Performance of Exterior Envelopes of Whole Buildings VIII
'Intergration of Building Envelopes'
Clearwater Beach (FL), December 2-7, 2001

Workshop on

'Thermal Mass and Its Effect on the Whole Building Energy Performance'

European concrete and masonry envelope technologies

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‘Thermal Mass and Its Effect on the Whole Building Energy Performance’

European concrete and masonry envelope technologies

Layout

- Introduction
- Brick masonry and floor technologies
  1) Brick masonry (multi-layer & cavity walls)
  2) Hollow brick masonry
  3) Reinforced brick masonry
  4) Additional application of **EIFS**
  5) Tile void slab and rib-and-slab floor systems
- Concrete envelope technologies
  1) Autoclaved Aerated Concrete (**AAC**)
  2) Prefabricated concrete and Cast-in-Place walls and floors
  3) Concrete Masonry Units (CMU): expanded clay-, slag-, sawdust- & EPS- concrete
  4) Insulating Concrete Forms (**ICF**)
  5) Additional application of **EIFS**
- Calcium-silicate masonry technologies
- Gypsum masonry technologies
- Concluding remarks

‘Thermal Mass and Its Effect on the Whole Building Energy Performance’

European concrete and masonry envelope technologies

Brief review done mainly from the viewpoint of “insulation and thermal mass” properties :

- application in construction of building
- evaluation of technology complexity
- typical structural and masonry elements
- typical thickness and thermal resistance of walls
- mass and thermal capacity per unit area of walls

BRICK MASONRY

Introduction

- dried clay brick – known from the 8th century B.C.
- burnt clay brick – known from the 4th century B.C.
- Used in ancient Mesopotanian, Persian and Chinese architecture
- **in Europe** – wider use of brick masonry started in Romanesque and Gothic architecture, the 9th - 11th century

BRICK MASONRY

Introduction

Pre-romanesque architecture

Baptysthery in Poitiers
(the 6th-7th century)

Saint-Philibert church in Tournus
(the 10th-11th century)

BRICK MASONRY

Introduction

Romanesque & Gothic architecture

Third church in Cluny

(the 11th century)

Cathedral in Alby

(the 14th century)

BRICK MASONRY

Introduction

Gothic architecture

Teutonic Knights Castle in Malbork

(14th-15th century)

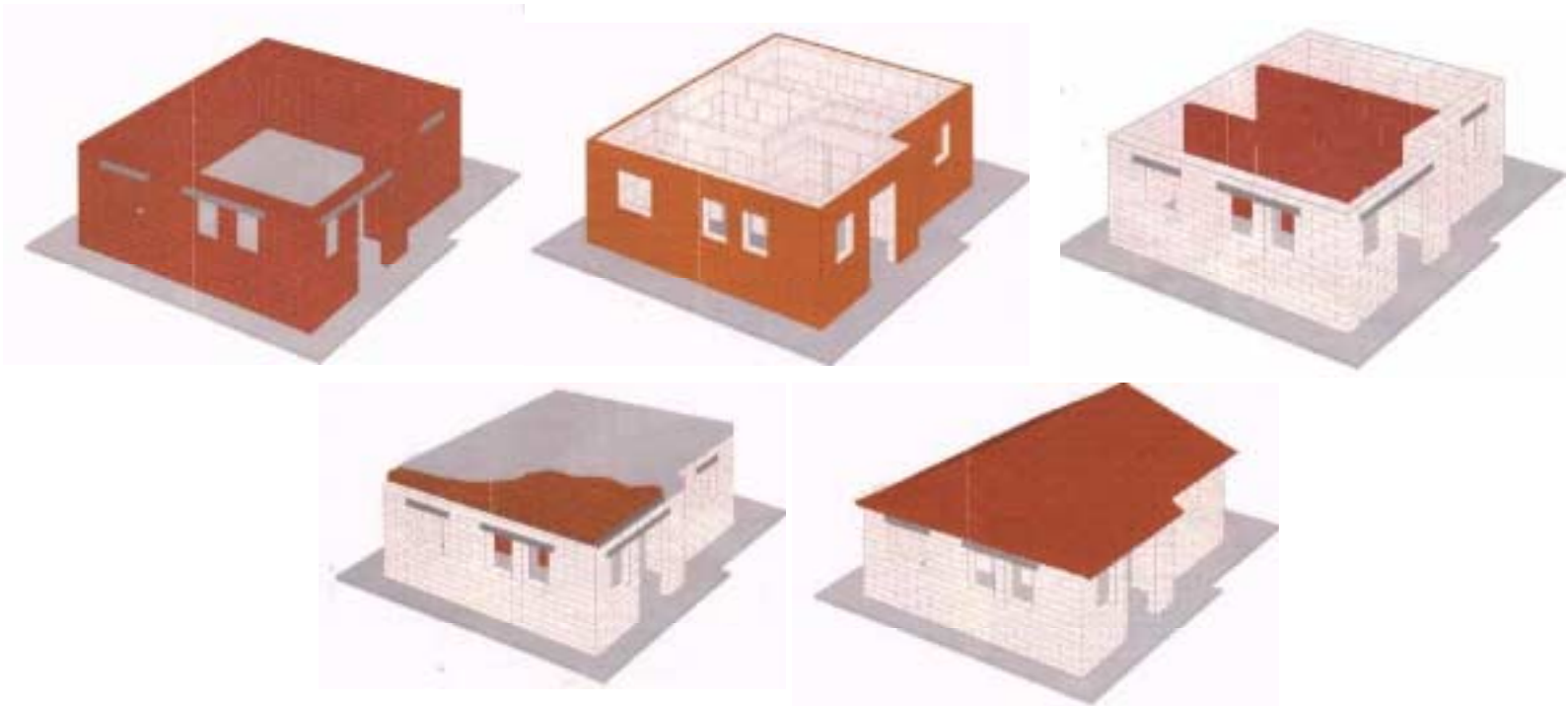
BRICK MASONRY TECHNOLOGIES

Application

- Single family houses, Multi-storeyed apartment houses, commercial & public buildings

BRICK MASONRY TECHNOLOGIES

Application

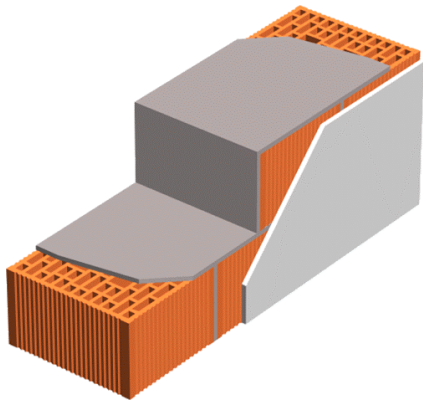


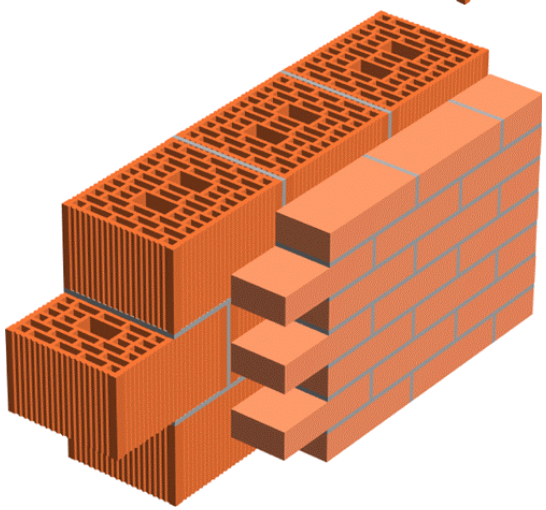
- Load-bearing & non-loadbearing walls, wall facades, floors and roofs

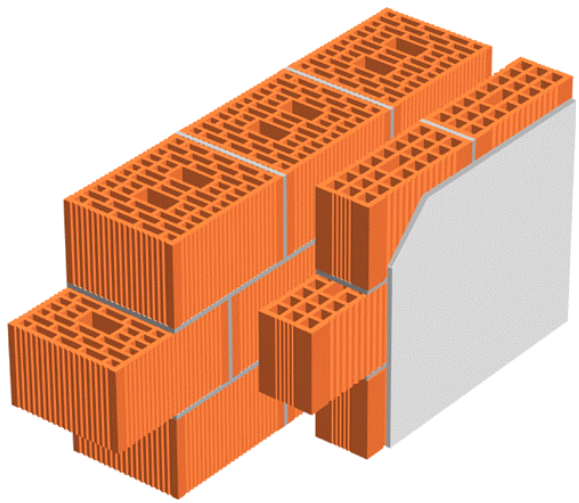
BRICK MASONRY TECHNOLOGIES

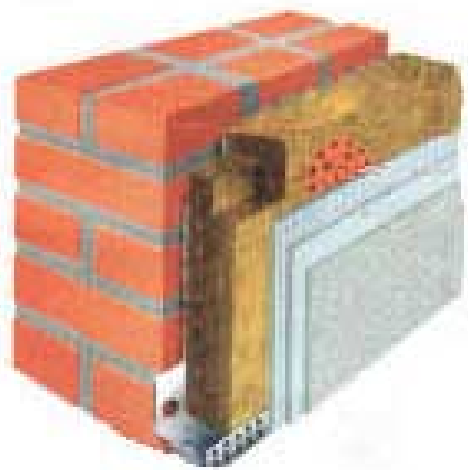
Application

Single-layer & multi-layer walls, cavity walls, walls with EIFS





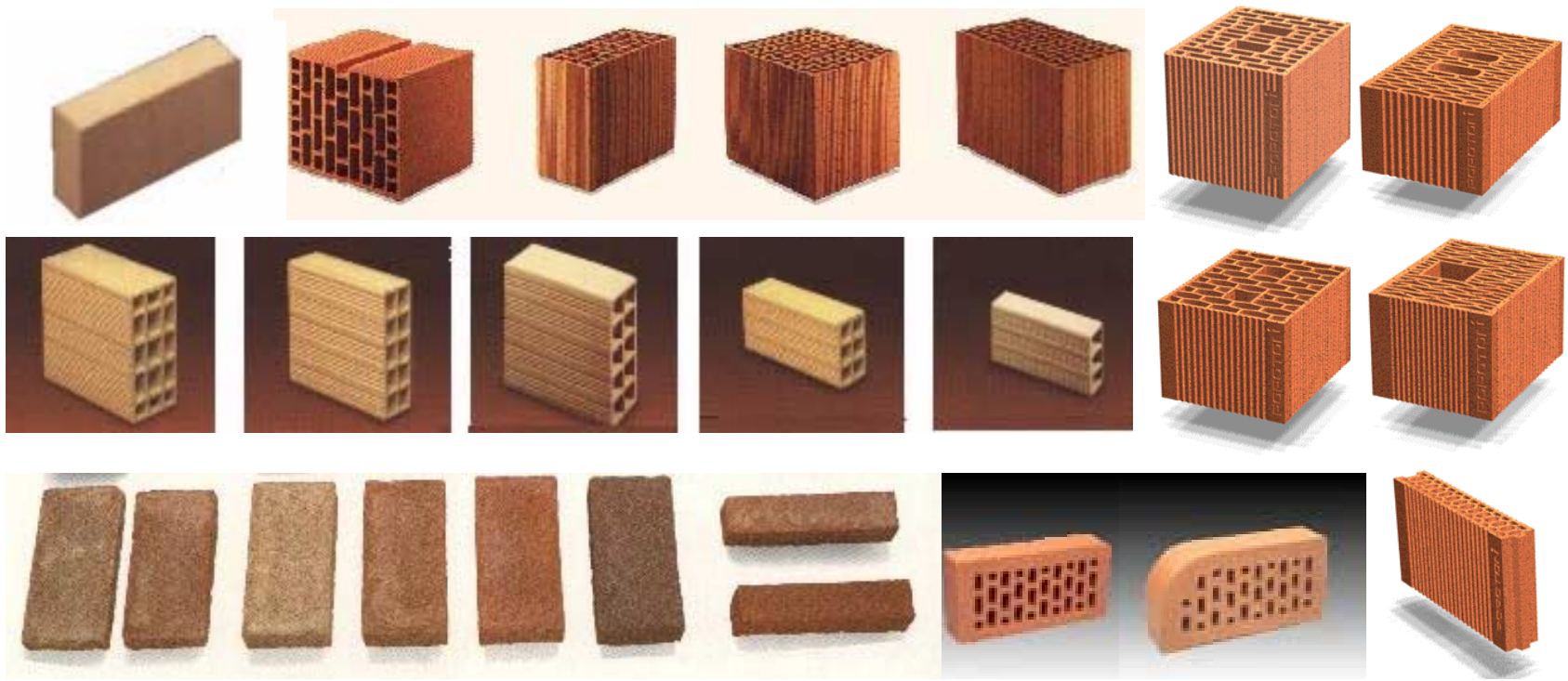




BRICK MASONRY TECHNOLOGIES

Clay brick structural elements

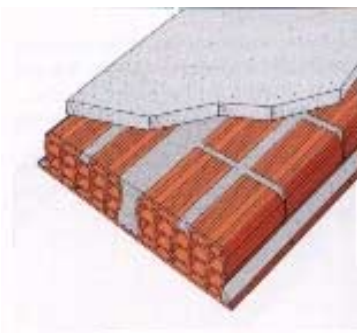
Masonry and face bricks, light porous clay bricks

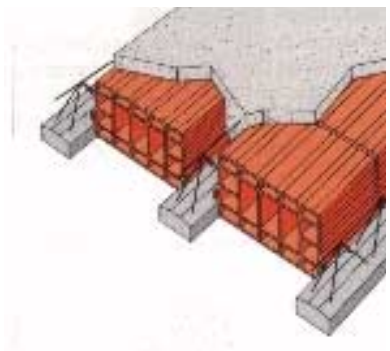


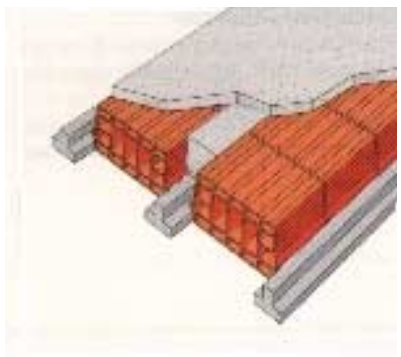
BRICK MASONRY TECHNOLOGIES

Clay brick structural elements

Structural clay floor tiles



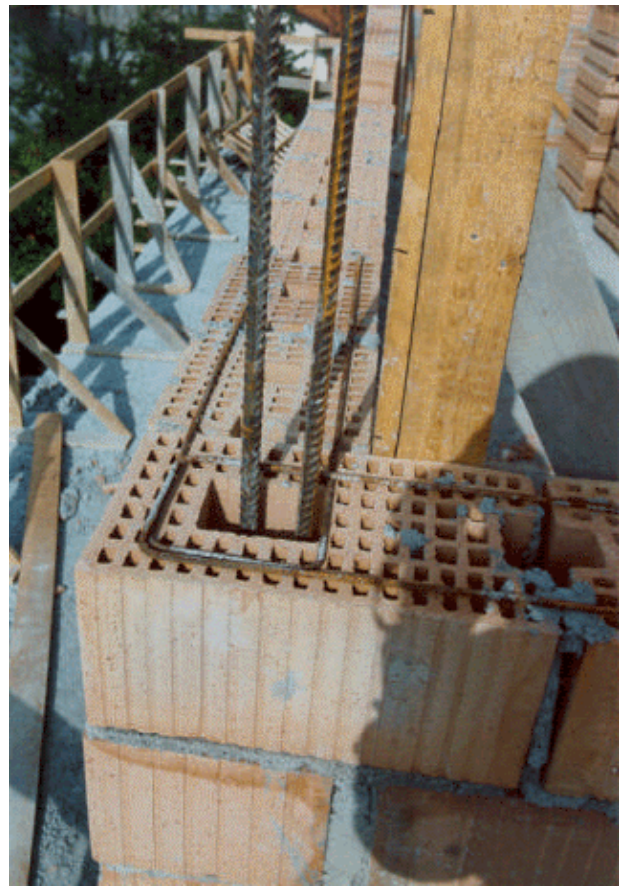




tile void slab floors: rib-and-slab floors, beam framed floor

BRICK MASONRY TECHNOLOGIES

Reinforced brick masonry



Buildings in seismic zones

BRICK MASONRY TECHNOLOGIES

Technology

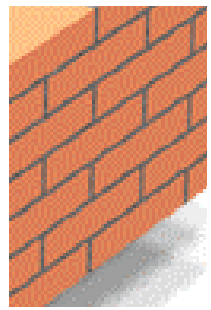
Difficult - well qualified and well equipped building crew is necessary

Well prepared instructions for house builders are available

BRICK MASONRY TECHNOLOGIES

Thermal properties

Common brick wall

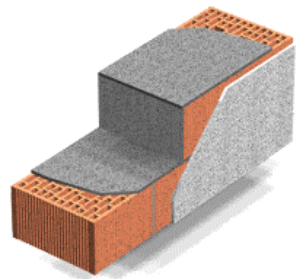


Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/$ Btu	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
1200	75.0	12	4.7	0.50	3.47	0.24	1.4	144	29.5	127	20.0
1200	75.0	25	9.8	0.50	3.47	0.50	2.8	300	61.5	264	41.7
1200	75.0	38	15.0	0.50	3.47	0.76	4.3	456	93.4	401	63.4
2000	125.0	12	4.7	0.96	6.67	0.13	0.7	240	49.2	211	33.3
2000	125.0	25	9.8	0.96	6.67	0.26	1.5	500	102.5	440	69.5
2000	125.0	38	15.0	0.96	6.67	0.40	2.2	760	155.7	669	105.6

BRICK MASONRY TECHNOLOGIES

Thermal properties

Hollow clay brick and light porous clay brick



Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ (h°F·ft^2)	m^{2}K/W	ft^2·h°F/ Btu	kg/m^2	lb/ft^2	kJ/ (m^{2}K)	Btu/ (°F·ft^2)
1400	87.5	12	4.7	0.62	4.31	0.19	1.1	168	34.4	148	23.3
1400	87.5	25	9.8	0.62	4.31	0.40	2.3	350	71.7	308	48.6
1300	81.3	29	11.4	0.42	2.92	0.69	3.9	377	77.3	332	52.4
1300	81.3	39	15.4	0.28	1.98	1.37	7.8	507	103.9	446	70.4
803	50.2	36	14.2	0.17	1.16	2.16	12.3	289	59.2	254	40.2
773	48.3	44	17.3	0.16	1.10	2.77	15.7	340	69.7	299	47.2
803*	50.2	36	14.2	0.15	1.05	2.39	13.6	289	59.2	254	40.2
773*	48.3	44	17.3	0.14	1.00	3.05	17.3	340	69.7	299	47.2

*) with thermo-insulating joints

CONCRETE ENVELOPE TECHNOLOGIES

Introduction

cement as a hydraulic binding agent:

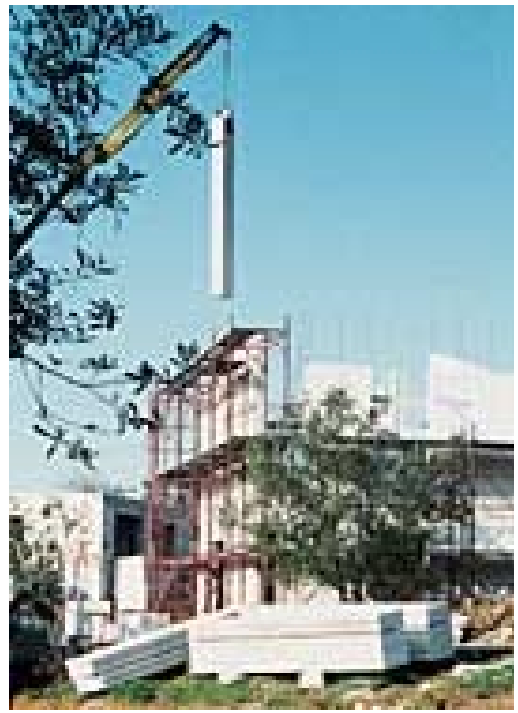
- Roman cement - 2nd-3rd century B.C.
  - application in ancient Roman architecture
- portland cement - J. Aspdin (1824)

concrete as a building material:

- **in Europe** – wider use of concrete from the end of the 19th and beginning of the 20th century

AAC ENVELOPE TECHNOLOGIES

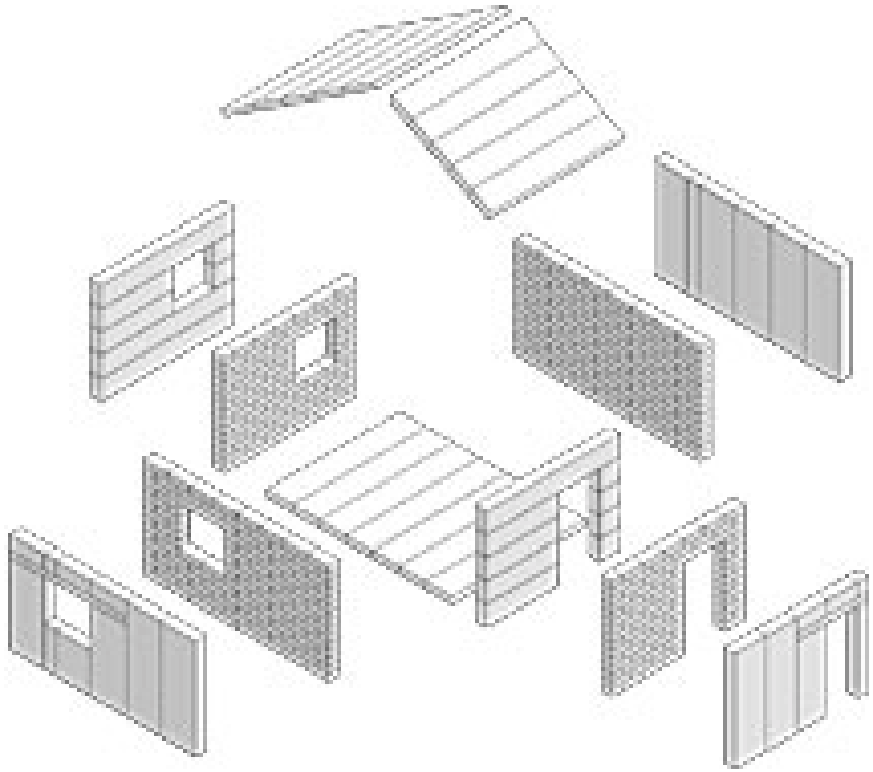
Application



- Single family houses, multi-storeyed apartment houses, commercial & public buildings

AAC ENVELOPE TECHNOLOGIES

Application



- Load-bearing & non-loadbearing walls, floors and ceilings

AAC ENVELOPE TECHNOLOGIES

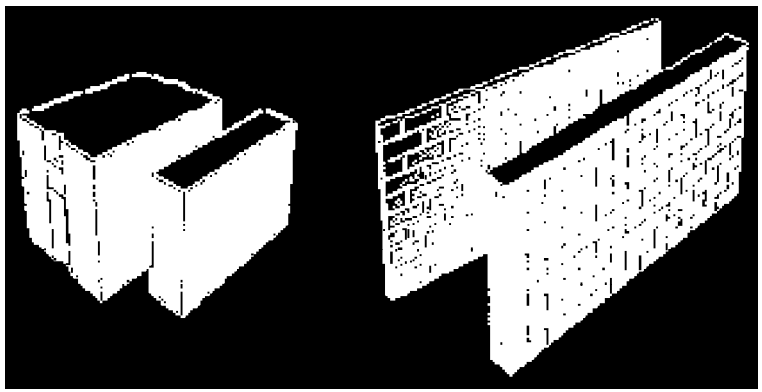
Application

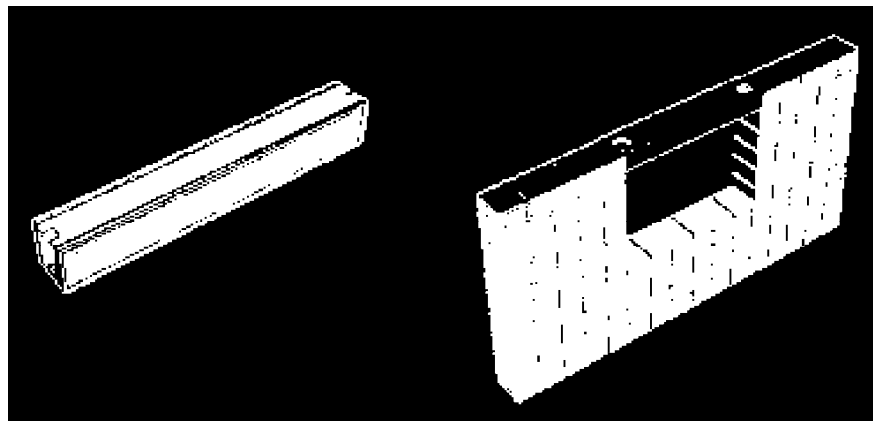
- Mainly single-layer walls and floors

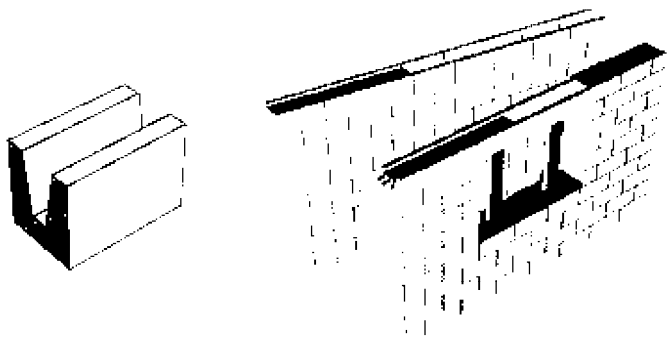
AAC ENVELOPE TECHNOLOGIES

Structural elements

Wall blocks, window- & door-heads, prefabricated floors







AAC ENVELOPE TECHNOLOGIES

Tools & equipment

Material easy to be cut, nailed & screwed like wood
For bigger elements crane is necessary

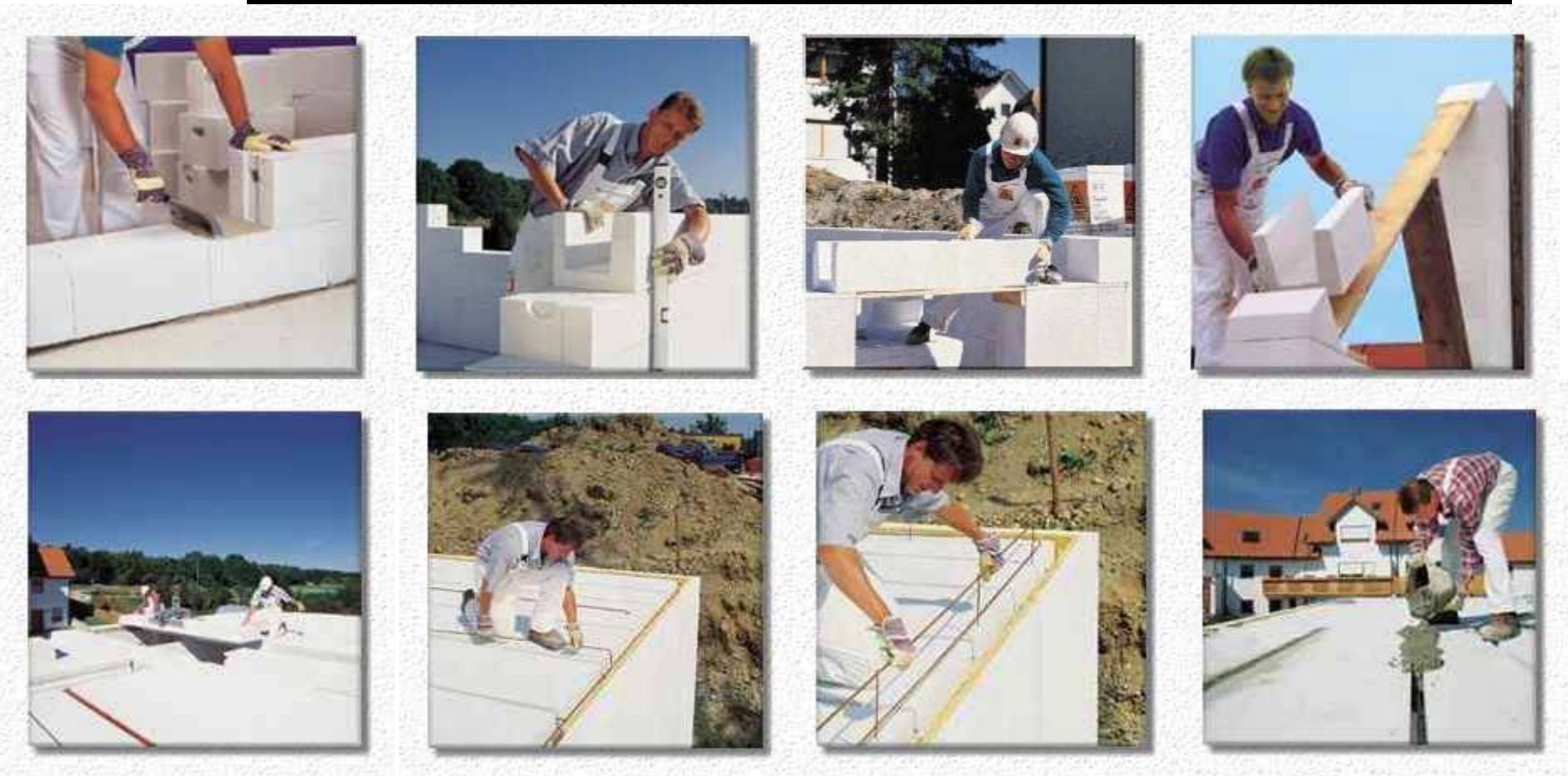
AAC ENVELOPE TECHNOLOGIES

Technology

- Not very difficult - qualified building crew is rather necessary

AAC ENVELOPE TECHNOLOGIES

Technology

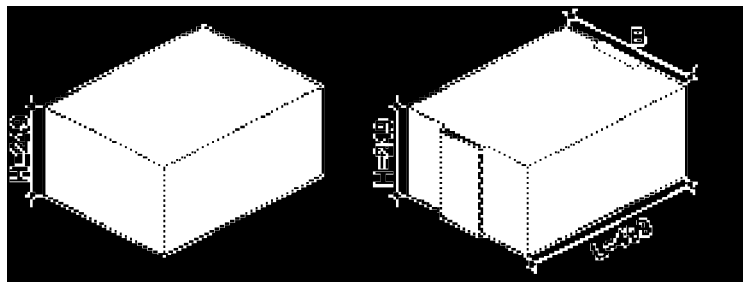


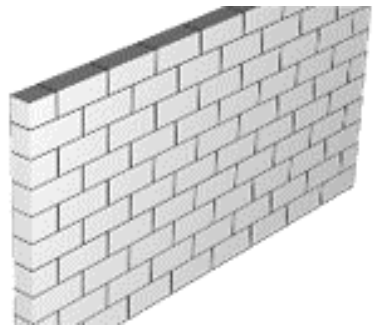
Very well prepared instructions for house builders are available

AAC ENVELOPE TECHNOLOGIES

Thermal properties

AAC blocks with normal joints



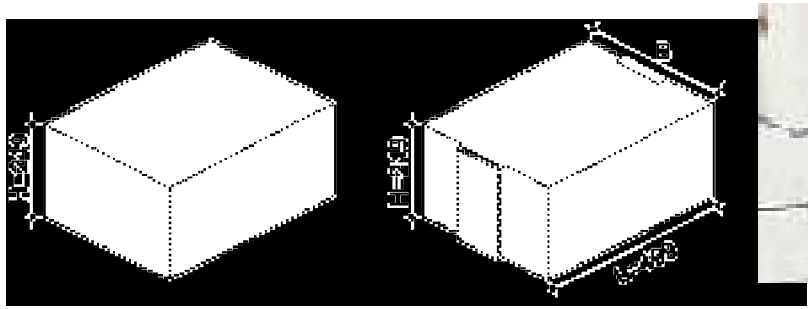


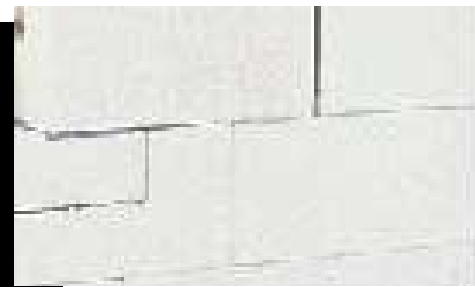
Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/$ Btu	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
500	31.3	15	5.9	0.25	1.74	0.60	3.4	75	15.4	63	9.9
500	31.3	20	7.9	0.25	1.74	0.80	4.5	100	20.5	84	13.3
500	31.3	25	9.8	0.25	1.74	1.00	5.7	125	25.6	105	16.6
800	50.0	15	5.9	0.38	2.64	0.39	2.2	120	24.6	101	15.9
800	50.0	20	7.9	0.38	2.64	0.53	3.0	160	32.8	134	21.2
800	50.0	25	9.8	0.38	2.64	0.66	3.7	200	41.0	168	26.5

AAC ENVELOPE TECHNOLOGIES

Thermal properties

AAC blocks with a thin layer of mortar or thermo-insulating joints

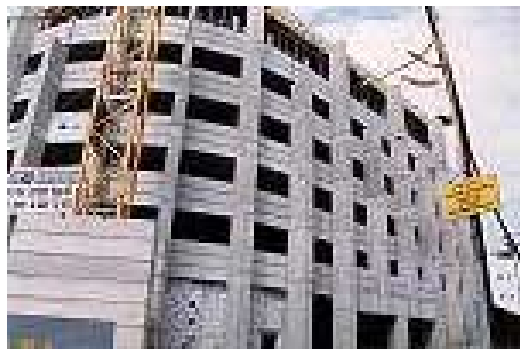




Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ (h°F·ft^2)	m^{2}K/W	ft^2·h°F/ Btu	kg/m^2	lb/ft^2	kJ/ (m^{2}K)	Btu/ (°F·ft^2)
400	25.0	15	5.9	0.14	0.97	1.07	6.1	60	12.3	50	8.0
400	25.0	20	7.9	0.14	0.97	1.43	8.1	80	16.4	67	10.6
400	25.0	25	9.8	0.14	0.97	1.79	10.1	100	20.5	84	13.3
600	37.5	15	5.9	0.21	1.46	0.71	4.1	90	18.4	76	11.9
600	37.5	20	7.9	0.21	1.46	0.95	5.4	120	24.6	101	15.9
600	37.5	25	9.8	0.21	1.46	1.19	6.8	150	30.7	126	19.9

CONCRETE ENVELOPE TECHNOLOGIES

Application



- All types of houses and constructions, including single family houses, multi-storeyed apartment houses, commercial & public buildings

CONCRETE ENVELOPE TECHNOLOGIES

Application & technology

Prefabricated concrete elements

Very difficult - very well qualified and equipped building crew is necessary
All types of building constructions

CONCRETE ENVELOPE TECHNOLOGIES

Cast-in-place technology

- Difficult - well qualified and equipped building crew is necessary
- Very fast house building is possible

CONCRETE ENVELOPE TECHNOLOGIES

Reinforced concrete structural elements

Prefabricated reinforced concrete elements

CONCRETE ENVELOPE TECHNOLOGIES

Thermal properties

Prefabricated and cast-in-place reinforced concrete

Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/Btu$	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
2500	156.3	10	3.9	1.70	11.81	0.06	0.3	250	51.2	210	33.2
2500	156.3	20	7.9	1.70	11.81	0.12	0.7	500	102.5	420	66.3

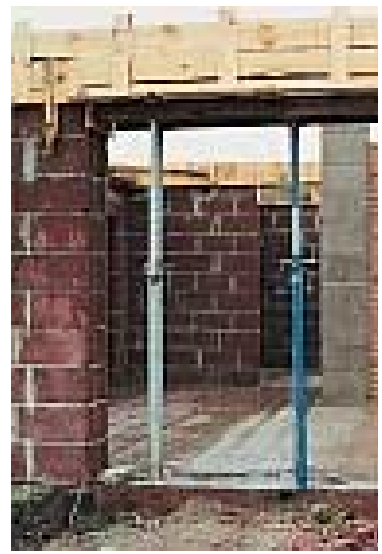
CONCRETE ENVELOPE TECHNOLOGIES

Lightweight CMUs - application

- Single family houses, non-loadbearing walls in multi-storeyed apartment houses

CONCRETE ENVELOPE TECHNOLOGIES

Lightweight CMUs - technology



- Difficult - qualified building crew is rather necessary
- Usually detailed instructions for house builders are available

CONCRETE ENVELOPE TECHNOLOGIES

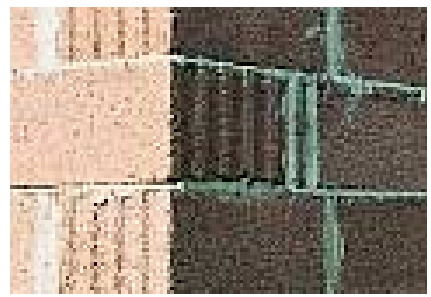
Lightweight-concrete structural elements

Expanded clay - concrete masonry units and structural floor tiles

CONCRETE ENVELOPE TECHNOLOGIES

Thermal properties

Hollow CMU (made of expanded clay aggregate) wall with normal joints



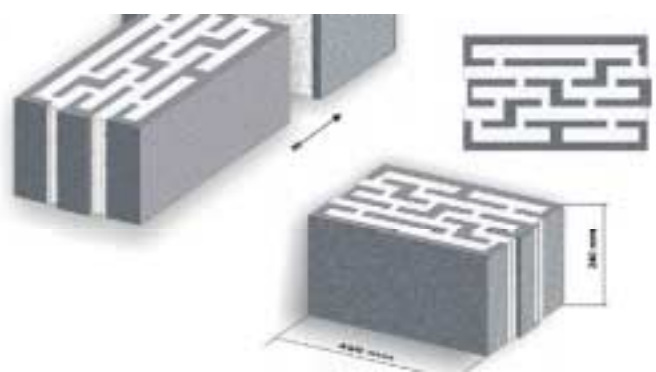
Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/Btu$	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
480	30.0	17.5	6.9	0.15	1.04	1.17	6.6	84	17.2	71	11.1
434	27.1	36.5	14.4	0.14	1.00	2.53	14.4	158	32.5	133	21.0
434*	27.1	36.5	14.4	0.11	0.77	3.28	18.6	158	32.5	133	21.0
567	35.4	24	9.4	0.62	4.27	0.39	2.2	136	27.9	114	18.0

*) with thermo-insulating joints

CONCRETE ENVELOPE TECHNOLOGIES

Thermal properties

CMU (made of expanded clay aggregate and with 18.5 cm EPS inserts) wall



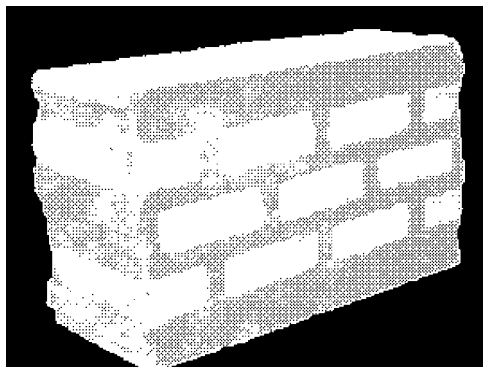
Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ (h°F·ft^2)	m^{2}K/W	ft^2·h°F/ Btu	kg/m^2	lb/ft^2	kJ/ (m^{2}K)	Btu/ (°F·ft^2)
826	51.6	31	12.2	0.06	0.41	5.26	29.9	256	52.5	215	34.0
826*	51.6	31	12.2	0.05	0.35	6.08	34.5	256	52.5	215	34.0

*) with thermo-insulating joints

CONCRETE ENVELOPE TECHNOLOGIES

Thermal properties

CMU (made of EPS-concrete) wall
with a thermo-insulating mortar



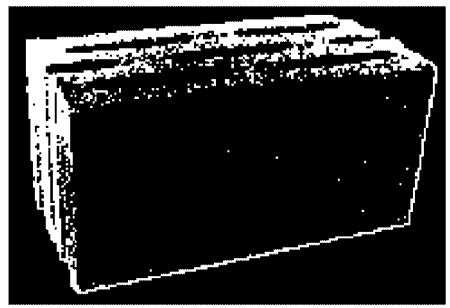
Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/Btu$	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
900	56.3	30	11.8	0.21	1.46	1.43	8.1	255	52.3	214	33.8
483#	30.2	30	11.8	0.25	1.72	1.21	6.9	145	29.7	122	19.2
483*	30.2	30	11.8	0.09	0.61	3.40	19.3	145	29.7	122	19.2

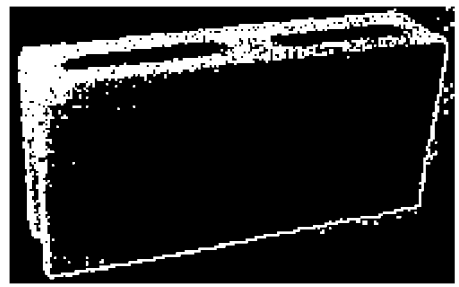
#) hollow bick *) with 13.5 cm EPS inserts

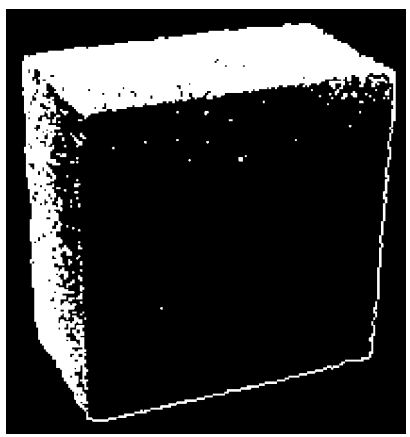
CONCRETE ENVELOPE TECHNOLOGIES

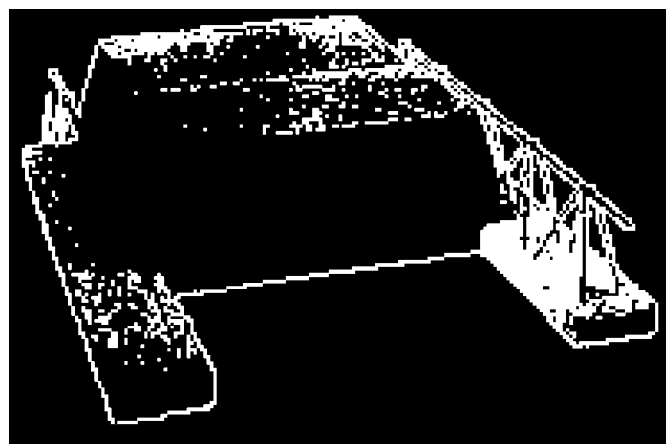
Lightweight-concrete structural elements

Lightweight CMUs and structural floor tiles (made of slag-concrete)





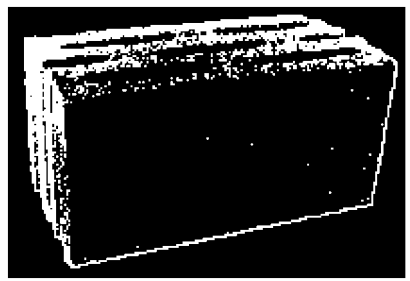


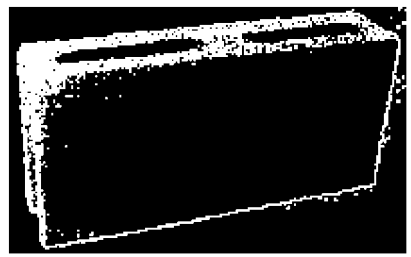


CONCRETE ENVELOPE TECHNOLOGIES

Thermal properties

Lightweight CMU (made of slag-aggregate) wall





Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/$ Btu	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
933	58.3	24	9.4	0.56	3.88	0.43	2.4	224	45.9	188	29.7

CONCRETE ENVELOPE TECHNOLOGIES

Sawdust CMU - technology

- Rather difficult - qualified building crew is necessary

CONCRETE ENVELOPE TECHNOLOGIES

Sawdust-concrete structural elements

Concrete masonry units and structural floor tiles

CONCRETE ENVELOPE TECHNOLOGIES

Thermal properties

CMU (made of sawdust concrete) wall

Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/$ Btu	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
396	24.7	40	15.7	0.20	1.36	2.05	11.6	158	32.4	133	21.0
396*	24.7	40	15.7	0.10	0.73	3.83	21.8	158	32.4	133	21.0

*) with a cellulose fiber fill

CONCRETE ENVELOPE TECHNOLOGIES

Insulating Concrete Forms - ICF (EPS)

Applications

- Detached and semi-detached family houses

CONCRETE ENVELOPE TECHNOLOGIES

ICF (EPS) - application

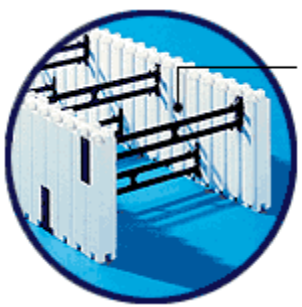
- Load-bearing & non-loadbearing walls, floors and ceilings

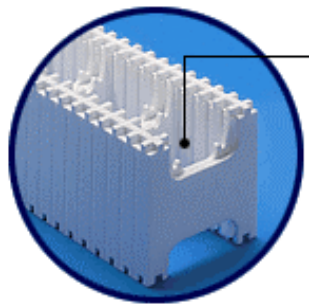
CONCRETE ENVELOPE TECHNOLOGIES

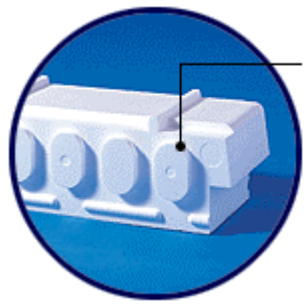
ICF (EPS) - structural elements

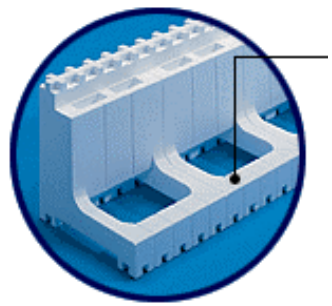
EPS forms for walls, floors & ceilings

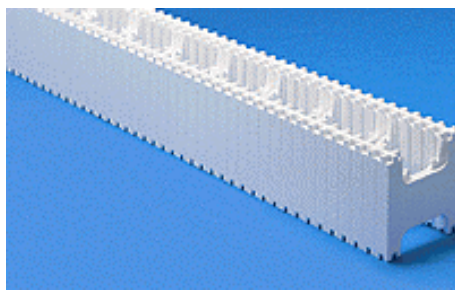
(pre-formed interlocking blocks or separate with plastic ties)











CONCRETE ENVELOPE TECHNOLOGIES

ICF (EPS) - technology

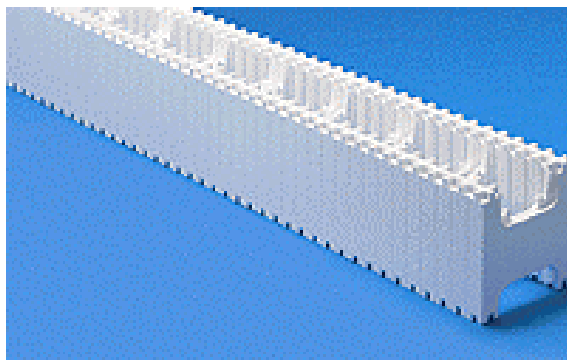
- Not difficult - qualified building crew is not necessary

Well prepared instructions for house builders are available

CONCRETE ENVELOPE TECHNOLOGIES

Thermal properties

ICF (made of EPS) wall



Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/$ Btu	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
1360	85.0	25	9.8	0.07	0.51	3.40	19.3	340	69.7	286	45.1
1133	70.8	30	11.8	0.06	0.43	4.83	27.4	340	69.7	286	45.1

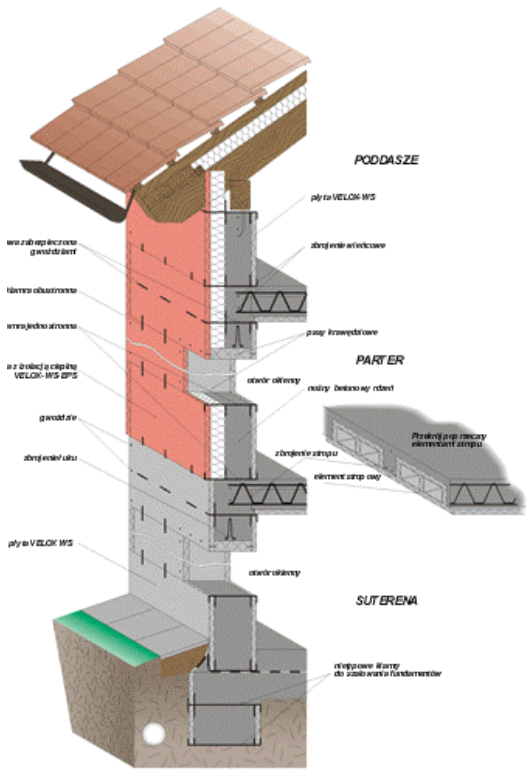
CONCRETE ENVELOPE TECHNOLOGIES

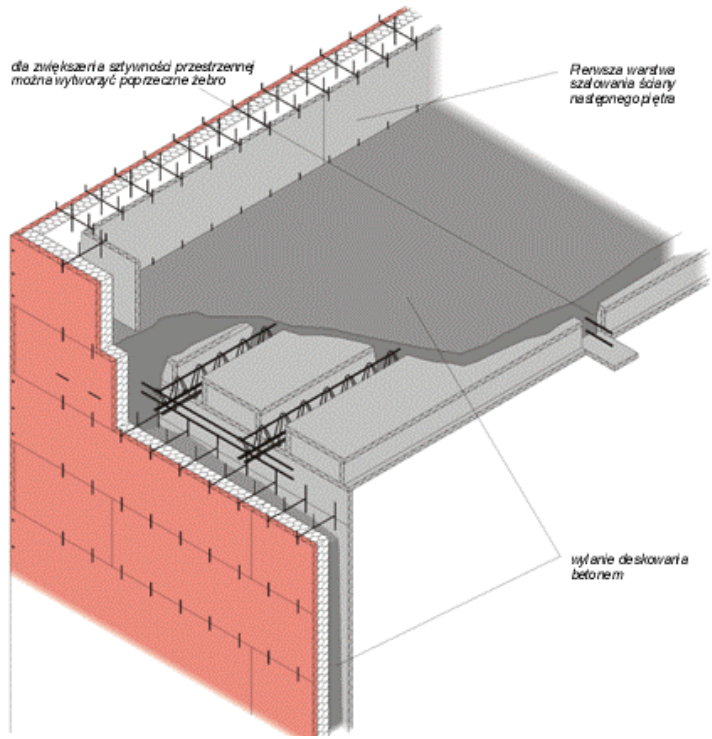
ICF (wood-concrete) - application

- Single family houses, multi-storeyed apartment houses

CONCRETE ENVELOPE TECHNOLOGIES

ICF (wood-concrete) - application



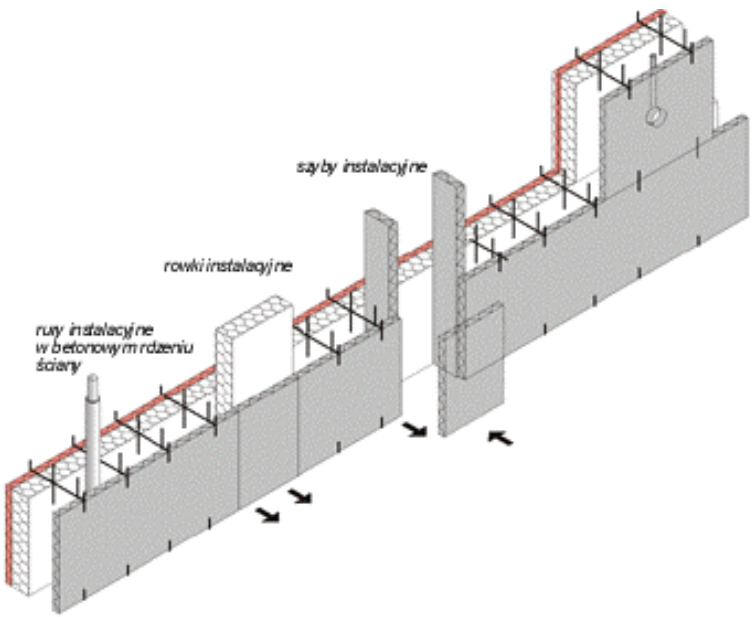


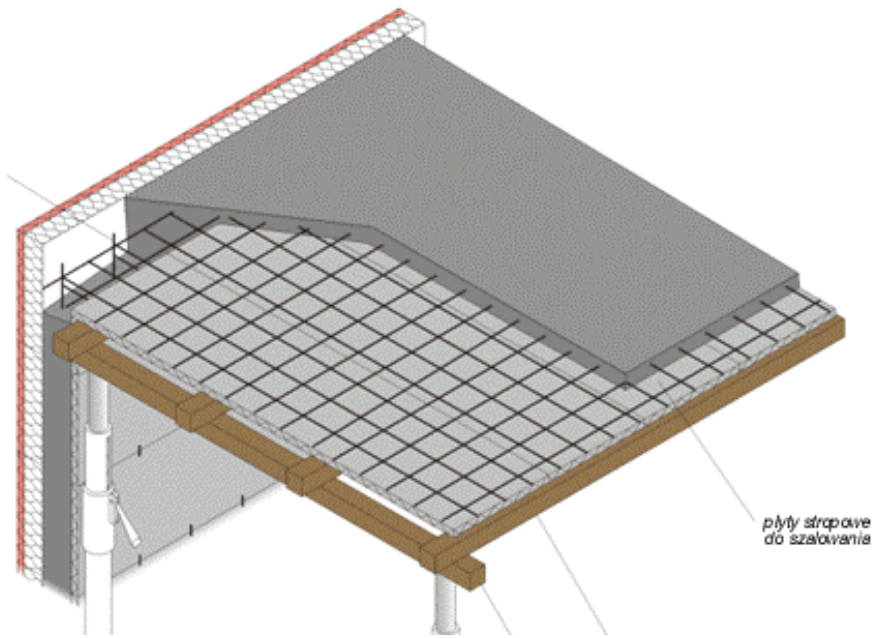
- Load-bearing & non-loadbearing walls, floors and ceilings

CONCRETE ENVELOPE TECHNOLOGIES

ICF (wood-concrete) - application

Multi-layer walls and floors

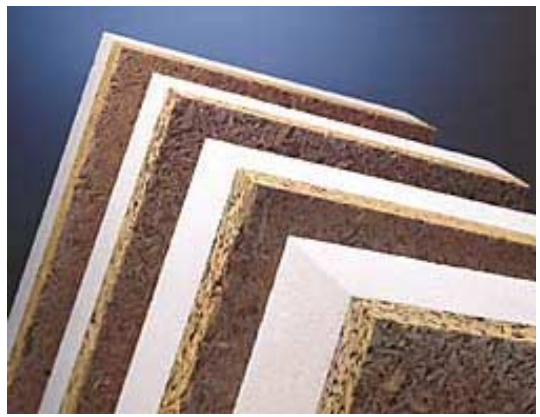


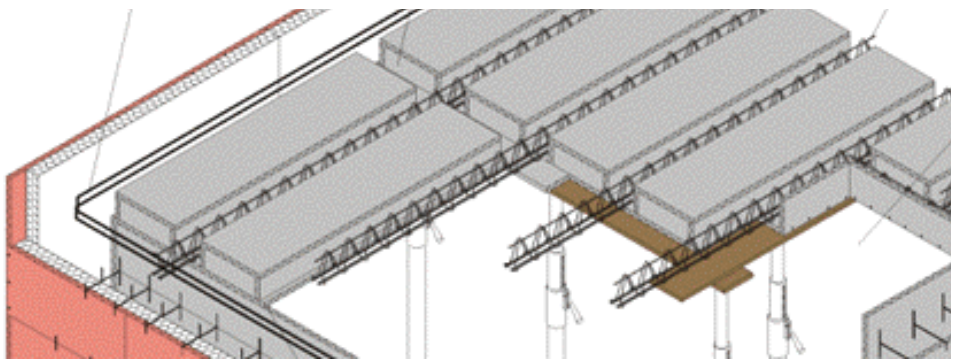


CONCRETE ENVELOPE TECHNOLOGIES

ICF (wood-concrete) - structural elements

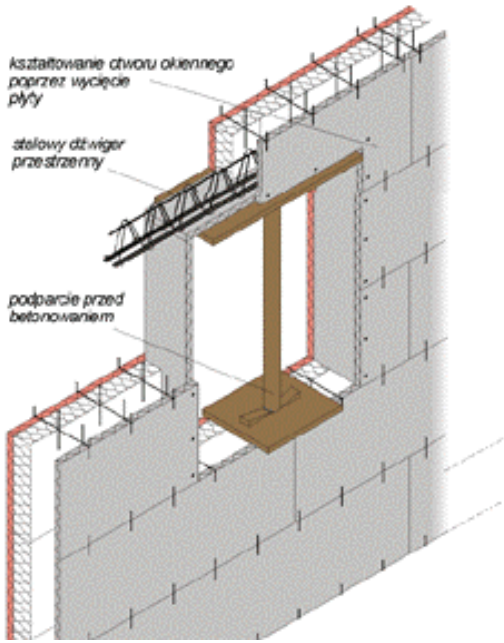
Wood concrete plates & prefabricated floors

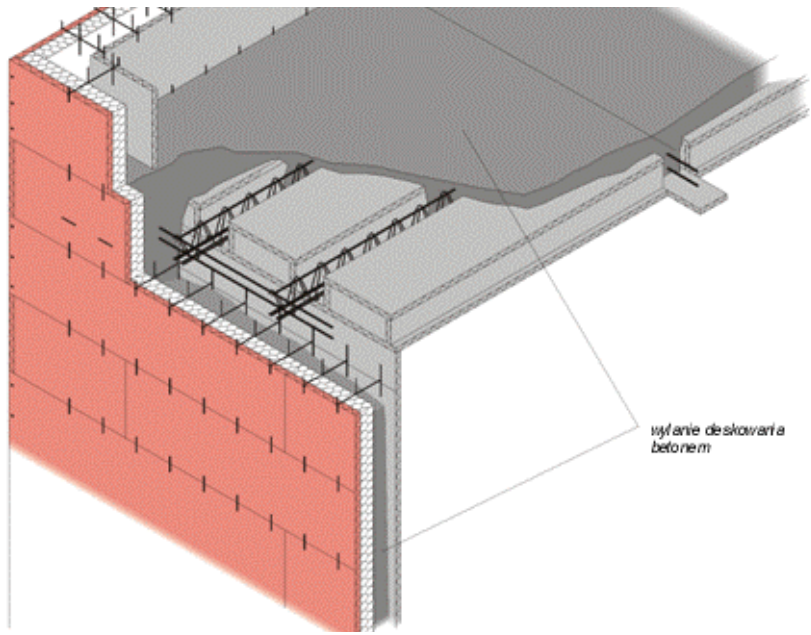




CONCRETE ENVELOPE TECHNOLOGIES

ICF (wood-concrete) - technology

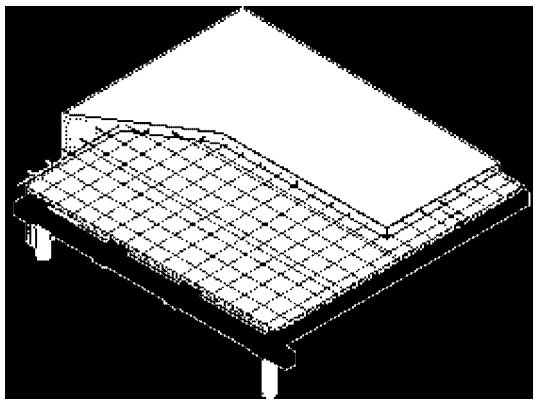


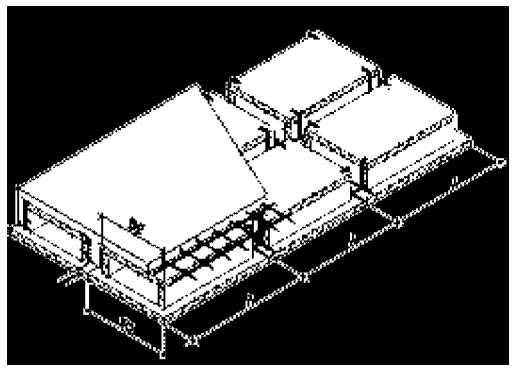


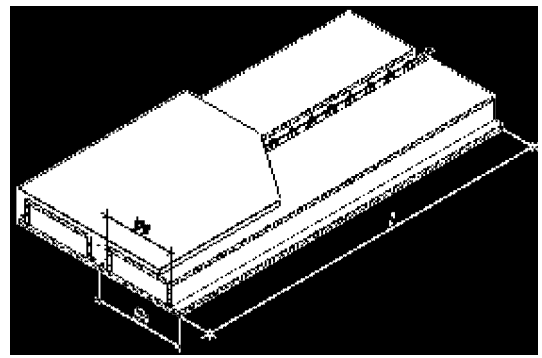
- Difficult - well qualified building crew is necessary

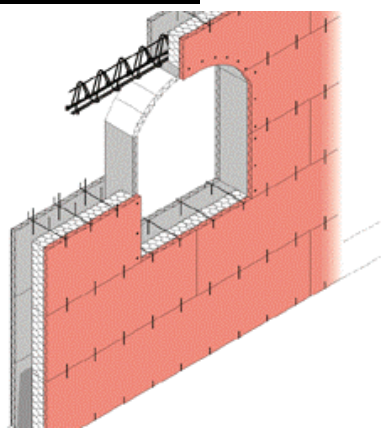
CONCRETE ENVELOPE TECHNOLOGIES

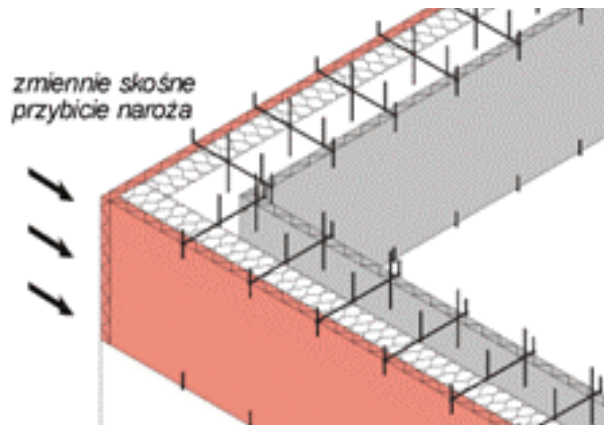
ICF (wood-concrete) - technology









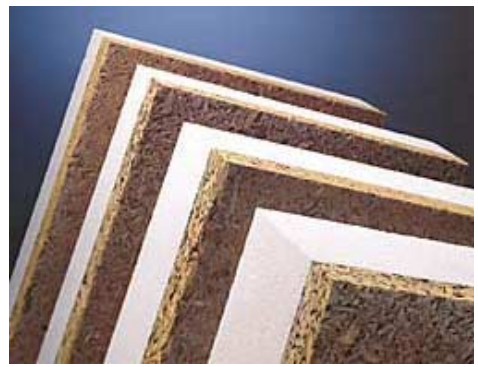


⌘Well prepared instructions for house builders are available

CONCRETE ENVELOPE TECHNOLOGIES

Thermal properties

ICF (wood-concrete) wall

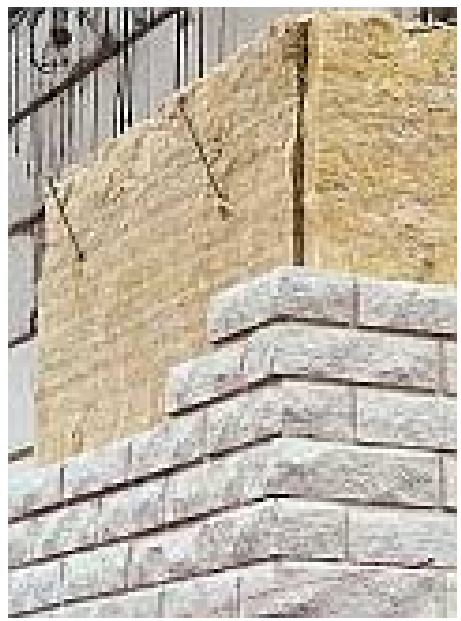


Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m.K)	Btu.in/ ($h^oF.ft^2$)	m^2K/W	$ft^2.h^oF/Btu$	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF.ft^2$)
1636	102.3	22	8.7	0.30	2.09	0.73	4.1	360	73.8	302	47.7
1333#	83.3	27	10.6	0.13	0.92	2.04	11.6	360	73.8	302	47.7
1122*	70.1	32	12.6	0.10	0.69	3.21	18.2	359	73.6	302	47.6

#) with 5 cm EPS layer *) with 10 cm EPS layer

CALCIUM SILICATE ENVELOPE TECHNOLOGIES

Application



- Single family houses, non-loadbearing walls in multi-storeyed apartment houses, commercial & public buildings

CALCIUM SILICATE ENVELOPE TECHNOLOGIES

Application

Load-bearing & non-loadbearing walls and wall facades

CALCIUM SILICATE ENVELOPE TECHNOLOGIES

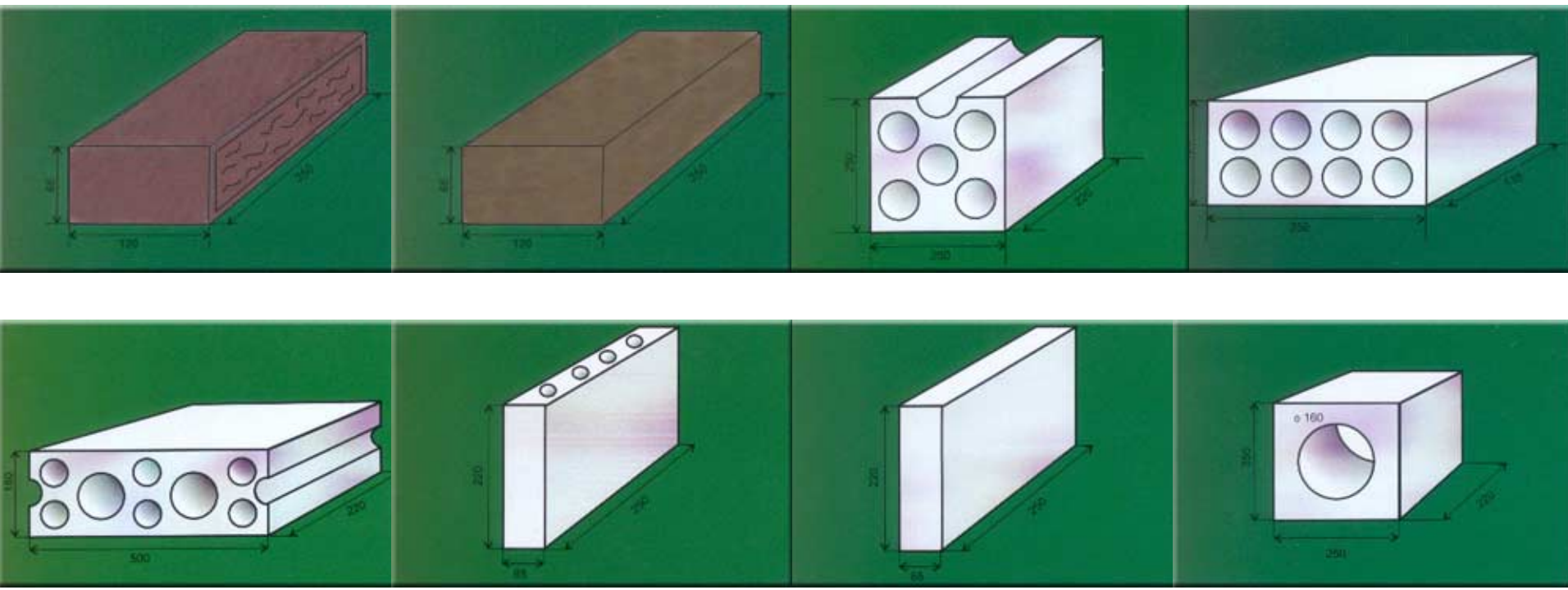
Technology

- Difficult - well qualified building crew is necessary

CALCIUM SILICATE ENVELOPE TECHNOLOGIES

Calcium silicate structural elements

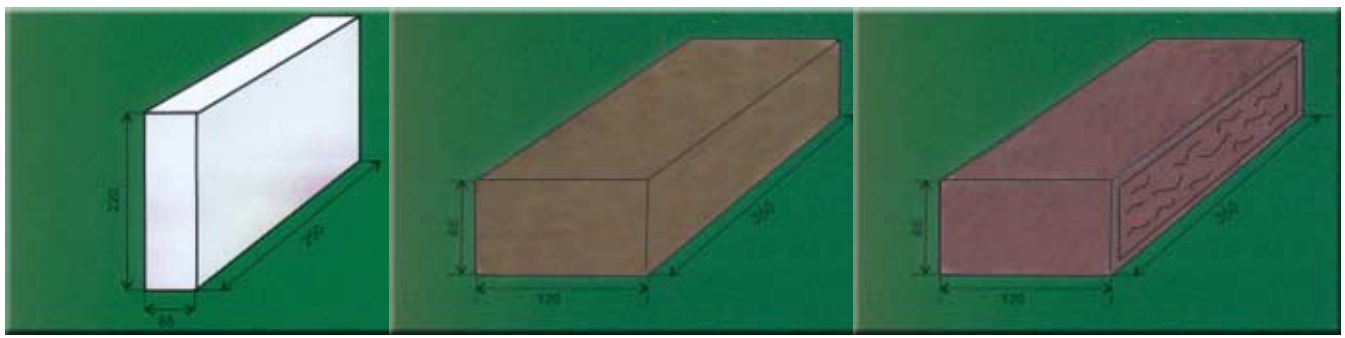
Masonry and face bricks



CALCIUM SILICATE ENVELOPE TECHNOLOGIES

Thermal properties

Calcium silicate wall with normal joints

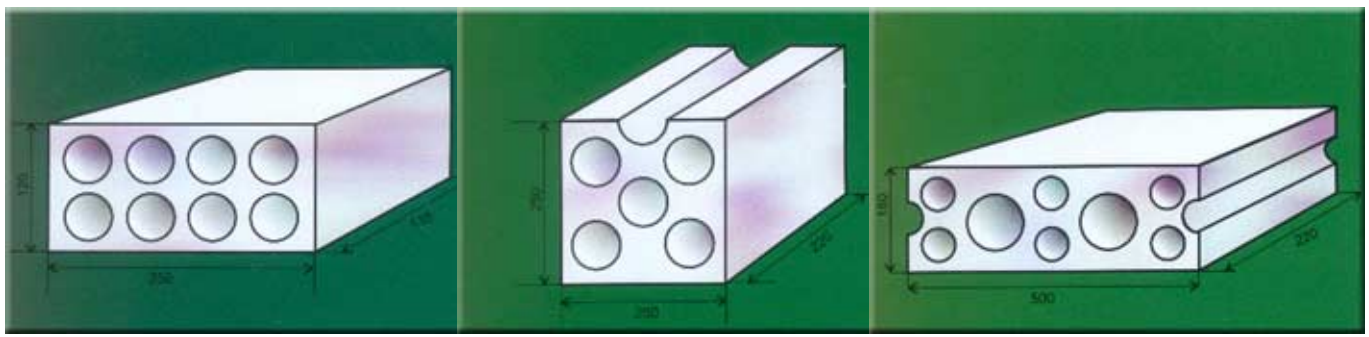


Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/Btu$	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
1900	118.8	12	4.7	1.00	6.94	0.12	0.7	228	46.7	201	31.7
1900	118.8	25	9.8	1.00	6.94	0.25	1.4	475	97.3	418	66.0
1900	118.8	38	15.0	1.00	6.94	0.38	2.2	722	148.0	635	100.3

CALCIUM SILICATE ENVELOPE TECHNOLOGIES

Thermal properties

Calcium silicate wall (hollow bricks) with normal joints



Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ (h°F·ft^2)	m^{2}K/W	ft^2·h°F/ Btu	kg/m^2	lb/ft^2	kJ/ (m^{2}K)	Btu/ (°F·ft^2)
1333	83.3	12	4.7	0.80	5.56	0.15	0.9	160	32.8	141	22.2
1280	80.0	25	9.8	0.80	5.56	0.31	1.8	320	65.6	282	44.5
1200	75.0	18	7.1	0.80	5.56	0.23	1.3	216	44.3	190	30.0

GYPSUM ENVELOPE TECHNOLOGIES

Applications

- Detached and semi-detached single family houses

GYPSUM ENVELOPE TECHNOLOGIES

Application & technology

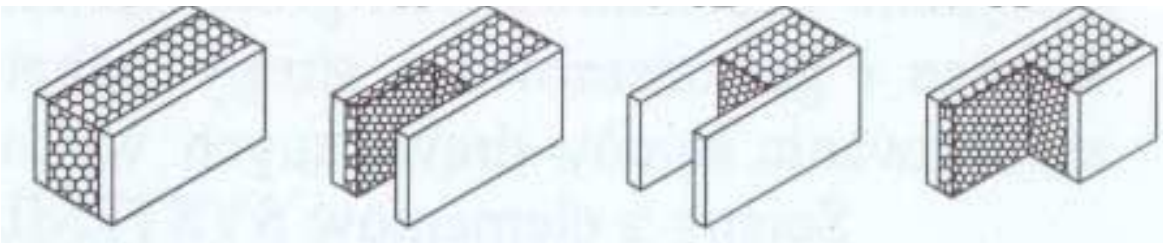
Load-bearing & non-loadbearing walls

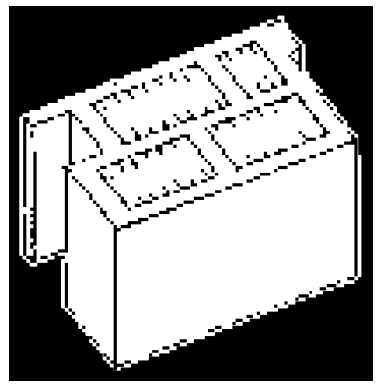
Well prepared instructions for house builders are available

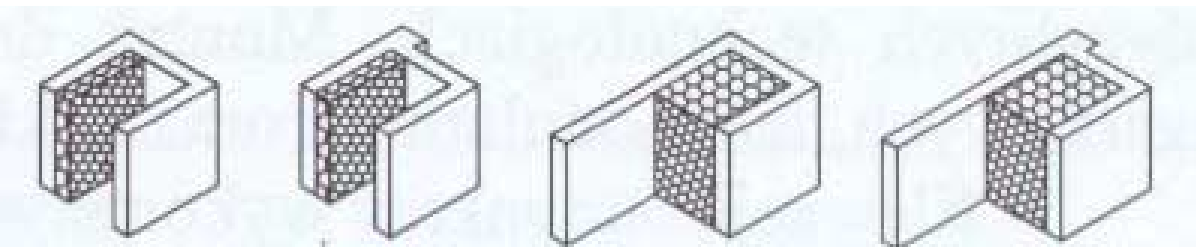
GYPSUM ENVELOPE TECHNOLOGIES

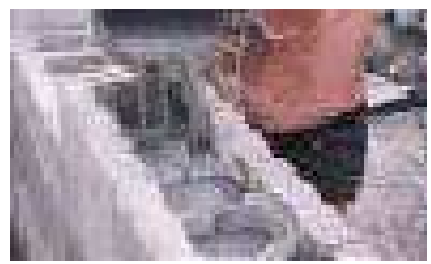
Structural elements

Gypsum Masonry Units (with- & without EPS inserts)





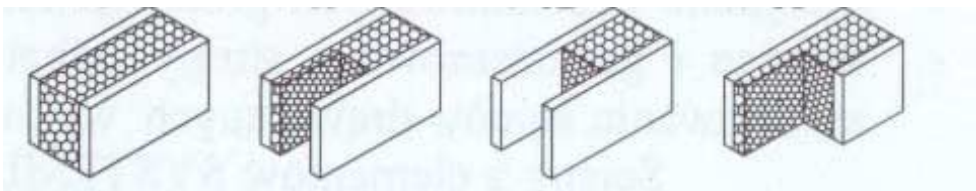




GYPSUM ENVELOPE TECHNOLOGIES

Thermal properties

Gypsum Masonry Unit (GMU) wall

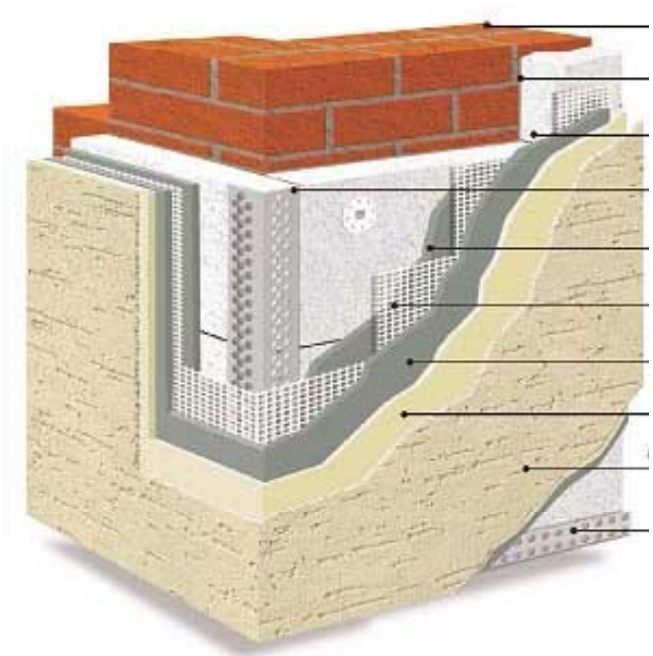


Apparent density		Wall thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m·K)	Btu·in/ ($h^oF·ft^2$)	m^2K/W	$ft^2·h^oF/Btu$	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF·ft^2$)
560	35.0	35	13.8	0.15	1.02	2.39	13.6	196	40.2	165	26.0
560#	35.0	35	13.8	0.10	0.66	3.68	20.9	196	40.2	165	26.0
481*	30.1	30	11.8	0.07	0.50	4.18	23.8	144	29.6	121	19.2
612*	38.3	25	9.8	0.09	0.65	2.69	15.3	153	31.4	129	20.3

#) with gypsum foam insulation *) with EPS inserts

ENVELOPE TECHNOLOGIES

External Insulating Finishing System (EIFS)

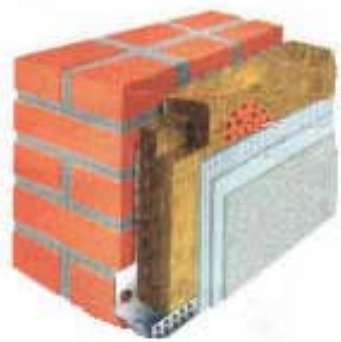


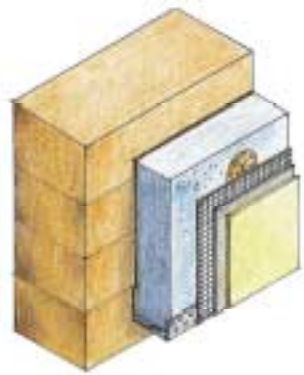
- EPS, XPS or mineral wool as an insulating material
- Insulation thicknes up to 25 cm (10 inches)

ENVELOPE TECHNOLOGIES

Thermal properties

External Insulation Finishing Systems (EIFS)





Apparent density		EIFS thickness		Apparrent conductivity		Thermal resistance		Wall mass per unit area		Thermal capacity per unit area	
kg/m^3	lb/ft^3	cm	inch	W/(m.K)	Btu.in/ ($h^oF.ft^2$)	m^2K/W	$ft^2.h^oF/Btu$	kg/m^2	lb/ft^2	kJ/ (m^2K)	Btu/ ($^oF.ft^2$)
75#	4.7	5.3	2.1	0.04	0.29	1.25	7.1	4	0.8	4	0.6
34#	2.2	20.3	8.0	0.04	0.28	5.00	28.4	7	1.4	8	1.3
167*	10.4	5.4	2.1	0.05	0.32	1.19	6.8	9	1.8	7	1.1
118*	7.4	20.4	8.0	0.04	0.30	4.76	27.0	24	4.9	18	2.9

#) with EPS insulation *) with rock-wool insulation

European concrete and masonry envelope technologies

Conluding remarks

- Dominating role of relatively "heavy" envelope technologies, especially in western, central & southern part of Europe
- Effect of "energy efficiency" & "sustainable development" policy on popularity of various building technologies
- Special shading (roller shades, window shutters) & ventilation strategy in "heavy houses" located in Southern Europe allow to maintain reasonable "thermal comfort" conditions even during hot summer weather
- Local popularity of various lightweight CMUs (slag, sawdust, EPS) and gypsum masonry technologies

European concrete and masonry envelope technologies

Main trends in present European envelope technologies

- increasing requirements of thermal codes & standards
- increasing popularity of hybrid technologies, e.g. concrete floors + brick masonry
- increasing popularity of light porous clay bricks & calcium silicate bricks
- increasing popularity of masonry and concrete walls with EIFS