THERMAL RESISTANCE AND MEAN TEMPERATURE:

A REPORT FOR BUILDING DESIGN PROFESSIONALS

EXECUTIVE SUMMARY

The Polyisocyanurate Insulation Manufacturers Association (PIMA) represents the leading North American manufacturers of high performance polyisocyanurate (polyiso) thermal insulation. For over 25 years, PIMA has been one of the nation's foremost advocates for energy-efficient practices and policies and has been recognized twice by the U.S. Environmental Protection Agency (EPA) for innovative products that increase energy efficiency and combat global warming.

In 2010, the National Roofing Contractors Association (NRCA)[1] published an article suggesting the thermal performance of polyiso roof insulation may diminish when exposed to extreme temperatures, especially in cold climates. Since that time, additional articles[2,3] have been published suggesting a similar conclusion. In order to provide a comprehensive response to questions about roof insulation R-value and temperature, PIMA has conducted an extensive critical review as well as additional research necessary to evaluate these articles. Data presented in this report suggest that the alleged reduction in thermal value of polyiso roofing insulation is due to the application of an unnecessarily low assumption of "mean reference temperature" to estimate R-values in cold climates. Although the NRCA and other studies appear to infer that this mean reference temperature may be as low as 20^{o} F or even lower, PIMA concludes that a significantly higher mean reference temperature is appropriate for establishing winter heating thermal values. This conclusion is supported by an extensive analysis of historical North American climate data included in Appendix A of this report.

Based on the detailed review included in this report, PIMA finds that the actual R-values identified in the referenced NRCA article, when calculated within the relevant testing temperature range, do not differ significantly from current PIMA member published R-values for polyiso roof insulation. As a result, PIMA concludes that roof insulation R-values currently published by PIMA members provide the best guide for roofing designers seeking insulation thermal performance information.

Important Note: The R-values discussed in this report apply only to polyiso ***roof*** insulation manufactured using gas-permeable facers. It should be noted that polyiso ***wall*** insulation, which is manufactured primarily with impermeable, or gas tight facers will exhibit R-values higher than the values discussed in this report and is not addressed by this report or any of the articles referenced in this report.

WHY IS R-VALUE REPORTED USING A MEAN REFERENCE TEMPERATURE OF 75°F?

All North American manufacturers of building thermal insulation report the R-value of their products in accordance with several important industry standards. First, the R-values of all building thermal insulation products are tested and reported using a uniform "mean reference temperature" of 75°F (24°C), which is cited in both ASTM (United States) and CAN/ULC (Canada) standards. In addition, the use of a uniform 75°F mean reference temperature has long been mandated by the U.S. Federal Trade Commission (FTC) in its regulations for all insulation products marketed to consumers.[3]

"MEAN REFERENCE TEMPERATURE" IS NOT THE SAME AS AVERAGE OUTDOOR TEMPERATURE

For thermal R-value testing applications, the appropriate mean reference temperature should be calculated by averaging the actual mean outdoor ambient temperature for a particular climate zone and the intended indoor design temperature. As a result, the most suitable mean reference temperature for any particular climate would be the mid-point between the average outdoor ambient temperature and the indoor building design temperature during the respective winter heating and summer air conditioning seasons. As an example, if the mean outdoor ambient temperature during the winter heating season for a given location is 34° F and the indoor design temperature is 68° F, the appropriate mean winter heating mean reference temperature for thermal testing would be [(34° + 68°) ÷ 2], or 51° F. In a similar manner, if the mean outdoor ambient temperature during the summer air conditioning season for a given location is 74° F and the indoor design temperature is 68° F, the appropriate mean summer air conditioning mean reference temperature for thermal testing would be [(74° + 68°) ÷ 2], or 71° F.

CALCULATING MEAN REFERENCE TEMPERATURE USING ACTUAL CLIMATE DATA

Long-term climate data reported in NOAA Historical Climatology studies[5] suggests that approximately 80% of the cold weather heating period for all climate zones in the United States occurs in the five months from November through March. In a similar manner, over 80% of the warm weather air conditioning period in all but the warmest climate zones occurs in three months from June through August. As a result, it would be reasonable to establish the mean reference temperature for determining winter heating and summer air conditioning R-values for polyiso insulation based on the historical outdoor temperature average for each climate zone during the respective 5-month winter heating and 3-month summer air conditioning periods. Appendix A of this report provides average monthly outdoor ambient temperature data for selected cities in representative climate zones across North America, including eleven U.S. cities located in seven different climate zones (ASHRAE Climate Zones 1-7) and three Canadian cities located in three different climate zones (ASHRAE Climate Zones 5-7). In addition, the tables provide a calculation of the appropriate winter and summer mean reference temperatures represented as the midpoint between the 5 month winter or 3 month summer average outdoor ambient temperature and an indoor design temperature of 68°F.

Figure 1 provides a summary of the winter heating mean reference temperatures for each of the 7 ASHRAE Climate Zones based on an average of the typical cities listed in Appendix A for each climate zone. As illustrated in Figure 1, average winter outdoor ambient temperature ranges from a low of 22° F in Zone 7 to a high of 71° F in Zone 1. Using 68° F as a constant indoor design temperature, the calculated winter heating mean reference temperature for these cities and climate zones varies from a low of 45° F in Zone 7 to a high of 70°F in Zone 1.

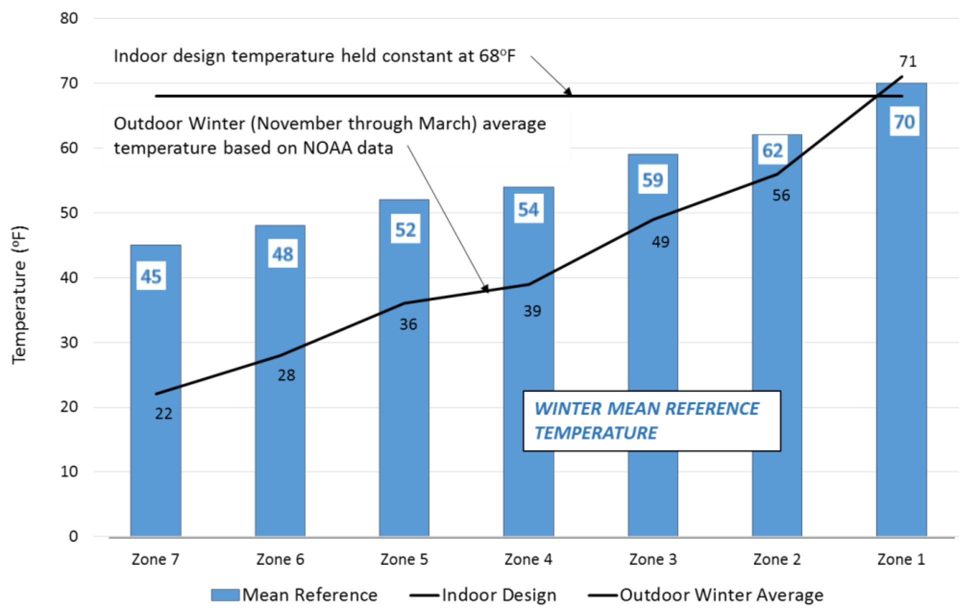

Figure 1: Mean Reference Temperatures by ASHRAE Climate Zone for Winter Conditions

In a similar manner, Figure 2 provides a summary of the summer air conditioning mean reference temperatures for each of the 7 ASHRAE Climate Zones based on an average of the typical cities listed in Appendix A for each climate zone. As illustrated in Figure 2, average summer outdoor ambient temperature ranges from a low of 66° F in Zone 7 to a high of 82° F in Zone 1. Using 68° F as a constant indoor design temperature, the calculated summer cooling mean reference temperature for these cities and climate zones varies from a low of 67° F in Zone 7 to a high of 76°F in Zone 1.

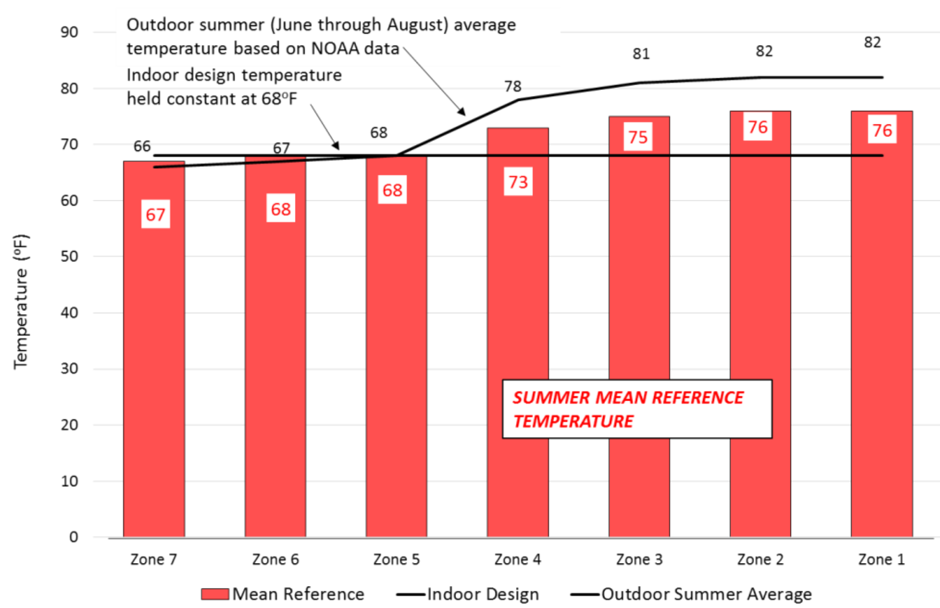

Figure 2: Mean Reference Temperatures by ASHRAE Climate Zone for Summer Conditions

It should be noted that actual winter and summer mean temperatures under field conditions may be higher than the mean reference temperatures shown in Figures 1 or 2. As an example, the outdoor temperature at the surface of the roofing assembly may be higher than the ambient air temperature due to solar heating during the day, which would tend to raise the mean reference temperature in all climate zones. In addition, outdoor temperatures at the surface of the roofing assembly also may continue to be higher than the ambient air temperature during the early evening.

WHAT IS THE POLYISO ROOF INSULATION R-VALUE FOR YOUR CLIMATE ZONE?

Using the actual average polyiso roof insulation R-value data reported in the 2010 NRCA study[1] PIMA calculated the temperature-related R-value for each of seven ASHRAE climate zones based on three different conditions:

1. Average R-value during the winter heating season
2. Average R-value during the summer air conditioning season
3. Average R-value for the entire year

These three average R-value calculations for each climate zone are shown in Figure 3.

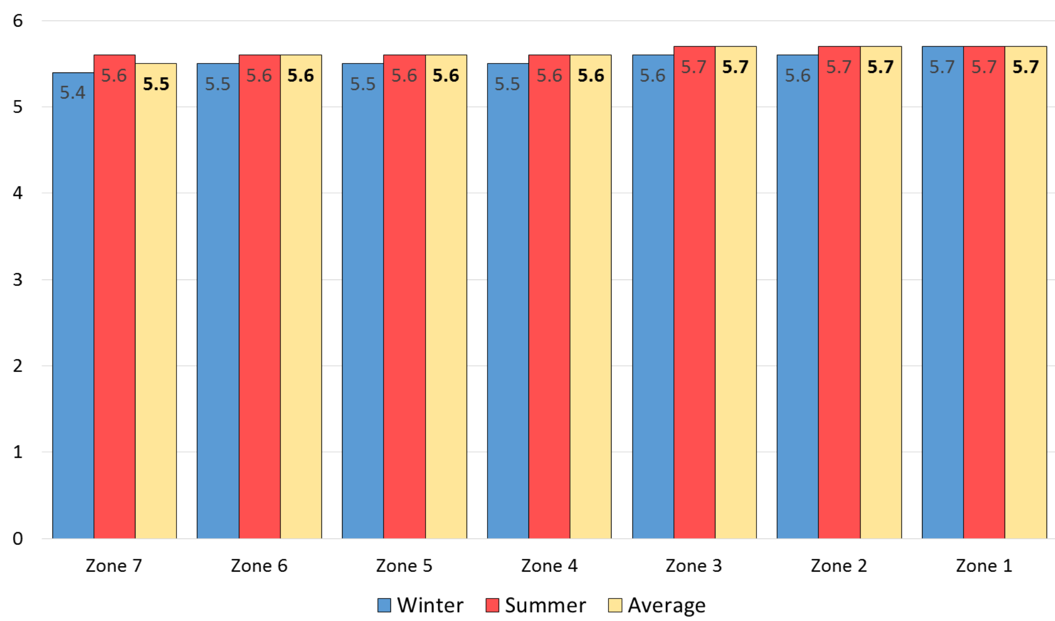

Figure 3: Polyiso Roof Insulation Average R-Value by ASHRAE Climate Zone
(Calculated from 2010 NRCA data and rounded to nearest 0.1 R[6])

As illustrated in Figure 3, the interpolated NRCA data suggest that the winter heating R-value of polyiso roof insulation ranges from a low of no less than 5.4 in the coldest climate zone to a high of at least 5.7 in the warmest climate zone, while the summer air conditioning R-value of polyiso roof insulation ranges from a low of 5.6 in the coldest climate zone to a high of 5.7 in the warmest climate zone. Applying these winter and summer R-values to an average annual value, the R-value of polyiso roof insulation falls within a similar range of 5.5 to 5.7. Over the entire year, the variation in average R-value for all but the coldest climate zone equals 0.1 R, or less than a 2 percent variation. In addition, it should be noted that these interpolated R-values for winter, summer, and annual average R-values shown in Figure 3 do not vary significantly from R-values for polyiso roof insulation currently published by polyiso insulation manufacturers across North America.

SUMMARY AND CONCLUSIONS

- **Mean Reference Temperatures for Cold Climates and Warm Climates**. Based on actual U.S. and Canadian climate data, the most suitable mean winter heating reference temperature for testing the R-value of polyiso or any other thermal insulation should be no less than 45° F for the coldest climates and up to 72° F for the warmest climates in North America.
- **Cold Climate and Polyiso Roof Insulation R-Values**. After previously published average R-value data for polyiso roof insulation are applied to this 45° F to 72° F mean reference temperature range, the R-values calculated do not vary significantly across the temperature range or as compared to PIMA member published values. As a result, separate cold climate and warm climate R-values for polyiso roof insulation do not appear to have any merit.

NOTES:

1. M. Graham (2010) R-value concerns. *Professional Roofing*, May.
2. Building Science Corporation (2013). BSC Information Sheet 502. Understanding the temperature dependence of R-values for polyisocyanurate roof insulation. Available: www.buildingscience.com
3. S. Marzella and R. Boyer (2015) R-values in our climates. *Professional Roofing*, February.
4. 16 CFR Part 460 Labeling and Advertising of Home Insulation
5. NOAA Historical Climatology Series 5.1 State, Regional, and National Monthly and Seasonal Heating Degree Days Weighted by Population 1931 – 1992.
6. It should be noted that the NRCA polyiso R-value data relevant to PIMA's calculations shown in Figure 3 were reported for two mean reference temperature points: 40°F and 75°F. Specifically, the NRCA reported an average polyiso R-value of 5.4 at a 40°F mean reference temperature and an average polyiso R-value of 5.7 at a 75°F mean reference temperature. Because these two temperature points occur at or near the upper and lower boundaries of the 45°F to 72°F mean temperature range identified in Figures 1 and 2, the R-values shown in Figure 3 are based on linear interpolation between these upper and lower boundary data points. It is possible that the R-values shown in Figure 3 may actually be higher, especially if the actual R-value / mean temperature curve contains higher R-vales at any temperature between the 40°F and 75°F data points of the previous studies. In any event, linear extrapolation provides a conservative calculation of actual polyiso R-values at any temperature within this range.
7. The R-values discussed in this report apply only to polyiso roof insulation manufactured using gas-permeable facers. It should be noted that polyiso wall insulation, which is manufactured primarily with impermeable, or gas tight facers will exhibit R-values higher than the values discussed in this report and is not addressed by this report or any of the articles referenced in this report.

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APPENDIX A:

MEAN OUTDOOR AND REFERENCE TEMPERATURES FOR SELECTED NORTH AMERICAN CITIES

Source: Country Studies Series, Federal Research Division of the Library of Congress
(http://countrystudies.us/united-states/weather/)

ASHRAE Zone 7 (Winter Mean Reference = 45°F, Summer Mean Reference = 66°F)

Duluth, MN (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	11	17	27	39	48	58	66	66	58	46	31	17	21	63
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	40	43	48	54	58	63	67	67	63	57	50	43	45	66

Calgary, AB, (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	15	21	28	39	49	57	62	60	51	42	27	17	22	61
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	42	45	48	54	59	63	65	64	60	55	48	43	45	65

ASHRAE Zone 6 (Winter Mean Reference = 48°F, Summer Mean Reference = 67°F)

Milwaukee, WI (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	20	25	35	46	59	68	74	72	64	53	39	26	29	71
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	44	47	55	57	64	68	71	70	66	61	54	45	49	70

Toronto, ON (^{0}F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	18	19	27	37	46	55	61	62	55	44	35	24	25	59
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	43	44	48	53	57	62	65	65	62	56	52	46	47	64

ASHRAE Zone 5 (Winter Mean Reference = 52°F, Summer Mean Reference = 68°F)

Indianapolis, IN (^{0}F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	26	30	40	51	62	71	75	73	66	54	42	31	34	73
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	47	49	54	60	65	70	72	71	67	61	55	50	51	71

Denver, CO (^{0}F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	30	33	39	48	57	67	73	71	62	51	39	31	34	70
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	49	51	53	58	63	67	71	69	65	60	53	49	51	69

Vancouver, BC (^{0}F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	37	40	43	48	54	59	63	63	58	50	43	38	40	62
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	53	54	55	58	61	64	66	66	63	59	55	53	54	65

ASHRAE Zone 4 (Winter Mean Reference = 54°F, Summer Mean Reference = 73°F)

Baltimore, MD (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	35	36	46	56	66	76	80	78	71	60	50	39	41	78
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	51	52	57	62	67	72	74	73	70	64	59	54	55	73

St. Louis, MO (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	29	34	45	56	66	75	79	77	69	58	46	34	37	77
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	48	51	56	62	67	72	74	73	69	63	57	51	53	73

ASHRAE Zone 3 (Winter Mean Reference = 59°F, Mean Reference = 75°F)

Atlanta, GA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	41	45	53	61	68	76	78	78	73	62	53	45	47	77
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	54	56	61	65	68	72	73	73	70	65	61	56	58	73

Dallas, TX (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	44	48	58	67	74	81	86	85	78	68	56	47	51	84
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	56	58	63	67	71	75	77	77	73	68	62	58	59	76

ASHRAE Zone 2 (Winter Mean Reference = 62°F, Summer Mean Reference = 76°F)

Tucson, AZ (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	51	54	58	66	73	83	86	84	81	70	59	51	55	84
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	60	61	63	67	71	75	77	76	74	69	63	60	61	76

Houston, TX (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	52	55	62	69	76	80	83	83	80	71	62	55	57	82
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	60	62	65	69	72	74	76	76	74	70	65	61	63	75

ASHRAE Zone 1 (Winter Mean Reference = 70°F, Summer Mean Reference = 76°F)

Miami, FL (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Winter Average	Summer Average
Mean Outdoor Ambient	68	69	71	74	79	82	83	84	83	80	75	70	71	83
Inside Design	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Reference (Mid-Point)	68	69	70	65	74	75	76	76	76	74	72	69	70	76