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Advanced Solar Low-Energy Buildings—Danish Work within IEA Task 13

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ABSTRACT

This paper describes the Danish contribution to the International Energy Agency's Task 13, Advanced Solar Low-Energy Buildings. Two low-energy houses have been designed as rowhouses, each approximately 1,075 ft² (100 m²) in size. Since window orientation is important for energy consumption but a south orientation is not always possible, one building has been designed with east/west-facing facades while the other has north/south-facing facades. The main goal of both designs is to attain an energy consumption for space heating lower than 5,120 kBtu/yr (1,500 kWh/yr) at approximately 3,000 base 62.6°F (17°C) degree-days.

Results of parametric studies of strategies to obtain the goal will be presented. The calculations were performed with the Danish PC-based building simulation program TSBI3. Some studies of an active solar system were performed with a modular simulation program for thermal systems. Two-dimensional analyses of construction details were also done but are not presented here.

INTRODUCTION

The Objective of Task 13

The objective of Task 13 of the International Energy Agency (IEA) is "to advance solar building technologies through identification, development, and testing of new and innovative concepts which have the potential for eliminating or minimizing the use of purchased energy in residential buildings while maintaining acceptable comfort levels."

In order to accomplish the objective, the task is organized in three subtasks: (a) development and evaluation of concepts, (b) testing and data analysis, and (c) documentation. As part of subtask (a), parametric studies were carried out and some results are presented in this paper.

Danish Goals

The chief aim of the Danish program during the four years of work within IEA Task 13 is to design and build a detached/semi-detached "zero energy" house (Saxhof et al. 1990).

This was interpreted as a semi-detached single-family house of approximately 1,075 ft² (100 m²) area with a total energy consumption of 20,500 kBtu/year (6,000 kWh/year) or less, including a maximum of only 3,410-5,120 kBtu/year (1,000-1,500 kWh/year) for space heating, the rest being for domestic hot water, lighting, and appliances. The energy consumption for space heating in a normal Danish detached single-family house is approximately 34,000 kBtu/year (10,000 kWh/year).

The Danish team decided to study rowhouse dwellings with both north-south and east-west orientations. The houses with east- and west-facing facades are the most interesting as they offer a real challenge. However, it is important to study this unfavorable orientation because a large number of building sites do not offer the possibility of building south-facing rowhouses. The design and construction principles are easily transferable to other building types, e.g., detached single-family houses or small apartment buildings.

The aim is to integrate energy conservation concepts in the whole building design so that energy considerations are included with other architectural considerations.

Simulations

The topics examined by the Danish team include sensitivity studies of improved windows, transparent/translucent insulation, roof space collectors, integrated ventilation and heating systems, and comfort control strategies.

Simulation Tools The first parametric studies of different house concepts were done with a PC-based simulation program (Johnsen et al. 1991). Some studies of an active solar system were conducted with a modular simulation program for thermal systems (Dutré 1991). This paper includes some preliminary results. Two-dimensional analyses of selected building constructions also were carried out to investigate the influence of different designs on the thermal behavior of the house. These studies used a computer program developed primarily to evaluate the thermal performance of window frame systems (EE 1991).

Assumptions The following calculations did not take into account the fact that part of the south facades possibly will be solar walls, which may reduce the heating demand by approximately 1,700 kBtu/year (500 kWh/year). It was assumed that an active solar system will supply most of the heating for domestic hot water and supplement the heating

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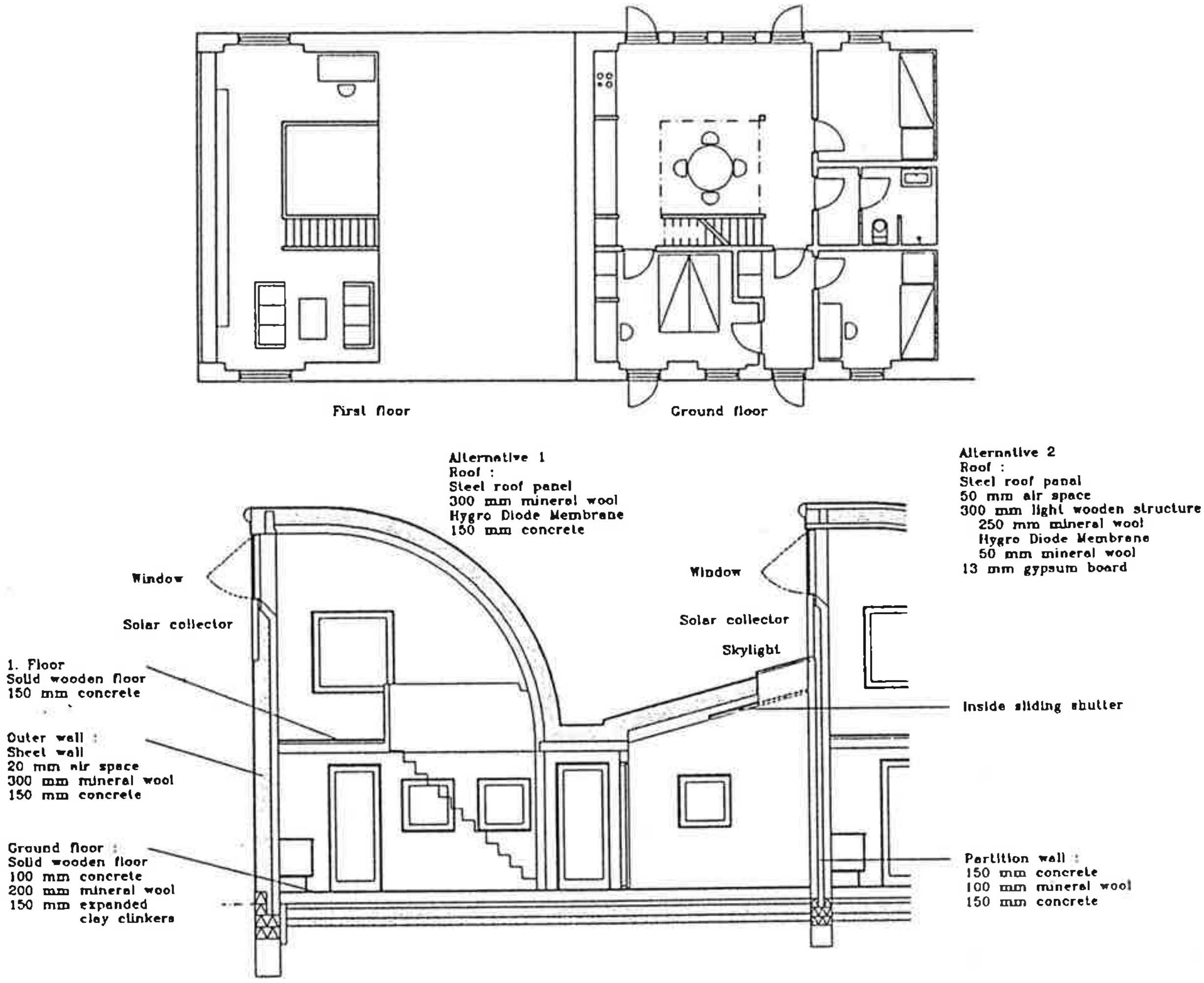


Figure 1 Plans and cross section of rowhouse with east/west-facing facades.

demand. For outdoor climatic data, the Danish Test Reference Year (TRY) was used, including the following parameters: outside dry-bulb temperature, wind speed, relative humidity, direct and global radiation, and the cloud cover index.

LOW-ENERGY HOUSE WITH EAST/WEST-FACING FACADES

House Description

The basic house is a two-story rowhouse built slab on ground. The total area is approximately 1,130 ft^2 (105 m^2). The plans and cross sections are shown in Figure 1. The heated volume of the house is 9,650 ft^3 (273 m^3).

The windows areas are as follows:

East	32.0 ft^2	3.0 m^2
West	40.7 ft^2	3.8 m^2
South	99.5 ft^2	9.2 m^2
Skylight	64.4 ft^2	6.0 m^2

The total window area is approximately 237 ft^2 (22 m^2) corresponding to 21% of the floor area, a relatively high percentage, since the maximum percentage in the Danish Building Code (*BR-82* 1983) is 15% in reference to double glazing.

Discussion of Architectural Design

The two houses were designed by Professor Boje Lundgaard of the Royal Academy of Fine Arts, Danish School of Architecture. Each apartment is partly two-story with the rooms facing either east or west. The corresponding window area is kept fairly small for obvious energy conservation reasons.

In order to utilize solar gains, the building has a continuous quarter-circular roof construction that allows for south-facing windows, which also give direct sunlight to the main rooms, i.e., the central open kitchen and the deck on the first floor (first being above ground level). Through this, untraditional rooms and light effects are achieved, as well as substantial solar gains, in spite of the building orientation. The vertical part of the arched roof construction also has room for a traverse array of solar collectors under the windows.

The dwelling contains traditional as well as more experimental room configurations. The apparently windowless bathroom gets daylight from a small skylight sloping to the south.

PARAMETRIC STUDIES, EAST/WEST-FACING LOW-ENERGY ROWHOUSE

Base Case

In the base case, calculations were carried out for a unit with a neighboring unit on each side. The house was divided into three zones. The base case has the following U-values:

U-values:	Btu/(h·ft²·°F)	W/(m²·K)
Walls (east and west)	0.019	0.11
Wall south	0.025	0.14
Roof with concrete inside (No. 1)	0.019	0.11
Roof with gypsum inside (No. 2)	0.023	0.13
Roof hall	0.030	0.17
Floor, exposed to ambient	0.018	0.10
Floor, ground contact	0.021	0.12
Partition wall, 100 mm concrete	0.546	3.10
Partition wall, 150 mm concrete	0.498	2.83
Wall to neighbors	0.285	1.62
Deck	0.269	1.53
Window glazing	0.176	1.00
Window frame	0.282	1.60
External doors	0.246	1.40

The following assumptions for the simulations were made: The transmittance of the window is 0.5. The ventilation rate is 0.5 ach with a heat recovery of 60%. The rooms are heated to 68°F (20°C) in most cases for the heating season (October to April). At night (from 10 p.m. to 5 a.m.), the heating system is turned off. All areas are calculated according to Danish Standard DS-418 (DSCCEME 1986). Generally speaking, internal measures are used. The effects of two- and three-dimensional heat flows have not been considered in the simulations. Ventilation is presumed to be 3 ach (without heat recovery) when the temperature exceeds 73.4°F (23°C).

Internal Gains

In Denmark there are no standard calculation values for internal gains that lower the heating load. The influence of the internal gain value must be investigated further, as the heat demand in highly insulated houses is very sensitive to the total gains.

In the base case, the internal gains from persons are 9,721 kBtu/yr (2,849 kWh/yr) corresponding to 27 kBtu/day (7.8 kWh/day). The internal gains from electricity use are 4,333 kBtu/yr (1,270 kWh/yr) corresponding to 12 kBtu/day (3.5 kWh/day).

Parametrics

A short description of the different cases is given below.

Case 1:	As described above in base case, with roof construction No. 1, concrete.
Case 2:	Same as 1, but with aerogel windows in the south facade and in the skylight, 163.6 ft² (15.2 m²).
Case 3:	Same as 2, but with insulating shutters for the rest of the windows.
Case 4:	Same as 1, but with ordinary double glazing plus shutters for east-west windows.
Case 5:	Same as 1, but with ordinary double glazing.
Case 6:	Same as 3, but with heating all year.
Case 7:	Same as 6, but without internal gains and solar radiation.
Case 8:	Same as 6, but without solar radiation.
Case 9:	Same as 1, but with U-values as in the Danish Building Code (*BR-82* 1983).
Case 10:	Same as 3, but with roof construction No. 2, 0.5 in. (13 mm) gypsum inside.

Preliminary calculations have shown that there is not a great difference in the energy demand when the window area is between 32.3 and 107.6 ft² (3 and 10 m²). The energy demand increases with increasing window area toward the east and west.

In Case 9 the U-values of the Danish Building Code (*BR-82* 1983) are used. They are as follows:

U-values:	Btu/(h·ft²·°F)	W/(m²·K)
Wall	0.053	0.3
Roof	0.035	0.2
Floor	0.053	0.3
Door	0.352	2.0
Window	0.511	2.9

In some cases, aerogel windows are used. The U-value for the glazing area is given as 0.11 Btu/(h·ft²·°F) (0.6 W/m²·K) and the solar transmittance as 75%.

In some of the cases, insulating shutters are introduced. In these cases, a resistance of 9.574 (h·ft²·°F)/Btu (1.685 m²·K/W) corresponding to a shutter thickness of 1.97 in. (50 mm) mineral wool equivalent is added every day in the heating season from 10 p.m. to 7 a.m.

Results

The results are listed in Table 1. The design transmission and ventilation heat loss in W are calculated according

TABLE 1
Results Simulations

	Heating load		Design heat loss	
	kBtu	kWh	Btu/h	W
Case 1	10085	2955	10358	3035
Case 2	7253	2125	9744	2855
Case 3	6843	2005	9198	2695
Case 4	16177	4740	13020	3815
Case 5	18020	5280	14676	4300
Case 6	6928	2030	9198	2695
Case 7	29420	8620	9198	2695
Case 8	16638	4875	9198	2695
Case 9	25700	7530	19505	5715
Case 10	7406	2170	9317	2730

to Danish Standard *DS-418* (DSCCEME 1986) based on an indoor temperature of 68°F (20°C) and an outdoor temperature of 10.4°F (-12°C). The figures in the design heat loss are without any heat recovery on the ventilation air (and without gains). The transmission heat loss in the design heat loss for Case 3 makes up a total of 4,198 Btu/h (1,230 W), while the ventilation heat loss is 5,000 Btu/h (1,465 W).

Figure 2 shows temperatures for case 3, the model with aerogel in the skylight and the window in the south facade plus shutters for the rest of the windows facing east and west. The time is February 19-25, a very sunny period after a period without sun. Zone 3 is the zone on the top floor with the south-facing windows, and zone 1 is on the ground floor.

It is seen that the temperature is barely below 68°F (20°C) in the nighttime even though the heating system is turned off.

Figure 3 shows the temperatures in June, also a sunny period.

The indoor temperature is rather high in both zones, so it will be necessary with more airing and/or shading.

LOW-ENERGY HOUSE WITH NORTH/SOUTH-FACING FACADES

House Description

The base house is a two-story rowhouse built slab on ground. The total area is 1,055 ft^2 (98 m^2). The plans and cross sections are shown in Figure 4. The heated volume of the house is 8,904 ft^3 (252 m^3).

In the base case, the window areas are:

North	42.09 ft^2	3.91 m^2
South	144.99 ft^2	13.47 m^2
Skylight	59.20 ft^2	5.50 m^2

The total window area is 248 ft^2 (23 m^2) corresponding to approximately 23% of the floor area.

Discussion of Architectural Design

Each apartment has two stories with the main rooms organized around a two-story-high family room in the

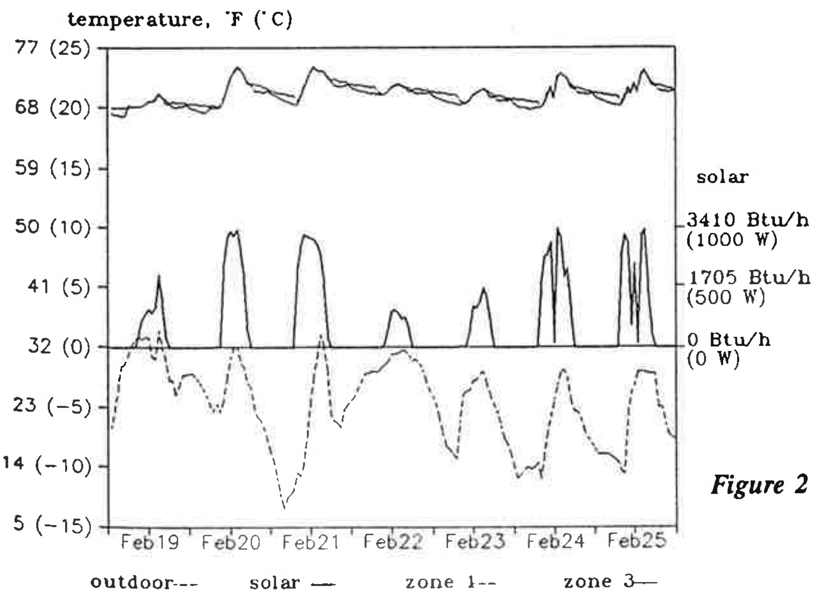


Figure 2 *Outdoor temperature and solar intensity plus indoor temperature for zones 1 and 3 for the period of February 19-25 in the Danish Test Reference Year.*

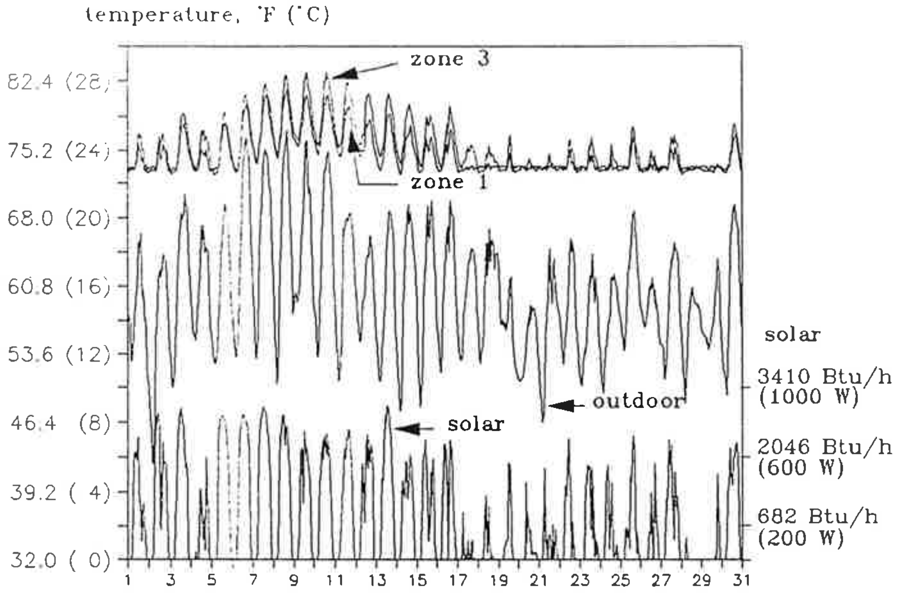
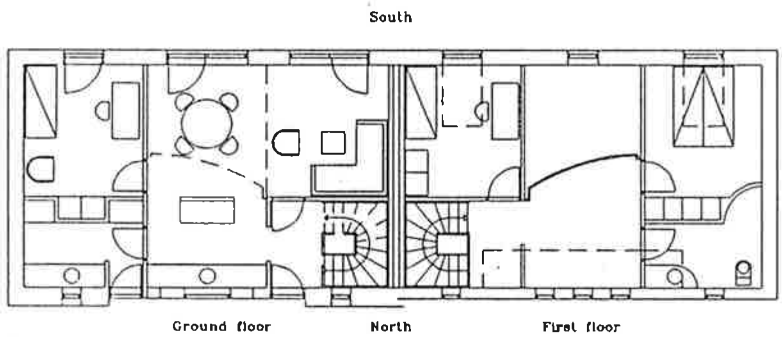


Figure 3 *Solar intensity and outdoor and indoor temperatures for zones 1 and 3 for a period in June in the Danish Test Reference Year.*



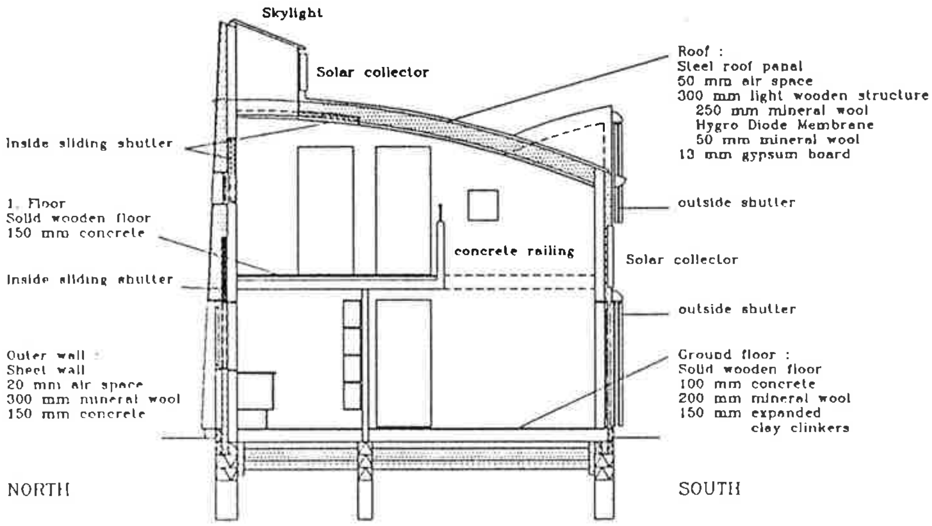


Figure 4 *Plans and cross section, rowhouse with north/south-facing facades.*

middle. All primary rooms and bedrooms are south facing, while secondary rooms, such as the entrance, stairs, kitchen, and bathroom, are placed along the north facade. In this way, optimal conditions for the utilization of passive gains are obtained for the main rooms.

The facades of the building are very different. The south facade has relatively large glazed areas and has areas suitable for solar wall applications. In contrast to this, the north facade has a closed appearance, having small windows and being covered with a trellis.

In order to get sunlight to the back rooms on the first floor, two fairly small dormer windows are placed in the roof, connected with an array of vertical solar collectors for an active combined system.

In order to further emphasize the asymmetry of the building, the building has a lopsided roof with a one-sided slope. At the same time, the slight curvature gives the inner rooms a spatial cavelike quality.

PARAMETRIC STUDIES, NORTH/SOUTH-FACING LOW-ENERGY ROWHOUSE

Base Case

In the base case, calculations are carried out for a unit with a neighboring unit on each side. The house has been divided into three zones.

The base case has the same U-values as given in the section on parametric studies for the east/west-facing house, except for the U-values of the south walls, which are 0.0194 Btu/(h·ft^2·°F) (0.11 W/[m^2·K]). All other assumptions are as mentioned above.

Parametrics

Parametric studies similar to the studies above were conducted. Only three cases are described in this paper:

Case a:	As described above in base case.
Case b:	Same as Case a, but with aerogel windows in the skylight, 59.2 ft^2 (5.5 m^2).
Case c:	Same as Case b, but with insulating shutters for the rest of the windows.

Results

The results are listed in Table 2. The design transmission and ventilation heat loss in W are calculated according to Danish Standard *DS-418* (DSCCEME 1986) based on an indoor temperature of 68°F (20°C) and an outdoor temperature of 10.4°F (-12°C). The figures in the design heat loss are without heat recovery (and without gains).

The transmission part of the design heat loss for Case c is 3,737 Btu/h (1,095 W), and the ventilation heat loss is 4,676 Btu/h (1,370 W).

ACTIVE SOLAR SIMULATIONS

A low-flow active solar system is presently being analyzed by means of a PC program developed within the European Community Research Programs, and the first calculations look promising.

Basic Assumptions

As the PC program is not an integrated part of the building energy simulation tool used, some assumptions on the energy demand have to be made. The assumptions chosen were close to the figures previously calculated for the house with north/south-facing facades, as follows:

Assumptions for the base case:

DHW: 34.3 gallons/day (130 L/day), heated from 50 to 122°F (10 to 50°C):	7536 kBtu (2208 kWh)
Space heating (total demand of the house):	3867 kBtu (1133 kWh)
Total heat demand:	11403 kBtu (3341 kWh)

Collector:	Absorber, 107.6 ft^2 (10 m^2), tilt 45°, south facing
Storage:	105.5 gallon (400 L) tank with mantle

Two simulation runs have been performed, changing only one assumption at the time:

a) Same as the basic assumption, but the solar heating system at a maximum can cover 70% of the space-heating demand.

b) Same as the basic assumption, but the tilt of the solar collector is increased to 90°.

TABLE 2
Results Simulations

	Heating load		Design heat loss	
	Btu	kWh	Btu/h	W
Case a	5802	1700	10137	2970
Case b	5290	1550	9898	2900
Case c	3942	1155	8413	2465

TABLE 3
Results from Simulations of Different Solar Collector and Storage Systems for Domestic Hot Water and Space-Heating Supply

case	Solar fraction			Energy to be bought	
	DHW	Space heating	total		
	%	%	%	kBtu	kWh
a	76.5	8.4	53.5	5300	1553
b	76.8	9.9	54.1	5232	1533

Results

Table 3 summarizes results from the simulation runs.

It is clear that with even a relatively small solar collector and a storage tank of 105.5 gallons (400 L), it is possible to cover more than 70% of the hot water consumption and additionally deliver approximately 10% of the space-heating demand in a low-energy house.

CONCLUSIONS

The analyses show clearly that it is possible to build a rowhouse with single-family units that have an energy consumption for space heating of less than 6,826 kBtu/year (2,000 kWh/year) in a climate with approximately 3,000 base 62.6°F (17°C) degree-days. Furthermore, analyses show that although the main orientation of the windows is of great importance to energy consumption, it is possible to build a rowhouse with facades facing east and west with an energy consumption of less than 6,826 kBtu/year (2,000 kWh/year) and even overcome some of the overheating problems that occur in more traditional designs.

To obtain this low-energy consumption in a rowhouse, one must take advantage of many different advanced building techniques, i.e., a high level of insulation, high-performance windows and frames, special foundation solutions, and active and passive solar features.

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