

Thermal Performance for AAC Block ^(*)

Residential Application

1.0 Introduction

Building design and material properties influence thermal performance and energy consumption for residential and commercial buildings. AAC wall, floor and roof systems provide an innovative combination of excellent **thermal conductivity**, **thermal mass** and low **air-infiltration**. This practical combination of properties in one system provides an excellent thermal insulation material and permits peak energy usage in the building to be shifted to off-peak hours, thus reducing operation cost for building users and owners, improving comfort of living and reducing the demand on power generation facilities.

2.0 Definitions.

It is important to remember that thermal performance of any building material is the result of several factors and may not be assumed either effective or ineffective on the basis of any one factor. In this section, there are definitions and examples of the various thermal properties that are used to determine the overall thermal efficiency of any building material. It will be shown how these thermal properties generally influence the design of the building envelope and specifically how the AAC thermal properties result in outstanding performance and energy savings. The values for the various AAC thermal properties are included in a later section of this chapter.

Thermal Conductivity “K” (Btu.in/h.Ft².F) is a measure of the material conductivity as tested in a laboratory procedure that measures the heat flow through building material under steady and constant climatic conditions. It is important to remember that these laboratory conditions do not reflect the normal climatic cycles. This issue will be discussed in further detail in the thermal mass section. Based on the above definition, it is obvious that the lower the K value the higher the insulating value. The following table gives the “K” value for different materials;

Designation	Thermal Conductivity, K (Btu.in/h.Ft ² .F)
AAC 32 pcf	0.96 ⁽¹⁾
Concrete (Density 150 pcf)	9.98 ⁽²⁾
Insulation Board (Polystyrene)	0.2 ⁽³⁾
Steel	329
Water	4.15

⁽¹⁾ Based on ASTM C518

⁽²⁾ ASHRAE

⁽³⁾ ASHRAE

Thermal Resistance “R” (h.Ft².F/Btu) is the opposite of the thermal conductivity and it is *the resistance of material to conduct or allow heat flow. R-value*

$$R = (1 / K) \times \text{Wall Thickness (in.)}$$

Designation	Thermal Resistance “R” (h.Ft ² .F/Btu)
8” AAC 32 pcf Wall System	10.0
8” Concrete 150 pcf Wall System	1.0
3 ½” Batt Insulation	13
1” Steel Plate	0.003

Note: Wall System and Concrete Wall System Consist of Plaster on both side of the wall

Heat Transmission Coefficient, U-value (Btu/h. Ft².°F) is defined as *the amount of heat, expressed in BTU’s transmitted in one hour through one square foot of a building envelope in 1 °F temperature difference.*

$$U = 1 / R$$

Designation	U-value (Btu/h.Ft ² .F)
8” AAC 32 pcf Wall System	0.10
8” Concrete 150 pcf Wall System	1.0
3 ½” Batt Insulation	0.077
1” Steel Plate	329

Note: AAC Wall System and Concrete Wall System Consist of Plaster on both side of the wall

In addition to the above basic material thermal properties, other thermal properties such as **specific heat** and **heat capacity** effect the performance of building envelope.

Specific heat, s (Btu/Ib.°F) is the amount of heat required to raise one pound of material one degree °F.

Designation	Specific heat (Btu/Ib.°F)
8” AAC 32 pcf Wall System	0.25
8” Concrete 150 pcf Wall System	0.21
3 ½” Batt Insulation	0.085
1” Steel Plate	0.125

Heat capacity, HC (Btu/Ft².°F) or sometimes is referred to as **“thermal mass”**, is a measure of how much heat a building component can store or hold per unit of mass. It is essentially the specific heat taking in account the thickness of the material.

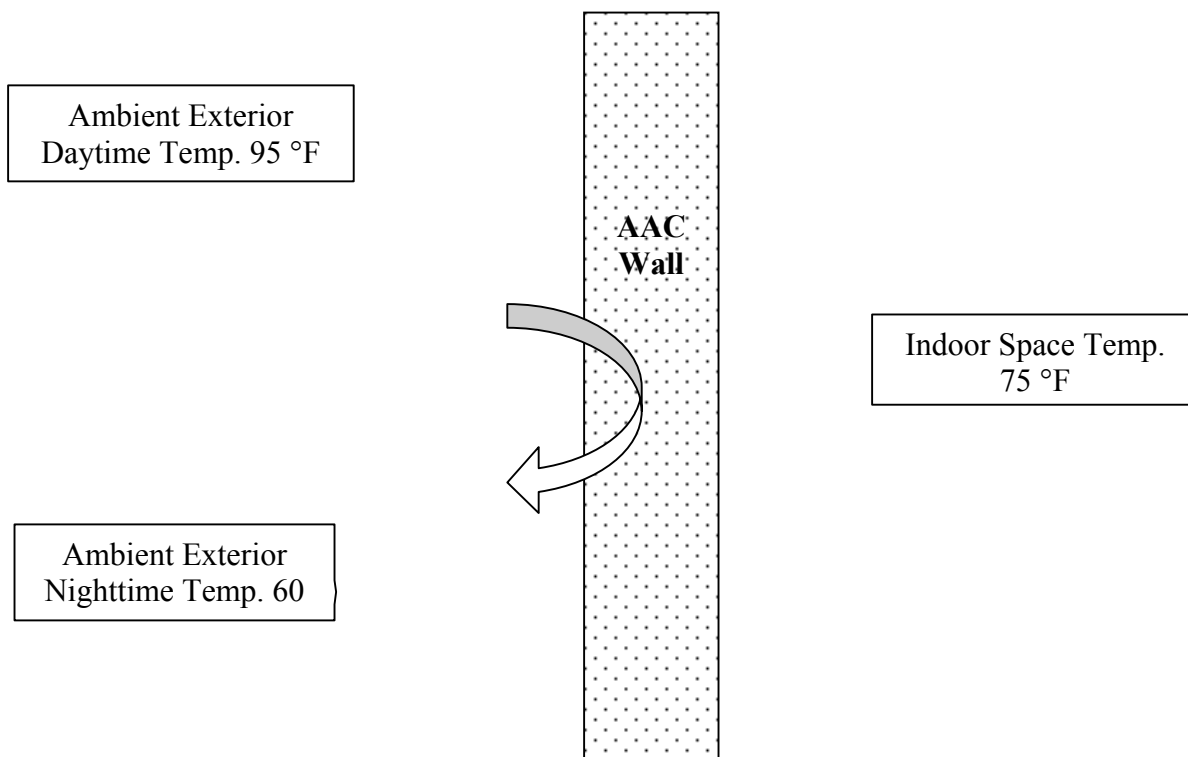
Designation	Heat capacity, HC (Btu/Ft ² .°F)
8" AAC 32 pcf Wall System	6.07
8" Concrete 150 pcf Wall System	23.0
3 ½" Batt Insulation	0.007
1" Steel Plate	5.10

Note: AAC Wall System and Concrete Wall System Consist of Plaster on both side of the wall

3.0 Understanding the Thermal Mass Benefit Concept

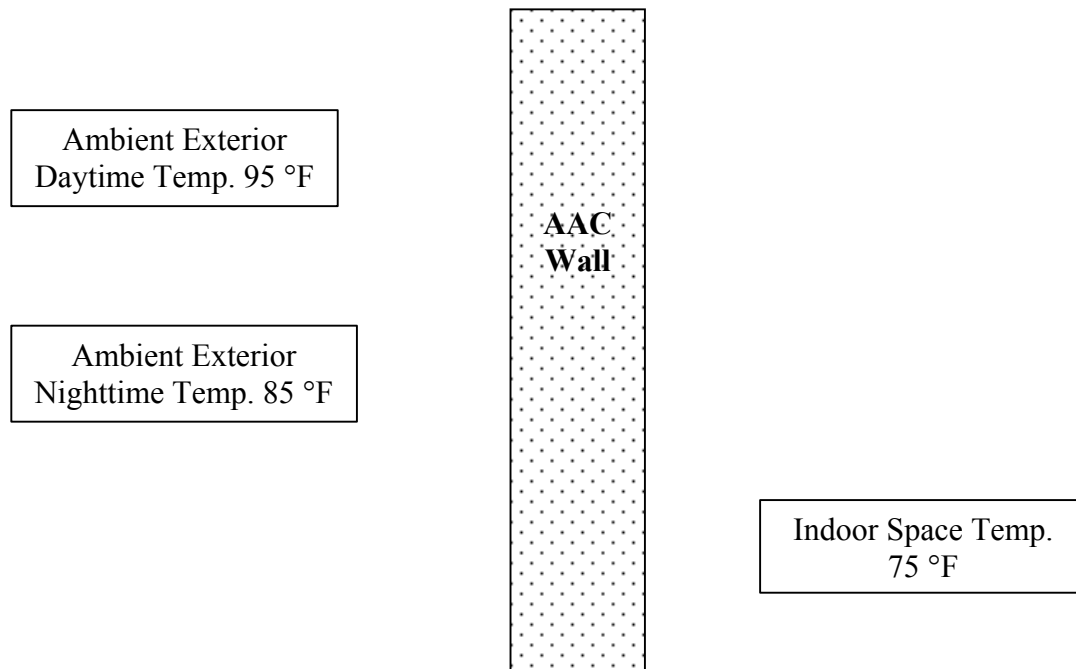
In the **“steady state”** thermal values obtained from laboratory testing, it is assumed that temperatures at both sides of a wall are constant and remain constant for a period of time, unlike what actually occurs in normal conditions. In actual conditions, the temperature levels on both sides of walls may change during a 24-hour period. In many cases, the exterior temperature may experience large temperature swings. These changes may cause a reversal in direction of the heat flow or at the least, “delay” the heat flow to the point where it substantially reduces the heat transfer to the inside the building envelope. The following diagrams illustrate each of these conditions.

3.1 Reversed Heat Flow Example - Amarillo, Texas



In Amarillo, Texas, it is not unusual that the outside day temperature may fluctuate from 95 °F down to 60 °F in the same 24 hour period while the indoor temperature is maintained at 75 °F. This drop in temperature and the excellent heat capacity of AAC materials cause a reversal in the direction of heat transfer back to the outside within the 24 hours. Subsequently, the total heat gain through the AAC wall system is significantly less than low thermal mass wall system such as framed wall. In this case, the combination of the heat capacity and the excellent thermal resistance exceeds the performance of a high “**steady state**” R-value. This dynamic process is known as the “**thermal mass benefit**” or “**mass-enhanced**” R-value.

3.2 Delayed Heat Flow Example – Orlando, Florida



In Orlando, it is not unusual that when the outside day temperature is 95 °F, the outside night temperature will only drop down to 85 °F. During the same time frame, the inside temperature could be at 75 °F. In this case, the drop in the outside temperature may not be enough to cause a reversal in the direction of heat transfer. However due to the wall thickness, its thermal conductivity (1.1.1) and its heat capacity (1.1.5) a time delay or “**Time lag**” results and shifts the peak temperature load to between 7 to 9 hours later.

Since HVAC systems are required to be designed for peak loads, this shift in timing of the peak load can result in a significant reduction in the size of mechanical equipment with a subsequent reduction in energy consumption and cost. Table 1.0 shows “**Time lag**” values for different building materials.

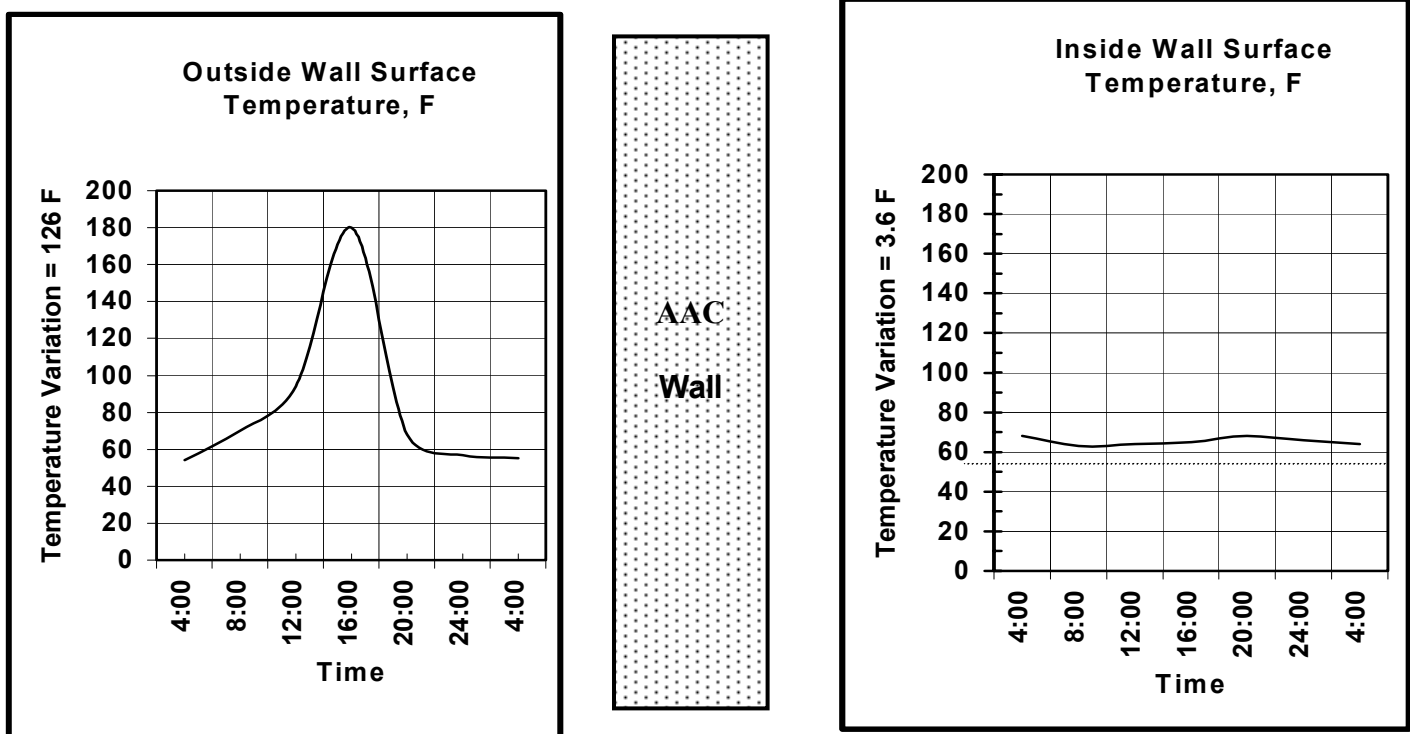
Table 1.0 shows “Time lag” values for different building materials.

Material	Time Lag, hr
8” AAC Wall	8
8” CMU Wall	6 ⁽¹⁾
2 x 4 Frame Wall	2 ⁽¹⁾

⁽¹⁾ NCMA Tek 6-3: Shifting Peak Energy Loads with Concrete Masonry Construction (1991)

In a previous test, AAC wall surface temperatures were measured over a 24 hours period on a west wall, which was painted black to increase surface temperature. The outside wall temperature fluctuated by as much as 126 °F. The inside temperature remained at a pleasant 68 °F without air conditioning with a mere 3.6 °F variation. Additionally, the peak temperature was shifted to a later time of the day when energy is no longer required to mechanically adjust the indoor temperature.

This “time lag” combined with the heat capacity of AAC results in substantial reduction of peak energy consumption. This reduction is considerable in residential buildings and represents financial saving for homeowner in addition to the comfort of living and pleasant steady interior climate.



4. Dynamic Benefit Analysis

The effectiveness of AAC material in providing and controlling interior climatic conditions was illustrated by testing a wall in conditions that simulate actual climatic conditions in a comprehensive energy analysis performed by Oak Ridge National Laboratory.

In the study performed by ORNL, the steady state and the dynamic thermal performance of a AAC wall system were analyzed using ORNL Building Technology Center Guarded Hot box. In the dynamic test of an 8 ft x 8 ft wall, the climatic boundary conditions were changed to simulate similar conditions to normal climatic cycle.

The results of ORNL steady state and dynamic analysis were used to develop a model for AAC wall systems using Department of Energy 2.1E software. The computer software was used to simulate the heating and cooling loads for a single family residence with AAC walls compared to an identical building simulated with lightweight stud frame wall and a Concrete Masonry Unit (CMU) wall. Figure 1.0 shows the house model and the floor plan used in the study performed by Oak Ridge National Laboratory for six representative U.S. climates.

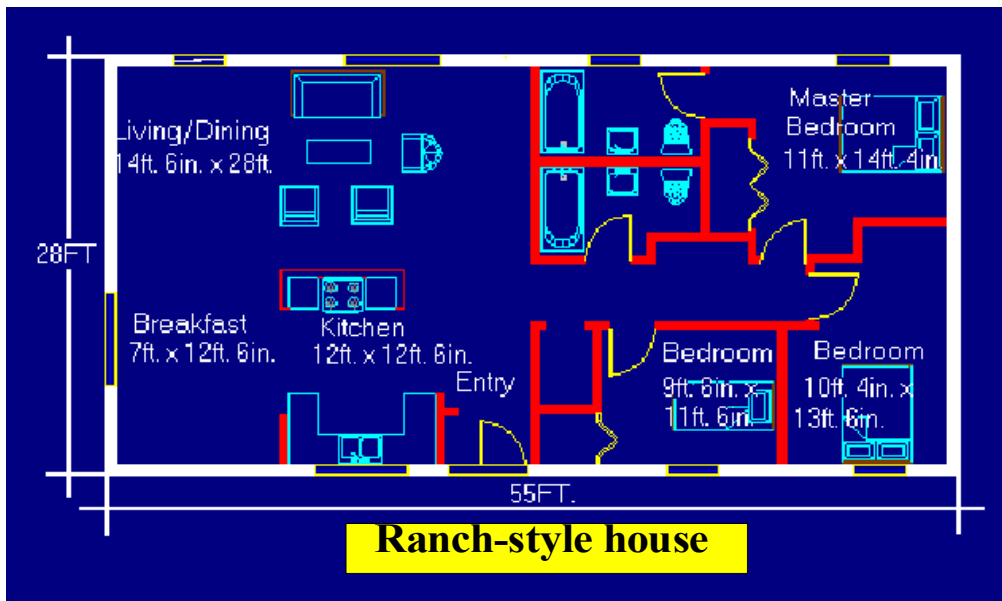


Figure 1.0 - Floor plan of one-story ranch-style house used in thermal modeling.

Table 2.0 - Simulated heating and cooling energy required for a ranch house built with AAC walls as shown in ORNL report "Whole Wall Rating / Label for AAC Wall Systems with Solid Autoclaved Cellular Concrete Blocks Part II - Dynamic Thermal Analysis dated February 8, 1999.

Location	Cooling Energy [MBtu]	Heating Energy [MBtu]	Total Energy [MBtu]
Atlanta	7.4	25.1	32.5
Denver	1.21	48.32	49.5
Miami	37.36	0.65	38.01
Minneapolis	2.05	82.72	84.77
Phoenix	31.73	5.27	37.0
Washington, D.C.	4.33	42.56	46.89

Additionally, the cooling and heating energy required for a wood framed house at different levels of thermal insulation was calculated to identify the saving in energy as shown in table 3.0. It is apparent that only increasing the R-value of a wall does not necessarily decrease the required energy, contrary to common conception. This can also be attributed to thermal mass benefit, control of air infiltration and construction details.

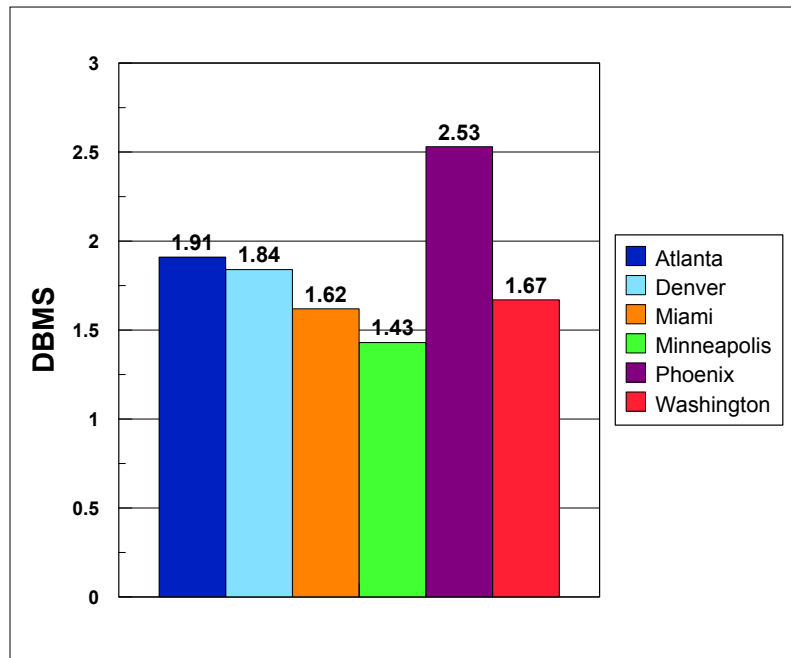
R-value	Atlanta	Denver	Miami	Minneapolis	Phoenix	Washington
Annual Cooling Loads [MBtu]						
12.5	8.98	2.72	37.42	2.94	32.68	5.65
15	8.53	2.48	36.61	2.77	31.51	5.29
20	7.93	2.14	35.85	2.47	30.20	4.83
29	7.41	1.83	34.86	2.18	28.62	4.39
37	7.42	1.92	34.58	2.20	28.36	4.41
Annual Heating Loads [MBtu]						
12.5	25.05	48.33	0.94	80.27	7.46	41.68
15	23.73	45.99	0.84	77.14	6.85	39.90
20	22.292	43.43	0.713	73.92	6.051	37.83
29	20.54	40.32	0.61	69.73	5.27	35.24
37	20.11	39.58	0.61	68.39	5.34	34.51

Table 3.0 - Simulated heating and cooling energy required for ranch house built with the wood framed walls as shown in ORNL report "Whole Wall Rating / Label for Wall Systems with Solid Autoclaved Cellular Concrete Blocks Part II - Dynamic Thermal Analysis dated February 8, 1999

These loads were then used to estimate the effective R-value which would be needed in ordinary construction to result in the same total heating and sensible cooling loads as the AAC wall system in each of the six climates as shown in table 2.0.

The resulting R-value is a steady R-value for AAC wall multiplied by DBMS (Dynamic Benefit for Massive Systems). DBMS is a function of climate, building type and base envelope system. (i.e., conventional 2x4 wood frame wall system) DBMS (Dynamic Benefit for Massive Systems) values for the AAC wall were obtained by comparison between total loads necessary for heating and cooling the light-weight wood-frame building and the AAC unit house for six U.S. climates and four building orientations. This factor accounts for not only the steady state R-value but also the inherent thermal mass benefit without considering air infiltration. Figure 2.0 and table 4.0 show DBMS values and effective R-value for AAC walls when compared to other wall systems.

Figure 2.0 - DBMS values for AAC Walls



City	AAC wall			Two-core CMU wall			2x4 Wood Stud Wall		
	steady-state R-value	DBMS	Effective R-value	steady-state R-value	DBMS	Effective R-value	Steady-state R-value	DBMS	Effective R-value
Atlanta	8.34	1.91	15.93	2.29	0.89	2.04	12.5	1.0	12.5
Denver		1.84	15.34		0.91	2.08			
Miami		1.62	13.51		0.62	1.42			
Minneapolis		1.43	11.93		0.57	1.31			
Phoenix		2.53	21.10		1.46	3.34			
Washington		1.67	13.93		0.78	1.78			

Table 4.0 - Dynamic thermal performance characteristics for AAC units, two-core CMU and wood frame walls.

In a review of the above charts, AAC wall outperformed the other wall systems for the energy consumption by using the lowest energy demands and showed the highest effective R-value.

Beyond the thermal properties already discussed thus far, test of actual buildings have shown the **air infiltration** of a structure to be 63% less than a wood stud framed structure and 48% less than an un-insulated 8" CMU wall. The impact of this on thermal performance and the resulting whole building annual energy demands of a building constructed using either AAC walls, CMU, or and frame walls were compared using different air-tightness values. Similar to earlier calculation, six climates were used for energy modeling and determination of the whole building energy demand of buildings with these different wall systems. Figure 3.0 shows that the increased air-tightness in houses constructed with AAC wall system significantly reduces the energy demand requirements.

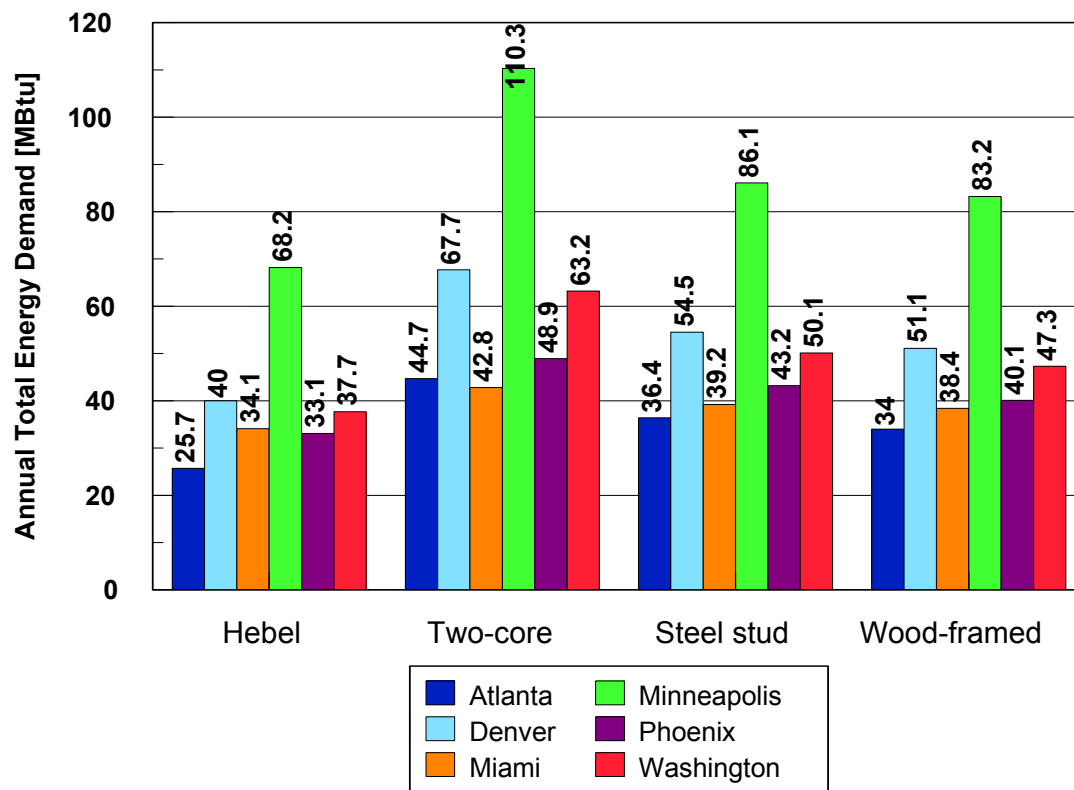


Figure 3.0 - Comparison of annual demands for different wall systems considering different air-leakage rates as shown in ORNL report "Whole Wall Rating / Label for Wall Systems with Solid Autoclaved Cellular Concrete Blocks Part II - Dynamic Thermal Analysis dated February 8, 1999.

According to the ORNL report, "the results of computer simulations for the six U.S. climates show that annual energy performance of the single family residence made of AAC walls is superior in comparison with a similar house built using either two-core CMU, steel studs, or conventional wood-framed walls. On average, energy demands of the AAC wall house are about **18%, 36%, and 23% lower** than similar houses constructed with **wood frame walls, two-core CMU, and steel studs walls**, respectively. Chart 1.0 shows

that AAC wall yielded the least operating energy cost when compared with other wall systems. In addition, as a result of lower demand on peak energy loads, the use of AAC walls reduces the size of mechanical equipment as shown in chart 2.0.

Chart 1.0 - Annual energy cost comparison for different wall systems.

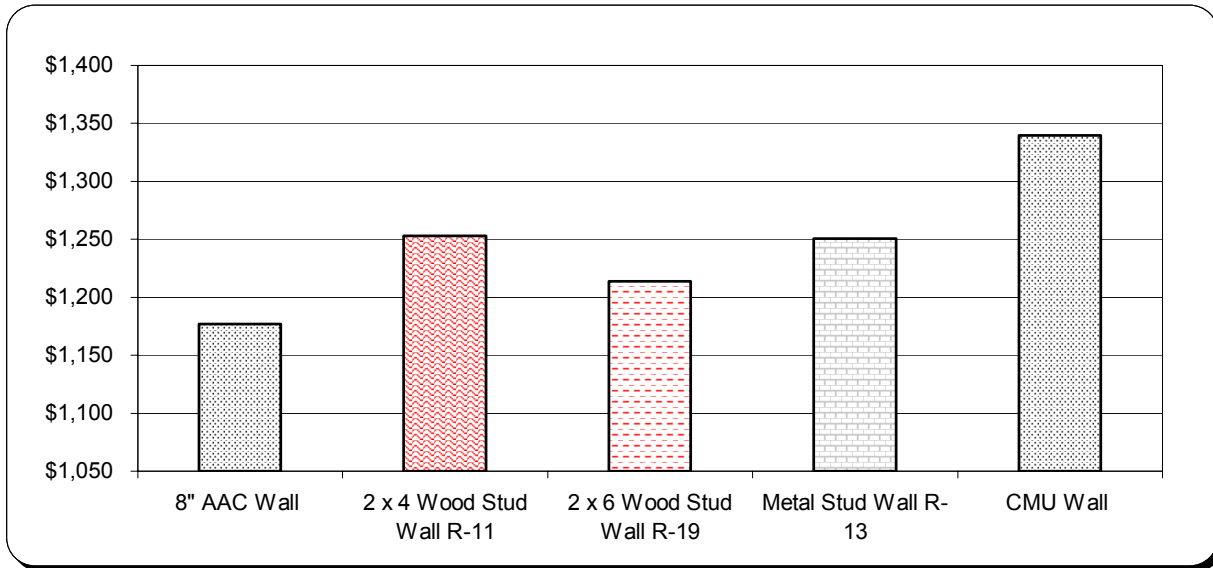
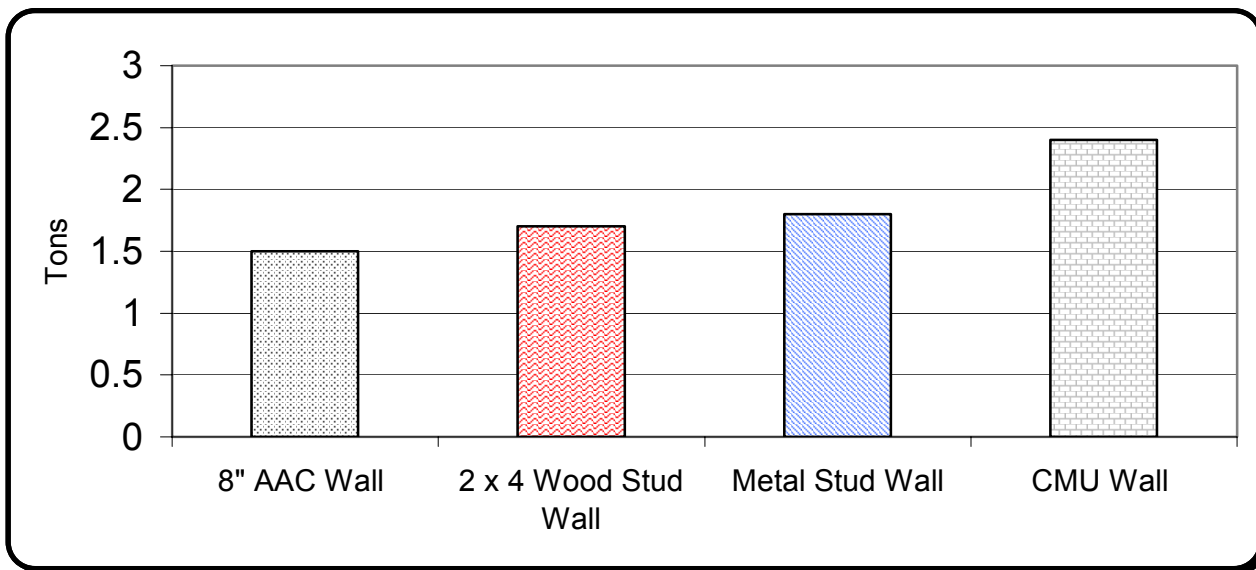


Chart 2.0 - Size of mechanical equipment (A/C Unit Capacity) for different wall systems



The example cited makes the point that AAC products can offer the homeowner and the designer several important benefits if the material's thermal properties are used appropriately. To aid in that, this chapter of the Residential Application Manual provides the information needed by the design professional to understand and utilize the properties and design values that will result in the utmost thermal efficiency when using AAC.

For the mechanical engineer, included are simple design tools, tips and general directions to assist in design of residential projects. All tables and design aids were developed by a mechanical engineering consulting firm and are based on current energy codes such as ASHRAE, Model Energy Code and State mandated code such as the Florida Energy Code. Step by step procedures are available for energy code compliance, load calculation and equipment sizing such as Manual J.

5.0 Design Aids – Thermal Properties for different AAC material

Table 1- Thermal Conductivity (K-value), R-value and U-value for AAC, Only

AAC Type	Density pcf	Thermal Conductivity	R-Value				U – Value			
			Thickness, in.				Thickness, in.			
			6	8	10	12	6	8	10	12
AAC 2.5 (AAC2)	26	0.79	7.59	10.13	12.66	15.19	0.13	0.10	0.08	0.07
AAC 2.5 (AAC2)	32	0.96	6.25	8.33	10.42	12.50	0.16	0.12	0.10	0.08
AAC 5.0 (AAC5)	38	1.15	5.22	6.96	8.70	10.43	0.19	0.14	0.12	0.10
AAC 7.5 (AAC6)	44	1.15	5.22	6.96	8.70	10.43	0.19	0.14	0.12	0.10

Table 2 - Thermal Conductivity (K-value), R-value and U-Value for AAC, exterior and interior plaster

AAC Type	Density pcf	Thermal Conductivity	R-Value				U – Value			
			Thickness, in.				Thickness, in.			
			6	8	10	12	6	8	10	12
AAC 2.5 (AAC2)	26	0.79	8.91	11.45	13.98	16.51	0.11	0.09	0.07	0.06
AAC 2.5 (AAC2)	32	0.96	7.57	9.65	11.74	13.82	0.13	0.10	0.09	0.07
AAC 5.0 (AAC4)	38	1.15	6.54	8.28	10.02	11.75	0.15	0.12	0.10	0.09
AAC 7.5(AAC6)	44	1.15	6.54	8.28	10.02	11.75	0.15	0.12	0.10	0.09

- $R\text{-value} = R_{\text{outside air}} (0.17) + R_{\text{ext plaster}} (0.36) + R_{\text{AAC}} + R_{\text{int plaster}} (0.11) + R_{\text{inside air}} (0.68)$

Table 3 - Thermal Conductivity (K-value), R-value and U-value for AAC, brick veneer and interior plaster

AAC Type	Density pcf	Thermal Conductivity	R-Value				U – Value			
			Thickness, in.				Thickness, in.			
			6	8	10	12	6	8	10	12
AAC 2.5 (AAC2)	26	0.79	10.00	12.54	15.07	17.60	0.10	0.08	0.07	0.06
AAC 2.5 (AAC2)	32	0.96	8.66	10.74	12.83	14.91	0.12	0.09	0.08	0.07
AAC 5.0 (AAC5)	38	1.15	7.63	9.37	11.11	12.84	0.13	0.11	0.09	0.08
AAC 7.5 (AAC6)	44	1.15	7.63	9.37	11.11	12.84	0.13	0.11	0.09	0.08

- R-value = $R_{\text{outside air}} (0.17) + R_{\text{4" brick}} (0.44) + R_{\text{Air space 1" (1.0)}} + R_{\text{AAC}} + R_{\text{int plaster}} (0.11) + R_{\text{inside air}} (0.68)$

Table 4 - Thermal Conductivity (K-value), R-value and U-Value for AAC, exterior plaster and glued ½" gypsum board

AAC Type	Density pcf	Thermal Conductivity	R-Value				U – Value			
			Thickness, in.				Thickness, in.			
			6	8	10	12	6	8	10	12
AAC 2.5 (AAC2)	26	0.79	9.25	11.79	14.32	16.85	0.11	0.08	0.07	0.06
AAC 2.5 (AAC2)	32	0.96	7.91	9.99	12.08	14.16	0.13	0.10	0.08	0.07
AAC 5.0 (AAC5)	38	1.15	6.88	8.62	10.36	12.09	0.15	0.12	0.10	0.08
AAC 7.5 (AAC6)	44	1.15	6.88	8.62	10.36	12.09	0.15	0.12	0.10	0.08

- R-value = $R_{\text{outside air}} (0.17) + R_{\text{ext plaster}} (0.36) + R_{\text{AAC}} + R_{\text{drywall}} (0.45) + R_{\text{inside air}} (0.68)$

Table 5 - Thermal Conductivity (K-value), R-value and U-Value for AAC, exterior plaster, furring, and ½" gypsum board

AAC Type	Density pcf	Thermal Conductivity	R-Value				U – Value			
			Thickness, in.				Thickness, in.			
			6	8	10	12	6	8	10	12
AAC 2.5 (AAC2)	26	0.79	10.20	12.74	15.27	17.80	0.10	0.08	0.07	0.06
AAC 2.5 (AAC2)	32	0.96	8.86	10.94	13.03	15.11	0.11	0.09	0.08	0.07
AAC 5 (AAC5)	38	1.15	7.83	9.57	11.31	13.04	0.13	0.10	0.09	0.08
AAC 7.5 (AAC6)	44	1.15	7.83	9.57	11.31	13.04	0.13	0.10	0.09	0.08

$$R\text{-value} = R_{\text{outside air}} (0.17) + R_{\text{ext plaster}} (0.36) + R_{\text{AAC}} + R_{\text{drywall + furring}} (1.4) + R_{\text{inside air}} (0.68)$$

Table 6 - Specific Heat (s) and Heat Capacity (HC) for AAC, exterior and interior plaster

AAC Type	Density pcf	Specific Heat	Heat Capacity			
			Thickness, in.			
			6	8	10	12
AAC 2.5 (AAC2)	26	0.25	4.00	5.08	6.17	7.25
AAC 2.5 (AAC2)	32	0.25	4.75	6.08	7.42	8.75
AAC 5.0 (AAC5)	38	0.25	5.50	7.08	8.67	10.25
AAC 7.5 (AAC6)	44	0.25	6.25	8.08	9.92	11.75

Table 7 - Specific Heat (s) and Heat Capacity (HC) for AAC, exterior plaster and ½” drywall

AAC Type	Density pcf	Specific Heat	Heat Capacity			
			Thickness, in.			
			6	8	10	12
AAC 2.5 (AAC2)	26	0.25	4.28	5.36	6.45	7.53
AAC 2.5 (AAC2)	32	0.25	5.03	6.36	7.70	9.03
AAC 5.0 (AAC5)	38	0.25	5.78	7.36	8.95	10.53
AAC 7.5 (AAC6)	44	0.25	6.63	8.36	10.20	12.03

Table 8 - Specific Heat (s) and Heat Capacity (HC) for AAC, brick veneer and interior plaster

AAC Type	Density pcf	Specific Heat	Heat Capacity Btu/ft ² .F			
			Thickness, in.			
			6	8	10	12
AAC 2.5 (AAC2)	26	0.25	12.51	13.59	14.68	15.76
AAC 2.5 (AAC2)	32	0.25	13.26	14.59	15.93	17.26
AAC 5.0 (AAC5)	38	0.25	14.01	15.59	17.18	18.76
AAC 2.5 (AAC2)	44	0.25	14.76	16.59	18.43	20.26

Table 9 - Specific Heat (s) and Heat Capacity (HC) for AAC, brick veneer and ½” glued drywall

AAC Type	Density pcf	Specific Heat	Heat Capacity Btu/ft ² .F			
			Thickness, in.			
			6	8	10	12
AAC 2.5 (AAC2)	26	0.25	12.79	13.88	14.96	16.04
AAC 2.5 (AAC2)	32	0.25	13.54	14.88	16.21	17.54
AAC 5.0 (AAC5)	38	0.25	14.29	15.88	17.46	19.04
AAC 2.5 (AAC2)	44	0.25	15.04	16.88	18.71	20.54

Brick 4”

Density = 135 pcf,

Specific heat = 0.20 Btu/lb. °F

(*) “Thermal Performance For AAC Block-Residential Application” was prepared by Hebel and is the property of Autoclaved Aerated Concrete Product Association (AACPA) and is only to be used by members of the AACPA.