components.

The transmission of heat energy from exterior surface to the interior surface, and vice versa, is a series circuit. Therefore, the one-dimensional resistance to the movement of heat energy is additive. For this study, only one thermal conductivity is necessary, as all of the roof membranes are over the same underlying insulation system. The different membranes present negligible differences in thermal conductivity to the roof system as a whole. The calculated value of thermal resistance (R) for this study is 4.79 $m^2 \cdot K/W$.

MODEL PERFORMANCE

Utilizing the model defined in the Roof Membrane Thermal Model section of this paper and the roof membrane properties measured in the Roof Membrane Properties section, the Manhattan, Kansas, field data were utilized as the input for the model. These data were collected at a sample rate of one sample every ten seconds. This sample rate was also used as the time step (Δt) in the model. Field data input into the model included global solar irradiance, global long-wave irradiance, wind speed, and air temperature. Roof membrane temperature was measured with Type T thermocouples directly under each membrane.

The MRCA test bed project ran for three years, collecting over 1 billion data points. For the purposes of this study, the data collected for the month of August 2010 were utilized. Each day was run in the model for each individual membrane. The aggregate performance of the model for the predicted temperature versus the thermocouple-measured temperature was 0.71% error for all membranes and all days in the August 2010 data set. *Figure 3* shows a plot of the model predicted temperature against the recorded temperature for a TPO membrane on a selected day.

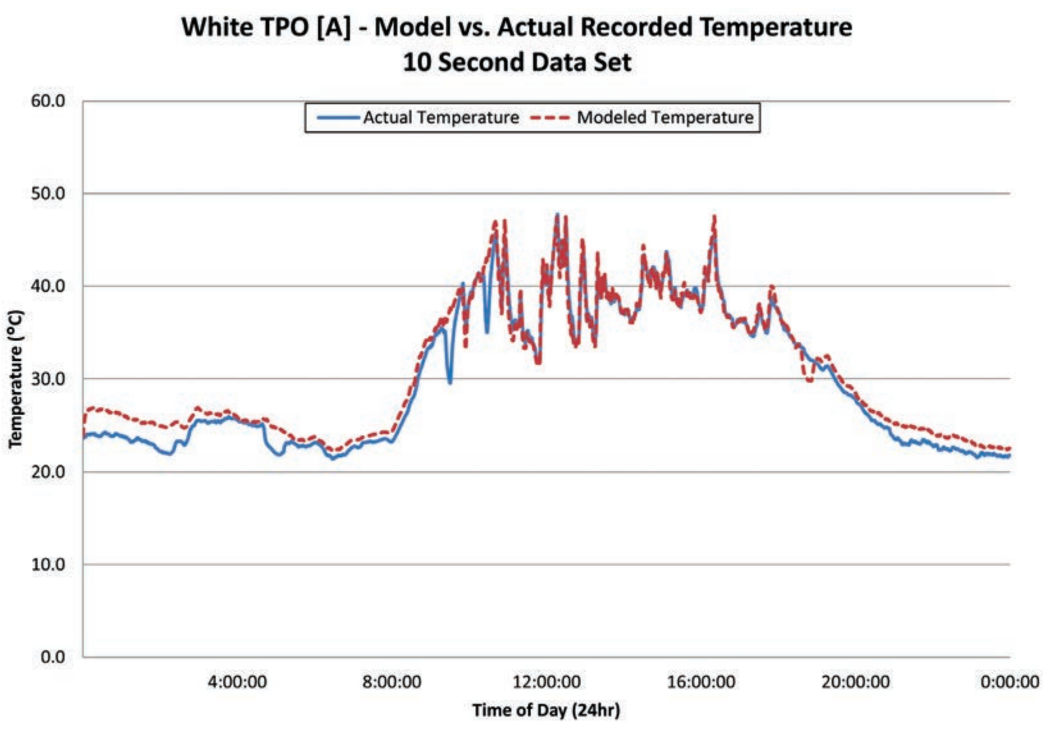

Figure 3 – Plot of predicted temperature against modeled temperature for white TPO [A] on August 4, 2010. The insolation on this day was highly varied. The model still appears to track very well.

TRANSIENT HEAT TRANSFER

Utilizing the model, combined with the membrane properties and field data, it is possible to analyze the different components of heat transfer, conduction, convection, and radiation in a transient manner and compare them simultaneously against the other membranes present at the MRCA site.

There are a large number of permutations for which one could analyze and present this analysis. Each of these permutations of membrane, day in the data set, and heat transfer mechanism may produce a beneficial analysis to answer a specific question posed. For the purposes of this study, two particular questions will be explored by showing the heat transfer mechanisms calculated for the individual membranes installed on the test bed. The first question relates to the air temperature above a membrane versus the solar reflectivity of that membrane.[11] The second issue that will be examined is the quantity of radiative energy emitted plus that which is reflected away against the membrane reflectivity.[12] In addition to these questions, a combined plot of heat transfer mechanisms will be displayed to demonstrate the utility.

To examine the first question, we will look at two days in the data set: August 10 and 24, 2010. Utilizing the model, we are able to select and plot the convective energy exchanged at the exterior surface of the membranes. To minimize the confusion in the plots, only two membranes will be plotted: white TPO [B] and black EPDM. These membranes were selected primarily for their solar reflectivity values being high and low, respectively. *Figures 4* and *5* show the results for August 10 and August 24, respectively.

As would be expected, the total magnitude of heat energy transferred away from the roof membrane peaks at midday on both days. However, using this methodology for comparing the membranes, we can visually see the much larger amount of heat energy convected away into the atmosphere by the black EPDM membrane versus the white TPO. In fact, at the maximum value, the convective heat transfer into the surrounding environment for these membranes, at approximately

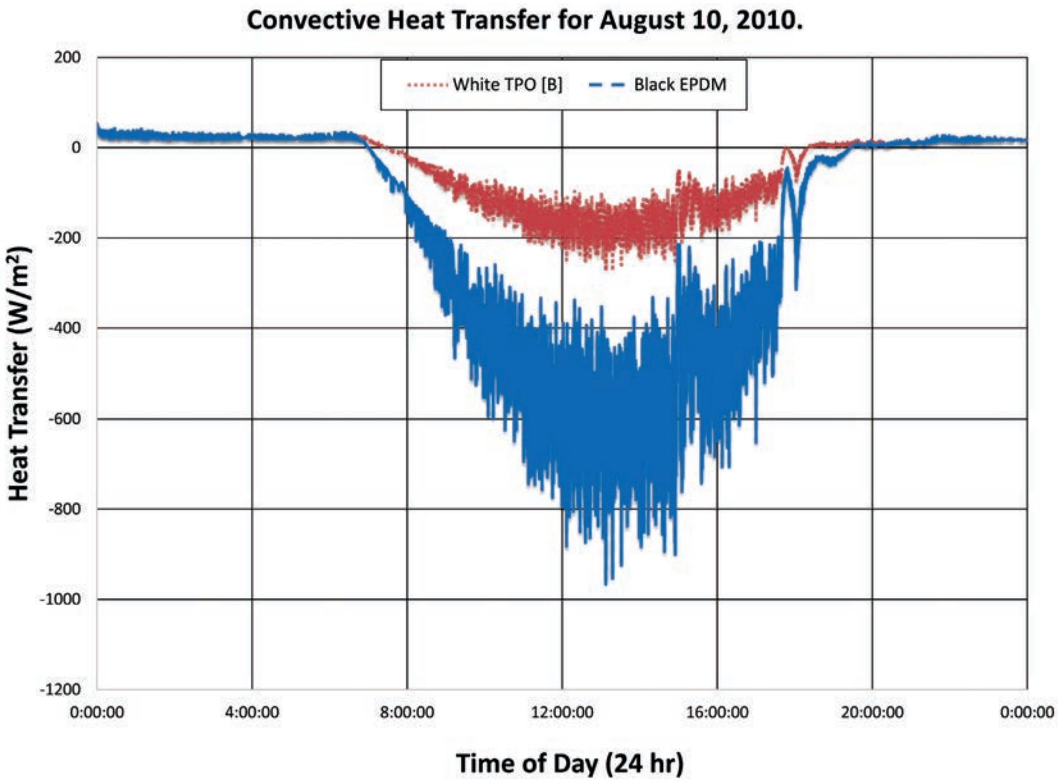

Figure 4 – Plot of convective energy exchanged at the membrane's exterior surface for August 10, 2010. Negative values indicate energy leaving the membrane; and conversely, positive values indicate energy being deposited into the membrane.

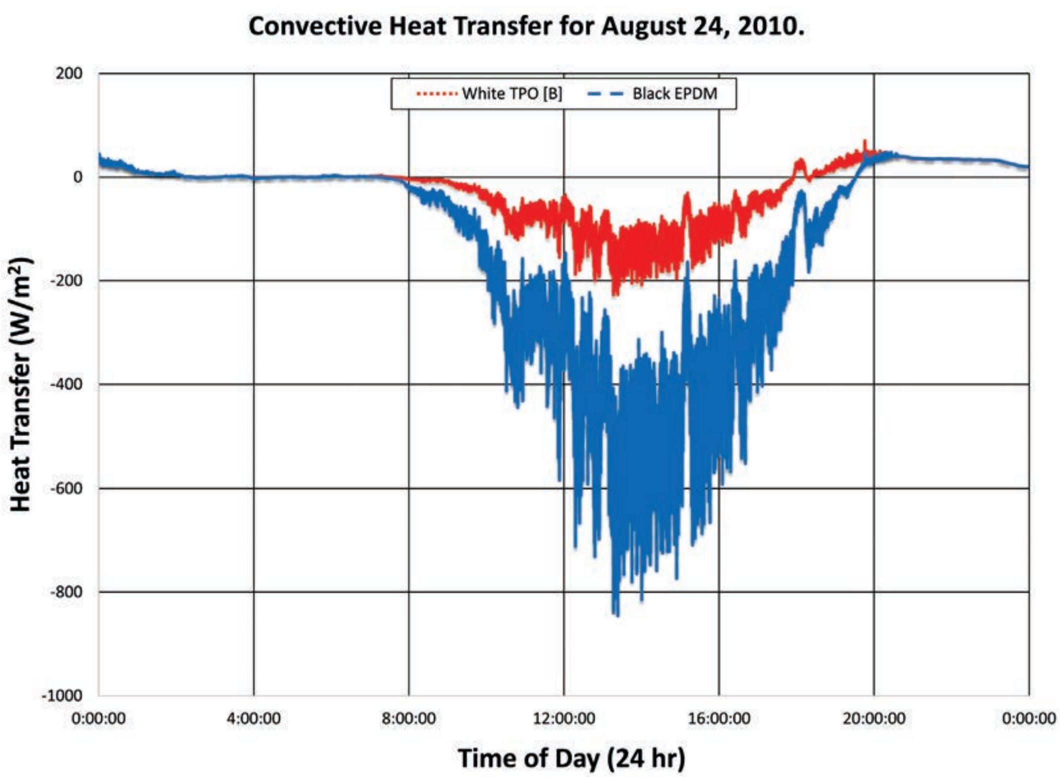

Figure 5 – Plot of convective energy exchanged at the membrane's exterior surface for August 24, 2010.

the same time, is three times higher for the black EPDM versus the white TPO. It should be noted that the magnitude of these convective differences appears to be related more to reflectivity, not specifically to membrane type. Space precludes their inclusion here, but a plot of heat transfer for a membrane such as white EPDM performs almost identically to the white TPO in *Figures 4* and *5*.

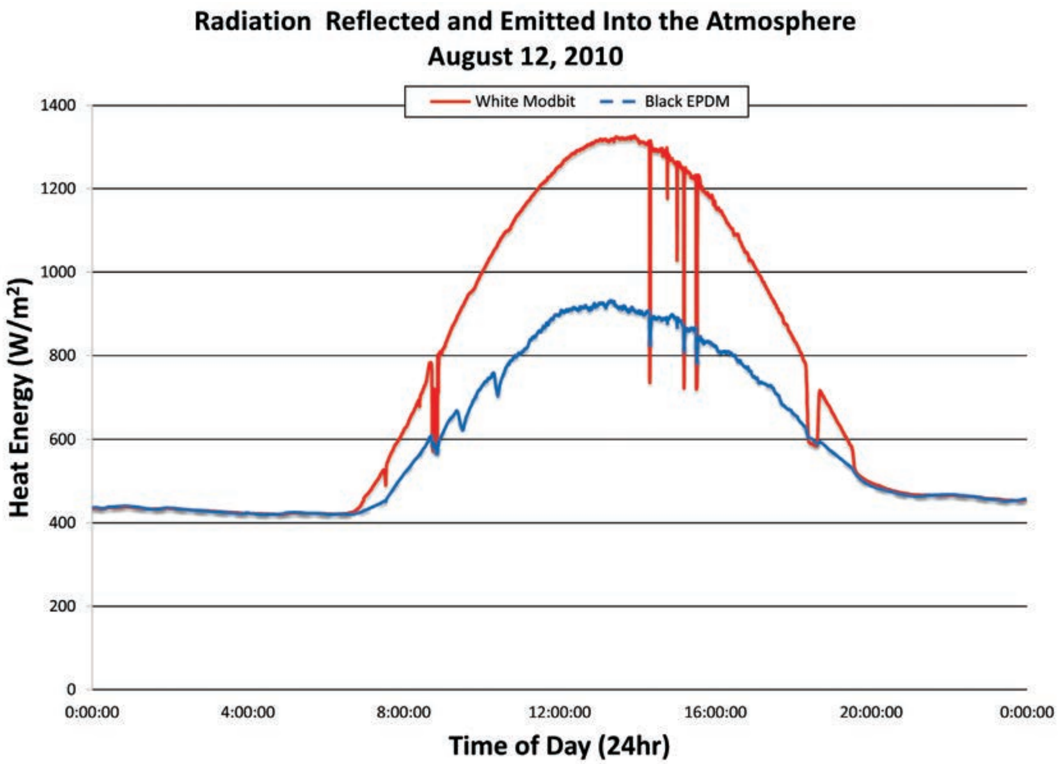

Figure 6 – Plot of net radiative heat energy emitted and reflected from the roof membrane surface for August 12, 2010.

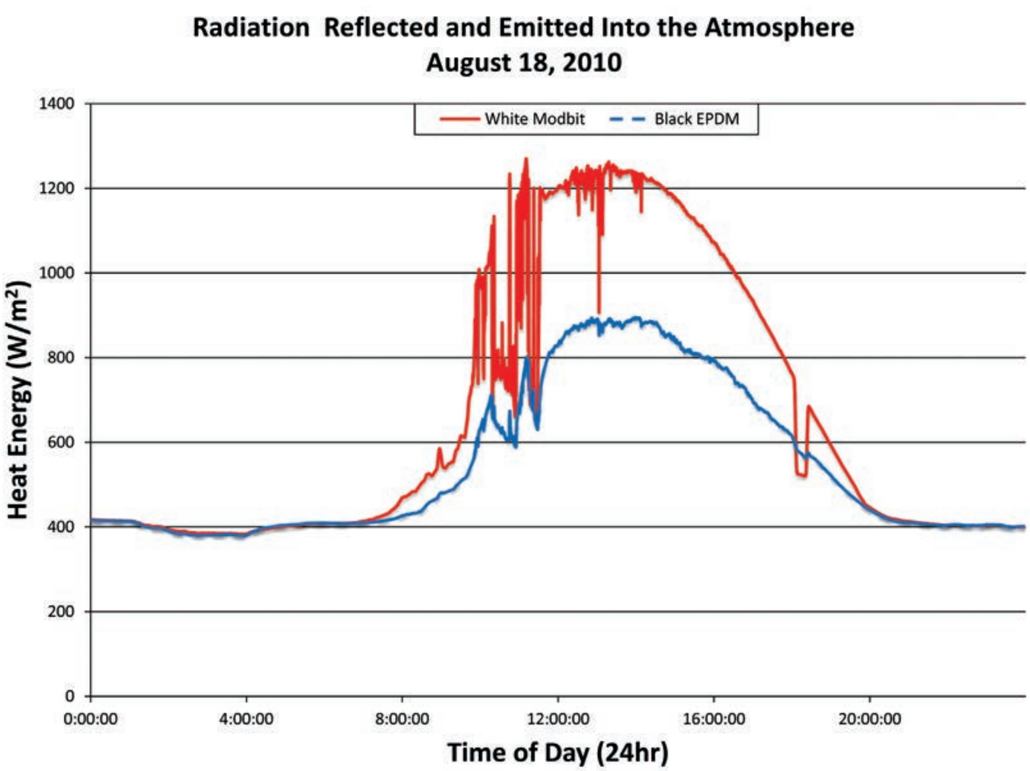

Figure 7 – Plot of net radiative heat energy emitted and reflected from the roof membrane surface for August 18, 2010.

This type of analysis into quantitative convective heat transfer for roof membranes reinforces the concept of the heat island effect. The heat energy convected away (specifically the additional amount by the low-reflectivity roof) must, by conservation of energy, increase the surrounding air temperature. Measuring this temperature increase—specifically above a roof membrane—is not a simple matter. Rayleigh-Benard convection cells develop at the roof surface and are all but invisible to the naked eye. These convection cells make placement of temperature sensors above a roof membrane impractical, as these cells will circulate and move. Therefore, calculation and simulation appear more practical in assessing the temperature impact of the roof membrane temperature on air temperature surrounding the roof.

Let us consider the question of net radiation reflected and emitted away from the different membranes.[12] Again, the model can assist in visually and quantitatively demonstrating the effects that the differing membranes have on this issue. Plotted in *Figures 6* and *7* are black EPDM and white polymer-modified bitumen for August 12 and 18, 2010. In these figures, the amount of solar irradiance reflected away is added to the amount of long-wave irradiance reflected away and the amount of long-wave energy emitted by the membrane. This amount calculated is the net amount of radiative heat transfer each membrane contributes to its surrounding environment.

We can see in *Figures 6* and *7* that the radiant energy reflected and emitted away from these two roof membranes is significantly different in daytime hours. The higher-reflectivity membrane does what we expect it to do and reflects a large portion of the incoming solar energy away.

The energy accounted for in the model represents a spectrum from 280nm to 50,000nm. Different portions of this spectrum will be absorbed and reflected differently, depending on what type of atmospheric matter it irradiates as it passes out of the atmosphere and into space. However, the figures above generally support the work by Jacobson[12] that the highly reflective membrane sends more radiation into the atmosphere than a nonreflective membrane.

To demonstrate the utility of examining the heat transfer in this manner, a final plot is displayed. *Figure 8* shows the three sources of heat transfer for black EPDM on August 10, 2010, on a single plot.

There are two major observations to make from *Figure 8*. The first is the order(s) of magnitude difference among radiation, convection, and conduction. The conduction term is approximately 1/100th of the other terms at peak temperatures. The second observation to be made is that convective heat transfer is the major force opposing solar irradiance in the daytime.

Another fascinating observation to make about *Figure 8* is the inversion that occurs at dawn and dusk. The radiation and convection terms reverse, visually identifying the nighttime radiative cooling phenomena.[13] *Figure 9* is a close-up view of the inversion shown in *Figure 8*.

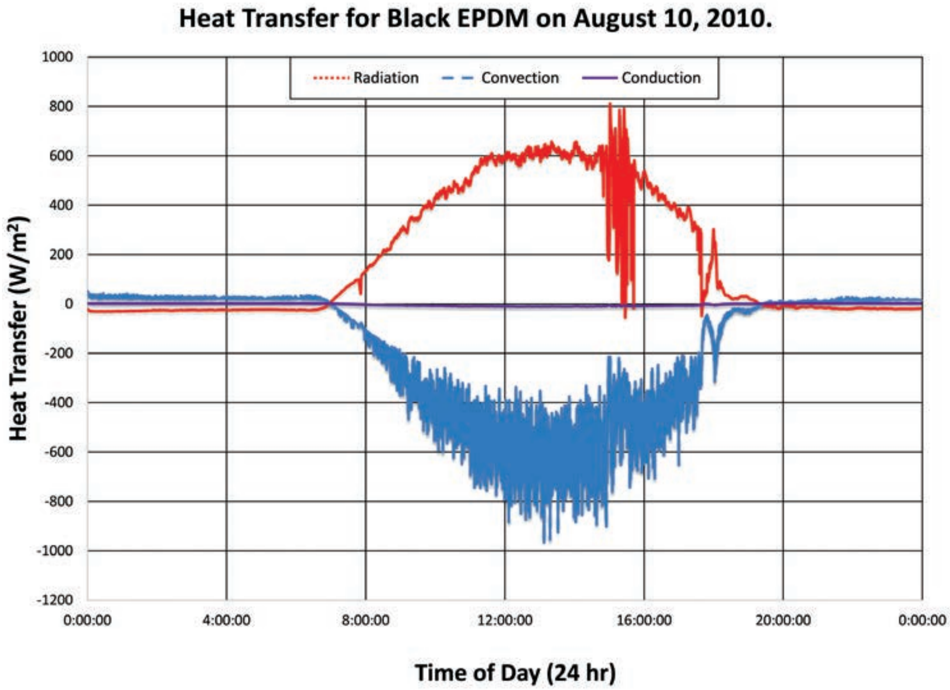

Figure 8 – Plot of the three sources of heat transfer for the black EPDM membrane on August 10, 2010. Again, negative values indicate energy leaving the membrane; and conversely, positive values indicate energy being deposited into the membrane.

CONCLUSIONS

The model developed and used in this paper is applicable to low-slope roof membranes. The only term requiring replacement for a different building could be the convective coefficient ($h_{Convection}$). This coeffi-

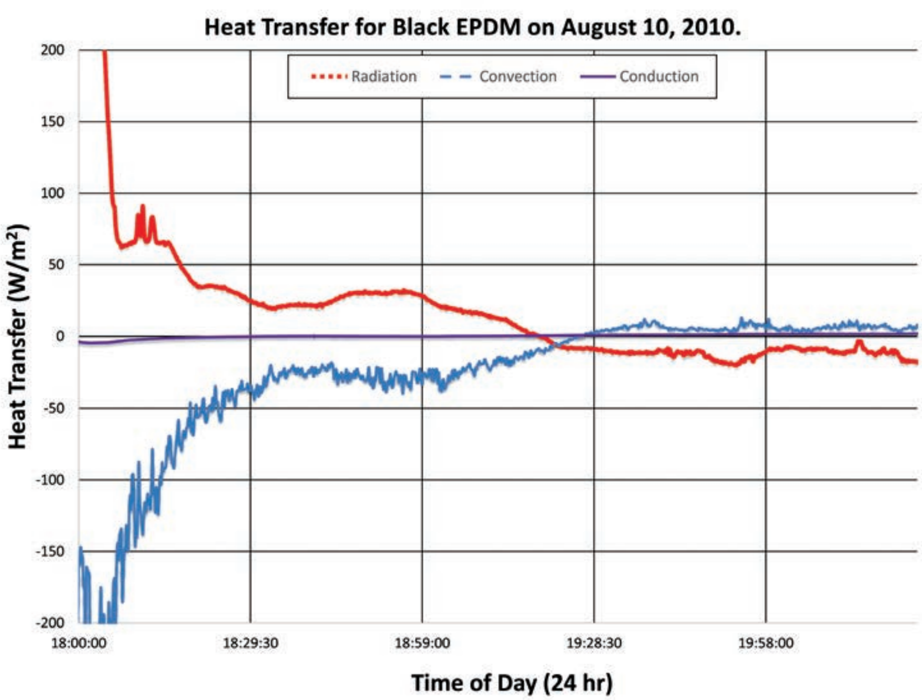

Figure 9 – A close-up plot of the thermal inversion seen in Figure 8.

cient can be calculated and measured, or a published value can be used. In fact, small errors in this term have a minimal impact on the accuracy of the calculated membrane temperature.[14] Material properties for the membranes must be measured, or published values must be used.

By plotting the transient heat transfer behavior of the roof membranes present at the Manhattan, Kansas, facility, it was possible to observe the convective heat transfer differential between roofs of low and high reflectivity. The net radiation expelled into the atmosphere by these same roof membranes was plotted for visual inspection and quantitative conclusions. In addition, plots of the three modes of heat transfer for a single membrane illustrated the diurnal thermal behavior of roof membranes.

By using this model or others (and, particularly, the analysis methodology presented here for heat transfer components of low-slope roof membranes), we gain additional insight into the heat transfer phenomena occurring and the diurnal thermal behavior of roof membranes. Future researchers into roof membrane temperatures and their environmental impact may wish to include this method of analysis in their models and analyses in order to gain a better visual understanding of the phenomena and effects occurring for roof membranes. Additionally, it should be a simple matter for future versions of hygrothermal simulation software to allow their resultant output data to show this type of data, as these programs will already have to make these calculations in the background.

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NAFS-17 Fenestration Standard Published

Photo by Zufrieden, via Wikimedia Commons.

The 2017 edition of AAMA/WDMA/CSA 101/I.S.2/A440, *NAFS — North American Fenestration Standard/Specification for Windows, Doors, and Skylights* (NAFS), has received final approval and is now available. This standard is the result of a multiyear effort by the American Architectural Manufacturers Association (AAMA), the Canadian Standards Association (CSA), and the Window & Door Manufacturers Association (WDMA). The updated 2017 standard replaces the 2011 edition of the joint standard.

The 2011 NAFS standard is already referenced in the 2015 editions of the International Building Code (IBC) and International Residential Code (IRC), with the new standard to be included in the 2018 editions of these codes. The new standard is being proposed to replace the 2011 edition in the National Building Code of Canada (NBCC) when it is updated. A Canadian Supplement to the standard has been created by the CSA A440 Technical Committee to address those few Canada-only items not included within the new NAFS standard.

The newest version of NAFS includes three more operator types than the previous edition: folding door systems, parallel opening windows, and top turn reversible windows.

Copies of AAMA/WDMA/CSA 101/I.S.2/A440-17 are available for online purchasing from the AAMA, the Canadian Standards Association, or the WDMA.

— WDMA

LUMBER PRICES UP

The tarriffs on Canadian lumber, coupled with old-fashioned supply and demand, have boosted lumber prices throughout the U.S. Todd Morgan, director of Forest Industry Research at the University of Montana's Bureau of Business and Economic Research, said lumber production fell in Montana from 506 million board-feet in 2016 to 481 million board-feet in 2017. Home builders are passing the costs onto consumers. "Lumber prices right now are really high," he said. "They went up at the beginning of 2017 and stayed consistently high. It's a combination of a gradual increase in new home construction, which helped create more demand, and fires through the West that restricted the supply of logs."

"Pricing fluctuates, but essentially the prices for materials are 25 percent more than a year ago," said Wade Hoyt of Hoyt Homes in Missoula, MT.

— Missoulian.com

