REPORT

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SIMULATION OF ENERGY AND COST-EFFECTIVENESS FOR A DETACHED SINGLE FAMILY HOUSE BUILT WITH SIPOREX MATERIALS

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SUMMARY

This report describes the service quotation project "Simulation of energy and cost-effectiveness for a detached single family house built with siporex materials," carried out by the King Fahd University of Petroleum & Minerals, Research Institute for LCC-SIPOREX, Riyadh.

The simulation and cost-effectiveness studies were carried out for comparable house designs, but assuming the houses were built with siporex blocks, clay bricks, sandlime bricks, concrete blocks, and prefabricated concrete (all with concrete roof slab), and from siporex materials using the DOE-2.1A computer program.

The total initial costs (wall and roof material + erection + A/C machine) of houses built with walls made of siporex blocks, clay bricks, sandlime bricks, concrete blocks, and prefabricated concrete and roofs from concrete slab are 0.959, 0.950, 0.987, 0.974, and 1.640 times, respectively, of the total initial cost of a house built with ***siporex materials (siporex block and siporex roof slab)***. The annual costs of electric energy for houses built with walls made of siporex blocks, clay bricks, sandlime bricks, concrete blocks, and prefabricated concrete and roofs from concrete slab are 1.678, 2.198, 2.602, 2.608, and 2.717 times, respectively, of a house built of siporex materials. Moreover, the house built with siporex materials (siporex block and siporex roof slab), as compared with the house built with siporex blocks and concrete roof slab, results in reduction of the air-conditioning machine capacity by about 25 percent and consequently reduction in the electric energy consumption by about 23 percent.

The additional cost recovery period for the typical house using siporex materials (siporex block and siporex roof slab) is about 17, 12, 2, and 5 months if the house had been built with walls made of siporex blocks, clay bricks, sandlime bricks, and concrete blocks and roof from concrete slab, respectively. The above additional cost recovery period for siporex materials is much lower than the life span of the typical house. The house built with prefabricated concrete and concrete roof slab, as compared with the house built with siporex materials (siporex block and siporex roof slab), has higher total initial cost and higher electrical energy cost.

In conclusion, the house constructed of siporex materials (siporex block and siporex roof slab) has the lowest thermal conductivity and siporex materials are more cost-effective (based on the assumptions considered) among those building materials used in this study.

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SECTION 1 INTRODUCTION

This is the report of the service quotation project titled ***Simulation of energy and cost-effectiveness for a detached single family house built with siporex materials.***

Buildings in Saudi Arabia consume more than 65 percent of the total electricity generated in the country, out of which 70 percent (45 percent of the total electricity generated) is consumed by their air-conditioning equipment [1,2]. The thermal load attributable to transmission through a building envelope (wall and roof) constitute an appreciable percent of the total [3]. Proper selection of building materials could reduce this transmission load appreciably.

Energy consumption in buildings is a complicated function of several parameters, e.g., weather conditions, thermal characteristics of buildings' envelopes, ventilation load, human behavior, and occupancy level. Other factors are building area and orientation, window area, shading and insulation characteristics. In order to design energy-efficient buildings the above factors need to be investigated at the design stage. This type of study is only possible with the use of computer models. Several computer models are available for the calculation of building cooling and heating loads but few are capable of simulating both buildings and systems, and performing hour-by-hour energy analysis using hourly weather data. The DOE-2.1A [4] program is this comprehensive and is widely used.

The major concerns of this project were to compare siporex materials with other commonly used masonry building materials, Table 1 [5] and Figure 1, from the points of view of electrical energy consumption and cost effectiveness. The DOE-2.1A computer program was used in the present study to calculate the energy consumption for comparable detached single family houses built from these building materials.

SECTION 2 OBJECTIVE

The objective of this work was to carry out energy and cost effectiveness analyses of a detached single family house built with siporex materials as compared to other masonry building materials commonly used in Dhahran, Saudi Arabia. The specific objectives were as follows:

1. Prepare input data for a typical detached single family house.
2. Make computer runs of the DOE-2.1A model.

3. Compare the case of siporex materials (siporex block and siporex roof slab) with siporex blocks, clay bricks, concrete blocks, sandlime bricks and prefabricated concrete wall (all with concrete roof slab), for energy consumption and cost-effectiveness. These materials and corresponding thermal conductivity data are listed below in Table 1.

Table 1. Physical and thermal properties of the building materials [5].
(in metric units)

Type	Description	k (range)	k (average)
Siporex blocks	Solid	0.144	0.144*
Clay bricks	Hollow	0.435 - 0.750	0.550
Sandlime bricks	Hollow	1.097	1.097
Concrete blocks	Hollow	0.96 - 1.389	1.129
Prefabricated Concrete	Solid	1.355	1.355

* For the density of 527 kg/m^3. However, the conductivity of 0.237 W/m.K was also measured for the samples with density of 592 kg/m^3 (which indicates that the high density samples were not dry but had a higher moisture content).

k = Thermal conductivity, W/m.K

SECTION 3 DISCUSSION OF THE WORK

3.1 SIMULATION

In Saudi Arabia, where the environment is hot and in some places hot and humid, thermal properties of building materials are essential factors to be considered in the design of buildings and consequently in the selection of air-conditioning systems. An appropriate selection of masonry building materials can lead to comfortable indoor conditions with minimum energy consumption. The least expensive way of making this kind of comparison is by a computer model.

3.1.1 The DOE-2.1A Computer Program

Models for estimating energy use in residential buildings have been developed since the energy crisis of the early 1970s. Several computer models are available for the calculation of building cooling and heating loads [6-11], but few are capable of

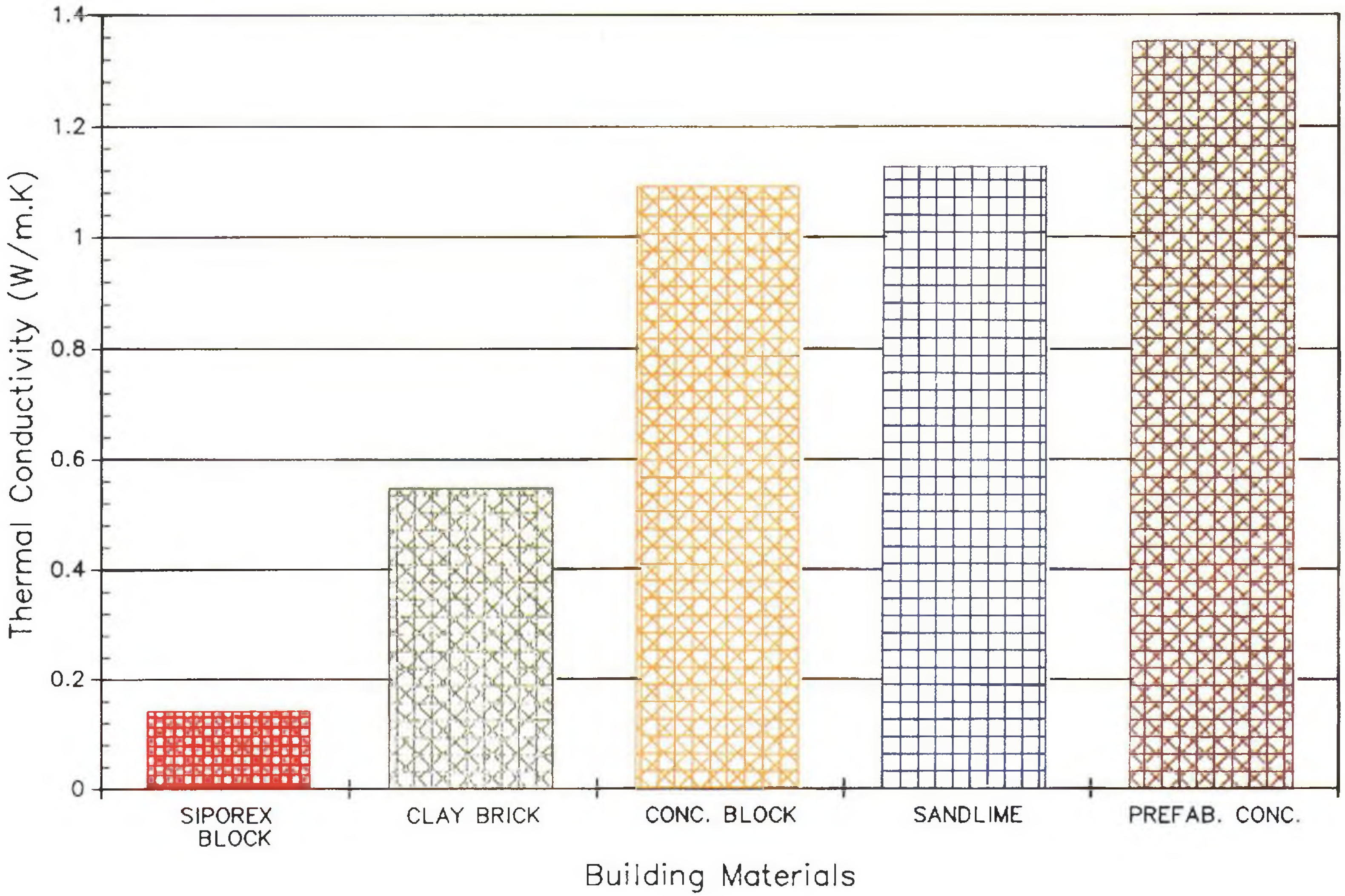


Figure 1. Average thermal conductivities of masonry building materials.

simulating both buildings and systems, and performing hourly energy analysis using hourly weather data. DOE-2.1A is this comprehensive and is a widely used program.

The simulation study was carried out using the DOE-2.1A computer program for a model house. The DOE-2.1A was developed by the Department of Energy in the USA and adapted to Saudi conditions in the Division of Energy Resources at the Research Institute. The DOE-2.1 computer program can simulate a number of energy conservation measures in buildings and it has been widely tested for accuracy. This program has also been validated for accuracy in the Dhahran area and it has shown an accuracy of about 3% on an annual basis and 8% for the cooling season against the measured values [12].

DOE-2.1A comprises one translation and library program which is called the ***Building Description Language (BDL)*** and four simulation subprograms. In addition, it has a utility program called the ***Weather Processor (WP)***, as shown in Figure 2. The ***BDL*** translates the input data into a computer recognizable form. The four simulation subprograms are the ***LOADS*** subprogram, the ***SYSTEMS (or secondary HVAC)*** subprogram, the ***PLANT (or primary HVAC)*** subprogram and the ***ECONOMICS*** analysis subprogram. The ***Weather Processor*** allows the user to transform various standard tapes to the DOE-2 compatible format, to edit the tapes, and to list them. Each of the above subprograms produces a printout of its calculations.

3.1.2 Model House

For the present study, the characteristics of a typical sample building were needed. This building was described in an interim report on KACST Project AR-8-049 [13]. In that study, the data were obtained from three sources:

- Review of building plans with municipal authorities
- Site visits to buildings under construction
- Interviews with owners and contractors

The characteristics of building, system, and operating conditions for this simulated typical house are given in Tables 2 and 3.

Table 2. Characteristics of the building for the simulated typical house.

Characteristics	Description
Orientation	Front elevation facing the east
Plan shape	Rectangular
Number of stories	2
Ceiling height	7.0 m
Floor dimensions	15.0 m × 17.5 m
Gross floor area (2 floors)	525.0 m^2
Gross wall area	455.0 m^2 (including windows)
Window area	13.29 % of Gross wall area
Windows setback	50 mm
Type of glass	Single pane with indoor shading by venetian blinds
External shading devices	None
Solar absorptivities[1] (for exterior surfaces)	0.30 for external walls (painted white) 0.50 for built-up roofing, white
External walls	12.7 mm plaster outside + Masonry unit[2] + 12.7 mm plaster inside
Floor	150 mm slab on grade
Roof	9.53 mm built-up roofing + 150 mm roof slab +12.7 mm plaster
People[3]	6
Lighting[3]	1.5 kW (lower level), 1.0 kW (upper level)
Appliances[3]	1.5 kW (lower level), 0.5 kW (upper level)
Infiltration type[3]	Residential[4]

[1] From DOE2.1A manual.
[2] See Figure 1 for the types of the masonry wall building materials.
[3] See Table 4 for schedules.
[4] Infiltration depend on wind speed and the inside-outside drybulb temperature difference.

Table 3. Characteristics of the air-conditioning system for the simulated typical house.

Characteristics	Description
System type	RESYS (Constant-Volume DX Air-Cooled A/C System with Electric Heating)
Thermostat type	Two-Position with dual (heating and cooling) set point
Thermostat setting	74 ^oF for heating and 76 ^oF for cooling
Minimum supply air temperature*	55 ^oF (average)
COP**	2.17
Ventilation	None
Heating and cooling	Available throughout the year
Weather file	For Dhahran, 1985

* Obtained from Carrier Corporation Catalog No. 525-067 (50TJ-1APD)
** From DOE2.1A manual.

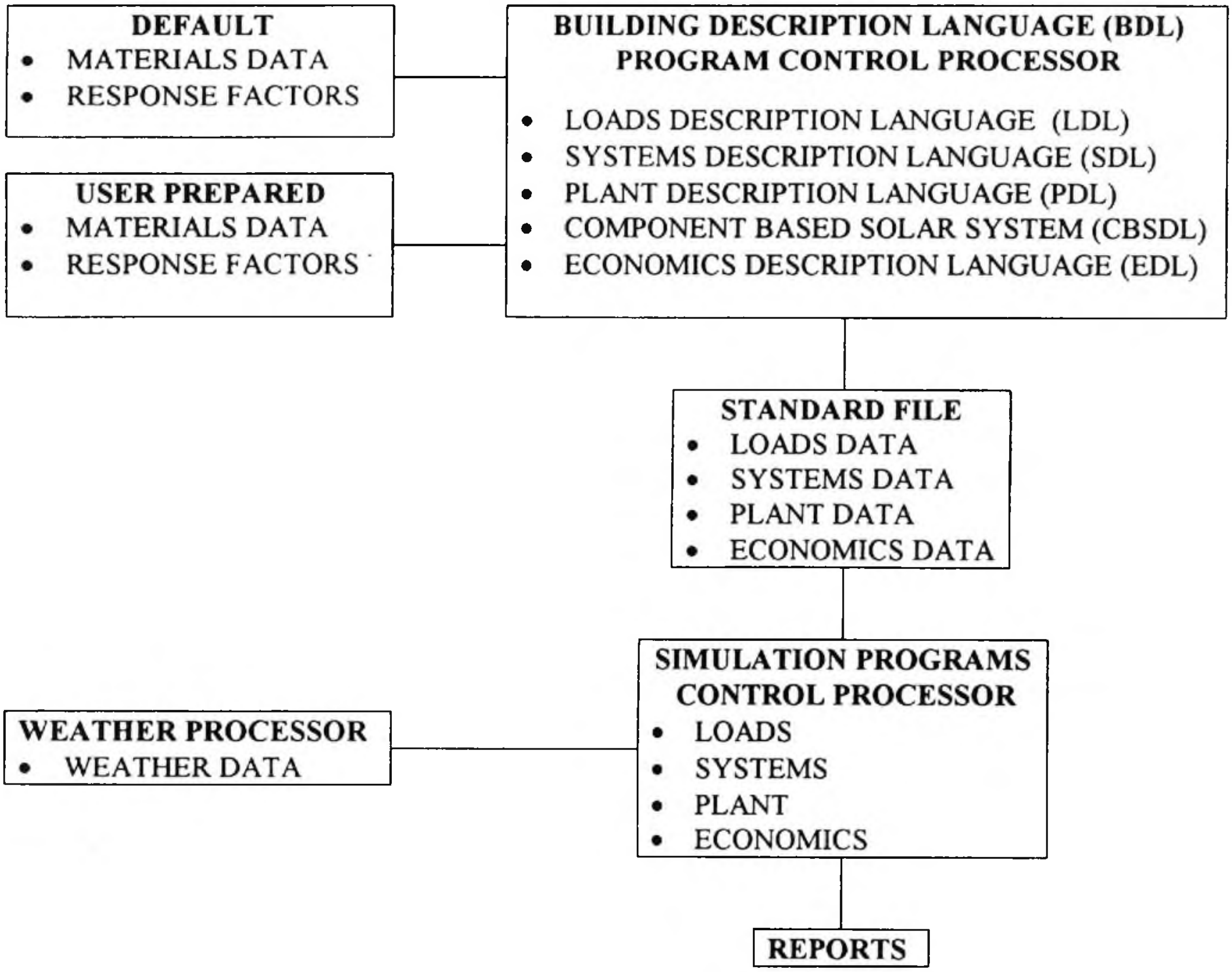


Figure 2. DOE-2.1A computer program configuration.

3.1.3 Input Data

The input data required by the DOE-2.1A computer program are as follows:

- Building envelope geometry, orientation, and dimensions
- Thermal and optical properties of the construction materials
- Air-conditioning system configuration
- Lighting types and distribution
- Schedule of occupancy
- Schedule of systems operation
- Internal loads (occupants, machines, etc.) and
- Hourly weather data for a representative year.

The geometrical dimensions of the typical house are shown in Figure 3. Wall and roof construction is shown in Figure 4. Schedules for occupancy, infiltration, lighting, air-conditioning, and equipment are given in Table 3. The Dhahran weather data file for the year 1985 was used for weather input data. Thermal and physical properties of building materials were taken from Table 1 and Figure 1.

3.2 COST ANALYSIS

The objective of this study was to demonstrate the cost-effectiveness of the model house if it was built of siporex materials (siporex block and siporex roof slab) as compared to other commonly used masonry building materials (i.e., walls made of siporex blocks, clay bricks, sandlime bricks, concrete blocks, and prefabricated concrete and roofs from concrete slab). The comparison is based on initial investment in the structure of the building, the installed air-conditioning system, and the energy consumption as obtained by the DOE-2 computer program. Maintenance cost is not considered.

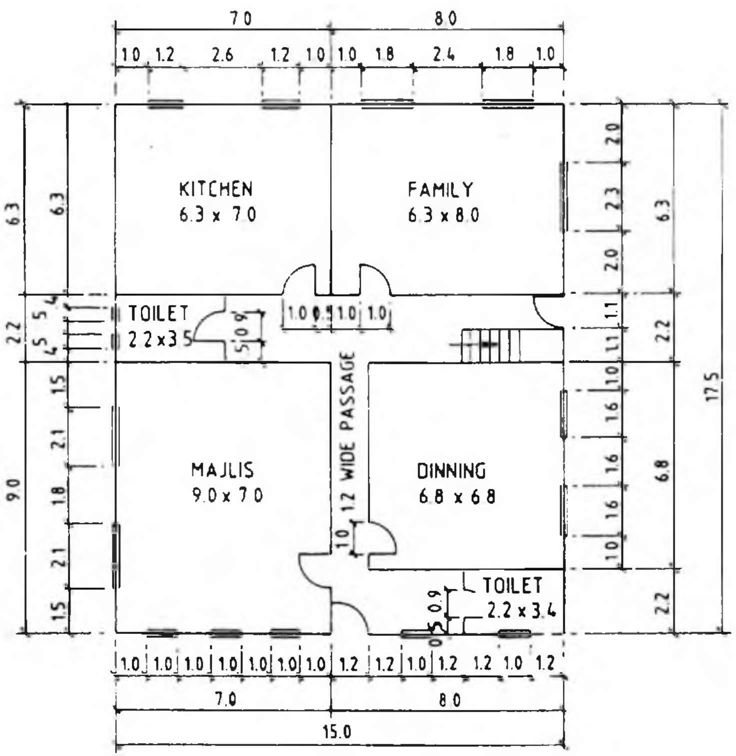
The payback period method was used in this study. The purpose of the payback period is to determine the time to repay an investment. A simple payback period, n, may be calculated as

$$n = P/A$$

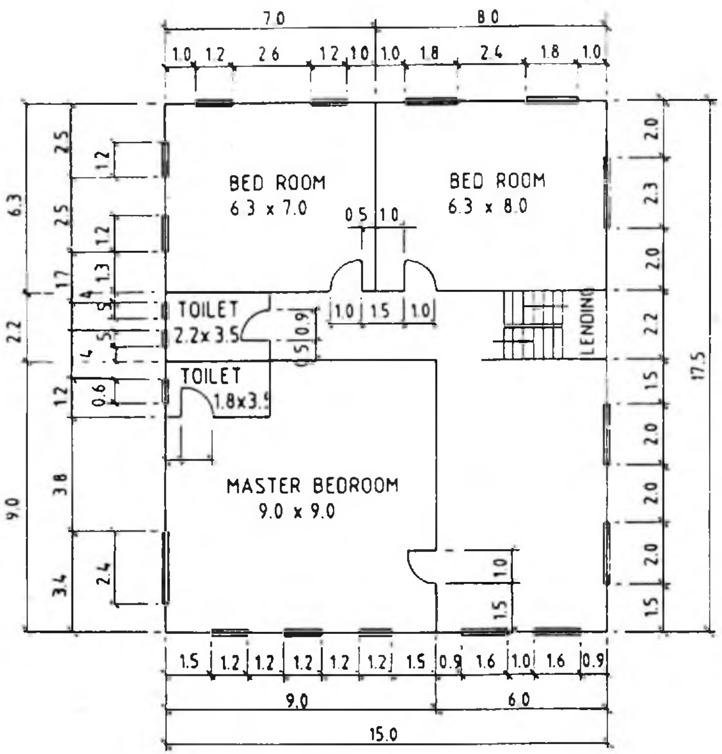
where,

P = difference in initial investment (SR)

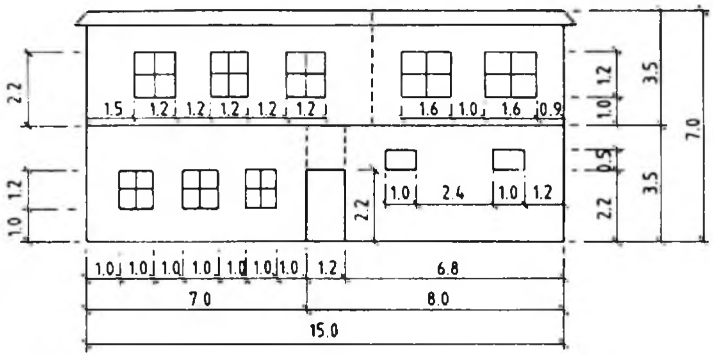
A = the cost of annual energy savings (SR)



GROUND FLOOR PLAN

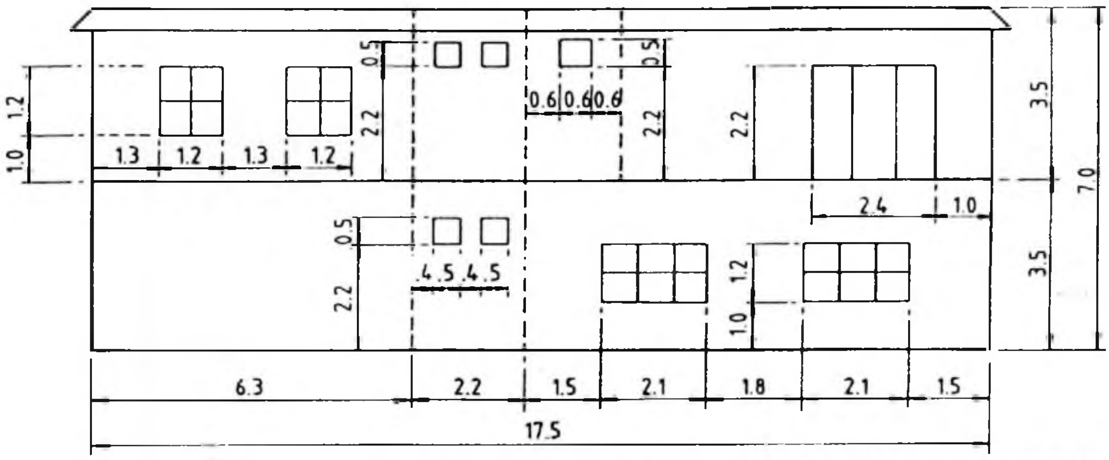


FIRST FLOOR PLAN



FRONT ELEVATION

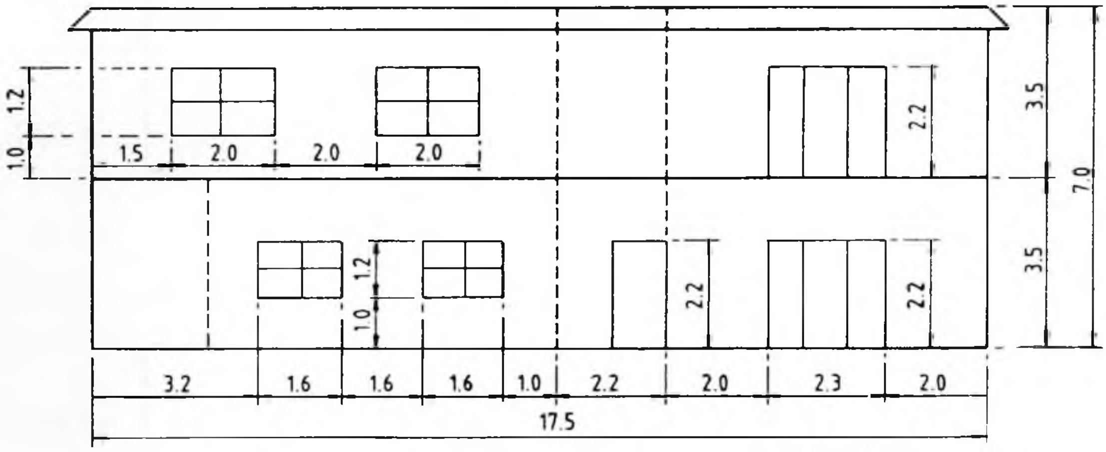
Figure 3a. Typical house: plans and front elevation.



LEFT SIDE ELEVATION

(N.T.S.)

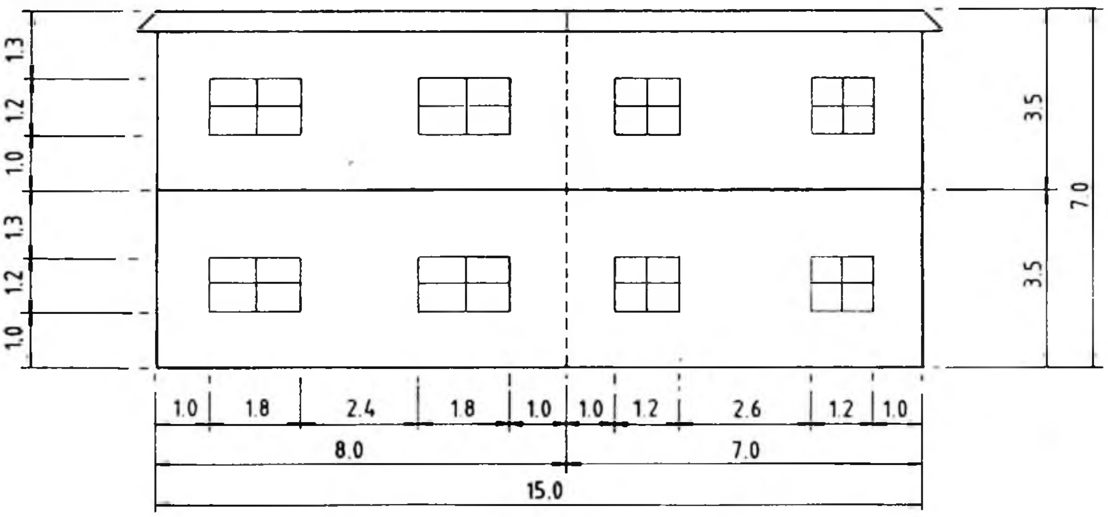
All dimensions are in meters.



RIGHT SIDE ELEVATION

(N.T.S.)

All dimensions are in meters.

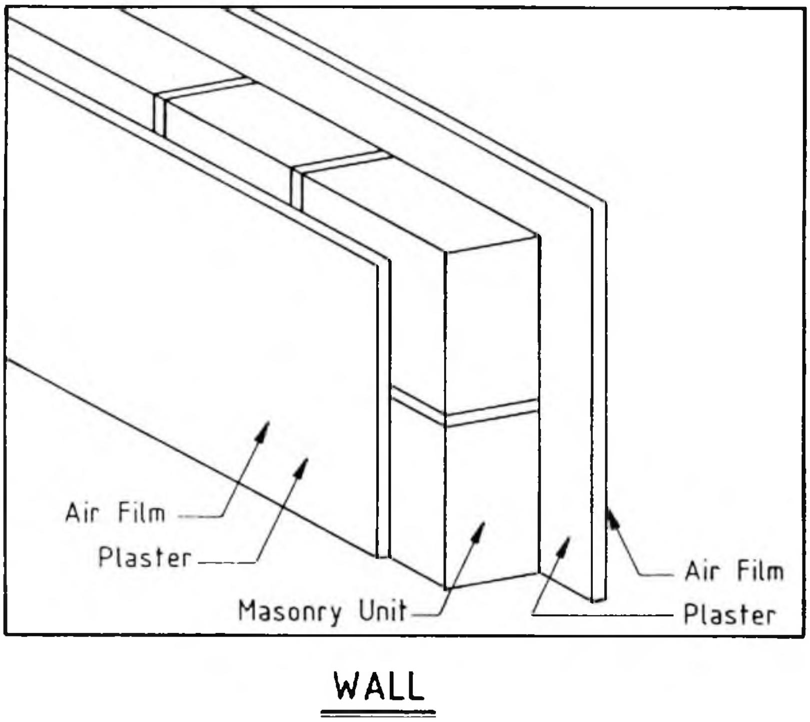


BACK VIEW

(N.T.S.)

All dimensions are in meters.

Figure 3b. Typical house: left side and right elevations and back view.



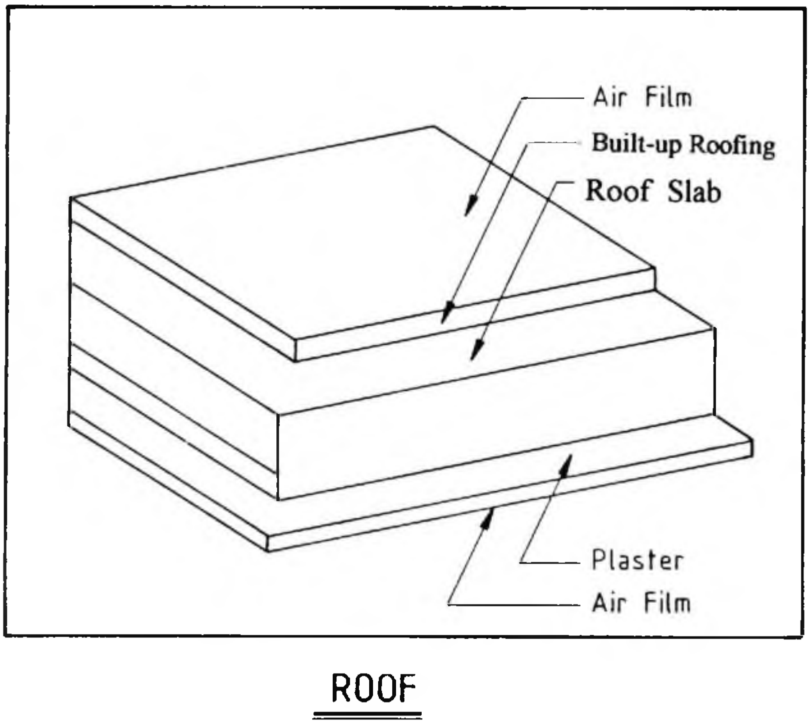


Figure 4. Wall and roof construction.

Table 4. Schedules

	Occupancy Schedule	
OC1-D	= Day-Schedule	Schedule for week-days (1,7)*(1.0)** (8,12)(0.5) (13)(1.0) (14,16)(0.5) (17,19)(1.0) (20,22)(0.8) (23,24)(1.0)
OC2-D	= Day-Schedule	Schedule for week-ends (1,7)(1.0) (8,12)(0.5) (13)(1.0) (14,16)(0.9) (17,20)(0.1) (21,24)(1.0)
OC1-W	= Week-Schedule	(Mon, Wed) OC1-D (Thu, Fri) OC2-D (Sat, Sun) OC1-D (Hol) OC2-D
OC1	= Schedule	Jan 1 Thru Dec 31 OC1-W
	Lighting Schedule	
LT1-D	= Day-Schedule	(1,6)*(0.05)** (7)(0.3) (8,17)(0.1) (18,19)(0.9) (20,22)(0.5) (23,24)(0.05)
LT1-W	= Week-Schedule	(All) LT1-D
LT1	= Schedule	Jan 1 Thru Dec 31 LT1-W
	Equipment Schedule	
EQ1-D	= Day-Schedule	(1,6)*(0.05)** (7)(0.5) (8,17)(0.3) (18,20)(0.6) (21,24)(0.05)
EQ1-W	= Week-Schedule	(All) EQ1-D
EQ1	= Schedule	Jan 1 Thru Dec 31 EQ1-W
	Infiltration Schedule	
INF1	= Schedule	Jan 1 Thru Dec 31 (All) (1,24)*(1)**
	A/C Schedule	
HEAT-1	= Schedule	Jan 1 Thru Dec 31 (All) (1,24)*(74)+
COOL-1	= Schedule	Jan 1 Thru Dec 31 (All) (1,24)(76)

* Hours (for example (1,7) means hours from 1 to 7)
** Fraction (for example (1.0) means 100 percent for the hours shown in *)
\+ Temperature in ^{o}F (for example (74) means $74^{o}F$ temperature for the hours shown in *)

SECTION 4 RESULTS AND DISCUSSION

The required air-conditioning system capacity and energy consumption for the typical house as built with siporex blocks or other commonly used masonry building materials used in Saudi Arabia and with concrete and siporex roof slabs are reported in Tables 5 and 6. The Table 6 shows the annual total electric energy consumption as well as the annual cooling electric energy consumption. Table 7 shows the initial cost of material and the air-conditioning system as well as the annual cost of electric energy. The effect of high thermal resistance of siporex blocks is demonstrated by the lower air-conditioning machine capacity and annual energy consumption reported in Tables 5 and 6. The same results are shown graphically in Figures 5 and 6. Moreover, the house built with ***siporex materials (siporex block and siporex roof slab),*** as compared with the house built with siporex blocks and concrete roof slab, results in reduction of the air-conditioning machine capacity by about 25 percent and consequently reduction in the electric energy consumption by about 23 percent.

The total initial costs of houses built with walls made of siporex blocks, clay bricks, sandlime bricks, concrete blocks, and prefabricated concrete and roofs from concrete slab are 0.959, 0.950, 0.987, 0.974, and 1.640 times, respectively, of a comparable house built of *siporex materials (siporex block and siporex roof slab).* The annual costs of electric energy for houses built with walls made of siporex blocks, clay bricks, sandlime bricks, concrete blocks, and prefabricated concrete and roofs from concrete slab are 1.678, 2.198, 2.602, 2.608, and 2.717 times, respectively, of a comparable house built of siporex materials.

For the payback period calculation, concrete blocks and clay bricks were used as reference for two reasons:

- The general trend in Saudi Arabia is to use concrete blocks and clay bricks.
- The cost of using the concrete blocks and clay bricks is lower than using siporex blocks and panels.

The additional cost recovery period for the typical house using siporex materials (siporex block and siporex roof slab) is about 17, 12, 2, and 5 months if the house had been built with walls made of siporex blocks, clay bricks, sandlime bricks, and concrete blocks, respectively, and roofs from concrete slab, as shown in Table 8. The above additional cost recovery period for siporex materials is much lower than the life span of the typical house. The house built with prefabricated concrete and concrete roof slab,

Table 5. DOE2.1A program designed parameters for Constant-Volume DX Air Cooled A/C Systems (RESYS) with electric heating for different types of building materials[1].

WALL	SPACE	SUPPLY FAN[2]		COOLING CAPACITY[3]	SHR	COP	TOTAL CAPACITY[4] (L+U)	ELECTRIC HEATING LOAD
	Concrete Slab Roof							
		m^3/s (CFM)	kW	kW (kBtu/hr)		kW/kW	kW (Tons)	kW (max.)
Siporex Block	Lower Level (L)	1.071 (2270)	0.829	19.8 (67.4)	0.61	2.17	**58.2**	8.772
	Upper Level (U)	2.251 (4770)	1.741	38.4 (130.9)	0.63		**(16.5)**	21.437
Clay Brick	Lower Level (L)	1.317 (2790)	1.018	23.9 (81.4)	0.61	2.17	**66.8**	11.605
	Upper Level (U)	2.530 (5360)	1.956	42.9 (146.4)	0.63		**(19.0)**	24.650
Sandlime Brick	Lower Level (L)	1.529 (3240)	1.183	27.4 (93.4)	0.62	2.17	**73.9**	14.260
	Upper Level (U)	2.751 (5830)	2.128	46.5 (158.8)	0.64		**(21.0)**	27.330
Concrete Block	Lower Level (L)	1.520 (3220)	1.175	27.2 (92.9)	0.62	2.17	**73.4**	14.081
	Upper Level (U)	2.733 (5790)	2.113	46.2 (157.7)	0.63		**(20.9)**	27.164
Prefabricated Concrete	Lower Level (L)	1.576 (3340)	1.219	28.2 (96.1)	0.62	2.17	**75.3**	14.784
	Upper Level (U)	2.789 (5910)	2.157	47.1 (160.9)	0.64		**(21.4)**	27.872
	Siporex Slab Roof[5]							
Siporex Block	Lower Level (L)	1.071 (2270)	0.829	19.5 (66.4)	0.61	2.17	**43.8**	9.034
	Upper Level (U)	1.364 (2890)	1.055	24.3 (82.8)	0.62		**(12.4)**	13.019

[1] Based on the parameters assumed in the tables 1, 2, 3, and 4 and thickness of all wall materials and roof slabs is taken as 200 mm and 150 mm, respectively.
[2] Maximum fan electric load in kW.
[3] At ARI design point (80 F db, 67 F wb indoor entering-air temperature and 95 F db air entering outdoor unit).
[4] For both the levels (upper level + lower level).
[5] k-value for the roof slab was taken as 0.144 W/m.K (provided by the client).

Table 6. Annual electric energy consumption obtained by DOE2.1A program for different types of building materials[1].

WALL	Concrete Slab Roof				
	SPACE	ANNUAL ELECTRIC ENERGY CONSUMPTION (kWh)			
		COOLING[2]	HEATING	APPLIANCES + LIGHTING	TOTAL[3]
Siporex Block	Lower Level (L)	25588	3406	5908	34902
	Upper Level (U)	48585	13896	2883	65364
	L+U	**74173**	**17302**	**8791**	**100,266**
Clay Brick	Lower Level (L)	31427	6305	5908	43640
	Upper Level (U)	54409	17021	2883	74313
	L+U	**85836**	**23326**	**8791**	**117,953**
Sandlime Brick	Lower Level (L)	35950	8666	5908	50524
	Upper Level (U)	58845	19461	2883	81189
	L+U	**94795**	**28127**	**8791**	**131,713**
Concrete Block	Lower Level (L)	36032	8721	5908	50661
	Upper Level (U)	58852	19497	2883	81232
	L+U	**94884**	**28218**	**8791**	**131,893**
Prefabricated Concrete	Lower Level (L)	37255	9372	5908	52535
	Upper Level (U)	60037	20156	2883	83076
	L+U	**97292**	**29528**	**8791**	**135,611**
	Siporex Slab Roof[4]				
Siporex Block	Lower Level (L)	26258	3734	5908	35900
	Upper Level (U)	31948	6485	2883	41316
	L+U	**58206**	**10219**	**8791**	**77,216**

1 Based on the parameters assumed in the tables 1, 2, 3, and 4 and thickness of all wall materials and roof slabs is taken as 200 mm and 150 mm, respectively.
2 Include supply fan energy.
3 Sum of the cooling, heating, and lighting & appliances electric energy consumption.
4 k-value for the roof slab was taken as 0.144 W/m.K (provided by the client).

Table 7. Comparison of initial investment and energy costs (SR) for different types of building materials.

Wall Materials[1]	Concrete Slab Roof			
	Material Cost[2]	Machine Cost[3]	Total Initial Cost	Annual Energy Cost[4]
Siporex Block	82,980	33,000	115,980	8,560
Clay Brick	76,875	38,000	114,875	11,213
Sandlime Brick	77,338	42,000	119,338	13,277
Concrete Block	75,950	41,800	117,750	13,304
Prefab. Concrete	155,500	42,800	198,300	13,862
	Siporex Slab Roof			
Siporex Block	96,105	24,800	120,905	5,102

[1] Thickness of all wall materials and roof slabs is taken as 200 mm and 150 mm respectively.
[2] Cost is considered for external wall net surface area (excluding windows, doors, and roof slabs areas) and two roof slabs only and the rates (ex-factory price plus erection cost) of the different types of building materials are provided by the client (see Appendix A).
[3] Cost for air-conditioning system is taken as SR 2000/ton (obtained from RI/KFUPM report PN 22037) and maintenance cost is not considered.
[4] Electric energy rate (on annual basis) is taken as, for first 48000 units as 0.05 SR/kWh, from 48001 to 72000 units as 0.08 SR/kWh, and from 72001 units onwards as 0.15 SR/kWh (obtained from the report of Ministry of Industry and Electricity, 1992).

Table 8. Cost-effectiveness of siporex materials[1] as compared to other building materials

Concrete Slab Roof			Siporex Wall and Siporex Slab Roof Total Initial Cost = SR 120,905 Annual Energy Cost = SR 5,102		
Wall Materials	Total Initial Cost (SR)	Annual Energy Cost (SR)	Incremental Investment, P (SR)	Energy Savings, A (SR)	Payback Period (months[2])
Siporex Block	115,980	8,560	4,925	3,458	17
Clay Brick	114,875	11,213	6,030	6,111	12
Sandlime Brick	119,338	13,277	1,567	8,175	2
Concrete Block	117,750	13,304	3,155	8,202	5
Prefab. Conc. Wall	198,300	13,862	Cost-effective		

[1] Siporex block and siporex roof slab.
[2] Approximated to the whole number.

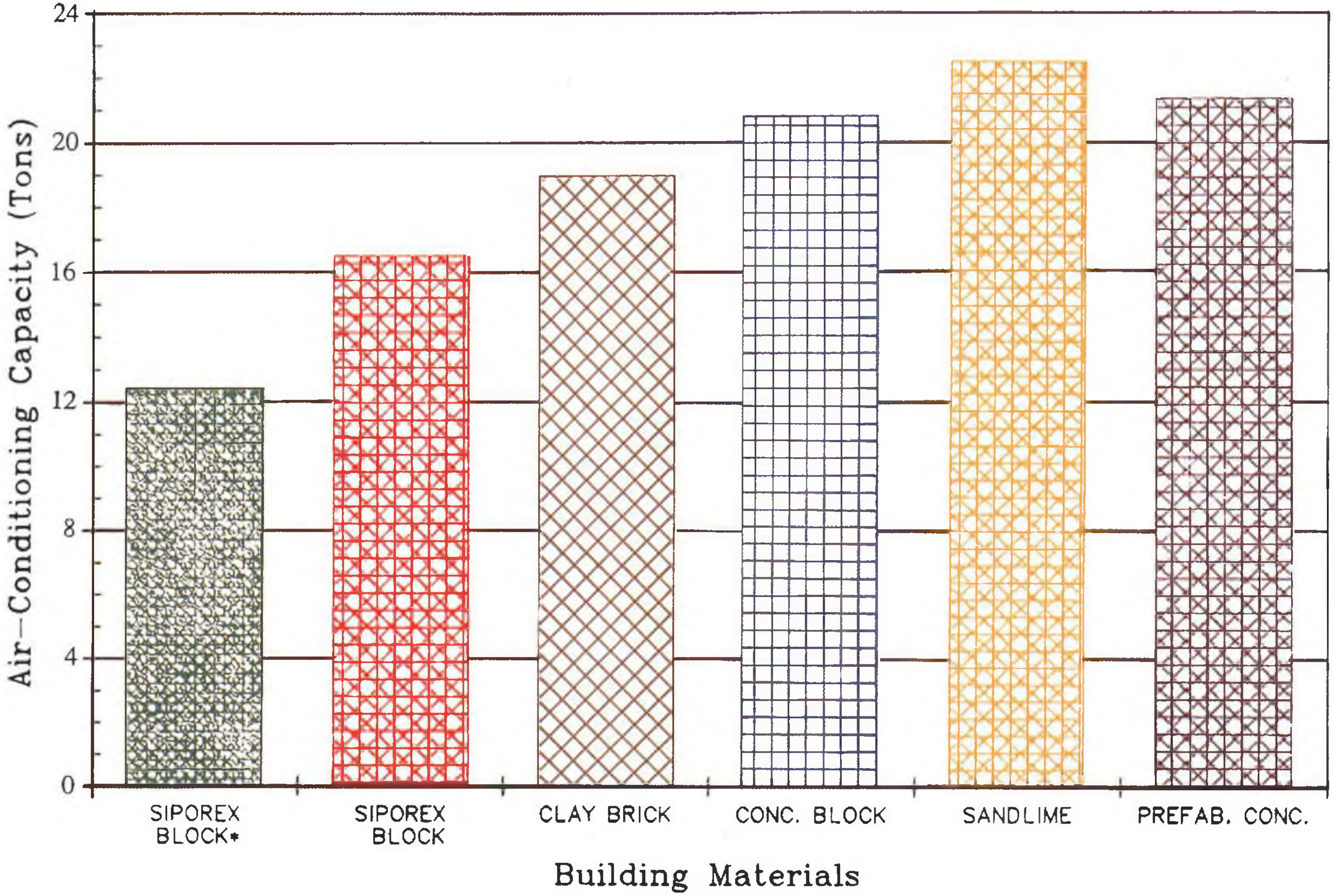


Figure 5. Capacity of air-conditioning systems for different wall materials.

* For siporex slab roof and other cases are for the concrete slab roof.

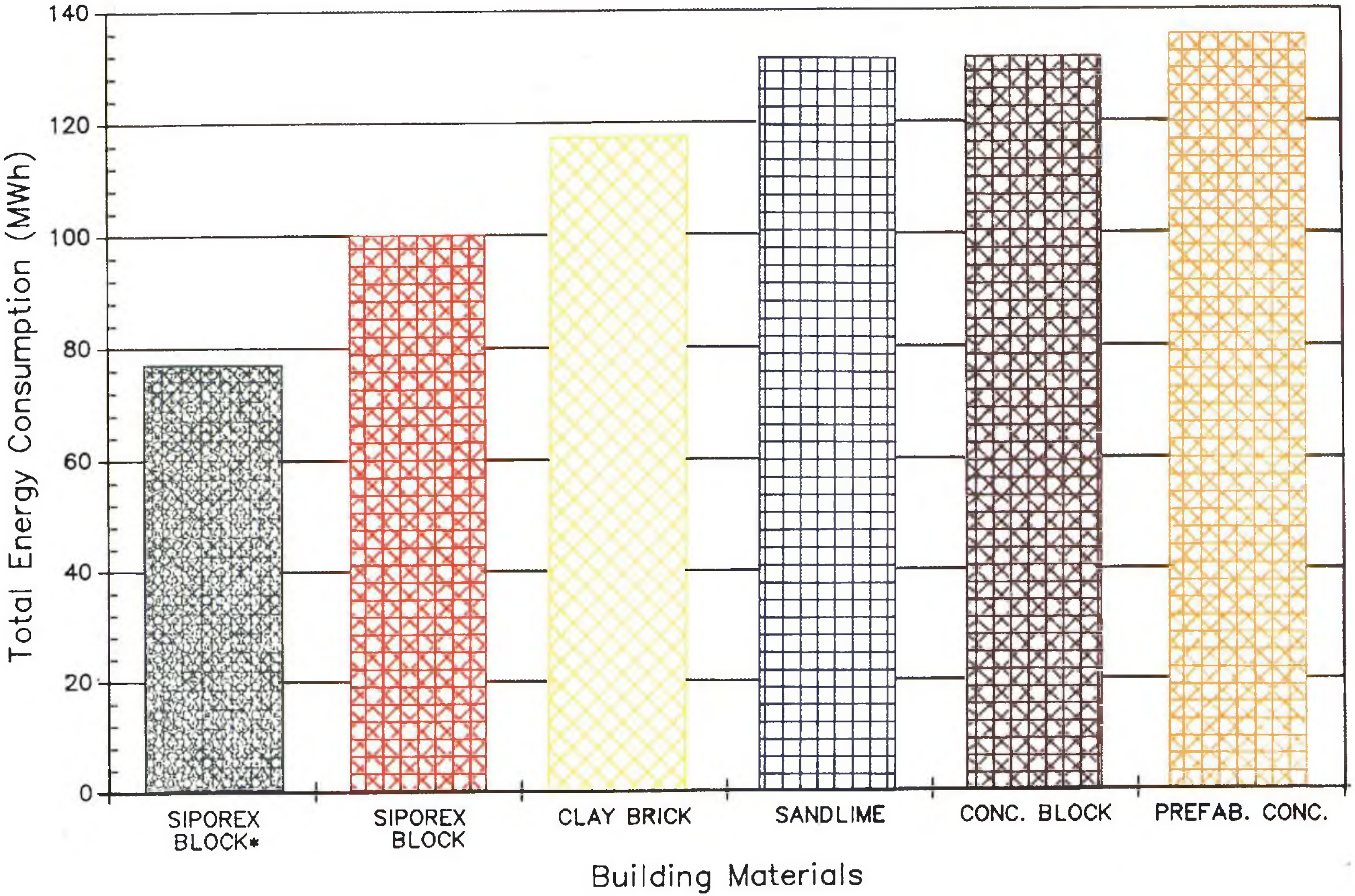


Figure 6. Total electric energy consumption for different wall materials.

* For siporex slab roof and other cases are for the concrete slab roof.

as compared with the house built with siporex materials (siporex block and siporex roof slab), has higher total initial cost and higher electrical energy cost.

SECTION 5 CONCLUSION

In conclusion, the house constructed of siporex materials (siporex block and siporex roof slab) has the lowest thermal conductivity and siporex materials are more cost-effective (based on the assumptions considered) among those building materials used in this study.

SECTION 6 REFERENCES

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