CHAPTER VI

BUILDING HEAT GAIN AND HEAT LOSS SIMULATIONS

In this chapter building heat gain and heat loss through walls, roof and windows were simulated using a computer model and the hourly weather data set which was prepared through Chapter V. Then, the output data were analyzed to identify the optimum building shapes for 16 different building orientations in Oklahoma City area.

6.1 Description of the Computer Model

A computer model for calculating building heat gain and heat loss was developed by applying the ASHRAE methods discussed in Chapter IV. This model was written in Microsoft QuickBASIC language for IBM-PC and its compatible machines.

For the calculation of building heat gain and heat loss, the following assumptions were made.

1) The building was assumed to be a box-shaped one-room enclosure.

2) The various external walls, roof and windows were treated as separate heat flow paths.

3) The conduction heat transfer through building components was assumed to be one-dimensional.

4) The heat transfer coefficients for the inside and outside surfaces of the building were considered constant.

5) All building materials were assumed to be homogeneous, having constant thermal and physical properties.

6) The temperature distribution inside the building were considered uniform.

7) The indoor design temperatures were set to 75 °F in cooling season and 70 °F in other season.

The main procedure of calculating heat gain and heat loss through building envelope includes:

1) input of building dimensions, materials and glass properties,

2) input of hourly weather data,

2) calculating hourly wall-solar azimuth angles and solar incident angles on walls,

3) calculating hourly total solar radiation on each building surface,

4) calculating hourly sol-air temperatures on roof and walls,

5) calculating transmission coefficient of each window using the hourly solar incident angle on the window,

6) calculating heat gain or heat loss through windows,

7) calculating conductive heat gain or heat loss through roof and walls,

8) and output of heat gain or loss amounts.

The procedures for calculating actual heating or cooling load and internal heat gain were not included because of the following reasons.

1) The use of this computer model was to produce the data for the comparison of the heat flow amount which would be different among the buildings having different length-to-width ratios and orientations. The comparison of heat flow amount through building envelope, as Olgyay did, might be enough to identify an optimum building shape for a given orientation of that building.

2) The buildings were assumed to have same use, number of occupants and amount of internal heat sources. So, the internal heat gain were assumed to be identical in the buildings.

Table 6.1 shows the input data for the heat gain and heat loss simulations. Among the data, those thermal transfer function coefficients of different materials for roofs and walls were taken from ASHRAE Handbook of Fundamentals 1977, and recorded on disk files. So, the values can be read by the program according to the ASHRAE roof and wall numbers specified in the input procedure. A box-shaped building having floor area of 1000 ft^2 and wall height of 10 ft was assumed. Then, total 41 different building shapes were pre-defined in terms of the building width-to-length ratios from 5:1 to 1:5.

Table 6.2 shows the actual building widths and lengths which constitute floor area of 1000 ft^2. In this study, in lieu of the conventional terms for walls, such as south, north, east and west walls, the terms of front, back, left and right walls were used because of the changing orientations of the main window wall which was called front wall.

Table 6.1 Input data for heat gain/loss simulations

Site location: Oklahoma City area (35.28°N, 97.32°W). Climatic data: Hourly Model Weather Data for OKC area. Indoor temperature: 70 °F in November through March. 75 °F in April through October. Ground reflectance : 20%. Building floor area : 1000 ft². Building shape: Box-shaped one single unit. Building orientation: 16 orientations (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW and NNW). Window area: 10% of floor area on main wall (100 ft²). 4% of floor area on other 3 walls (40 ft²). Wall material: ASHRAE wall #32 (4-in. concrete with 2-in. insulation on the outside). Roof material: ASHRAE roof #30 (4-in.h.w. concrete with 2-in. insulation)

Table 6.2 Actual building widths and lengths (Unit=ft)

Width ratio	Length ratio	Actual width	Actual length	Width ratio	Length ratio	Actual width	Actual length
5.0	1.0	70.71	14.14	1.0	1.1	30.15	33.17
4.5	1.0	67.08	14.91	1.0	1.2	28.87	34.64
4.0	1.0	63.25	15.81	1.0	1.3	27.74	36.06
3.5	1.0	59.16	16.90	1.0	1.4	26.73	37.42
3.0	1.0	54.77	18.26	1.0	1.5	25.82	38.73
2.5	1.0	50.00	20.00	1.0	1.6	25.00	40.00
2.4	1.0	48.99	20.41	1.0	1.7	24.25	41.23
2.3	1.0	47.96	20.85	1.0	1.8	23.57	42.43
2.2	1.0	46.90	21.32	1.0	1.9	22.94	43.59
2.1	1.0	45.83	21.82	1.0	2.0	22.36	44.72
2.0	1.0	44.72	22.36	1.0	2.1	21.82	45.83
1.9	1.0	43.59	22.94	1.0	2.2	21.32	46.90
1.8	1.0	42.43	23.57	1.0	2.3	20.85	47.96
1.7	1.0	41.23	24.25	1.0	2.4	20.41	48.99
1.6	1.0	40.00	25.00	1.0	2.5	20.00	50.00
1.5	1.0	38.73	25.82	1.0	3.0	18.26	54.77
1.4	1.0	37.42	26.73	1.0	3.5	16.90	59.16
1.3	1.0	36.06	27.74	1.0	4.0	15.81	63.25
1.2	1.0	34.64	28.87	1.0	4.5	14.91	67.08
1.1	1.0	33.17	30.15	1.0	5.0	14.14	70.71
1.0	1.0	31.62	31.62				

6.2 Simulation Procedure

From the input data, building heat gain and heat loss in Oklahoma City area were determined through a series of computer simulations.

For the computer simulations, sixteen IBM-AT compatible machines[1] were employed at a time. One of the 16 different orientations was given to each machine and 8760 hours' heat gain and loss were simulated.

First of all, hourly total solar radiation intensity on each building surface was calculated from the hourly solar radiation values on a horizontal surfaces which were recorded in the weather data set. Tables 6.3.1 through 6.3.4 show the hourly solar radiation intensities on a unit surface area (BTU/h/ft^2) of the roof and walls of 16 different orientations on March 21, June 21, September 21 and December 21, respectively. And figures 6.1.1 through 6.4 show the plots of these values. As shown in the figures, the hourly solar radiation intensities on the walls vary in connection with the sun positions, cloud cover ratios and wall orientations.

The hourly heat gain and loss (BTU/h) values were calculated by summing those through the roof, walls and windows. Then, the hourly values were accumulated separately in gain and loss to get daily sums of heat gain and heat loss (BTU/24hrs). Again, the daily sum values were added up to get monthly sums of heat gain and heat loss (BTU/month). Finally averages of daily heat gain and heat loss (BTU/day) were calculated

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[1] These machines were equipped with 10 MHz INTEL 80286 processors and 80287 numeric Co-processors. About 6 hour running time was needed to complete a 8760 hours' heat gain and heat loss simulation on one machine.

by dividing the monthly sum by the total number of days in each month.

Table 6.3.1 March 21. Hourly solar radiation on unit surface area [BTU/h/ft²]

TM	CC	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	RF
7	9	16	16	32	46	55	59	55	46	33	16	16	16	16	16	16	16	29
8	9	32	32	41	54	64	69	68	62	51	38	32	32	32	32	32	32	62
9	10	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	62
10	10	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	77
11	10	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	88
12	10	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	93
13	10	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	94
14	9	64	64	64	64	64	64	75	85	92	94	92	85	76	64	64	64	128
15	9	57	57	57	57	57	57	62	74	84	89	90	85	77	65	57	57	115
16	9	48	48	48	48	48	48	48	59	71	79	83	81	74	63	50	48	95
17	10	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	48
18	10	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	26

Table 6.3.2 June 21. Houlry solar radiation on unit surface area [BTU/h/ft²]

TM	CC	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	RF
7	2	37	37	124	200	250	269	252	202	127	38	37	37	37	37	37	37	86
8	2	47	47	101	182	242	273	269	232	166	83	47	47	47	47	47	47	141
9	2	57	57	72	152	218	260	270	248	198	125	57	57	57	57	57	57	190
10	3	72	72	72	116	176	220	242	237	208	158	95	72	72	72	72	72	225
11	4	84	84	84	87	138	181	209	218	207	177	132	84	84	84	84	84	244
12	5	91	91	91	91	107	145	175	193	195	181	153	116	91	91	91	91	246
13	5	94	94	94	94	94	121	157	183	196	194	176	146	108	94	94	94	255
14	5	94	94	94	94	94	94	134	169	192	200	193	170	136	95	94	94	255
15	5	91	91	91	91	91	91	107	149	182	201	203	189	159	119	91	91	246
16	6	82	82	82	82	82	82	82	114	147	170	180	174	155	125	88	82	206
17	7	67	67	67	67	67	67	67	80	109	131	144	145	134	113	85	67	157
18	8	49	49	49	49	49	49	49	50	71	88	100	103	99	87	69	49	106
19	9	30	30	30	30	30	30	30	30	37	46	53	57	56	51	43	33	58
20	9	19	19	19	19	19	19	19	19	23	32	40	44	44	41	35	26	36

Table 6.3.3 September 21. Houlry solar radiation on unit surface area [BTU/h/ft²]

TM	CC	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	RF
8	0	27	27	105	222	310	354	349	295	200	78	27	27	27	27	27	27	82
9	0	33	33	54	171	267	328	343	312	237	132	33	33	33	33	33	33	144
10	0	37	37	37	111	212	286	323	315	266	182	75	37	37	37	37	37	195
11	0	41	41	41	47	149	234	290	307	285	225	137	41	41	41	41	41	234
12	0	43	43	43	43	81	173	247	289	293	260	193	104	43	43	43	43	260
13	0	44	44	44	44	44	108	196	261	293	286	243	170	77	44	44	44	271
14	0	44	44	44	44	44	44	141	225	282	303	284	229	145	46	44	44	270
15	0	42	42	42	42	42	42	82	184	263	310	315	279	207	110	42	42	254
16	0	40	40	40	40	40	40	40	137	236	305	334	318	260	168	57	40	225
17	0	36	36	36	36	36	36	36	87	201	289	339	343	300	217	107	36	183
18	0	31	31	31	31	31	31	31	36	158	261	329	351	325	254	150	31	129
19	0	26	26	26	26	26	26	26	26	111	221	302	341	331	275	182	64	65

Table 6.3.4 December 21. Houlry solar radiation on unit surface area [BTU/h/ft²]

TM	CC	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	RF
8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	16
9	10	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	37
10	10	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	53
11	10	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	63
12	10	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	69
13	10	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	68
14	10	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	62
15	10	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	51
16	10	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	35
17	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	14

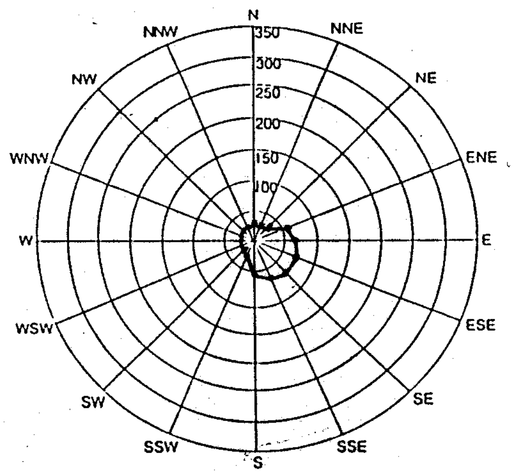

Fig. 6.1.1 Solar radiation on unit surface area [BTU/h/ft^2], March 21, 8:00 a.m., Cloud cover = 9

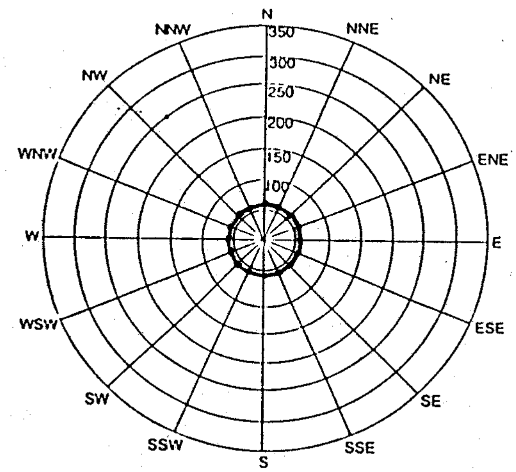

Fig. 6.1.2 Solar radiation on unit surface area [BTU/h/ft^2], March 21, 12:00 noon, Cloud cover = 10

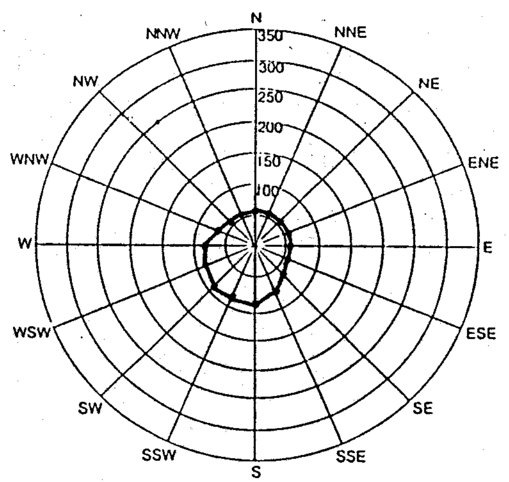

Fig. 6.1.3 Solar radiation on unit surface area [BTU/h/ft^2], March 21, 3:00 p.m., Cloud cover = 9

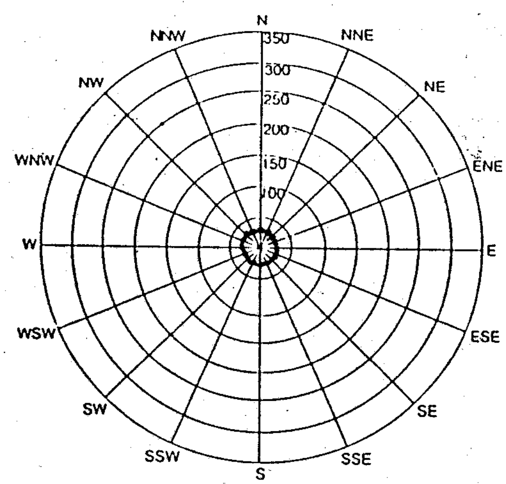

Fig. 6.1.4 Solar radiation on unit surface area [BTU/h/ft^2], March 21, 5:00 p.m., Cloud cover = 10

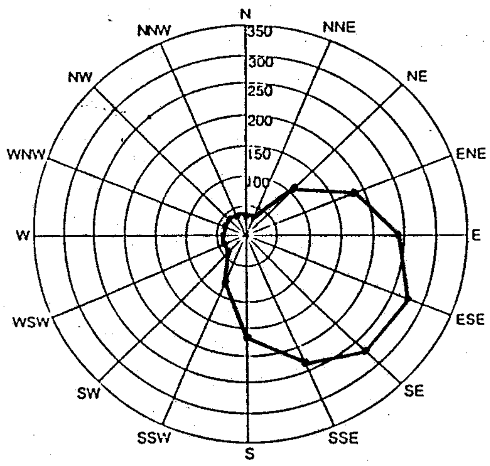

Fig. 6.2.1 Solar radiation on unit surface area [BTU/h/ft²], June 21, 8:00 a.m., Cloud cover = 2

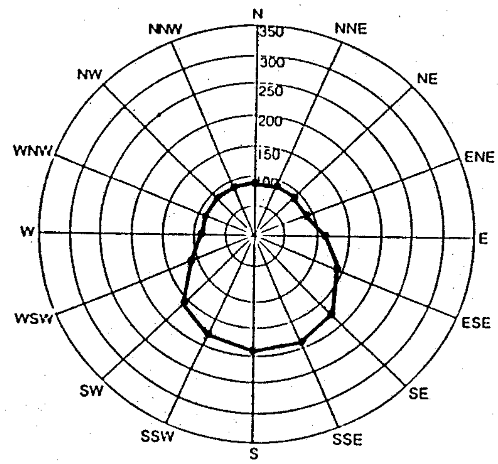

Fig. 6.2.2 Solar radiation on unit surface area [BTU/h/ft²], June 21, 12:00 noon, Cloud cover = 5

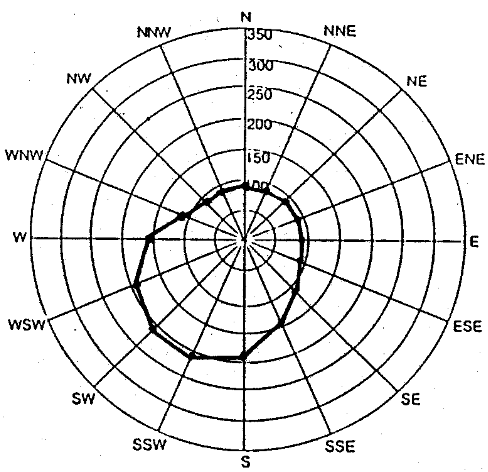

Fig. 6.2.3 Solar radiation on unit surface area [BTU/h/ft²], June 21, 3:00 p.m., Cloud cover = 5

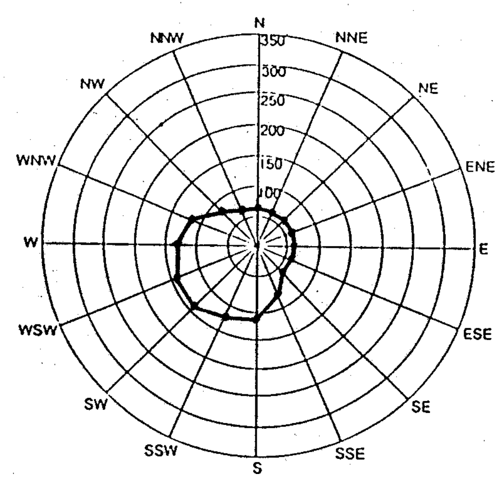

Fig. 6.2.4 Solar radiation on unit surface area [BTU/h/ft²], June 21, 5:00 p.m., Cloud cover = 7

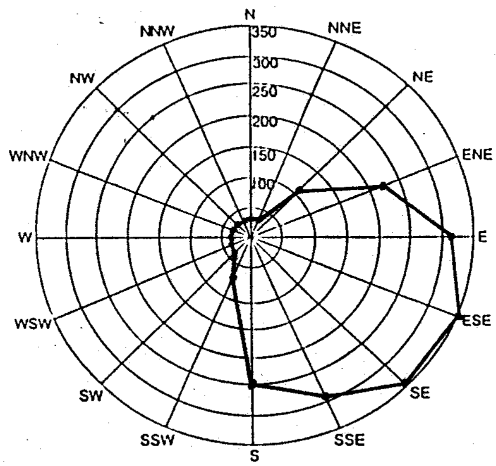

Fig. 6.3.1 Solar radiation on unit surface area [BTU/h/ft²], September 21, 8:00 a.m., Cloud cover = 0

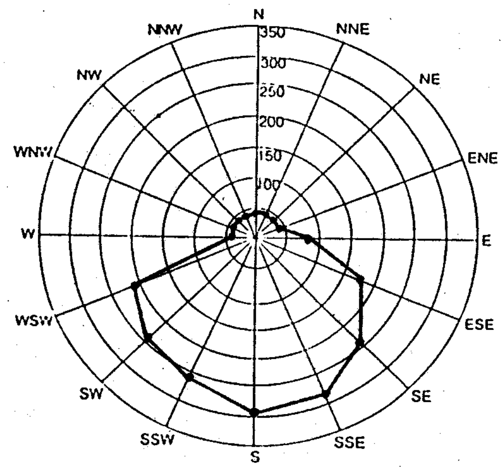

Fig. 6.3.2 Solar radiation on unit surface area [BTU/h/ft²], September 21, 12:00 noon, Cloud cover = 0

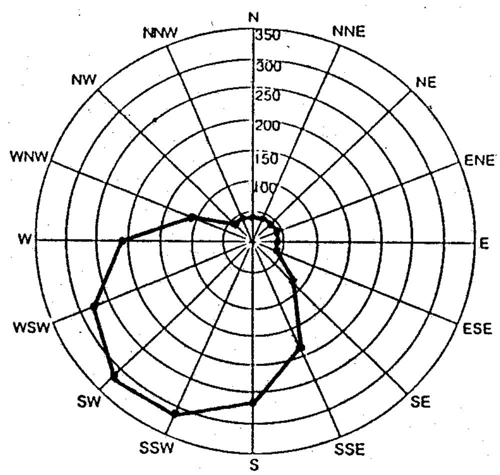

Fig. 6.3.3 Solar radiation on unit surface area [BTU/h/ft²], September 21, 3:00 p.m., Cloud cover = 0

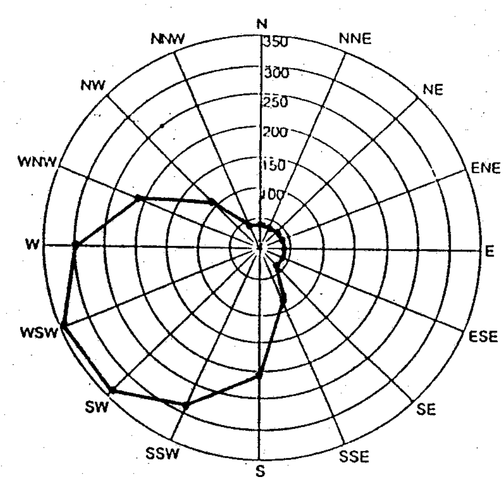

Fig. 6.3.4 Solar radiation on unit surface area [BTU/h/ft²], September 21, 5:00 p.m., Cloud cover = 0

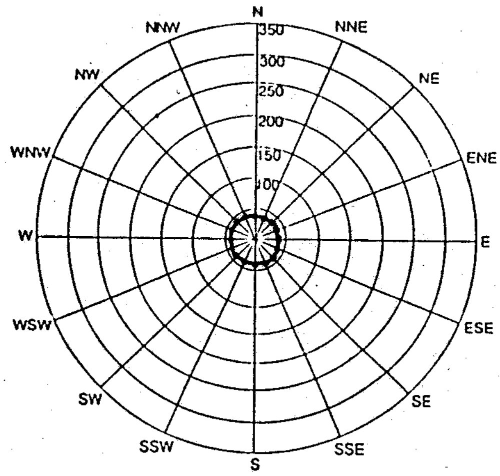

Fig. 6.4 Solar radiation on unit surface area [BTU/h/ft²], December 21, 12:00 noon, Cloud cover = 10

Among the averages of daily sum values, those of December, January, and February were selected for winter heat loss amount calculations and those of June, July and August were selected for summer heat gain amount calculations for the 41 different building shapes and 16 different orientations. Tables 6.4 and 6.5 give the averages of daily total heat flow amounts through the unit surface area of the walls in summer and winter. And the values were plotted as shown in figures 6.5.1 and 6.5.2.

Table 6.4 Average of daily total heat gain through unit surface area in summer [Btu/day/ft²]

Mo\Or	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Roof
Jun.	21	23	25	27	27	26	24	21	20	22	25	27	28	28	26	23	26
Jul.	38	40	44	47	48	47	43	38	36	38	44	47	49	48	45	40	43
Aug.	35	37	41	44	45	45	44	41	39	41	44	46	47	45	42	38	38
Ave.	31	33	37	39	40	39	37	33	32	34	38	40	41	40	38	34	36

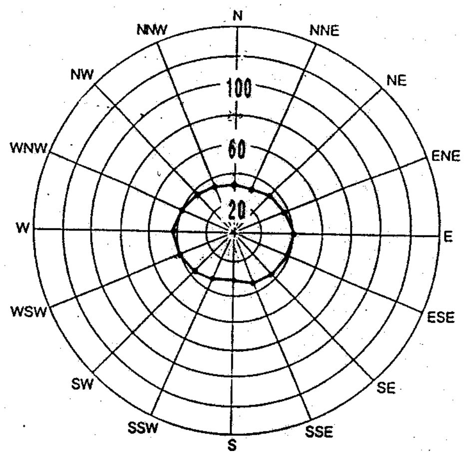

Fig. 6.5.1 Summer heat gain through unit surface area [BTU/day/ft²]

Table 6.5 Average of daily total heat loss through unit surface area in winter [Btu/day/ft²]

Mo\Or	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Roof
Dec.	-86	-86	-85	-81	-77	-72	-68	-65	-63	-65	-68	-72	-76	-81	-84	-86	-91
Jan.	-99	-99	-98	-95	-92	-88	-84	-81	-79	-81	-84	-88	-91	-95	-98	-99	-105
Feb.	-90	-90	-89	-86	-83	-80	-78	-76	-75	-75	-76	-78	-81	-85	-88	-90	-95
Ave.	-92	-92	-91	-87	-84	-80	-77	-74	-72	-74	-76	-79	-83	-87	-90	-92	-97

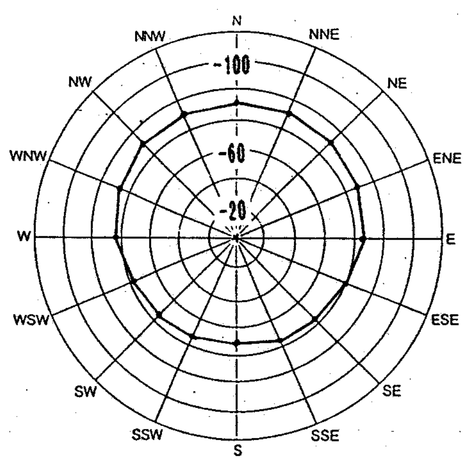

Fig. 6.5.2 Winter heat loss through unit surface area [BTU/day/ft²]

As shown in the figures 6.4 and 6.5, winter heat loss is greater than summer heat gain in Oklahoma City area. In summer, east and west walls passed more heat into the building than north and south walls. This indicates that the low altitude angles of the early morning and late afternoon sun in summer season caused greater direct solar radiation intensities on the east and west walls. In winter, differently from the summer case, north wall caused greatest heat loss due to no direct solar radiation on the wall in this season.

Table 6.6 shows an example of the average of daily total heat gain and loss for 12 calendar months in the building which had the width-to-length ratio of 1:1 and the front wall azimuth angle of 0° south.

Table 6.6 An example of average of daily total heat gain and loss in each month

BLDG ORIENTATION = South WIDTH : LENGTH = 1 : 1		
Month	HEAT LOSS	HEAT GAIN
1	<u>-305590</u>	32759
2	<u>-266966</u>	24552
3	-126485	68172
4	-66808	98527
5	-55325	103249
6	-10592	<u>195309</u>
7	-1711	<u>278446</u>
8	-4100	<u>259641</u>
9	-21186	180001
10	-90613	100379
11	-160223	75922
12	<u>-258292</u>	50107
SUMMER GAIN : 244465(BTU/day) WINTER LOSS : -276950(BTU/day)		

6.3 The Output Data of the Simulations

The final output data sets were obtained by tabulating the summer heat gain and winter heat loss values (BTU/day) for entire 41 building shapes as shown in tables 6.7.1 and 6.7.2. These tables show, as an example, the daily average heat gain and heat loss in the buildings having south orientation. As in Olgyay's work (Olgyay, Victor, 1963, p. 88), the values of heat gain and loss in square house were considered as starting reference points, and therefore set to zero. The heat gain or heat loss amounts in other forms were linearly transformed by subtracting the square building's heat gain and loss amounts.

Table 6.7.1 Final output data set for winter heat loss and summer heat gain [BTU/Day], Orientation 0°S

W : L	Winter	Summer	Loss	Gain
5.0 : 1.0	-306651	254531	-29701	10066
4.5 : 1.0	-303290	252916	-26340	8451
4.0 : 1.0	-299113	251286	-22163	6821
3.5 : 1.0	-294869	249652	-17919	5187
3.0 : 1.0	-290578	248041	-13628	3576
2.5 : 1.0	-286305	246505	-9355	2040
2.4 : 1.0	-285464	246214	-8514	1749
2.3 : 1.0	-284631	245931	-7681	1466
2.2 : 1.0	-283809	245658	-6859	1193
2.1 : 1.0	-283001	245396	-6051	931
2.0 : 1.0	-282210	245147	-5260	682
1.9 : 1.0	-281439	244915	-4489	450
1.8 : 1.0	-280696	244702	-3746	237
1.7 : 1.0	-279985	244512	-3035	47
1.6 : 1.0	-279314	244350	-2364	-115
1.5 : 1.0	-278692	244222	-1742	-243
1.4 : 1.0	-278133	244136	-1183	-329
1.3 : 1.0	-277653	244102	-703	-363
1.2 : 1.0	-277274	244133	-324	-332
1.1 : 1.0	-277026	244246	-76	-219
1.0 : 1.0	-276950	244465	0	0

Table 6.7.2 Final output data set for winter heat loss and summer heat gain [BTU/day], Orientation 0°S

W : L	Winter	Summer	Loss	Gain
1.0 : 1.1	-277076	244785	-126	320
1.0 : 1.2	-277370	245166	-420	701
1.0 : 1.3	-277791	245591	-841	1126
1.0 : 1.4	-278310	246049	-1360	1584
1.0 : 1.5	-278906	246533	-1956	2068
1.0 : 1.6	-279562	247035	-2612	2570
1.0 : 1.7	-280266	247551	-3316	3086
1.0 : 1.8	-281009	248078	-4059	3613
1.0 : 1.9	-281781	248613	-4831	4148
1.0 : 2.0	-282578	249153	-5628	4688
1.0 : 2.1	-283396	249697	-6446	5232
1.0 : 2.2	-284230	250244	-7280	5779
1.0 : 2.3	-285077	250792	-8127	6327
1.0 : 2.4	-285934	251339	-8984	6874
1.0 : 2.5	-286799	251887	-9849	7422
1.0 : 3.0	-291180	254600	-14230	10135
1.0 : 3.5	-295568	257250	-18618	12785
1.0 : 4.0	-299905	259821	-22955	15356
1.0 : 4.5	-304166	262313	-27216	17848
1.0 : 5.0	-308337	264728	-31387	20263

6.4 Interpretation of the Output Data

The output data sets of same formats shown in the tables 6.7.1 and 6.7.2 were plotted for 16 different orientations. Then, from the tables and figures the optimum building shapes for 16 different orientations in the Oklahoma City area were identified.

An optimum building shape for each season, summer or winter, was identified from the tables, then, an optimum shape concerning both seasons was suggested by examining the heat gain and heat loss patterns of the figures.

6.4.1 Optimum Building Shape for South Orientation

As indicated in table 6.8 and figure 6.6, the minimum summer heat gain was yielded by the building having width-to-length ratio of 1.3:1.0. In winter, however, the square building produced minimum heat loss.

For a building oriented toward the south, the width-to-length ratios between 1:1 and 1.3:1 which should be elongated along the east and west axis might be suggested as the optimum shapes. Any shape between these width-to-length ratios might produce not far more heat loss in winter and less heat gain in summer than the square form.

Since the buildings of any other width-to-length ratios produced greater heat loss in winter, which has dominant impact on building energy requirements in the Oklahoma City area, any more elongation along the east and west axis or any elongation along the south and north axis might not be desirable.

Table 6.8 Daily average heat gain and heat loss in buildings oriented to the south [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-205168	80841	-3362	-84
1.5 : 1.0	-204452	80705	-2646	-220
1.4 : 1.0	-203811	80611	-2005	-314
1.3 : 1.0	-203263	80570	-1457	-355
1.2 : 1.0	-202834	80596	-1028	-329
1.1 : 1.0	-202559	80706	-753	-219
1.0 : 1.0	-201806	80925	0	0
1.0 : 1.1	-202654	81247	-95	322
1.0 : 1.2	-203014	81633	-455	708
1.0 : 1.3	-203523	82064	-964	1139
1.0 : 1.4	-204145	82531	-1586	1606
1.0 : 1.5	-204856	83023	-2297	2098
1.0 : 1.6	-205637	83536	-3078	2611

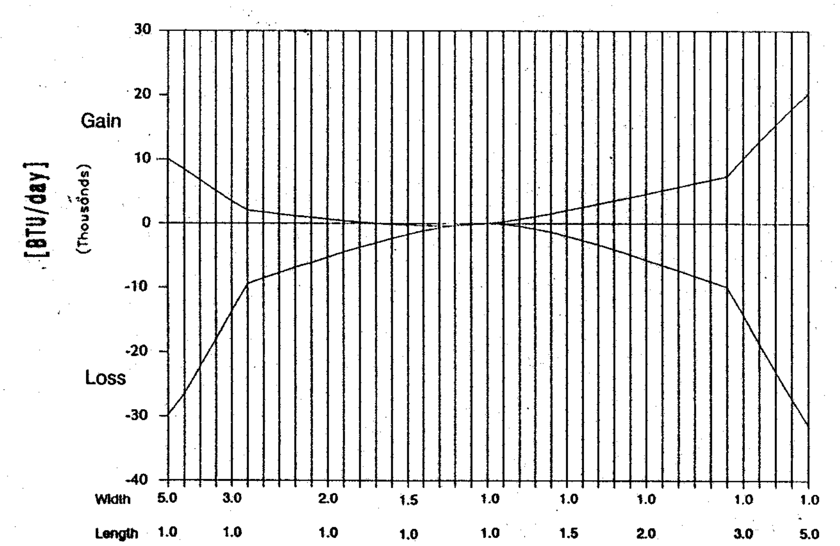

Fig. 6.6 Daily average heat gain and heat loss for the south orientation

6.4.2 Optimum Building Shape for North Orientation

As shown in table 6.9 and figure 6.7, for a building oriented toward the north, the width-to-length ratios between 1:1 and 1.3:1 which should be elongated along the east and west axis might be suggested as the optimum shapes.

6.4.3 Optimum Building Shape for East Orientation

As indicated in table 6.10 and figure 6.8, for a building oriented toward the east, the width-to-length ratios between 1:1 and 1:1.3 which should be elongated along the east and west axis might be suggested as the optimum shapes.

6.4.4 Optimum Building Shape for West Orientation

As indicated in table 6.11 and figure 6.9, for a building oriented toward the west, the width-to-length ratios between 1:1 and 1:1.3 which should be elongated along the east and west axis might be suggested as the optimum shapes.

After all, for the buildings oriented toward above 4 orientations, the optimum width-to-length ratios were between 1:1 and 1:1.3 or between 1:1 and 1.3:1 elongated along the east and west axis.

Table 6.9 Daily average heat gain and heat loss in buildings oriented to the north [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-290702	245043	-2573	-115
1.5 : 1.0	-290025	244915	-1896	-243
1.4 : 1.0	-289416	244829	-1287	-329
1.3 : 1.0	-288894	244794	-765	-364
1.2 : 1.0	-288481	244825	-352	-333
1.1 : 1.0	-288212	244938	-83	-220
1.0 : 1.0	-288129	245158	0	0
1.0 : 1.1	-288268	245478	-139	320
1.0 : 1.2	-288589	245858	-460	700
1.0 : 1.3	-289048	246283	-919	1125
1.0 : 1.4	-289615	246742	-1486	1584
1.0 : 1.5	-290265	247225	-2136	2067
1.0 : 1.6	-290981	247727	-2852	2569

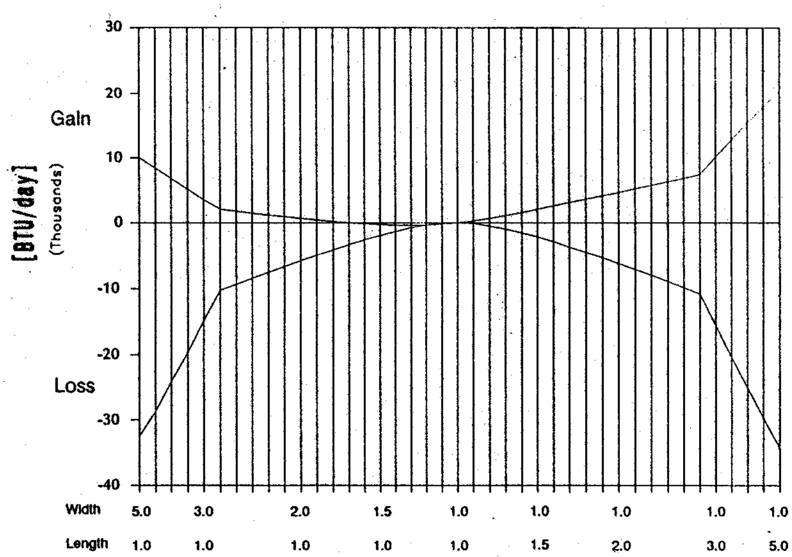

Fig. 6.7 Daily average heat gain and heat loss for the north orientation

Table 6.10 Daily average heat gain and heat loss in buildings oriented to the east [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-284056	263014	-2749	2570
1.5 : 1.0	-283368	262512	-2061	2068
1.4 : 1.0	-282743	262028	-1436	1584
1.3 : 1.0	-282197	261570	-890	1126
1.2 : 1.0	-281754	261145	-447	701
1.1 : 1.0	-281443	260764	-136	320
1.0 : 1.0	-281307	260444	0	0
1.0 : 1.1	-281384	260225	-77	-219
1.0 : 1.2	-281639	260112	-332	-332
1.0 : 1.3	-282031	260081	-724	-363
1.0 : 1.4	-282529	260115	-1222	-329
1.0 : 1.5	-283110	260201	-1803	-243
1.0 : 1.6	-283756	260329	-2449	-115

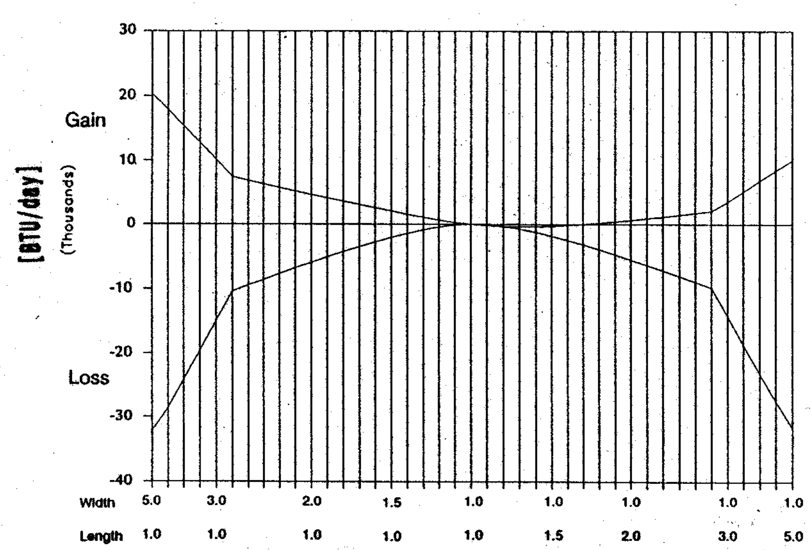

Fig. 6.8 Daily average heat gain and heat loss for the east orientation

Table 6.11 Daily average heat gain and heat loss in buildings oriented to the west [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-288207	265118	-2770	2568
1.5 : 1.0	-287509	264616	-2072	2066
1.4 : 1.0	-286876	264133	-1439	1583
1.3 : 1.0	-286325	263675	-888	1125
1.2 : 1.0	-285880	263250	-443	700
1.1 : 1.0	-285569	262870	-132	320
1.0 : 1.0	-285437	262550	0	0
1.0 : 1.1	-285522	262331	-85	-219
1.0 : 1.2	-285789	262218	-352	-332
1.0 : 1.3	-286195	262187	-758	-363
1.0 : 1.4	-286710	262221	-1273	-329
1.0 : 1.5	-287308	262307	-1871	-243
1.0 : 1.6	-287973	262435	-2536	-115

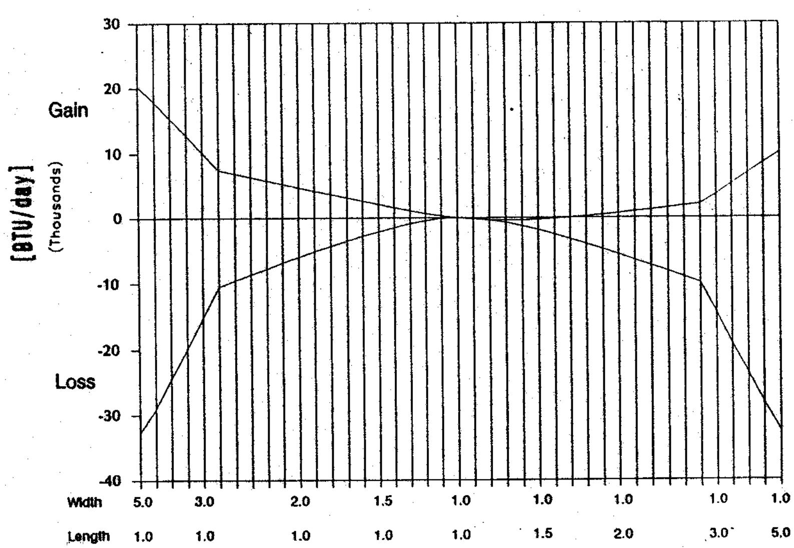

Fig. 6.9 Daily average heat gain and heat loss for the west orientation

6.4.5 Optimum Building Shapes for SE, SW, NE and NW Orientations

As shown in tables 6.12 through 6.15 and figures 6.10 through 6.13, both minimum summer heat gains and winter loss were yielded by the buildings of square forms.

6.4.6 Optimum Building Shapes for SSE, SSW, ESE and WSW Orientations

As shown in tables 6.16 through 6.19 and figures 6.14 through 6.17, the minimum summer heat gains were shown at width-to-length ratios of 1.2:1 for SSE and SSW orientations and 1:1.2 for ESE and WSW orientations. In winter, however, the square building yielded the minimum heat loss.

Considering that the differences between the heat gains in square buildings and 1.2:1.0 shaped buildings are minimal, a square building shape is recommended for these orientations.

6.4.7 Optimum Building Shapes for NNE, NNW, ENE and WNW Orientations

As shown in tables 6.20 through 6.23 and figures 6.18 through 6.21, the minimum summer heat gains were shown at width-to-length ratios of 1.2:1.0 for NNE and NNW orientations and 1.0:1.2 for ENE and WNW orientations. In winter, however, the square building had minimum heat loss. Considering that the differences between the heat gains in square buildings and 1.2:1.0 shaped buildings are minimal, a square building shape is recommended for these orientations.

Table 6.12 Daily average heat gain and heat loss in buildings oriented to the SE [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-206426	83589	-3671	1319
1.5 : 1.0	-205665	83253	-2910	983
1.4 : 1.0	-204975	82949	-2220	679
1.3 : 1.0	-204377	82685	-1622	415
1.2 : 1.0	-203896	82472	-1141	202
1.1 : 1.0	-203567	82327	-812	57
1.0 : 1.0	-202755	82270	0	0
1.0 : 1.1	-203549	82320	-794	50
1.0 : 1.2	-203860	82458	-1105	188
1.0 : 1.3	-204325	82664	-1570	394
1.0 : 1.4	-204908	82922	-2153	652
1.0 : 1.5	-205584	83221	-2829	951
1.0 : 1.6	-206332	83552	-3577	1282

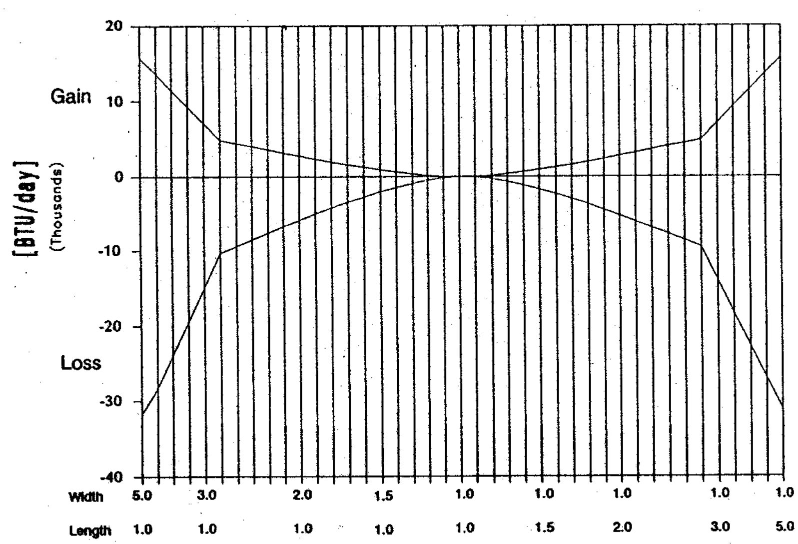

Fig. 6.10 Daily average heat gain and heat loss for the SE orientation

Table 6.13 Daily average heat gain and heat loss in buildings oriented to the SW [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-287942	264965	-2419	1265
1.5 : 1.0	-287298	264640	-1775	940
1.4 : 1.0	-286720	264347	-1197	647
1.3 : 1.0	-286226	264093	-703	393
1.2 : 1.0	-285839	263890	-316	190
1.1 : 1.0	-285590	263752	-67	52
1.0 : 1.0	-285523	263700	0	0
1.0 : 1.1	-285670	263752	-147	52
1.0 : 1.2	-285992	263889	-469	189
1.0 : 1.3	-286446	264092	-923	392
1.0 : 1.4	-287003	264346	-1480	646
1.0 : 1.5	-287640	264639	-2117	939
1.0 : 1.6	-288339	264964	-2816	1264

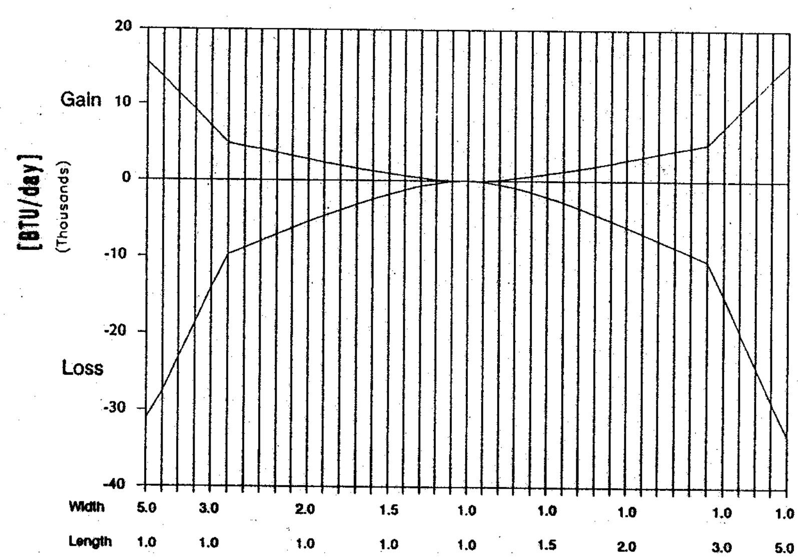

Fig. 6.11 Daily average heat gain and heat loss for the SW orientation

Table 6.14 Daily average heat gain and heat loss in buildings oriented to the NE [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-292536	263392	-2601	1265
1.5 : 1.0	-291850	263067	-1915	940
1.4 : 1.0	-291233	262774	-1298	647
1.3 : 1.0	-290705	262520	-770	393
1.2 : 1.0	-290289	262317	-354	190
1.1 : 1.0	-290018	262179	-83	52
1.0 : 1.0	-289935	262127	0	0
1.0 : 1.1	-290078	262179	-143	52
1.0 : 1.2	-290405	262316	-470	189
1.0 : 1.3	-290871	262519	-936	392
1.0 : 1.4	-291446	262773	-1511	646
1.0 : 1.5	-292106	263066	-2171	939
1.0 : 1.6	-292832	263391	-2897	1264

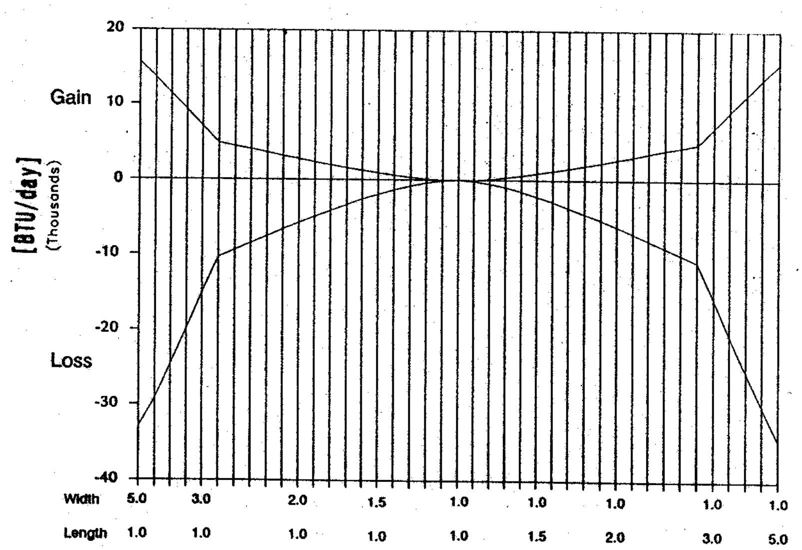

Fig. 6.12 Daily average heat gain and heat loss for the NE orientation

Table 6.15 Daily average heat gain and heat loss in buildings oriented to the NW [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-294099	265090	-2900	1263
1.5 : 1.0	-293372	264766	-2173	939
1.4 : 1.0	-292712	264473	-1513	646
1.3 : 1.0	-292136	264219	-937	392
1.2 : 1.0	-291668	264016	-469	189
1.1 : 1.0	-291341	263879	-142	52
1.0 : 1.0	-291199	263827	0	0
1.0 : 1.1	-291282	263879	-83	52
1.0 : 1.2	-291554	264017	-355	190
1.0 : 1.3	-291971	264220	-772	393
1.0 : 1.4	-292500	264474	-1301	647
1.0 : 1.5	-293118	264767	-1919	940
1.0 : 1.6	-293806	265091	-2607	1264

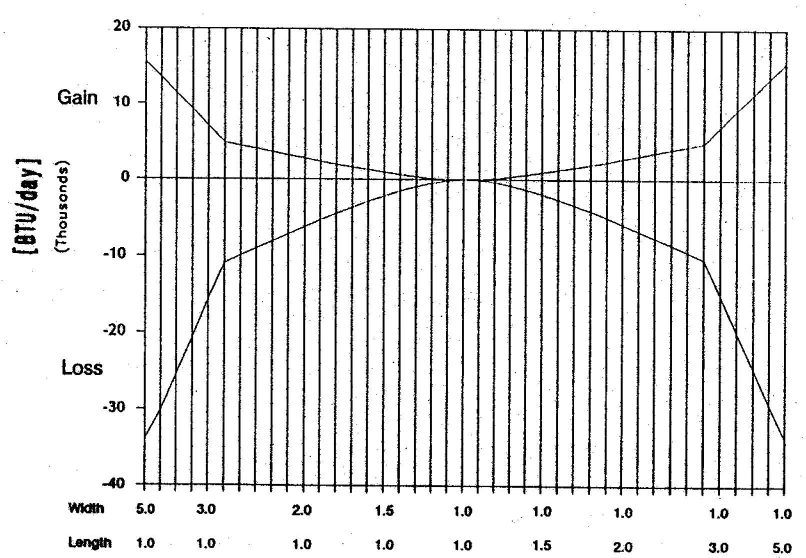

Fig. 6.13 Daily average heat gain and heat loss for the NW orientation

Table 6.16 Daily average heat gain and heat loss in buildings oriented to the SSE [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-280495	251949	-2592	330
1.5 : 1.0	-279839	251757	-1936	138
1.4 : 1.0	-279244	251603	-1341	-16
1.3 : 1.0	-278727	251498	-824	-121
1.2 : 1.0	-278310	251454	-407	-165
1.1 : 1.0	-278022	251486	-119	-133
1.0 : 1.0	-277903	251619	0	0
1.0 : 1.1	-277989	251854	-86	235
1.0 : 1.2	-278247	252158	-344	539
1.0 : 1.3	-278637	252513	-734	894
1.0 : 1.4	-279128	252907	-1225	1288
1.0 : 1.5	-279699	253332	-1796	1713
1.0 : 1.6	-280334	253779	-2431	2160

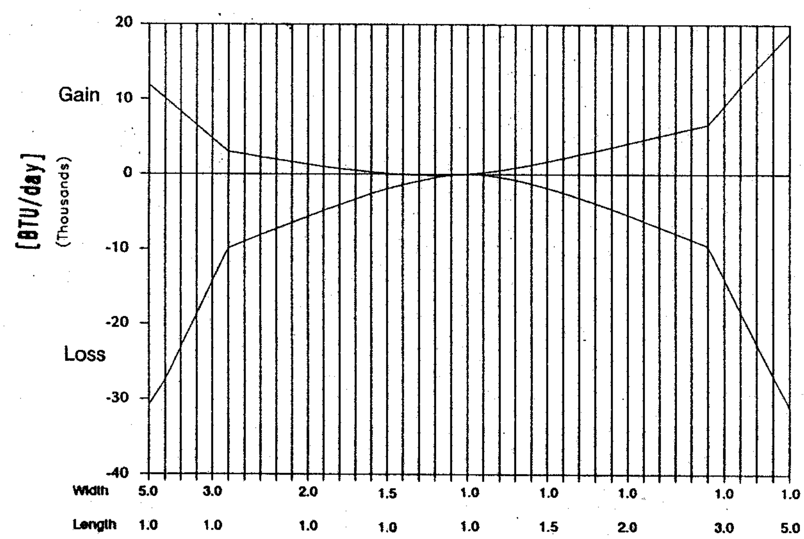

Fig. 6.14 Daily average heat gain and heat loss for the SSE orientation

Table 6.17 Daily average heat gain and heat loss in buildings oriented to the SSW [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-283636	252293	-2324	330
1.5 : 1.0	-283014	252101	-1702	138
1.4 : 1.0	-282457	251948	-1145	-15
1.3 : 1.0	-281981	251842	-669	-121
1.2 : 1.0	-281610	251798	-298	-165
1.1 : 1.0	-281373	251830	-61	-133
1.0 : 1.0	-281312	251963	0	0
1.0 : 1.1	-281460	252198	-148	235
1.0 : 1.2	-281776	252501	-464	538
1.0 : 1.3	-282220	252856	-908	893
1.0 : 1.4	-282764	253251	-1452	1288
1.0 : 1.5	-283385	253675	-2073	1712
1.0 : 1.6	-284067	254121	-2755	2158

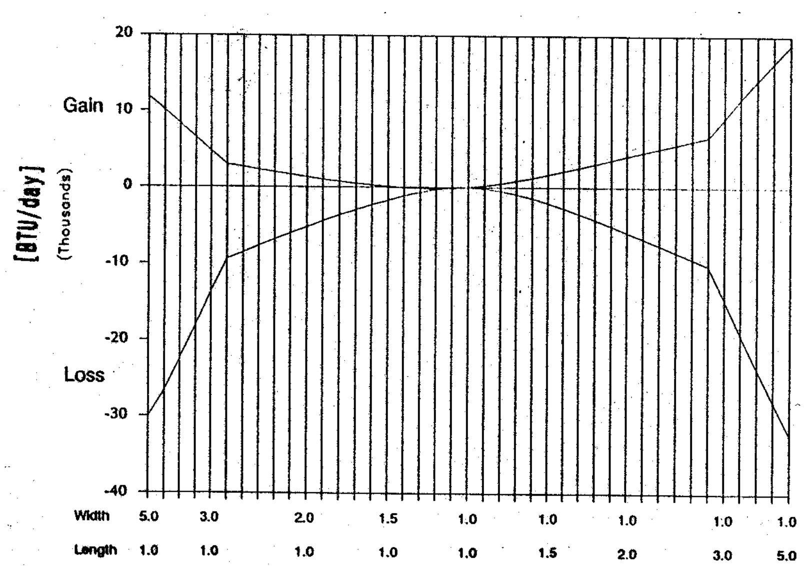

Fig. 6.15 Daily average heat gain and heat loss for the SSW orientation

Table 6.18 Daily average heat gain and heat loss in buildings oriented to the ESE [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-283402	264778	-2793	2158
1.5 : 1.0	-282711	264331	-2102	1711
1.4 : 1.0	-282081	263907	-1472	1287
1.3 : 1.0	-281530	263513	-921	893
1.2 : 1.0	-281079	263158	-470	538
1.1 : 1.0	-280758	262854	-149	234
1.0 : 1.0	-280609	262620	0	0
1.0 : 1.1	-280670	262487	-61	-133
1.0 : 1.2	-280910	262454	-301	-166
1.0 : 1.3	-281286	262499	-677	-121
1.0 : 1.4	-281769	262604	-1160	-16
1.0 : 1.5	-282334	262758	-1725	138
1.0 : 1.6	-282965	262950	-2356	330

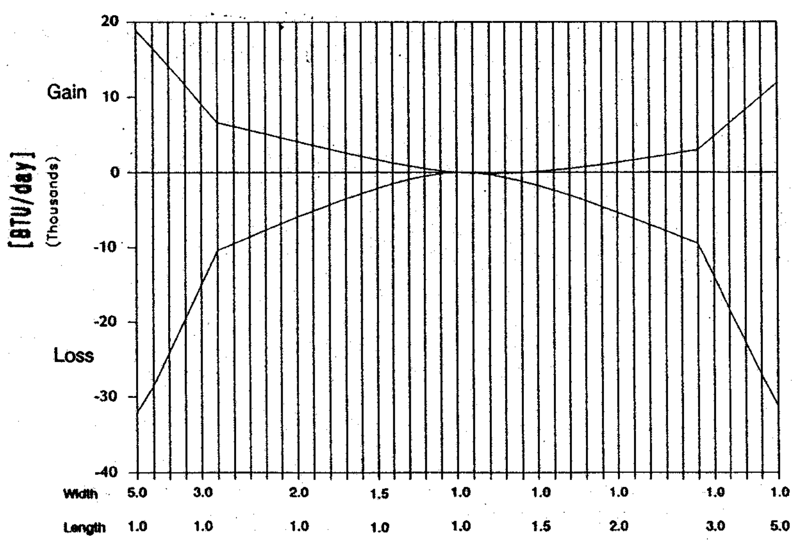

Fig. 6.16 Daily average heat gain and heat loss for the ESE orientation

Table 6.19 Daily average heat gain and heat loss in buildings oriented to the WSW [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-287890	266975	-2573	2159
1.5 : 1.0	-287220	266528	-1903	1712
1.4 : 1.0	-286617	266104	-1300	1288
1.3 : 1.0	-286098	265710	-781	894
1.2 : 1.0	-285685	265354	-368	538
1.1 : 1.0	-285410	265051	-93	235
1.0 : 1.0	-285317	264816	0	0
1.0 : 1.1	-285440	264683	-123	-133
1.0 : 1.2	-285742	264650	-425	-166
1.0 : 1.3	-286179	264695	-862	-121
1.0 : 1.4	-286721	264800	-1404	-16
1.0 : 1.5	-287345	264954	-2028	138
1.0 : 1.6	-288034	265145	-2717	329

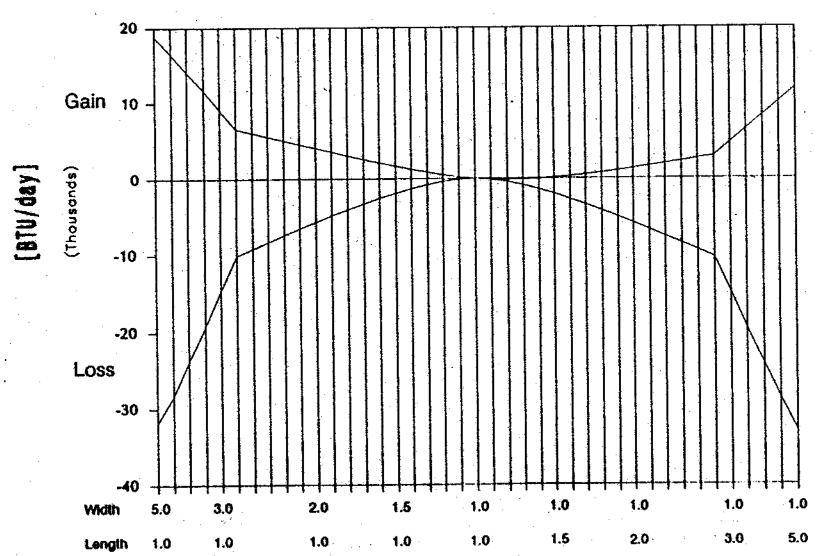

Fig. 6.17 Daily average heat gain and heat loss for the WSW orientation

Table 6.20 Daily average heat gain and heat loss in buildings oriented to the NNE [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-292865	252059	-2564	330
1.5 : 1.0	-292184	251867	-1883	138
1.4 : 1.0	-291574	251713	-1273	-16
1.3 : 1.0	-291052	251608	-751	-121
1.2 : 1.0	-290642	251563	-341	-166
1.1 : 1.0	-290376	251596	-75	-133
1.0 : 1.0	-290301	251729	0	0
1.0 : 1.1	-290449	251963	-148	234
1.0 : 1.2	-290781	252267	-480	538
1.0 : 1.3	-291251	252622	-950	893
1.0 : 1.4	-291830	253016	-1529	1287
1.0 : 1.5	-292492	253440	-2191	1711
1.0 : 1.6	-293220	253887	-2919	2158

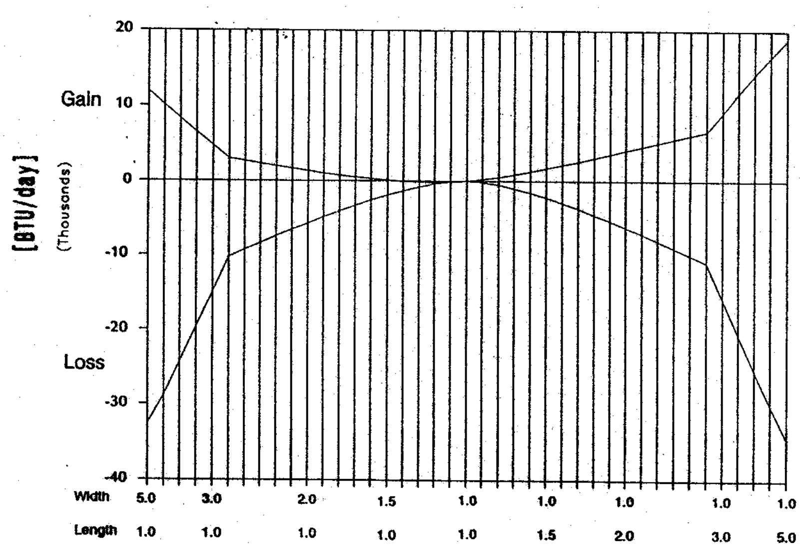

Fig. 6.18 Daily average heat gain and heat loss for the NNE orientation

Table 6.21 Daily average heat gain and heat loss in buildings oriented to the NNW [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-292431	253366	-2770	330
1.5 : 1.0	-291723	253174	-2062	138
1.4 : 1.0	-291083	253021	-1422	-15
1.3 : 1.0	-290529	252915	-868	-121
1.2 : 1.0	-290083	252871	-422	-165
1.1 : 1.0	-289779	252903	-118	-133
1.0 : 1.0	-289661	253036	0	0
1.0 : 1.1	-289767	253271	-106	235
1.0 : 1.2	-290059	253575	-398	539
1.0 : 1.3	-290494	253930	-833	894
1.0 : 1.4	-291038	254324	-1377	1288
1.0 : 1.5	-291669	254748	-2008	1712
1.0 : 1.6	-292368	255195	-2707	2159

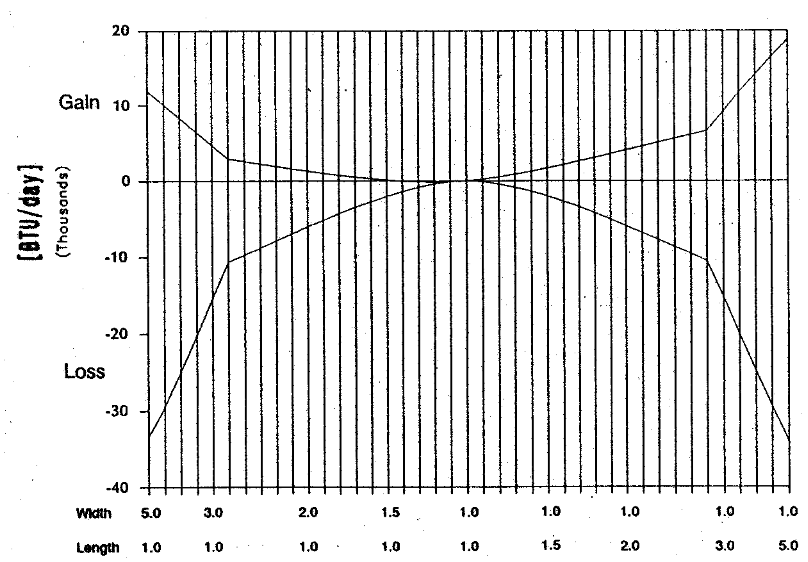

Fig. 6.19 Daily average heat gain and heat loss for the NNW orientation

Table 6.22 Daily average heat gain and heat loss in buildings oriented to the ENE [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-287900	264418	-2630	2159
1.5 : 1.0	-287221	263971	-1951	1712
1.4 : 1.0	-286607	263547	-1337	1288
1.3 : 1.0	-286078	263152	-808	893
1.2 : 1.0	-285656	262797	-386	538
1.1 : 1.0	-285372	262493	-102	234
1.0 : 1.0	-285270	262259	0	0
1.0 : 1.1	-285385	262126	-115	-133
1.0 : 1.2	-285680	262093	-410	-166
1.0 : 1.3	-286112	262138	-842	-121
1.0 : 1.4	-286651	262243	-1381	-16
1.0 : 1.5	-287272	262396	-2002	137
1.0 : 1.6	-287960	262588	-2690	329

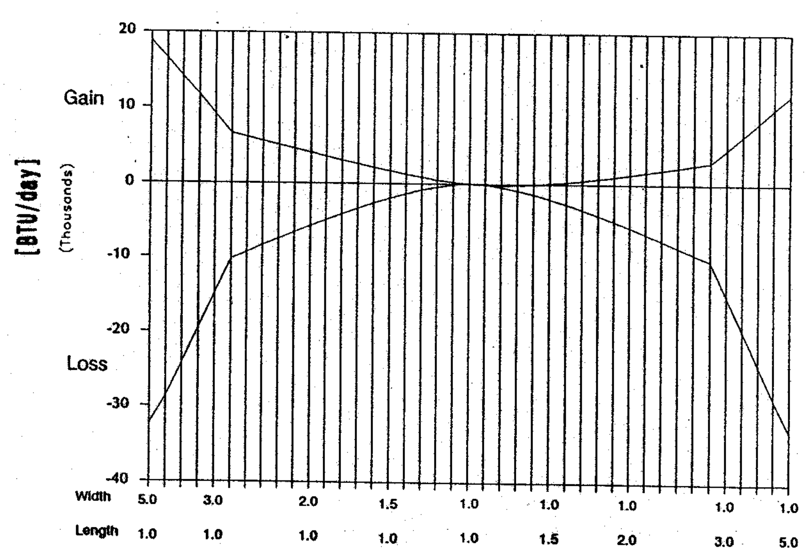

Fig. 6.20 Daily average heat gain and heat loss for the ENE orientation

Table 6.23 Daily average heat gain and heat loss in buildings oriented to the WNW [BTU/day]

W : L	Winter loss	Summer gain	Loss diff.	Gain diff.
1.6 : 1.0	-291691	266269	-2877	2158
1.5 : 1.0	-290973	265822	-2159	1711
1.4 : 1.0	-290320	265399	-1506	1288
1.3 : 1.0	-289749	265004	-935	893
1.2 : 1.0	-289286	264649	-472	538
1.1 : 1.0	-288960	264346	-146	235
1.0 : 1.0	-288814	264111	0	0
1.0 : 1.1	-288890	263978	-76	-133
1.0 : 1.2	-289153	263946	339	-165
1.0 : 1.3	-289558	263991	-744	-120
1.0 : 1.4	-290075	264096	-1261	-15
1.0 : 1.5	-290678	264249	-1864	138
1.0 : 1.6	-291351	264441	-2537	330

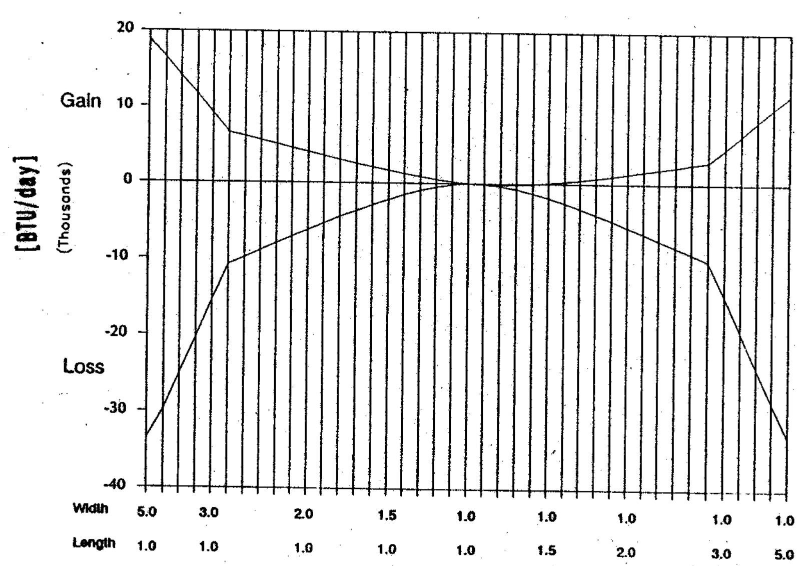

Fig. 6.21 Daily average heat gain and heat loss for the WNW orientation