

Section 3: Material Properties

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3.1 Thermal Insulation

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 a building material under steady and constant climate conditions. It is important to remember that these laboratory conditions do not reflect the normal climate cycles (see DBMS). This issue is 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 insulation value. Table 3.1 gives the "k" values for AAC and other materials.

Table 3.1: Thermal conductivity k of AAC and Other Materials

Designation	Thermal Conductivity k (Btu in/h Ft ² F)
AAC-2/400 (25 pcf)	0.80 ⁽¹⁾
AAC-4/500 (31 pcf)	0.97 ⁽¹⁾
Concrete Density 150 pcf	9.98 ⁽²⁾
Insulation Board (Polystyrene)	0.20 ⁽²⁾
Steel	329.0
Water	4.15

(1) Based on ESR 2447 in accordance with ASTM C 1386

(2) ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers)

The figures for AAC in Table 3.1 consider the typical moisture content of AAC during the lifespan. The moisture content at equilibrium for AAC depends on the bulk density and climate conditions. Usually the moisture content ranges from 3 to 5% if the surrounding conditions are 73.4 °F (23°C) and 80% relative humidity. The conversion factor between a dry value of AAC and the equilibrium value (as shown in Table 3.1) is about 1.05, i.e. in order to calculate a dry value the value in Table 3.1 has to be divided by 1.05.

3.2 Thermal Resistance (R-value)

Defined as the inverse of the time rate of heat flow through a body from one of its bounding surfaces to the other surface for a unit temperature difference between the two surfaces, under steady state conditions, per unit area (h ft² °F/Btu) [(m² · K)/W].

To that effect the Thermal Resistance "R" (h ft² °F/Btu) is the opposite of the thermal conductivity and it is the resistance of a material to conduct or allow heat flow. Thermal resistance measures how well a material or series of materials retards heat flow. Thermal resistance (insulation) is rated using R-values. As the R-value of an element or assembly increases, the heat loss or gain through that element or assembly decreases. Table 3.2 shows the thermal resistance calculated based on equation 1 for AAC.

$$R = (1 / k) \times \text{Wall Thickness (inch)} \tag{1}$$

Table 3.2: Thermal Resistance of AAC

Designation	Thermal Resistance “R” (h.ft ² .°F/Btu)
8” AAC-2/400 Wall	10.00
10” AAC-2/400 Wall	12.50
12” AAC-2/400 Wall	15.00
8” AAC-4/500 Wall	8.25
10” AAC-4/500 Wall	10.31
12” AAC-4/500 Wall	12.37

In order to achieve an R_T-value (total assembly R-value) for AAC construction the additional resistances of the wall assembly are added together. Table 3.3 shows an example calculation of a single-wythe wall of AAC with render and stucco.

Table 3.3: Calculation of R_T-value of a Single-wythe Wall with AAC-4/500 (31 pcf)

Material	Thickness (inch)	Thermal Conductivity k (Btu.in/h.ft ² .°F)	R-value (h ft ² °F/Btu)
surface inside			0.68
plaster inside	0.19	6.74	0.028
Hebel AAC-4/500	10.00	0.97	10.31
stucco	0.63	2.40	0.26
surface outside			0.17
ΣR = R _T -value			11.45

3.3 Coefficient of Heat Transmission

U-Factor (Thermal Transmittance)

The U-factor is defined as the coefficient of heat transmission (air to air) through a building component or assembly, equal to the time rate of heat flow per unit area and unit temperature difference between the warm side and cold side air films (Btu/h · ft² · °F) [W/(m² · K)].

Thermal transmittance, U-factor, is a measure of how well a material or series of materials conducts heat. Low U-values represent high insulation.

$$U = \frac{1}{R_T - \text{value}} \quad (2)$$

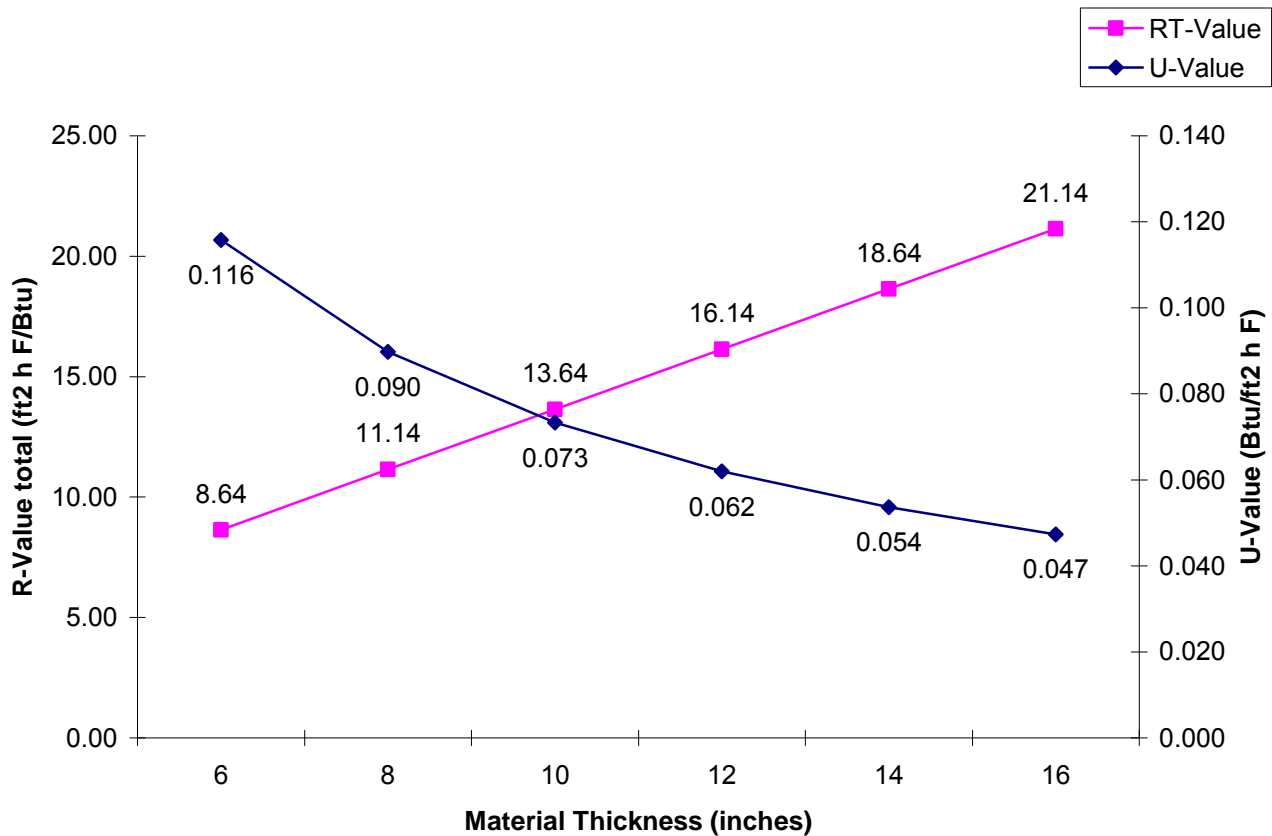
Table 3.4 shows a calculation of the U-value based on the data presented in Table 3.3.

Table 3.4: Calculation of R_T-value of a Single-wythe Wall with AAC-4/500 (31 pcf)

Material	Thickness (inch)	Thermal Conductivity k (Btu.in/h.ft ² .°F)	R-value (h ft ² °F/Btu)
surface air film inside			0.68
plaster inside	0.19	6.74	0.028
Hebel AAC-4/500	10.00	0.97	10.31
stucco	0.63	2.40	0.26
surface air film outside			0.17
ΣR = R _T -value			11.45
U-value			0.087 (Btu/h Ft ² °F)

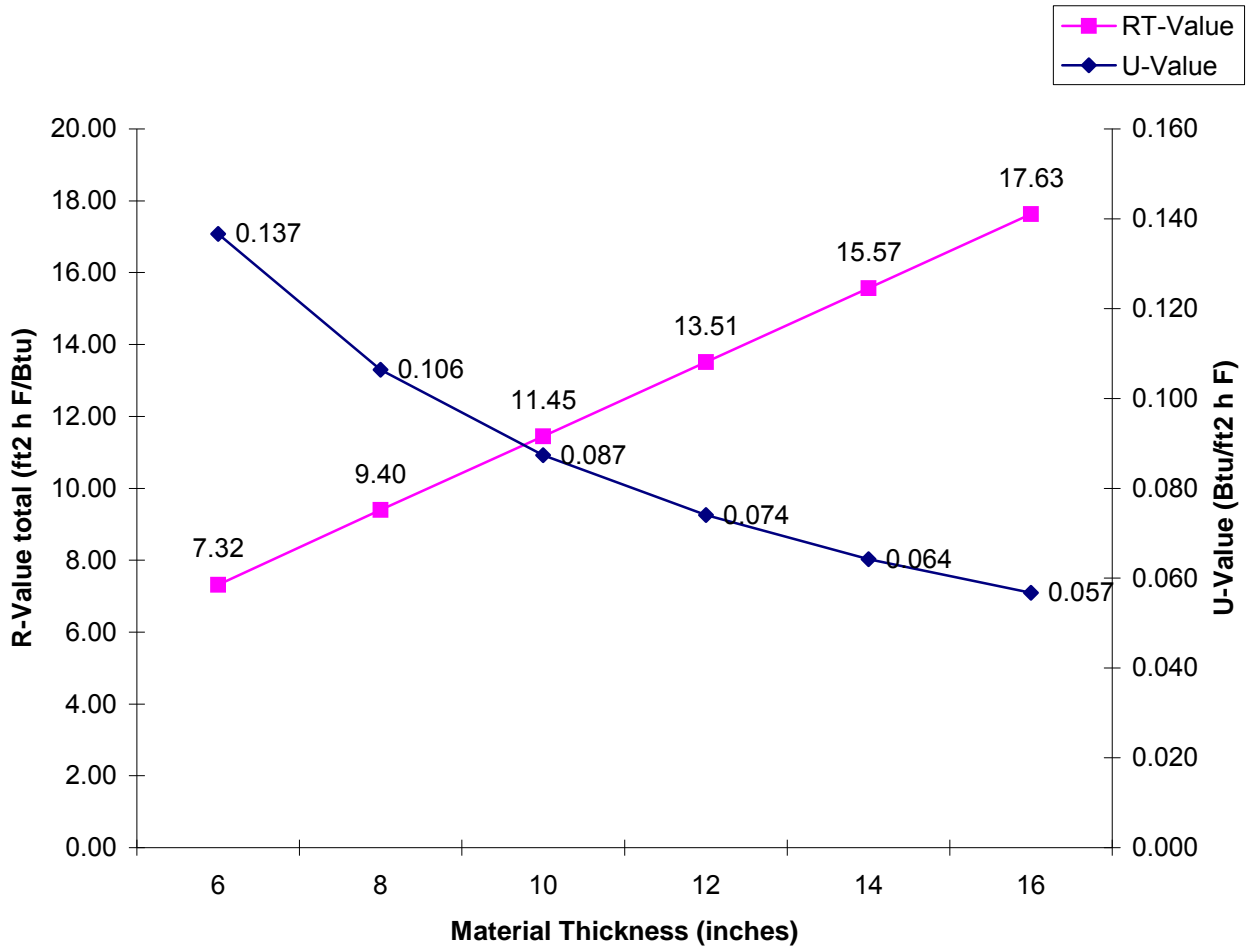
The interaction between R_T-value and U-value is shown in Graph 3.1.

Graph 3.1: R_T-value vs. U-value (AAC-2/400)



With $R_T = 1.25 \cdot t$ (thickness of AAC in inch) + 1.14

Graph 3.2: R_T-value vs. U-value (AAC-4/500)



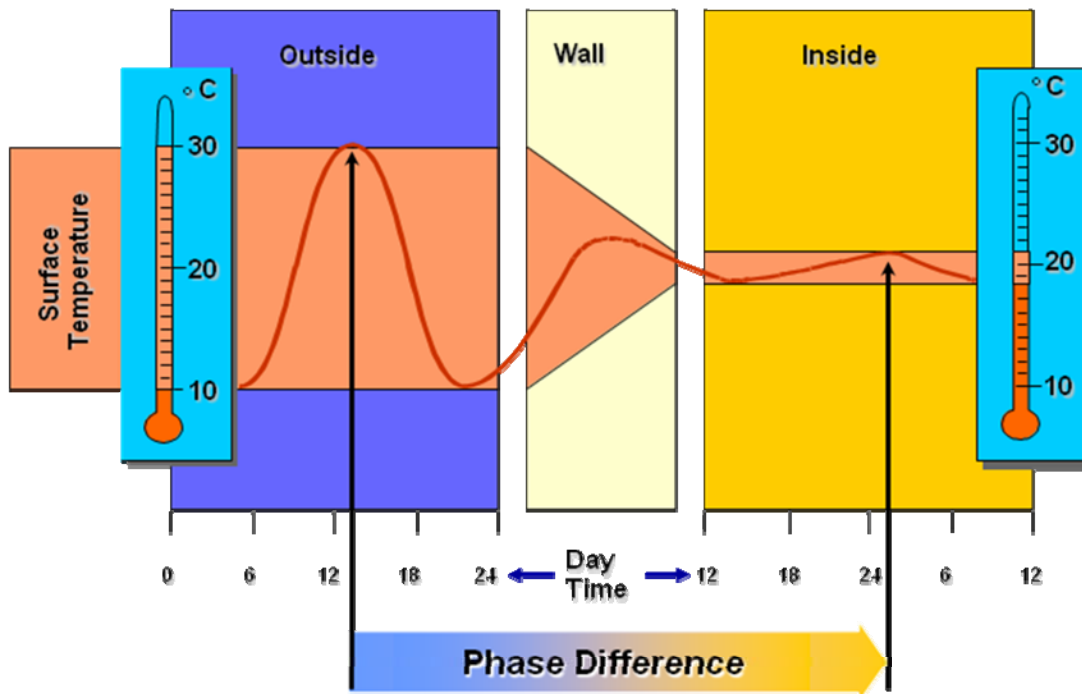
With $R_T = 1.03 \cdot t + 1.14$

3.4 Dynamic Thermal Performance

The above mentioned definitions describe only one kind of heat transport through a material or wall assembly based on temperature difference at the surfaces. What about the real behavior of the wall assembly under permanent changing internal and external conditions in winter or summer? Does the thermal mass of the wall assembly have an influence on the heat flux and room temperature? The thermal protection requirements for the external wall elements (as specified in the energy codes) of buildings are generally categorized into two groups, either summer or winter. In both cases the most important property of the material is a low thermal conductivity (or high R-value) combined with heat storage capacity. Both properties lead to a lower heat flux through the wall and therefore to a lower heating and cooling demand. Diagram 3.1 shows the fundamental behavior of a mass wall for this context.

Diagram 3.1: Phase Difference within the Wall for a 24 Hour Period

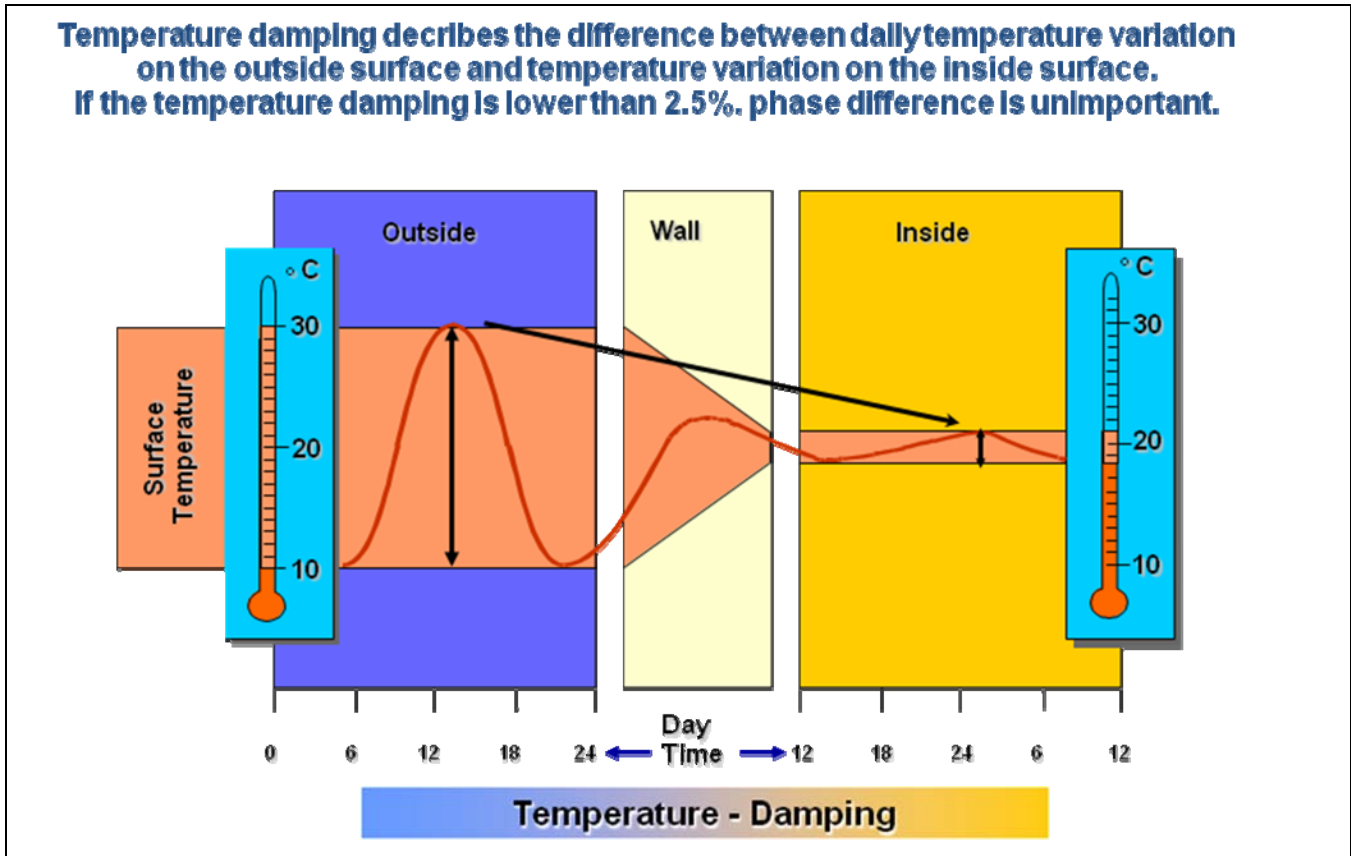
Phase difference is the time lag between the peak outside surface temperature and peak inside surface temperature
Good values are between 8 and 12 hours



The phase difference expresses the time lag between the external and internal amplitude of temperature. Example: Outside temperature: 86° F, Amplitude: 68 °F (difference from low to high temperature), around 12 o'clock. Inside: The amplitude occurs after around 12 hours on the surface. The damping of the incoming amplitude leads to the second fundamental behavior of a massive wall: temperature damping.

Due to high heat capacity of massive walls like Hebel AAC, the heat transport from one side to the other side of the wall assembly is linked to heat dissipation. Diagram 3.2 describes this occurrence as the damping process which is responsible for a lower heat transport. Especially in summer the damping process guarantees a lower internal temperature and consequently a lower cooling demand for the building.

Diagram 3.2: Temperature Damping with the wall for a 24 Hour Period



Example: Outside temperature: 86° F, Amplitude: 68 °F (difference from low to high temperature), around 12 o'clock. Inside: The amplitude occurs after around 12 hours on the surface. The maximum increase of the surface temperature amounts to about 2 °F.

General properties of Hebel AAC:

Phase difference: 10 to 15 hours (depending on bulk density and thermal conductivity)

Temperature damping: 2 to 4 % (depending on bulk density and thermal conductivity)

Temperature damping of 2 to 4 % means the following:

If the amplitude of temperature changing outside is 68 °F the amplitude inside will be $68 \cdot 0.04 = 2.7$ °F. This is very low and negligible.

And what about non massive walls like wooden frame construction? Usually, the phase difference of wooden frame construction is from 3 to 6 hours and the damping is 25 – 35 %, according to calculation standards. This leads to the situation that the maximum amplitude comes in within 3-6 hours and is only damped with 65 – 75 % (94 – 98 % in case of massive walls).

But what is defined as massive wall?

The 2006 IECC defines mass walls as follows:

- ◇ Chapter 4 – Residential – section 402.2.3 Mass Walls: “Mass walls for the purpose of this Chapter shall be considered walls of concrete block, concrete... and solid timber/logs.”
- ◇ Chapter 5 – Commercial Energy Efficiency – section 502.2.3 Above-grade walls: “...’Mass walls’ shall include walls weighing at least (1) 35 pounds per square foot (170 kg/m²) of wall surface area or (2) 25 pounds per square foot (120 kg/m²) of wall surface area if the material weight is not more than 120 pounds per cubic foot (1900 kg/m³).”
- ◇ ASHRAE Standard 90.1-2007 references mass walls as “walls with HC exceeding (1) 7 Btu/ft² F or (2) 5 Btu/ft² F, provided that the wall has a material unit weight not greater than 120 lb/ft³.”

In general terms, the heat capacity is a measure of how well a material stores heat. The higher the heat capacity of a material the greater the amount of heat that can be stored in the material.

Table 3.5 shows the calculated heat capacity for different thicknesses and bulk densities of Hebel AAC. In this calculation a specific heat of 0.25 Btu/lb °F (or 1.00 kJ/kg K) is used.

Table 3.5: Heat Capacity of Different AAC Elements

AAC Type	Thickness inch	Heat Capacity Btu/(ft ² °F)
AAC-2/400 (25 pcf)	8	4.2
AAC-2/400 (25 pcf)	10	5.2
AAC-2/400 (25 pcf)	12	6.3
AAC-4/500 (31 pcf)	8	5.2
AAC-4/500 (31 pcf)	10	6.5
AAC-4/500 (31 pcf)	12	7.8

What is DBMS and how can it influence the heating and cooling demand of a building?

Heating and cooling energies calculated for structures with massive walls are compared to the heating and cooling demand for identical buildings simulated with lightweight wood-frame exterior walls. To find a relationship between wall R-value and heating and cooling demand, several buildings are simulated. This simulation was performed on ten U.S. climates using TMY2 weather files for a total of 120 simulations. The energy output data generated by these whole building simulations is used to estimate the R-value equivalents that would be needed in conventional wood-frame construction to produce the same energy demand as for the structure with massive walls in each of the ten climates. The resulting values account for not only the steady state R-value but also the inherent thermal mass benefit.

To enable simple comparisons of dynamic energy performances of wall systems, ORNL's BTC introduced in 1995 the Dynamic Benefit for Massive Systems model (DBMS) [Kosny et al 1998]. DBMS is a dimensionless multiplier of steady-state R-value. The product of DBMS and steady-state R-value is called "Dynamic R-value Equivalent for Massive Systems." It should be used only as an answer to the question: "What wall R-value should a structure with wood frame walls need to obtain the same space heating and cooling energy consumption as a similar structure containing massive walls?"

Table 3.6 and Table 3.7 contain the results of a simulation carried out by AZ path dated July 2002, "A Comparison of Innovative Exterior Wall Construction Techniques", Del E Webb School of Construction at Arizona State University.

Table 3.6: DBMS and Equivalent R-values for AAC-2/400 (25 pcf)

	8" AAC			10" AAC		
	R	DBMS	R _{equiv}	R	DBMS	R _{equiv}
Phoenix	10.85	2.48	26.9	13.35	2.51	33.5
Flagstaff	10.85	1.99	21.6	13.35	1.99	26.6
Los Angeles	10.85	1.54	16.7	13.35	1.57	21.0
Sacramento	10.85	2.44	26.5	13.35	2.44	32.6
San Diego	10.85	1.42	15.4	13.35	1.44	19.2
San Francisco	10.85	1.78	19.3	13.35	1.79	23.9
Denver	10.85	1.9	20.6	13.35	1.92	25.6
Miami	10.85	1.73	18.8	13.35	1.76	23.5
Atlanta	10.85	1.93	20.9	13.35	1.94	25.9
Minneapolis	10.85	1.48	16.1	13.35	1.5	20.0
Albuquerque	10.85	2.06	22.4	13.35	2.09	27.9
Santa Fe	10.85	2.14	23.2	13.35	2.17	29.0
Las Vegas	10.85	2.46	26.7	13.35	2.49	33.2
Reno	10.85	2.05	22.2	13.35	2.06	27.5
Eugene	10.85	2.14	23.2	13.35	2.16	28.8
El Paso	10.85	2.31	25.1	13.35	2.34	31.2
Salt Lake City	10.85	2.11	22.9	13.35	2.11	28.2
Washington D.C.	10.85	1.7	18.4	13.35	1.72	23.0
Seattle	10.85	1.39	15.1	13.35	1.41	18.8
Spokane	10.85	1.85	20.1	13.35	1.86	24.8

Example:

In order to obtain the same heating and/or cooling demand for a building with AAC-2/400 (8") in Miami the wooden frame construction has to have an R-value 18.8 h.ft².°F/Btu.

Table 3.7: DBMS and Equivalent R-values for AAC-4/500 (31 pcf)

	8" AAC			10" AAC		
	R	DBMS	R _{equiv}	R	DBMS	R _{equiv}
Phoenix	9.10	2.48	22.6	11.16	2.51	28.0
Flagstaff	9.10	1.99	18.1	11.16	1.99	22.2
Los Angeles	9.10	1.54	14.0	11.16	1.57	17.5
Sacramento	9.10	2.44	22.2	11.16	2.44	27.2
San Diego	9.10	1.42	12.9	11.16	1.44	16.1
San Francisco	9.10	1.78	16.2	11.16	1.79	20.0
Denver	9.10	1.90	17.3	11.16	1.92	21.4
Miami	9.10	1.73	15.7	11.16	1.76	19.6
Atlanta	9.10	1.93	17.6	11.16	1.94	21.7
Minneapolis	9.10	1.48	13.5	11.16	1.5	16.7
Albuquerque	9.10	2.06	18.7	11.16	2.09	23.3
Santa Fe	9.10	2.14	19.5	11.16	2.17	24.2
Las Vegas	9.10	2.46	22.4	11.16	2.49	27.8
Reno	9.10	2.05	18.7	11.16	2.06	23.0
Eugene	9.10	2.14	19.5	11.16	2.16	24.1
El Paso	9.10	2.31	21.0	11.16	2.34	26.1
Salt Lake City	9.10	2.11	19.2	11.16	2.11	23.5
Washington D.C.	9.10	1.7	15.5	11.16	1.72	19.2
Seattle	9.10	1.39	12.6	11.16	1.41	15.7
Spokane	9.10	1.85	16.8	11.16	1.86	20.8

Example:

In order to obtain the same heating and/or cooling demand for a building with AAC-4/500 (8'') in Miami the wooden frame construction has to have an R-value 15.7 h.ft².°F/Btu.

Another investigation has been carried out at the Solar Energy Center in Florida to compare several weather conditions in Florida. The basis for the comparison was 8 inch AAC 2 with an R-value 11 and a wooden frame wall. The results for several conditions are obtained in Table 3.8. To achieve the same heat flux through the wall, the wooden frame construction must have an R-value of 16.4 to 20.4, therefore the DBMS amounts to 1.85 what underlines the value in the table above.

Table 3.8: Frame Wall Equivalent R-values for AAC Wall

Simulation Basis	Equivalence Based on Summation of All Fluxes	Equivalence Based on Fluxes Summed in Load Direction Only
Peak Summer Day	17.4	17.9
Average Summer Day	16.4	20.4
Peak Winter Day	16.7	16.7
Average Winter Day	16.5	16.5
Cooling Season	16.5	19.6
Heating Season	16.5	16.9

The DBMS or equivalent R-value is embedded for instance in the IECC or in diverse national Energy Codes.

Table 3.9 contains the IECC-2006 requirements for residential buildings:

Table 3.9: Insulation and Fenestration Requirements by Component (Extract)

Climate Zone	Fenestration U-Factor	Ceiling R-Value	Wood Frame Wall R-Value	Mass Wall R-Value	Floor R-Value	Basement Wall R-Value	Slab R-Value & Depth
1	1.20	30	13	3	13	0	0
2	0.75	30	13	4	13	0	0
3	0.65	30	13	5	19	0	0
4 except Marine	0.40	38	13	5	19	10 / 13	10.2 ft
5 and Marine 4	0.35	38	19 or 13+5	13	30 ^f	10 / 13	10.2 ft
6	0.35	49	19 or 13+5	15	30 ^f	10 / 13	10.4ft
7 and 8	0.35	49	21	19	30 ^f	10 / 13	10.4ft

The requirement for the massive wall of a residential building in climate zone 3 is R 5. This requirement is satisfied when using AAC-4/500 at 6" thickness. To enable the same amount of energy demand for a building erected with wooden frame construction, the requirement is R 13. Please consider that the reverse direction is not allowed, i.e. if the requirement for a massive wall R 13 it is required to use the static R-value as expressed in table 2.

3.5 Thermal Bridges

A **thermal bridge** is created when materials that are poor insulators come in contact, allowing heat to flow through the path created. Insulation around a bridge is of little help in preventing heat loss or gain due to thermal bridging; the bridging has to be eliminated, rebuilt with a reduced cross-section or with materials that have better insulating properties, or with an additional insulating component (a thermal break). Thermal or heat bridges in buildings are often (incorrectly) called "Cold Bridge".

Thermal bridges are characterized by multi-dimensional heat flow, and therefore by the fact that they cannot be adequately approximated by the one-dimensional models of calculation typically used in standards for the thermal performance of buildings (U-values). Surface moisture due to condensation (typically occurring in such regions as floor-wall connections, window installations, etc.) as well as mold growth in humid environments can also be effectively prevented by means of multi-dimensional evaluation during planning and detail design.

Typical thermal bridges are:

- Geometrical thermal bridges (for instance corners);
- Changing of material regarding thermal conductivity (for instance rafters, concrete columns, concrete slab – exterior wall);
- Connection of wall to roof (normally combination of first two points);
- Connection of wall to floor slab (normally combination of first two points);
- Window and door connections (reveal, lintel, parapet);
- Break of the thermal insulation (for instance balcony);

Based on the fact that Hebel AAC has the same thermal conductivity in all directions thermal bridges are greatly reduced in buildings with Hebel AAC walls and panels. Calculations and testimonials show that it is possible to reduce the energy demand by more than 20% when using Hebel AAC.

3.6 Moisture Resistance

Moisture resistance is needed for protecting a building against water to ensure a long life cycle and a healthy indoor climate. Moisture can get into a structure in various ways. It can be a result of the manufacturing process of building components as well as storage, transportation and installation (i.e. rain during construction) of materials. People, animals and plants increase humidity inside a building. Another possibility for the appearance of moisture inside a structure is condensation on cold surfaces of building materials. Although building components can absorb a certain amount of moisture it's important to protect them against humidity to avoid damage.

3.7 Resistance to Pelting Rain

Building components have to be protected against climate influences like pelting rain. Therefore appropriate measures like rendering, coating, flashing, or cladding are necessary to secure the quality of a building. Minimum thicknesses for weather coverings on unit masonry are defined in the International Building Code, section 1405.2. If stucco or exterior Portland cement plaster is used then a minimum thickness of 0.625 inches is required for a three-coat application and 0.5 inches for a two-coat application.

In general it is important for the rendering and coating to use materials which are suitable for the use on the material on which they are applied. This refers to mechanical and physical properties like compressive strength and vapor permeability. That means that the materials shall have similar properties so they will react in a similar way to climate conditions like rain and temperature variations. Otherwise the surface treatment can be damaged by these influences and moisture can penetrate the structure of buildings.

The manufacturers of renderings, coatings and stuccos give recommendations for the use of their products which should be kept to create damage-free facades.

3.8 Resistance to Condensation Moisture

The amount of water vapor which can be absorbed by air depends on the air temperature. The warmer the air the more water vapor can be absorbed. When air reaches 100 % humidity at a certain temperature this is called dew point. If this air is cooled down from this condition fog develops. If this air meets a cold surface condensation forms there.

We would like to know the temperature in the middle of the wall.

$$T = T_w - (q \cdot R_1)$$

Where:

T	temperature on the wanted point in °F
T _w	temperature on the warmest side (in this case outside)
R ₁	thermal resistance – sum from the warmest side to the desired point

The R1 is: 0.17 (air film outside) + 6.25 (½ R width of the wall) = 6.42

$$T = 90^\circ\text{F} - (1.5 \cdot 6.42) = 80.37^\circ\text{F} \text{ or } 26.9^\circ\text{C} > \text{dew point}$$

Conclusion: The condensation within the wall under extreme summer conditions occurs in the second half of the wall.

In the case of condensation within the Hebel AAC there is no need for worry because AAC has a tremendous capability to storing water. AAC can compensate extreme conditions from both sides of the surface. This leads to a good interior climate and to a lower demand of dehumidification and humidification provided by the air-conditioning systems. This is the primary reason that vapor barriers are not needed in most applications.

3.9 Diffusion Behavior

For all load carrying components made of mineral materials, AAC has the lowest vapor diffusion resistance. Monolithic AAC walls don't need additional layers with thermal insulation. This fact helps to build simple, permanently insulated wall assemblies. Basic rules which help to get good diffusion behavior of building materials are listed below:

- permeability of a material must increase from inside to outside (s_d value must decrease from inside to outside)
- penetrated moisture must be able to diffuse out
- for multi-layered construction assemblies, the outer layer should be ventilated

These rules are fulfilled for usual wall assemblies with Hebel AAC products. Values for the permeability and the resistance to vapor diffusion of selected materials are shown in Table 3.10.

Table 3.10: Resistance to Vapor Diffusion for Different Building Materials

Material	Permeability Π [perm in]	Resistance to Vapor Diffusion μ [-]
Hebel AAC components	26/13	5/10
mineral exterior coating	13	10
silicone resin exterior coating	0.5	250
acrylic exterior coating	0.2	580
mineral fiber	130	1
foam plastics	6/0.4	20/300
cored bricks / hollow blocks	26/13	5/10
sand-lime brick	26/5	5/25
cement, mortar and stuccos	13/4	10/35
wood	3	40
concrete	2/0.9	70/150
plastic roofing membrane	0.01/0.002	10000/80000

3.10 Water Absorption

Water absorption of materials can be classified by the water absorption coefficient. The water absorption coefficient gives information about how much water is absorbed in a defined time period. Hebel AAC has a very low water absorption coefficient in comparison to other building materials. The special inner structure of AAC, which consists mainly of closed pores (micro pores and macro pores), prevents the capillary transport of moisture over long distances. In Table 3.11 the water absorption coefficients for some selected building materials are shown.

Table 3.11: Water Absorption Coefficients for Different Building Materials

Material	Water Absorption Coefficient [lb/(in ² · s ^{0.5})]	Water Absorption Coefficient [kg/(m ² · h ^{0.5})]
gypsum boards	8.3E-4 – 1.7E-3	35 – 70
solid bricks	4.7E-4 – 7.1E-4	20 – 30
hollow bricks	2.1E-4 – 5.9E-4	9 – 25
solid sand-lime bricks	9.5E-5 – 1.9E-4	4 – 8
Hebel AAC	5.9E-5 – 1.7E-4	2.5 – 7
concrete	2.4E-6 – 1.2E-5	0.1 – 0.5
gypsum	8.3E-4	35
lime-cement plaster	4.7E-5 – 9.5E-5	2 – 4
cement plaster	4.7E-5 – 7.1E-5	2 – 3
dispersion coating	1.2E-6 – 4.7E-6	0.05 – 0.2

3.11 Mold Growth Prevention Plan

Generally, growth of mold on the surface of materials will occur when the following conditions exist:

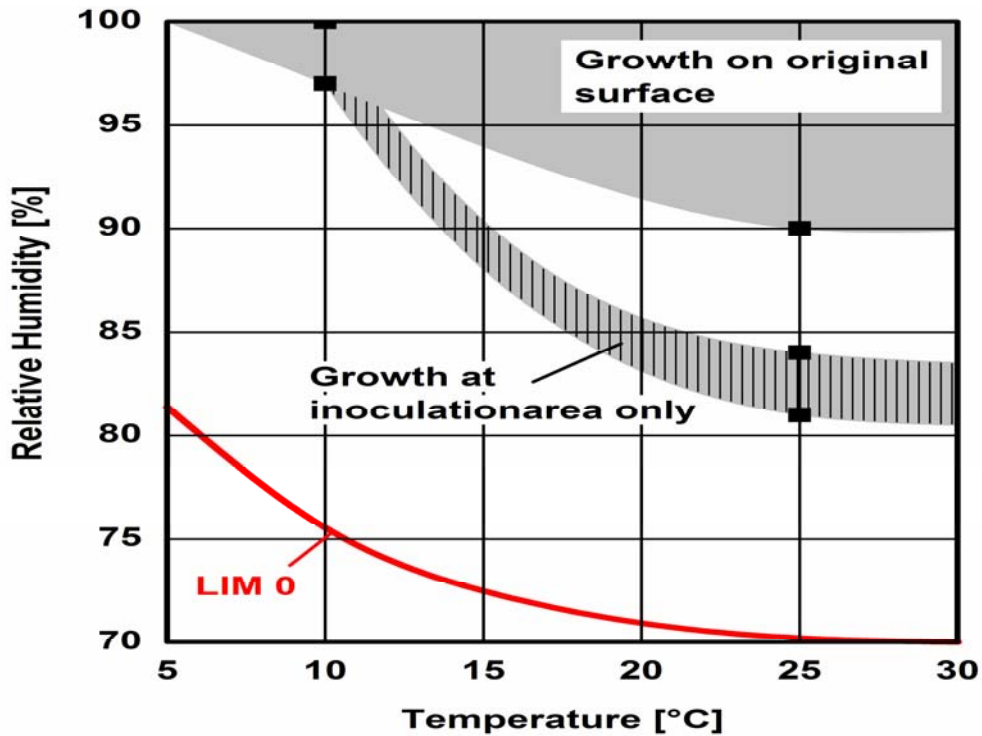
- high relative humidity on the surface (ordinarily above 70 % RH)
- presence of nutrients (e.g. organic compounds)
- pH value between 4.5 and 8

Hebel AAC is a non-organic mineral material (organic content below 0.1 w%). In order to investigate under which conditions mold growth might be possible, Xella has carried out an investigation together with the Institut für Bauphysik in Germany.

Results of measurements regarding mold resistance are expressed in a so called isopleth system. Using data of twelve different test climates a range can be given in which the material specific border isopleth is found. That means below the range shown no mold growth is to be expected whereas above the range mold growth will occur within 100 days. On the surface of the test specimen it can be distinguished between the inoculation zone and the original material surface. Since spores do contain some nutrients for germination and because little (very little because the spores are washed in distilled water) amount of adhering nutrients from growth media or parts from mycelia might provide an additional source of nutrients, usually the area of inoculation is excluded from the results. Graph 3.3 shows the differentiation between inoculation zone and the original AAC material surface. It is obvious,

that at the inoculation zone growth is recognized at more harsh conditions, whereas the original material surface is more resistant. Therefore the inoculation zone can be regarded as material behavior under the influence of contamination from the environment.

Graph 3.3: Isopleth Model for AAC



It is distinguished between the inoculation area (where traces of nutrients might be) and original material surface. The “lowest isopleth of mold” (LIM 0) indicates conditions below which no growth can occur on any surfaces.

What does it mean for the practical side?

Considering the isopleth, the relative humidity on the interior surface should not exceed the value given in Graph 3.3. This can be achieved by proper design of the air-conditioning system (if necessary dehumidification) and by avoiding of thermal bridges in the building envelop.

Example:

10 inch AAC-4/500 wall

Climate condition: Miami.

Air-conditioning system with dehumidification

ARCH: 0.35

Set point for heating: 64.4 °F (18 °C)

Set point for cooling: 71.6 °F (22 °C)

RH control set point: 60 % RH

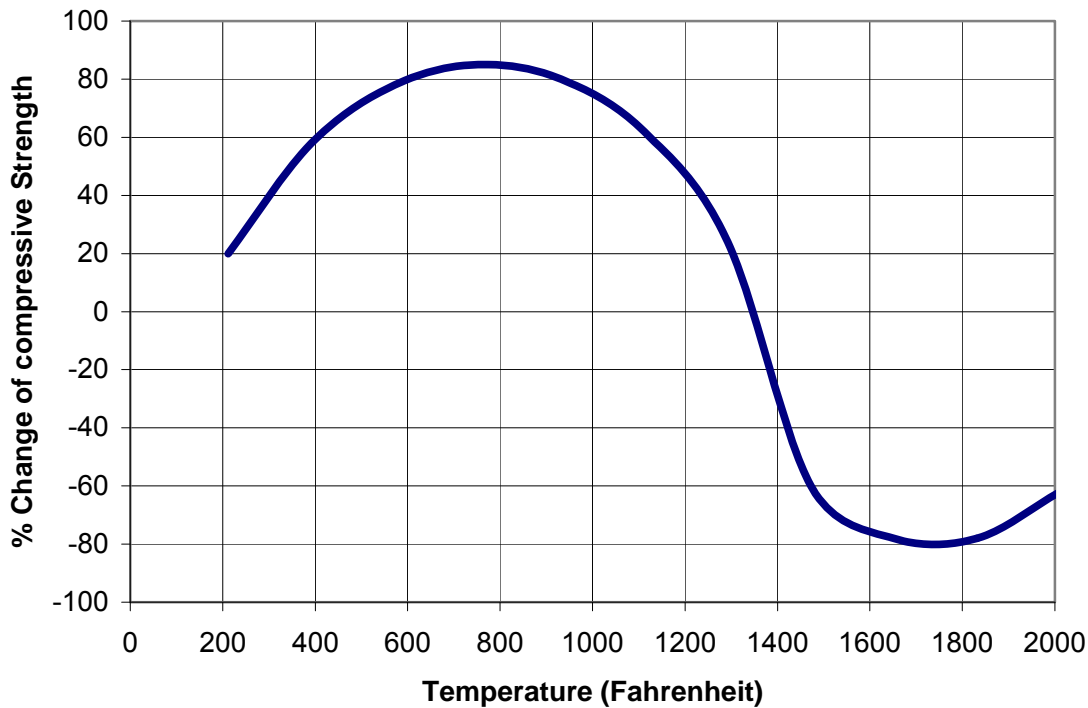
Conclusion: Under these conditions, mold growth on the surface will not occur because the maximum RH is under 80 % and therefore not sufficient.

3.12 Fire Resistance Properties

Hebel AAC is a non-combustible material which provides a safer structure in the case of fire. AAC structures provide a high level of fire containment to delay the spread of fire to other areas of the building. For example, a wall with a thickness of 8 inch made out of Hebel AAC provides a fire rating of four hours. During a fire, no toxic gases or vapors are emitted by AAC. By using fire resistive materials like AAC, the owner of buildings qualify for a reduction in fire insurance premiums.

AAC contains bound water which escapes above 800°C and tobermorite transforms to another mineral (β -wollastonite). The melting point is reached at approximately 1200°C. Compressive strength of AAC increases (up to a maximum limit) with rising temperature (see Graph 3.4 below) meanwhile shrinkage increases in this process which can cause the appearance of cracks.

Graph 3.4: Change in Compressive Strength vs. Increased Temperature



3.13 Requirements of Standards and Model Codes

In the International Building Code 2006 (IBC 2006) the most important terms for fire rated assemblies are defined as follows:

- **Fire walls** are fire-resistance-rated walls having protected openings, which restrict the spread of fire, with sufficient structural stability under fire conditions to allow collapse of construction on either side without collapse of the wall. Fire-resistance ratings for fire walls are defined in table 705.4 in IBC 2006.
- **Fire-resistance rating** is the period of time a building element, component or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both, as determined by tests.

The proof for the material properties regarding fire-resistance is done by testing. The requirements for testing the fire resistance of building materials are defined in ASTM E 119.

3.14 Test Results

Fire endurance testing of Hebel AAC material in accordance with ASTM E 119 (ANSI UL 263) was performed at Underwriters Laboratories (UL) and was witnessed by a Factory Mutual Research Co. (FMRC) representative. Testing included non-load bearing walls, load bearing walls and slab panel assemblies. Results of these tests generated the fire ratings presented in Table 3.12 which are included in UL 1998 fire resistance directory. UL classification and FMRC listing agreements enrolled Hebel AAC into a follow up service program focused on quality assurance of AAC material.

Table 3.12: UL Design Assemblies Using AAC

Type of Element	Fire Resistance Rating	Minimum Thickness of AAC materials	UL Design Number(s)	Comments
Floor Panels	4-Hour	6" Nominal	K909	Restrained or Unrestrained
Roof Panels	4-Hour	6" Nominal	P932	Restrained or Unrestrained
Block / Wall Panel	4-Hour	4" Nominal 6" Nominal 8" Nominal	U916, U917 U918, U919, U920 U921	Non-bearing or Bearing Wall
	2-Hour	3" Nominal	V420	Bearing Wall attached to 3 ½" Steel Stud System
	4-Hour	4" Nominal 8" Nominal	X901	Steel Column Protection
Boards	2-Hour	2" Nominal	U212, U213	Bearing or Non-bearing
Block / Wall Assembly	2-Hour	6" Nominal	C-AJ-1556	Through Penetration Firestop
Floor, Roof or Wall Assembly	4-Hour	6" Nominal	C-BJ-1037	Through Penetration Firestop
Floor, Roof or Wall Assembly	3-Hour	6" Nominal	C-BJ-8010	Through Penetration Firestop
Wall Assembly	4-Hour	6" Nominal	W-J-8009	Through Penetration Firestop
Floor Assembly	1 ½ to 4 Hour	4" Nominal	FF-D-0017, FF-D-0018, FF-D-0019, FF-2-20, FW-D-0012, FW-D-0013, FW-D-0014, FW-D-0015, HW-D-0166, HW-D-0177, HW-D-0367, WW-D-0022, WW-D-0023, WW-D-0024	Joint System

3.15 Acoustic Properties

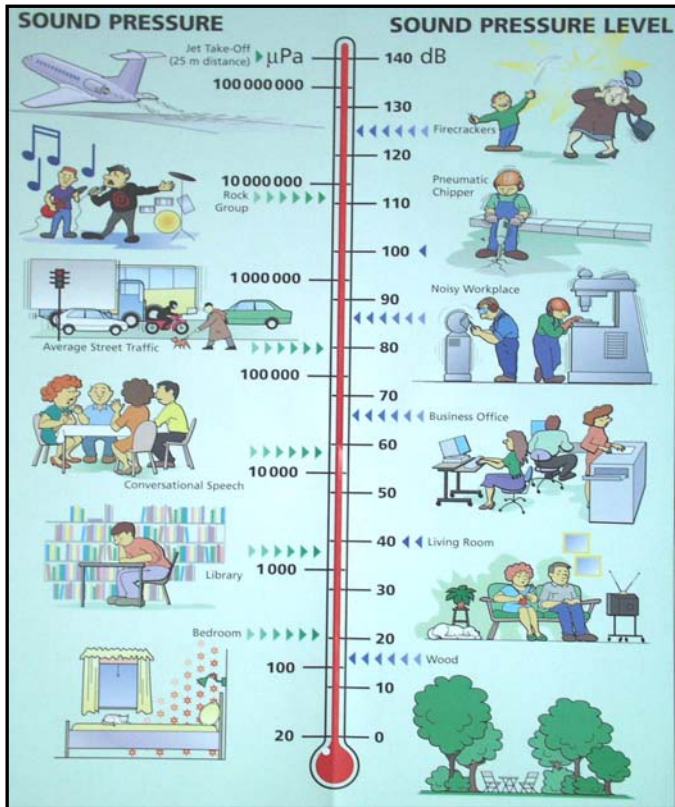
Noise control in buildings is of great significance for the health and well-being of the occupants, especially in residential dwellings, since they must provide an environment that is restful and relaxing. The building envelope must also maintain privacy for the occupants. Noise control is also an important factor in other types of buildings such as schools, hospitals, and offices.

Hebel AAC, a porous concrete material, provides a sound insulation value of up to 7 dB greater than other building materials of the same weight (mass per area). Hebel's surface mass coupled with the mechanical vibration energy damping within its porous structure produces a building material with exceptional sound insulation properties.

In addition to using a wall material with superior sound insulation properties in relation to its mass per area, it is always essential to construct the wall in a manner that closes off air leaks and paths by which noise can go around or through the assembly. Hairline cracks or small holes will increase the sound transmission through the wall at the higher frequencies. Hebel's simple construction methods and details help to eliminate these cracks and holes in the walls, thus providing a final wall assembly, which offers superior sound insulation characteristics for the occupant.

The **sound pressure level** is the most important physical value to describe or quantify airborne noise inside and outside buildings. It is defined as the ratio between a base sound pressure in our atmosphere (ca. 20 μPa) and the sound pressure caused by noise. The threshold of pain corresponds to a sound pressure of approximately 100,000,000 μPa , similar to a jet plane taking off at a distance of approximately 50 yards. The relationship of sound pressure to sound level is represented using a logarithmic scale.

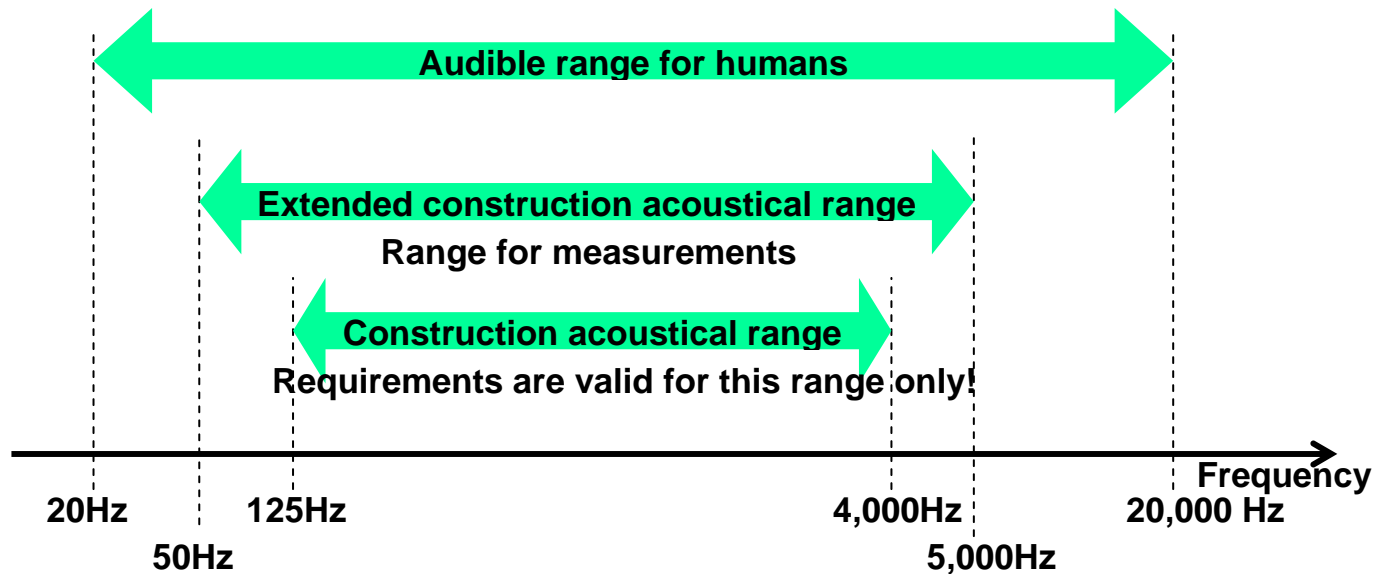
Diagram 3.3: Relationship of Sound Pressure vs. Sound Pressure Level



In fact, the logarithmic scale of the sound level is appropriate because the perception of loudness by the human ear is also logarithmic. Therefore, a 10 dB increase in the sound pressure is perceived as a doubling of the sound loudness.

The **frequency range** of human beings depends on the individual state of health. The range of human acoustic perception starts approximately at 20 Hz and ends at 20 kHz. STC measurements in buildings normally reference frequencies between 50 Hz and 5 kHz. In the USA, requirements for STC values are determined by the frequency range between 125 Hz and 4 kHz.

Graph 3.5: Frequency Range



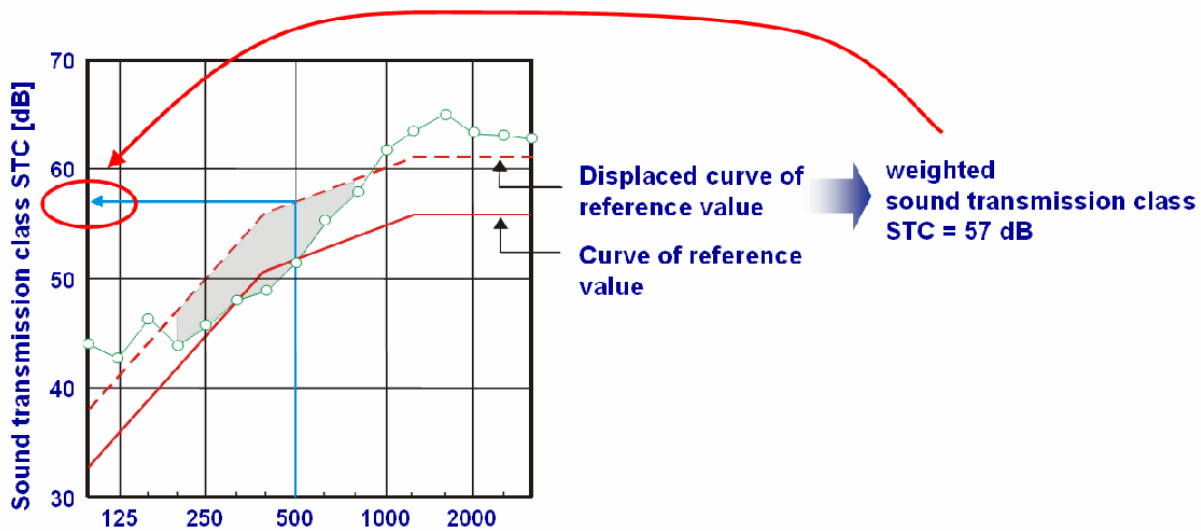
Building components used for sound insulation must be able to perform for a wide range of frequencies. That makes it difficult to evaluate a representative single value, e.g. an average that is easier to handle instead of the 15 different frequencies in one-third octave. Because of this complicated situation, the levels of all measured frequencies are combined using a special weighting of values fixed in ASTM 413 (see “sound transmission loss”).

For different frequencies at the same sound level, sounds will not be perceived as being equally loud. For example, a 54 dB sound at 3 kHz will sound as loud as a 79 dB sound at 50 Hz. Therefore, it is necessary to weight sound according to frequency in order to get a more meaningful measure of the effects of sound. The doubling of the frequency corresponds to one octave. This means the range from 125 Hz to 250 Hz corresponds to one octave.

The **sound transmission loss (TL)** describes the reduction of airborne sound transmission in each frequency between two rooms through partition components like walls or ceilings. The TL is evaluated by the difference between the sound pressure level of the sending and receiving rooms including the sound absorption of the receiving room and geometrical conditions. Several sound transmission loss values corresponding to a specified frequency band may be represented in a sound transmission loss curve.

According to ASTM 413, a standardized evaluation is used to obtain a sound transmission class (STC) from the measured TL. Graph 3.6 shows a sound transmission loss curve corresponding to 16 airborne sound transmission loss values. The TL-values were measured for a one-third-octave band frequency through an “airborne sound transmission loss” laboratory test or a field measurement in accordance to the American standard ASTM E 90.

Graph 3.6: TL-values of a Partition Component



The **sound transmission class** is a single number rating providing a convenient way to describe the sound transmission loss (TL) values. It provides an estimation of the performance of the wall or floor in certain common sound insulation conditions. The STC is determined by comparing its sound transmission curve with a standard reference curve. The reference curve is superimposed over the sound transmission loss curve and shifted upwards or downwards, relative to the TL-curve, taking in consideration certain conditions of ASTM 413. The sound transmission class (STC) is taken to be the transmission loss value, measured in decibels (dB), corresponding to the intersection of the reference curve and the 500 Hz frequency line.

Between neighboring rooms there is a transport of sound straight through the partition assembly. In massive buildings there is in addition to this **sound transmission**, bypass noise transportation along flanking components called **flanking sound transmission**. The lower the flanking sound transmission the higher the TL. It is very important to regard this flanking sound transmission as well because there might be a large influence on the result of the TL.

3.16 Relationship Between Sound Transmission Class and Sound Reduction Index (R'_w)

In European countries there are two important terms to describe the acoustic performance of assemblies. R_w [dB] is the abbreviation for TL or sound reduction index (SRI) without flanking sound transmission (e. g. in laboratories). When describing the sound reduction of partition components in buildings it is necessary to describe the complete sound transmission (direct and bypass) using R'_w [dB].

The difference between STC and R_w is not very wide. The approximate relationship between the two can be expressed by the equation $STC = R_w + 1$ [dB]. The safest calculation is to set $STC = R_w$ [dB]. The small difference between these two parameters is caused by the discrepancy of the range of frequencies considered.

Sounds generated by pedestrian foot traffic in buildings in adjacent rooms are referred to as impact **noise**. This type of noise is easily perceived by occupants of space beneath the space where the impact occurs. The most important value to interpret a floor/ceiling construction is the **impact insulation class (IIC)**.

The equivalent of IIC according to the European standards is $L'_{n,w}$ [dB]. The calculation of IIC according to ASTM E 989 (edition 1989) is in general synonymous with building $L'_{n,w}$ [dB] according to ISO 717-2 (edition 2006). So it is acceptable to work with the following relationship:

$$IIC \approx L'_{n,w}$$

3.17 Code Requirements

Building regulations governing acoustic performance are sometimes only recommendations and not usually enforceable by law. In addition to the requirements for design of the building elements, the overall design of the building, the quality of construction and workmanship can have marked effects on the actual sound insulation within a building.

In general the acoustic performance of walls and ceilings between neighboring dwellings in apartment houses must have a $STC \geq 45$. In areas with high noise, e. g. between a living unit and public space or service areas, the requirement increases up to $STC \geq 50$ dB. In some buildings and regions in the USA the required acoustic performance is satisfied if a field sound transmission class (FSTC) of 5 dB below the code required STC is measured.

3.18 Acoustic Performance of AAC

The most important character of a solid homogenous single wythe partition element is to describe its acoustical performance is the mass per area or surface-related mass (thickness times density). The higher the mass per area of a wall assembly the higher the STC will be.

AAC has been shown to provide better insulation to sound transmitted by air than other building materials, for example concrete under comparable conditions. The inner damping of AAC is one of the significant reasons for the high sound insulating performance of AAC. In comparison with other materials of the same mass per area, AAC has up to a 7 dB higher STC. The German standard DIN 4109 (1989) allows a 2 dB increase in sound insulation for AAC walls, with a surface-related mass in the range of 85 - 250 kg/m² (17 - 51 lbs/ft²).

3.19 Design for Sound Insulation Based on Tables

Table 3.13: Surface-related Mass vs. Sound Insulation is valid for all single wythe wall assemblies made of AAC. Regarding the SRI there is no difference between single layer walls (inside and outside), ceilings or roof assemblies. An AAC roof and wall score the same SRI in the case that the components have the identical surface-related mass.

Table 3.13: Surface-related Mass vs. Sound Insulation

Mass per Area		For All Massive Materials R'_w According to DIN 4109 (dB)	For AAC (incl. AAC Bonus)		For CMU Walls $STC = 23*(w)^{0.2}$ According to NCMA TEK 13-1
m' (kg/m ²)	W (lb/ft ²)		R'_w According to DIN 4109 (dB)	R_w According to new DIN 4109 (dB)	
80	16	33	35	40	40
85	17	34	36	40	41
90	18	35	37	41	41
95	19	35	37	42	42
105	21	37	39	43	42
115	23	38	40	45	43
125	26	39	41	46	44
135	28	40	42	47	45
150	31	41	43	48	46
160	33	42	44	49	46
175	36	43	45	50	47
190	39	44	46	51	48
210	43	45	47	52	49
230	47	46	48	53	50
250	51	47	49	54	51
Legend:					
R'_w : Sound transmission loss with flanking sound transmission along bypasses in buildings.					
R_w : Sound transmission loss without flanking sound transmission along bypasses in buildings.					

Note: Plaster should also be included in the calculation of surface-related mass.

Table 3.14: Sound Transmission Class of Single Wythe AAC Components

Thickness		Dry Bulk Density		STC [dB]
[mm]	[in]	[kg/m ³]	[lbs/ft ³]	
200	8	500	31	42
250	10	500	31	44
300	12	500	31	46

3.20 Surrounding Noise

Increasing noise levels caused by road traffic or industry is an increasing problem for existing and new building sites. Facades, windows, and outside walls also have to work as sound barriers.

Traffic noise, caused by cars, trucks, busses, trains or aircrafts; generate high occurrences of low frequencies. The STC primarily is defined for noise spectra caused by common behavior of people in buildings and human speech, lower frequencies are not considered in the calculation of STC.

To address the lower frequencies from outside noise an additional ranking has been established. The single-number rating of the outdoor-indoor transmission class (OITC) includes lower frequencies.

The sound reduction in lower frequencies of nearly all materials is usually smaller at higher frequencies. The weighting of sound transmission loss (TL) according to ASTM E 1332 transforms the STC to OITC.

The “rule of thumb” is as follows: OITC usually is 5 – 10 dB less than STC.

3.21 References

International Building Code 2006; International Code Council

NCMA TEK 13-1 (1990) National Concrete Masonry Association; "Sound Transmission Class Ratings for Concrete Masonry Walls"

NCMA TEK 13-2 (1983) National Concrete Masonry Association; „Noise control with concrete masonry in multi-family housing“

ASTM E 90 – 90 „Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions

NCMA TEK 69A (1978) National Concrete Masonry Association; „New Data on Sound Reduction with Concrete Masonry Walls“

ASTM E 989 – 2006 „Standard Classification for Determination of Impact Insulation Class (IIC)“

ASTM E 492 "Single-number rating is called impact insulation class (IIC)"

ASTM E 1007 "Single-number rating is called field impact insulation class (FIIC)"

Hebel-Manual USA; approximately end of 1997

www.stcratings.com/assemblies.html

Recommendations for constructions of ceilings developed by Mr. Bestel (Hebel) approximately in 2002

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