Thermal Energy System Resilience: Thermal Decay Test (TDT) in Cold/Arctic Climates, Modeling & Parametric Analysis

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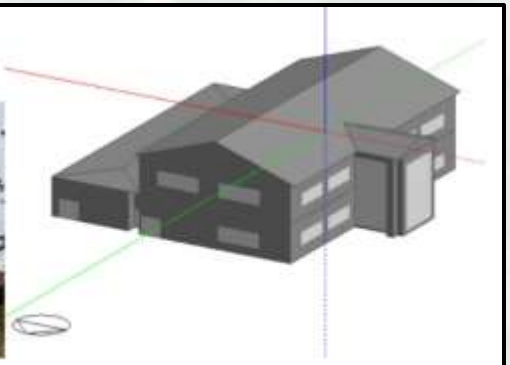
US Army Corps of Engineers

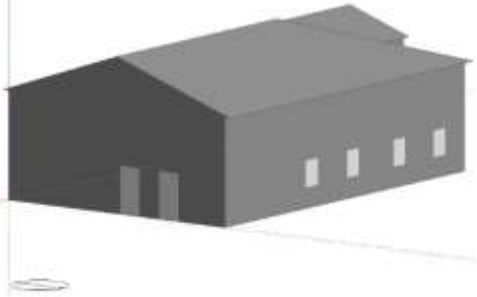
BUILDING STRONG®

Building Models Ft. Wainwright & Ft. Greely

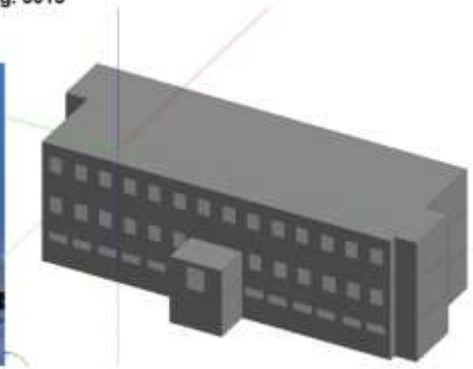
Ft Wainwright



a. Bldg. 3002

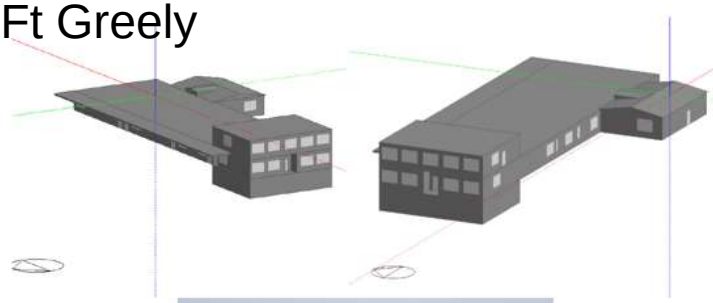


b. Bldg. 3013

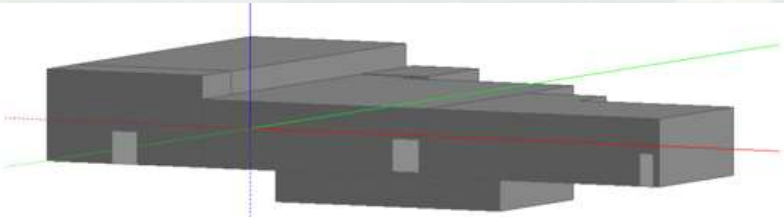


c. Bldg. 4070

Ft Greely



a. Bldg. 603



b. Bldg. 650

Building Air Leakage Test Results

FTG & FTW ABT-2019	Year of Const.	Bldg. Const. Type	Six-Sided Area (ft^2/m^2)	CFM75/ ft^2 ($m^3/h.m^2$)	EqLA75 (ft^2/m^2)	ACH
FTW 3002	2016	IMP	39,822 / 3,703.5	0.208 / 3.744)	5.7 / 0.53	0.342
FTW 3013	1999	Wood Framed	8,488.8 / 789.5	0.095 / 1.710	0.5 / 0.047	0.217
FTW 4070	1950s	CMU Upgraded				
FTG 603	1955	CMU/Concrete/EIFS	32005.6 / 2,976.5209	0.155 / 2.790	3.3 / 0.307	0.399
FTG 650	1955	CMU/Concrete/EIFS	28,501.6 / 2,650.6489	0.146 / 2.628	2.8 / 0.260	0.261

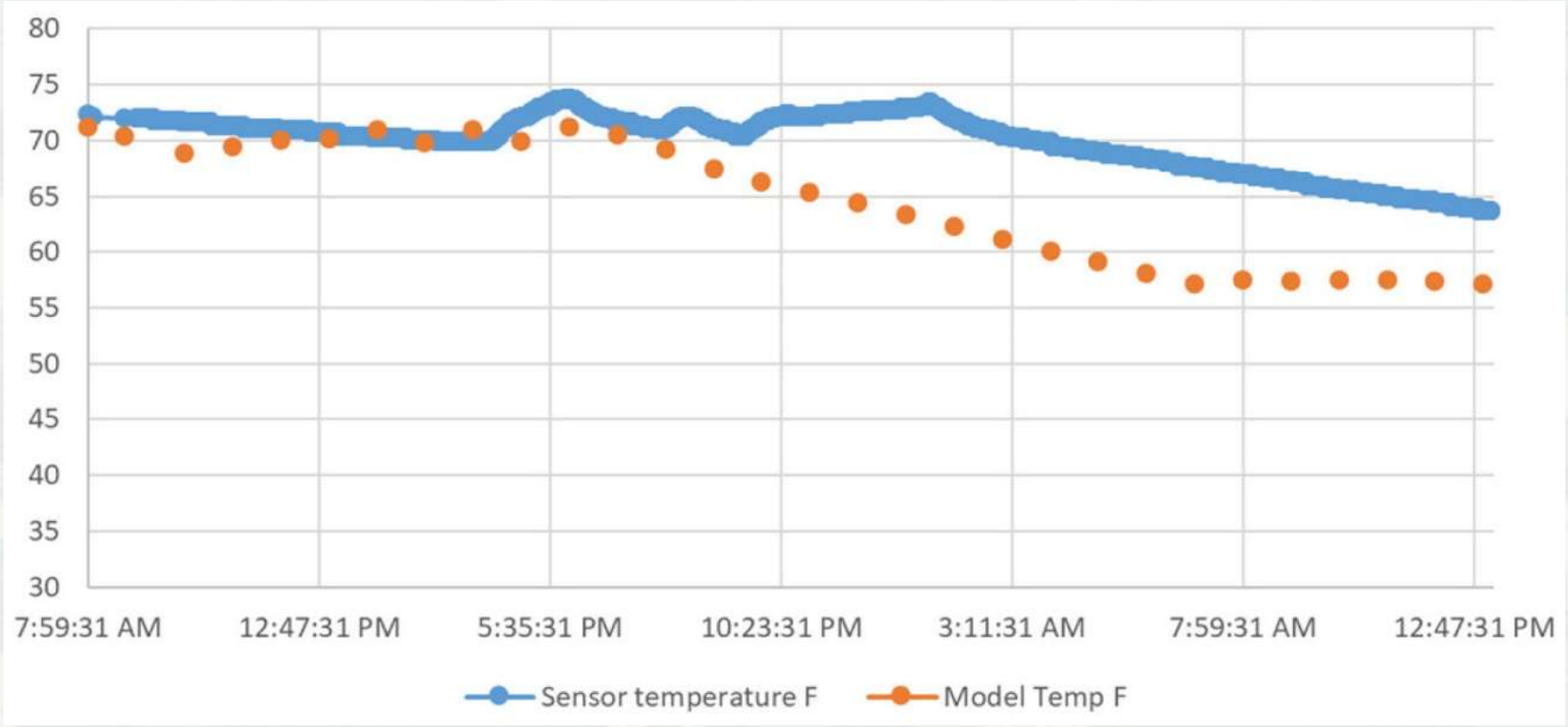
* Alaska Thermal Imaging, Inc, Palmer, Alaska, **http://alaskathermalimaging.com/Home_Page.html**

† CFM75 is air leakage rate in cubic feet per minute at 75 Pa, i.e., the static pressure between the building's interior and the buildings ambient; and CFM is air leakage rate in cubic feet per minute at standard pressure and EqLA75 is Equivalent Leakage Area at 75 Pa.

FTW Building 3013 Model Construction Properties

- Constructed 1999
- Wooden frame and metal siding
- Eave height of 16 feet
- Internal ceiling drop is 9 feet
- total of six windows width of 36 inches and a height of 48 inches with low emissivity coatings
- Wall are estimated to have a total R value = 26
- Roof is estimated as having a total R value = 30
- Building has a low intensity slab heating in the floors and ceilings with mechanical ventilation for fresh air.
- Single Story with 2640 Ft^2 conditioned area.

FTW Building 3013 Model & TDT Test Results

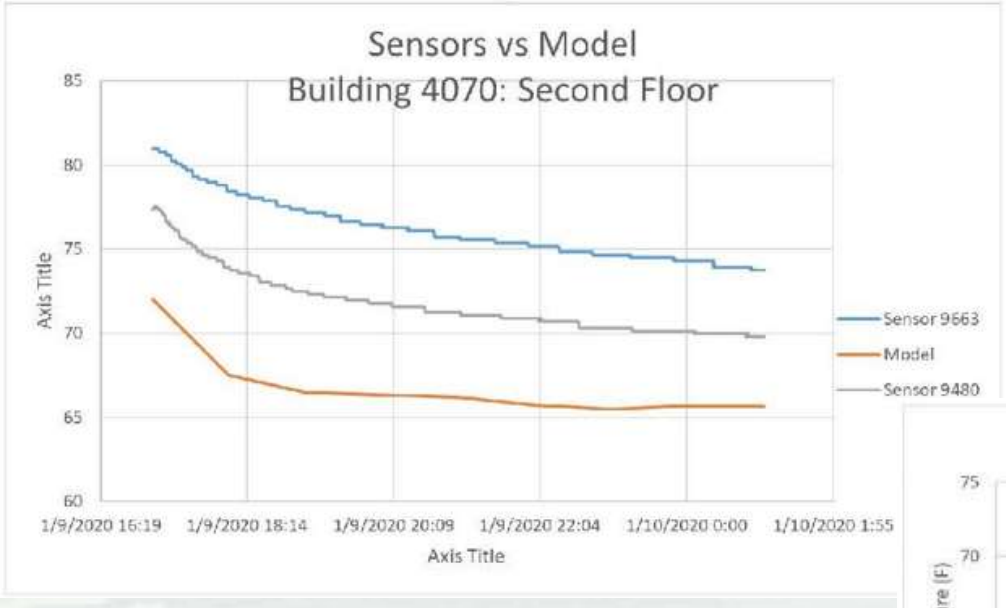


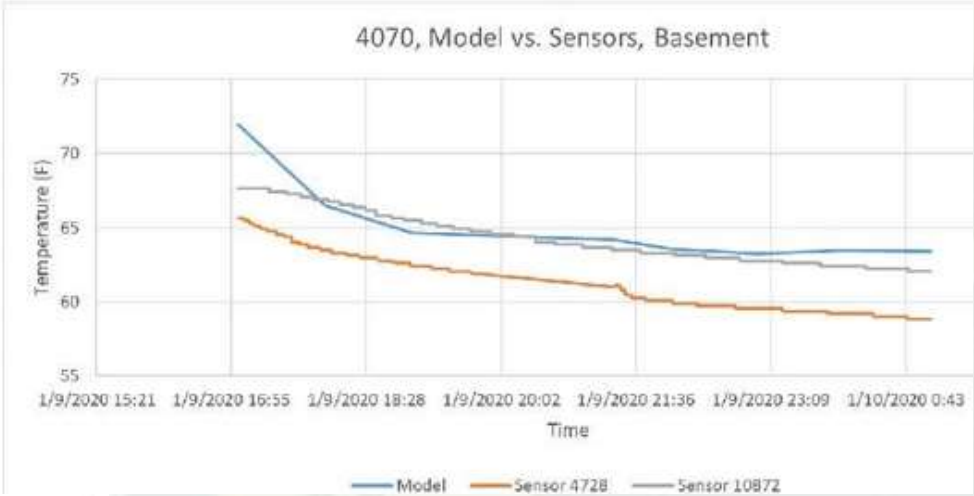
- Good agreement until 1700, while radiant floor temperature decays.
- Do not want model to under-predict the time to repair

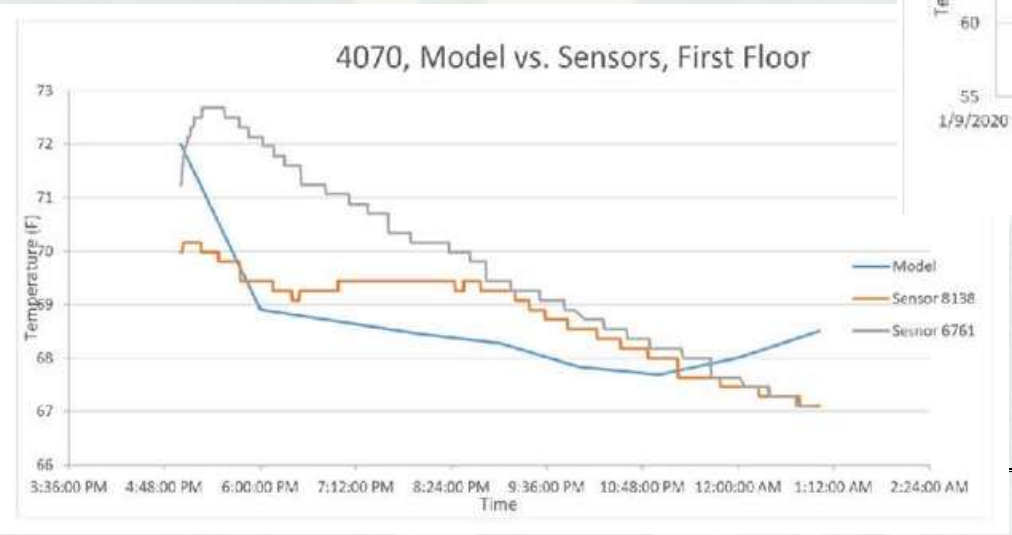
FTW Building 4070 Model Construction Properties

- Constructed 1950s with recent major renovation
- Facility is 2 floors and a basement
- Operated as a office building with lab spaces
- Total window area 1343 ft2 and WWR = 8.4%
- Window U-value = 0.478
- CMU walls with 4” EPS added during renovation R=29.7
- Roof is estimated as having a total R value = 25
- Building described as “tight” and modeled with ACH = 0.3
- Multi Story with 17008 ft^2 conditioned area.

FTW Building 4070 Model & TDT Test Results



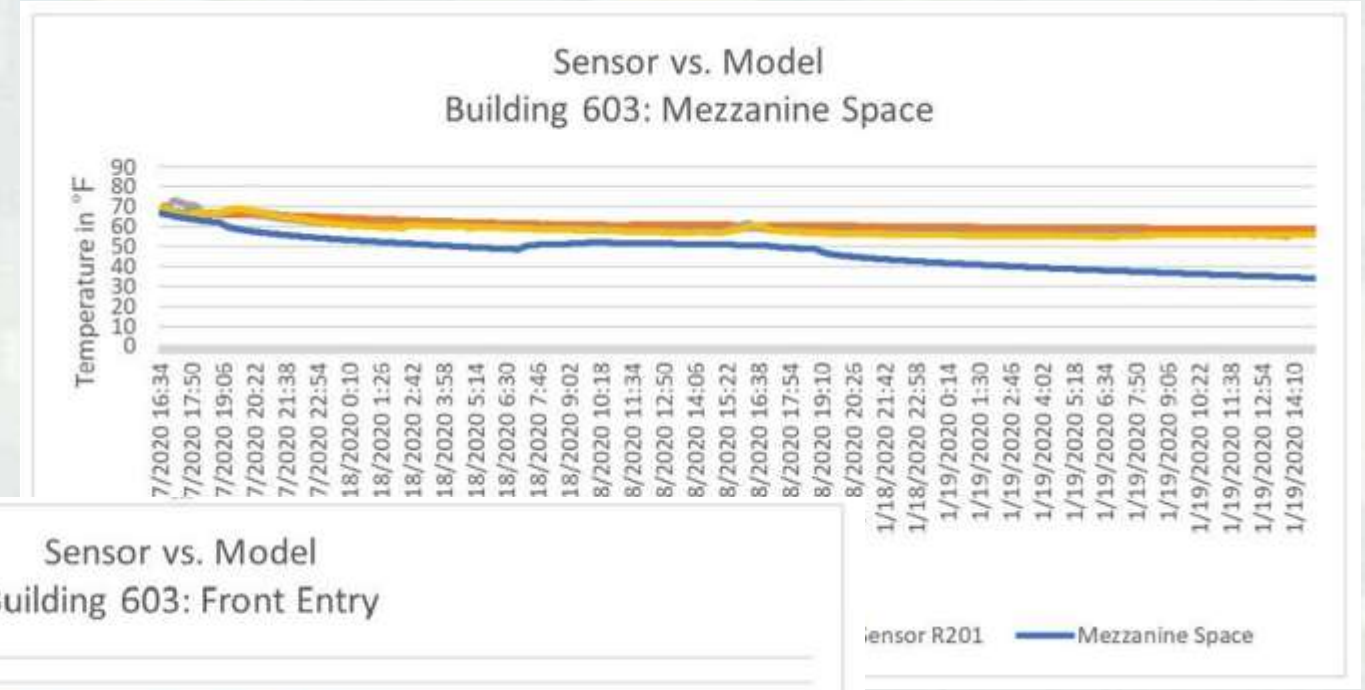


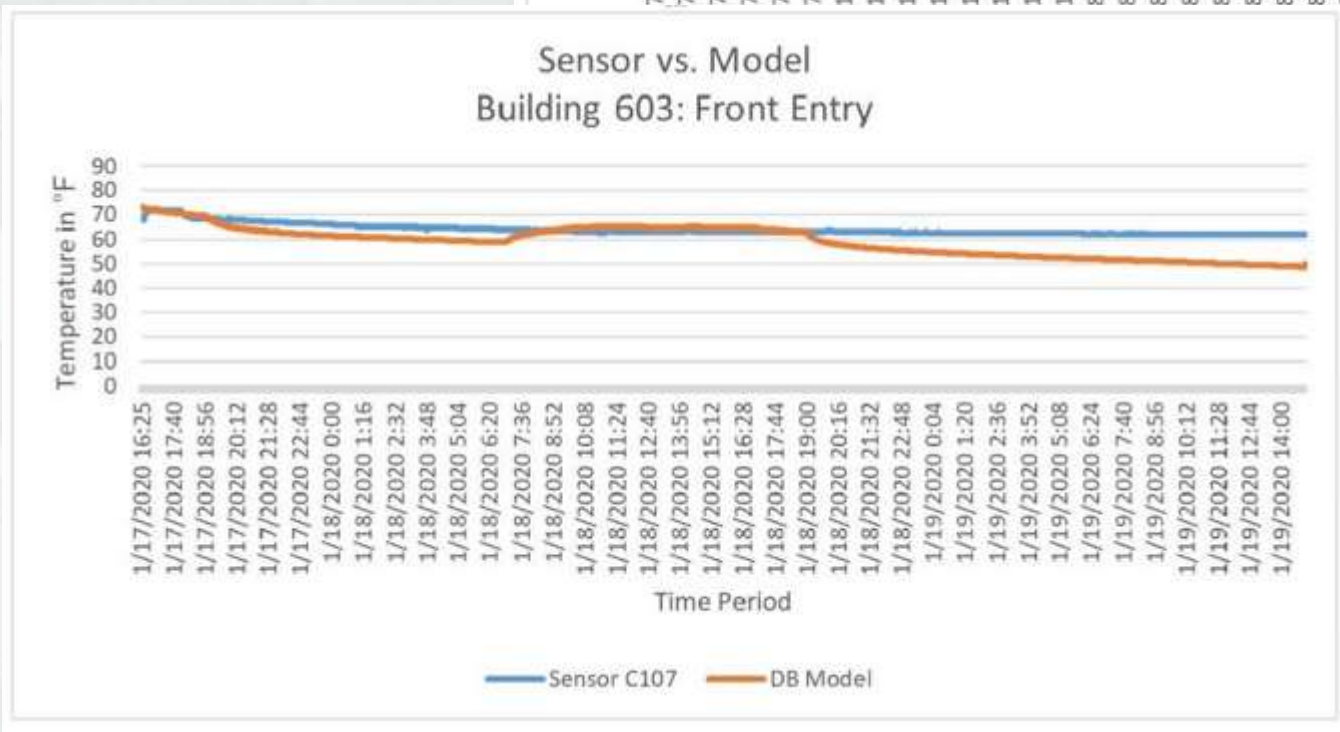


FTG Building 603 Model Construction Properties

- Constructed 1955
- 2 Story CMU building with an EIFS exterior
- Operated as an office building
- Total window area 1080 ft2 and WWR = 14.6%
- Window U-value = 0.478
- Wall are estimated to have a total R value = 28
- Roof is estimated as having a total R value = 25
- Multi Story with 11425 ft^2 conditioned area.

FTG Building 603 Model & TDT Test Results





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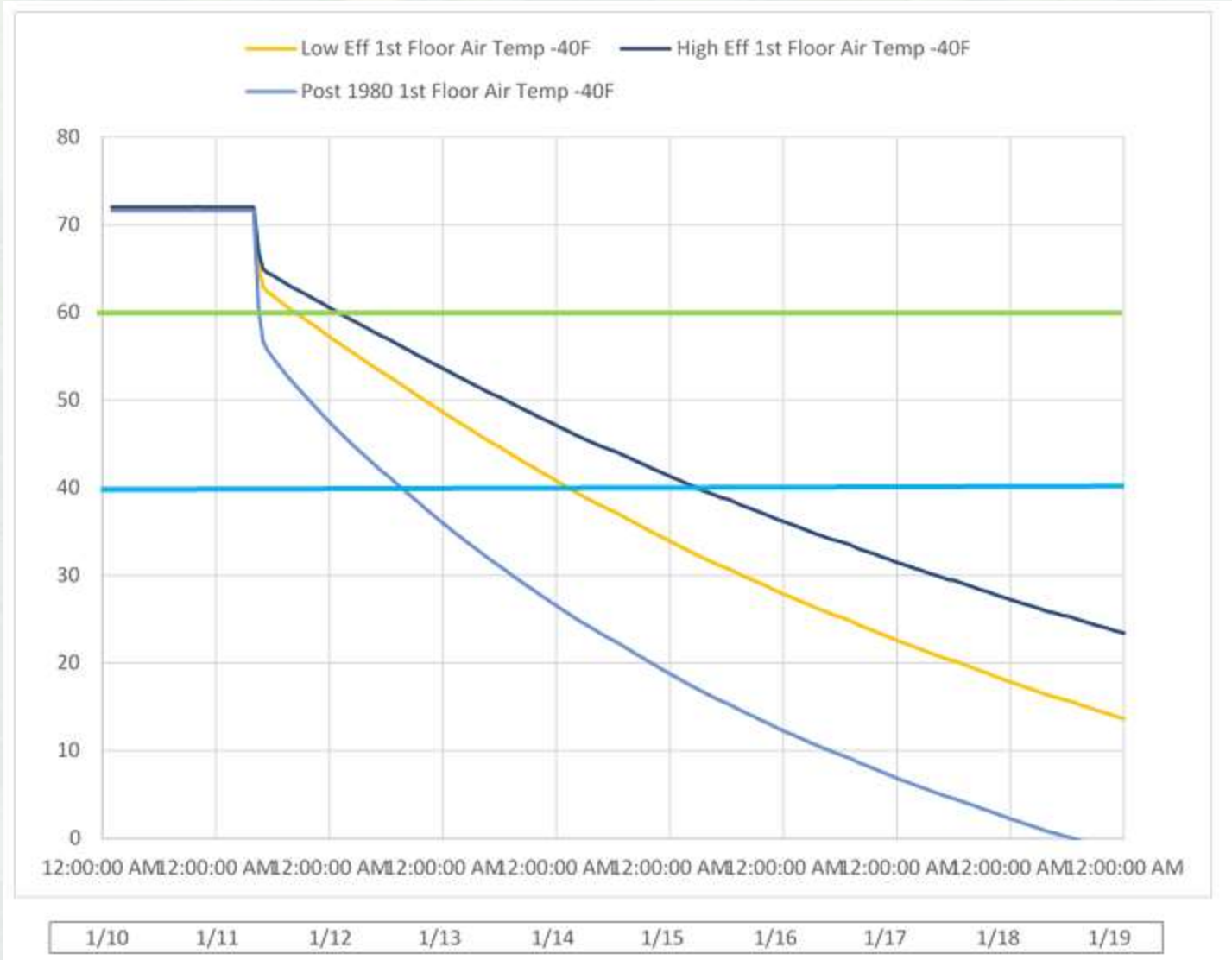
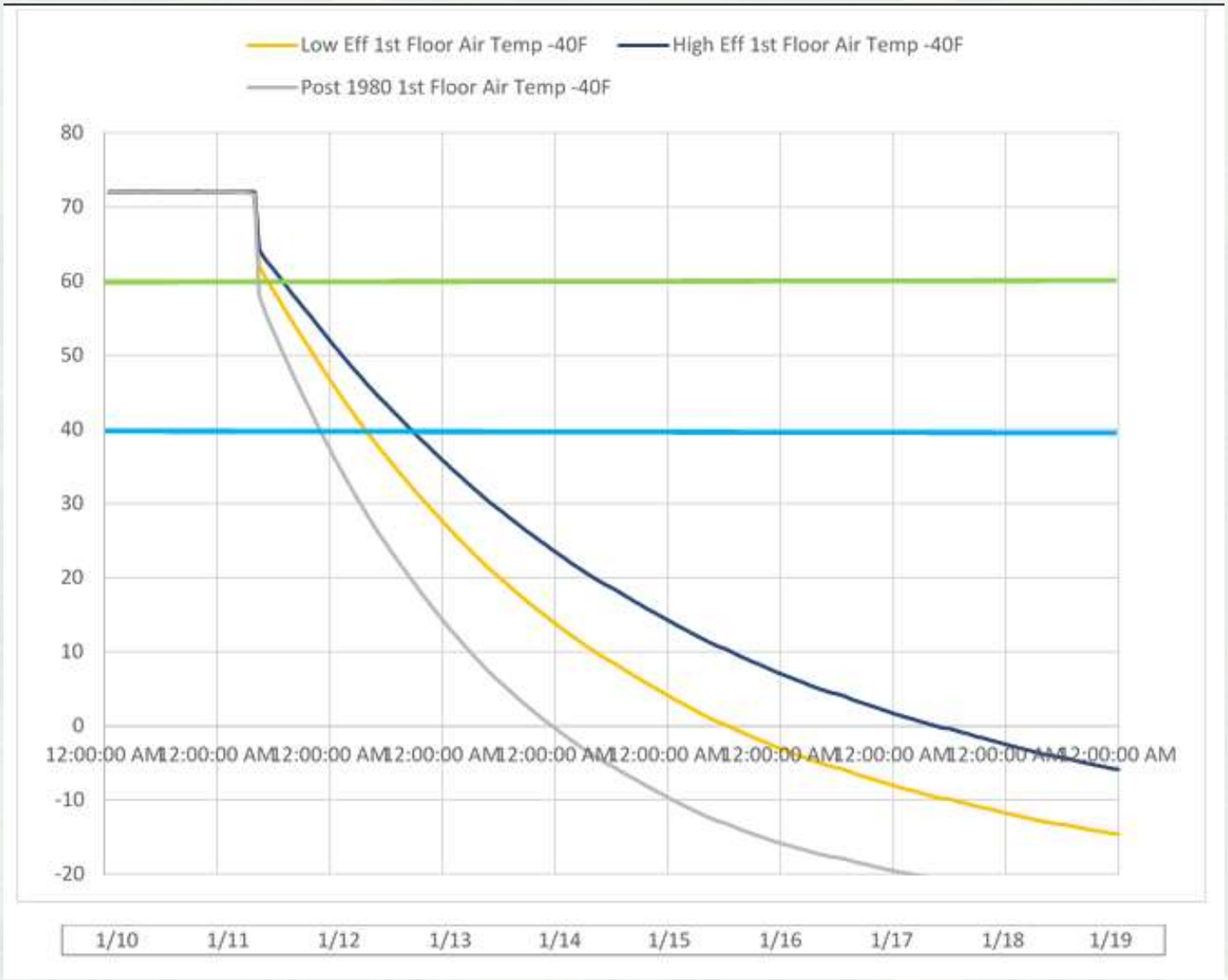
Parametric Analysis Using the Bldg. 4070 Model

Building Parameters	Temp ODB	Mass Building			Frame Building		
		Typical/Post 1980	Low Efficiency	High Efficiency	Typical/Post 1980	Low Efficiency	High Efficiency
Walls (R-Value IP)		20.5	40	50	20.5	40	50
Roof (R-value IP)		31.5	45	60	31.5	45	60
Air Leakage (ACH)		0.4	0.25	0.15	0.4	0.25	0.15
Window (R-Value / U value)		Double Pane; R= 1.78 / U=.56	Double Pane; R= 3.34 / U=.3	Triple Pane; R= 5.25 / U=.19	Double Pane; R= 1.78 / U=.56	Double Pane; R= 3.34 / U=.3	Triple Pane; R= 5.25 / U=.19
MTTR Hab. (60F)	-60 F	< 1 hours	2 hours	5 hours	<< 1 hour	1 hours	2 hours
MTTR Sust. (40F)	-60 F	9 hours	28 hours	41 hours	4 hours	14 hours	21 hours
MTTR Hab. (60F)	-40 F	1 hours	3 hours	10 hours	< 1 hour	2 hours	4 hours
MTTR Sust. (40F)	-40 F	20 hours	36 hours	51 hours	10 hours	18 hours	24 hours
MTTR Hab. (60F)	-20 F	2 hours	6 hours	15 hours	1 hour	3 hours	6 hours
MTTR Sust. (40F)	-20 F	31 hours	46 hours	60 hours	15 hour	22 hours	28 hours
MTTR Hab. (60F)	0 F	3 hours	13 hours	29 hours	2 hours	5 hours	9 hours
MTTR Sust. (40F)	0 F	43 hours	59 hours	90 hours	21 hours	28 hours	33 hours
MTTR Hab. (60F)	20 F	10 hours	28 hours	45 hours	3 hour	8 hours	15 hours
MTTR Sust. (40F)	20 F	60 hours	78 hours	95 hours	28 hours	35 hours	40 hours
MTTR Hab. (60F)	40 F	29 hours	54 hours	72 hours	8 hour	17 hours	23 hours
MTTR Sust. (40F)	40 F	93 hours	112 hours	123 hours	41 hours	47 hours	50 hours

Mass Building: High efficiency, Low efficiency, & Typical 1980
Heating Failure Results -40 °F (-40.0 °C) Weather



Frame Building: High efficiency, Low efficiency, & Typical 1980 Heating Failure Results -40 °F (-40.0 °C) Weather



Simulation Results Bldg. 4070 by Room & Floor (-60 °F)

Date/Time	Failure Hours	ODB	2	2	2	2	2	2	1	1	1	1	1	1	B	B	B	B	B	B
01/11 01:00:00	0	-60	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
01/11 02:00:00	0	-60	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
01/11 03:00:00	0	-60	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
01/11 04:00:00	0	-60	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
01/11 05:00:00	0	-60	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
01/11 06:00:00	0	-60	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
01/11 07:00:00	0	-60	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
01/11 08:00:00	0	-60	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
01/11 09:00:00	1	-60	64	66	65	65	64	64	67	64	64	65	66	62	61	64	62	62	64	61
01/11 10:00:00	2	-60	62	65	63	62	63	62	65	61	61	63	64	59	56	61	58	57	62	56
01/11 11:00:00	3	-60	61	64	63	61	62	61	65	61	60	62	64	58	55	60	57	56	62	55
01/11 12:00:00	4	-60	61	64	62	61	62	61	64	60	60	62	63	58	55	59	56	55	61	55
01/11 13:00:00	5	-60	61	64	62	60	62	60	64	60	59	61	63	57	54	59	56	55	60	54
01/11 14:00:00	6	-60	60	63	61	60	61	60	64	59	59	61	63	57	53	58	55	54	60	53
01/11 15:00:00	7	-60	60	63	61	60	61	59												
01/11 16:00:00	8	-60	59	63	61	59	61	59												
01/11 17:00:00	9	-60	59	62	60	59	59	58												
01/11 18:00:00	10	-60	58	62	60	59	58	58												
01/11 19:00:00	11	-60	58	62	59	58	58	57												
01/11 20:00:00	12	-60	58	60	59	58	57	57												

Process to determine MTTR for Habitability Criteria (60F)

Process to determine MTTR for Sustainability Criteria (40F)

Date/Time	Failure Hours	ODB	2	2	2	2	2	2	1	1	1	1	1	1	B	B	B	B	B	B
01/12 08:00:00	24	-60	52	55	54	53	52	52	55	52	51	52	54	50	44	47	44	43	48	42
01/12 09:00:00	25	-60	52	54	54	52	52	51	55	52	51	52	53	49	44	47	44	42	48	42
01/12 10:00:00	26	-60	51	54	54	52	53	51	54	51	51	51	53	49	44	46	44	42	47	41
01/12 11:00:00	27	-60	51	53	53	52	53	51	54	51	50	51	53	48	43	46	44	41	47	41
01/12 12:00:00	28	-60	51	53	53	52	53	50	53	51	50	50	52	48	43	45	44	41	46	40
01/12 13:00:00	29	-60	50	53	53	51	52	50	53	50	50	50	52	48	42	45	43	40	46	40
01/12 14:00:00	30	-60	50	52	52	51	52	50	53	50	49	49	51	47	42	45	43	40	46	39
01/12 15:00:00	31	-60	49	52	52	51	52	50	52	49	49	49	51	47	42	44	43	40	45	39
01/12 16:00:00	32	-60	49	52	52	51	52	49	52	49	48	49	51	46	41	44	42	39	45	39
01/12 17:00:00	33	-60	49	51	51	50	51	49	51	48	48	48	50	46	41	43	42	39	44	38
01/12 18:00:00	34	-60	48	51	51	50	50	49	51	48	48	48	50	46	40	43	42	38	44	38
01/12 19:00:00	35	-60	48	50	51	50	49	48	51	48	47	47	50	45	40	42	40	38	43	37
01/12 20:00:00	36	-60	48	50	50	49	49	48	50	47	47	47	49	45	40	42	40	38	43	37
01/12 21:00:00	37	-60	47	50	50	49	48	47	50	47	46	47	49	45	39	42	39	37	42	36
01/12 22:00:00	38	-60	47	49	50	47	48	47	49	47	46	46	48	44	39	41	39	37	42	36
01/12 23:00:00	39	-60	46	49	49	46	47	47	49	46	46	46	48	44	38	41	38	36	42	36
01/12 24:00:00	40	-60	46	49	49	45	47	46	49	46	45	46	48	43	38	40	38	36	41	35
01/13 01:00:00	41	-60	46	48	48	45	46	46	48	45	45	45	47	43	38	40	37	36	41	35
01/13 02:00:00	42	-60	45	48	48	44	46	45	48	45	45	45	47	43	37	40	37	35	40	35

Quick Review: Parametric Analysis Using the Bldg. 4070 Model or Office Building

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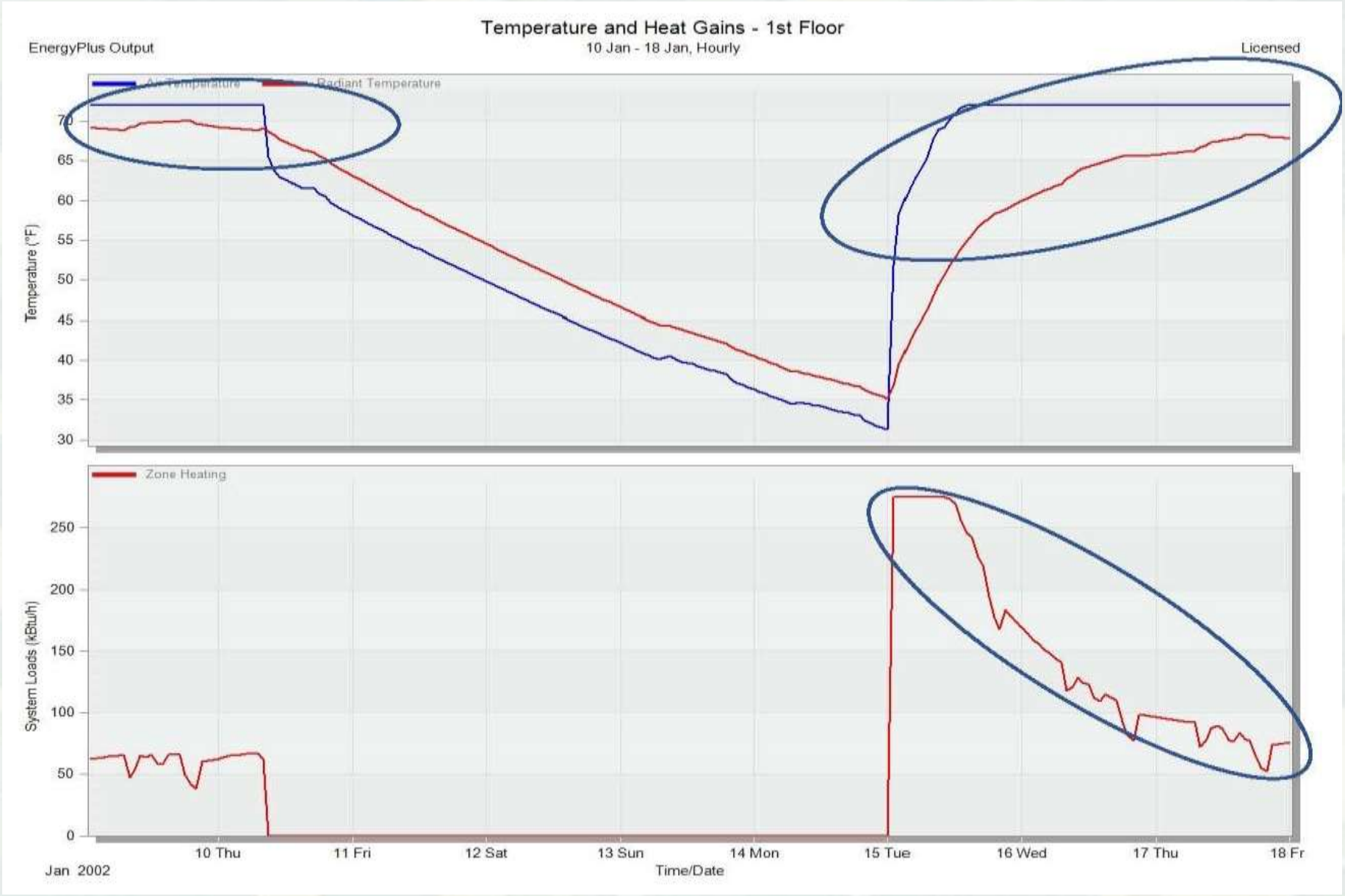

Conclusions

- The 40 ^{o}F limit is a good metric as a response time for heating restoration.
- The slope on the air temperature decay is an indicator of the efficiency of the building envelope and its operation
- Any envelope efficiency changes, i.e. reduction in insulation levels or decrease in building air tightness, will decrease the thermal resiliency
- The rate of temperature decay, minimum temperature asymptote, length of recovery are all significant aspects of the building's thermal resiliency, with the more efficient structure being more resilient.