

LIST OF CONTENTS

Chapter	Page
I INTRODUCTION	1
Overview	1
Objectives of the study	4
Hypothesis of the study	4
Scope of the study	4
II THEORY AND RELATED LITERATURE REVIEW	6
History of the autoclaved aerated concrete	6
Materials Used in Manufacture	7
Quality classes of autoclaved aerated concrete	9
Tobermorite	9
Phase change materials (PCMs)	11
Classification	11
Organic PCMs	11
Inorganic PCMs	12
Eutectics	13
Transition of PCMs for building materials	14
Traditional PCM	14
Encapsulated PCM	15
Shape-stabilized PCM	16
Heat transfer	17
Conduction	17
Plane wall	19
Convection	21
Radiation	22
Emission of radiation	23
The heat flux time lag and decrement factor	24
Life-Cycle Assessment	26

LIST OF CONTENTS (CONT.)

Chapter	Page
Data analysis	33
Variants	33
III EXPERIMENTAL PROCEDURES	35
Materials Used	36
Experimental instruments.....	37
Experimental procedure in the part of technique	40
Optimum composition for the preparation of autoclaved aerated concrete.....	40
Compressive strength, flexural strength, density, water absorption and tobermorite phase measurement	41
Phase transition behavior of the salt hydrated phase change materials by the differential scanning calorimeter (DSC)	44
Optimum content of applied salt hydrated phase change materials on the autoclaved aerated concrete surface	45
Design and build the 4 test houses with various wall materials.....	48
Test the actual use of 4 houses with various wall materials	49
Experimental procedure in the part of economics.....	52
Payback period (PbP)	52
Net Present Value (NPV)	52
Internal rate of return (IRR)	53
Experimental procedure in the part of environment	53
Goal and scope definition.....	53
Functional Unit.....	54
System boundaries.....	54
Life cycle inventory.....	54
Cut off.....	54

LIST OF CONTENTS (CONT.)

Chapter	Page
Reference.....	54
Procedure of life cycle assessment.....	54
Procedure of autoclaved aerated concrete manufacturing.....	55
IV RESULT AND DISCUSSION	59
Technique analysis.....	59
Analysis results of optimal proportion for autoclaved aerated concrete.....	59
Analysis result of phase change material (PCM).....	73
Phase formation analysis result of autoclaved aerated concrete by X-ray diffraction	75
Microstructure analysis result by the scanning electron microscopy	79
Thermal test results of optimal proportion of autoclaved aerated concrete with different contents of phase change material.....	81
Time lag and decrement factor of the brick wall	81
Time lag and decrement factor of AAC at different conditions	84
Time lag and decrement factor of AAC with containing sugar sediment at different conditions.....	96
Test results of houses with different house walls in actual condition of use	107
Test results in the summer	107
Test results in the simulated rainy season.....	140
Economic analysis.....	172
The part of the consumer.....	172
The part of the manufacturer	176

LIST OF CONTENTS (CONT.)

Chapter	Page
Environmental analysis	178
Impact from the obtaining of raw materials stage, manufacture stage, distribution stage, use stage and disposal stage.....	178
Life cycle impact of improved autoclaved aerated concrete	178
Life cycle impact of commercial autoclaved aerated concrete	186
Life cycle impact of average database of autoclaved aerated concrete	192
Comparison of weighting results of autoclaved aerated concrete in the three conditions.....	198
Impact from the obtaining of raw materials stage, manufacture stage, distribution stage and use stage.....	200
Life cycle impact of improved autoclaved aerated concrete	200
Life cycle impact of commercial autoclaved aerated concrete	206
Life cycle impact of average database of autoclaved aerated concrete	212
Comparison of weighting results of autoclaved aerated concrete in the three conditions	218
V CONCLUSION	220

LIST OF CONTENTS (CONT.)

Chapter	Page
REFERENCES.....	224
BIOGRAPHY	235

LIST OF TABLES

Table	Page
1 Quality class based on the Thai Industrial Standard 1505-1998	9
2 Organic PCMs for residential building using radiant floor heating systems.....	12
3 Inorganic PCMs for residential building using radiant floor heating systems.....	13
4 Eutectics for residential building using radiant floor heating systems.....	14
5 Content of raw materials in AAC: the variation between wet fine sand and sugar sediment (AAC-S)	43
6 Content of raw materials in AAC: the variation between lime and sugar sediment (AAC-L)	44
7 Content of raw materials in AAC: the variation among fine sand, sugar sediment and fine recycling powder (AAC-SSR).....	44
8 The position of the thermocouple lines for the actual use test	51
9 The average density, humidity, water absorption, open porosity volume, compressive strength and flexural strength of AAC-S with the variation between sand and sugar sediment.....	63
10 The average density, humidity, water absorption, open porosity volume, compressive strength and flexural strength of AAC-L with the variation between lime and sugar sediment.....	68
11 The average density, humidity, water absorption, open porosity volume, compressive strength and flexural strength of AAC-SSR with the variation among sand, sugar sediment and fine recycling powder	72
12 The ratio of phase formation of AAC with different compositions	79
13 The total thermal resistance (R), the heat conduction (Q), wall temperature (T_w), and the room temperature (T_{room}), the time lag (τ), and decrement factor (λ) of brick	83

LIST OF TABLES (CONT.)

Table	Page
14 The total thermal resistance (R), the heat conduction (Q), wall temperature (T_w), and the room temperature (T_{room}), the time lag (τ), and decrement factor (λ).....	93
15 The total thermal resistance (R), the heat conduction (Q), wall temperature (T_w), and the room temperature (T_{room}), the time lag (τ), and decrement factor (λ).....	105
16 The characterized properties of construction materials.....	172
17 Electricity consumption of cooling load in the air condition system of the 4 houses.....	173
18 Rate of electricity consumption for the residency.....	174
19 Electricity consumption, electric charge including the service fee and percent energy saving of each house	175
20 The cost for each house construction (Considered only the wall material cost).....	176
21 Comparison of the payback period (PBP), net present value (NPV) and internal rate of return (IRR) with brick wall construction cost.....	177
22 Energy saving from the dig and milling procedure of sand	178
23 Impact assessment of the improved AAC	181
24 Impact assessment of the improved AAC	183
25 Single value of the improved AAC in the each procedure.....	185
26 Impact assessment of Insee superblock AAC	187
27 Impact assessment of Insee superblock AAC	189
28 Single value of Insee superblock AAC in the each procedure	191
29 Impact assessment of average database of AAC in Thailand.....	193
30 Impact assessment of average database of AAC in Thailand.....	195
31 Single score of the average database of AAC used in Thailand.....	197
32 Impact assessment of AAC in the three conditions.....	199
33 Impact assessment of the improved AAC	201

LIST OF TABLES (CONT.)

Table		Page
34	Impact assessment of the improved AAC	203
35	Single value of the improved AAC in the each procedure.....	205
36	Impact assessment of Insee superblock AAC	207
37	Impact assessment of Insee superblock AAC	209
38	Single value of Insee superblock AAC in the each procedure	211
39	Impact assessment of average database of AAC in Thailand	213
40	Impact assessment of average database of AAC in Thailand	215
41	Single score of the average database of AAC used in Thailand	217
42	Impact assessment of AAC in the three conditions.....	219

LIST OF FIGURES

Figures		Page
1	Model of tobermorite structure consisting of protonated silicate ions and water	10
2	Temperature distribution $T(x)$ and heat flow by conduction through a slab	19
3	Temperature distribution for a slab with prescribed temperature at both surfaces	20
4	The schematic of heat flux time lag and decrement factor.....	25
5	The schematic of heat transfer in the wall.....	26
6	Life Cycle Assessment	27
7	Life-cycle of product	28
8	Illustration of LCA flame work.....	29
9	Data for LCA analysis	30
10	Relative analysis between the input process and output process of target product	30
11	Environmental impacts for life-cycle assessment	31
12	The procedure of life-cycle impact assessment.....	32
13	Pattern of Life-cycle assessment	34
14	The diagram of experimental procedure	36
15	Procedure of optimum composition preparation of AAC	42
16	Procedure of physical properties test.....	43
17	The procedure of DSC analysis.....	45
18	Procedure of optimum PCM content study for AAC	47
19	Schematic diagram of the experimental set up.....	47
20	The thermal testing position of AAC	48
21	House pattern for testing	49
22	The setting position of the thermocouple lines of 4 houses	51
23	Autoclaved aerated concrete production procedure	57

LIST OF FIGURES (CONT.)

Figures		Page
24	Life cycle process flow diagram: Autoclaved aerated concrete (G4 type with 20x60x7.5 cm in size).....	58
25	The density of AAC-S with various contents of sugar sediment	60
26	The humidity of AAC-S with different contents of sugar sediment	60
27	(a) The water absorption ratio and (b) the open porous volume of AAC-S with different sugar sediment contents	62
28	(a) The compressive strength and (b) the flexural strength of AAC-S with different contents of sugar sediment.....	63
29	The density of AAC-L with various contents of sugar sediment	64
30	The humidity of AAC-L with different contents of sugar sediment.....	65
31	(a) The water absorption ratio and (b) the open porous volume of AAC-L with different sugar sediment contents.....	66
32	(a) The compressive strength and (b) the flexural strength of AAC-L with different contents of sugar sediment.....	67
33	The density of AAC-SSR with various contents of fine recycling powder	69
34	The humidity of AAC-SSR with different contents of fine recycling powder.....	70
35	(a) The water absorption ratio and (b) the open porous volume of AAC-SSR with different fine recycling powder contents	71
36	(a) The compressive strength and (b) the flexural strength of AAC-SSR with different contents of fine recycling powder	73
37	DSC plots showing the melting point of PCM: (a) S32 and (b) S44	75

LIST OF FIGURES (CONT.)

Figures		Page
38	X-ray diffraction patterns of AAC with different compositions in the 2θ range of 5° to 70° : (I) AAC-S0, (II) AAC-S30, (III) AAC-L7.5, (IV) AAC-SSR0 and (V) AAC-SSR20	78
39	SEM photographs of AAC surface at different systems: (a) AAC, (b) AAC-SS30, (c) AAC-L7.5, (d) AAC-SSR0 and (e) AAC-SSR20.....	80
40	Temperature revolution of brick wall at the test temperature of 40°C	82
41	Temperature revolution of brick wall at the test temperature of 50°C	82
42	Temperature revolution of brick wall at the test temperature of 60°C	83
43	Temperature revolution of AAC at the test temperature of 40°C	85
44	Temperature revolution of AAC at the test temperature of 50°C ...	86
45	Temperature revolution of AAC at the test temperature of 60°C	86
46	Temperature revolution of PCM-coated AAC wall (0.050 kg or $\sim 0.417\text{ kg/m}^2$) at the test temperature of 40°C	87
47	Temperature revolution of PCM-coated AAC wall (0.050 kg or $\sim 0.417\text{ kg/m}^2$) at the test temperature of 50°C	87
48	Temperature revolution of PCM-coated AAC wall (0.050 kg or $\sim 0.417\text{ kg/m}^2$) at the test temperature of 60°C	88
49	Temperature revolution of PCM-coated AAC wall (0.10 kg or $\sim 0.833\text{ kg/m}^2$) at the test temperature of 40°C	88
50	Temperature revolution of PCM-coated AAC wall (0.10 kg or $\sim 0.833\text{ kg/m}^2$) at the test temperature of 50°C	89
51	Temperature revolution of PCM-coated AAC wall (0.10 kg or $\sim 0.833\text{ kg/m}^2$) at the test temperature of 60°C	89

LIST OF FIGURES (CONT.)

Figures		Page
52	Temperature revolution of PCM-coated AAC wall (0.050 kg or ~0.417 kg/m ²) with cement coating in both sides at the test temperature of 40 °C	90
53	Temperature revolution of PCM-coated AAC wall (0.050 kg or ~0.417 kg/m ²) with cement coating in both sides at the test temperature of 50 °C	90
54	Temperature revolution of PCM-coated AAC wall (0.050 kg or ~0.417 kg/m ²) with cement coating in both sides at the test temperature of 60 °C	91
55	Temperature revolution of PCM-coated AAC wall (0.01 kg or ~0.833 kg/m ²) with cement coating in both sides at the test temperature of 40 °C	91
56	Temperature revolution of PCM-coated AAC wall (0.01 kg or ~0.833 kg/m ²) with cement coating in both sides at the test temperature of 50 °C	92
57	Temperature revolution of PCM-coated AAC wall (0.01 kg or ~0.833 kg/m ²) with cement coating in both sides at the test temperature of 60 °C	92
58	Temperature revolution of AAC-SSR wall at the test temperature of 40 °C	97
59	Temperature revolution of AAC-SSR wall at the test temperature of 50 °C	98
60	Temperature revolution of AAC-SSR wall at the test temperature of 60 °C	98
61	Temperature revolution of PCM-coated AAC-SSR wall (0.050 kg or ~0.417 kg/m ²) at the test temperature of 40 °C	99
62	Temperature revolution of PCM-coated AAC-SSR wall (0.050 kg or ~0.417 kg/m ²) at the test temperature of 50 °C ...	99

LIST OF FIGURES (CONT.)

Figures	Page
63	Temperature revolution of PCM-coated AAC-SSR wall (0.050 kg or $\sim 0.417 \text{ kg/m}^2$) at the test temperature of 60°C ... 100
64	Temperature revolution of PCM-coated AAC-SSR wall (0.10 kg or $\sim 0.833 \text{ kg/m}^2$) at the test temperature of 40°C 100
65	Temperature revolution of PCM-coated AAC-SSR wall (0.10 kg or $\sim 0.833 \text{ kg/m}^2$) at the test temperature of 50°C 101
66	Temperature revolution of PCM-coated AAC-SSR wall (0.10 kg or $\sim 0.833 \text{ kg/m}^2$) at the test temperature of 60°C 101
67	Temperature revolution of PCM-coated AAC-SSR wall (0.050 kg or $\sim 0.417 \text{ kg/m}^2$) with cement coating in both sides at the test temperature of 40°C 102
68	Temperature revolution of PCM-coated AAC-SSR wall (0.050 kg or $\sim 0.417 \text{ kg/m}^2$) with cement coating in both sides at the test temperature of 50°C 102
69	Temperature revolution of PCM-coated AAC-SSR wall (0.050 kg or $\sim 0.417 \text{ kg/m}^2$) with cement coating in both sides at the test temperature of 60°C 103
70	Temperature revolution of PCM-coated AAC-SSR wall (0.10 kg or $\sim 0.833 \text{ kg/m}^2$) with cement coating in both sides at the test temperature of 40°C 103
71	Temperature revolution of PCM-coated AAC-SSR wall (0.10 kg or $\sim 0.833 \text{ kg/m}^2$) with cement coating in both sides at the test temperature of 50°C 104
72	Temperature revolution of PCM-coated AAC-SSR wall (0.10 kg or $\sim 0.833 \text{ kg/m}^2$) with cement coating in both sides at the test temperature of 60°C 104
73	Variation of temperature and solar radiation..... 108

LIST OF FIGURES (CONT.)

Figures		Page
74	Variation of relative humidity and solar radiation	109
75	Variation of relative humidity and temperature	109
76	The temperature variation of exterior improved autoclaved aerated concrete wall surfaces	111
77	The temperature variation of interior improved autoclaved aerated concrete wall surfaces	111
78	The temperature change of northerly aspect exterior and interior improved autoclaved aerated concrete wall surfaces.....	113
79	The temperature change of southerly aspect exterior and interior improved autoclaved aerated concrete wall surfaces.....	113
80	The temperature change of easterly aspect exterior and interior improved autoclaved aerated concrete wall surfaces.....	114
81	The temperature change of westerly aspect exterior and interior improved autoclaved aerated concrete wall surfaces.....	114
82	The temperature variation of exterior cement block wall surfaces ..	116
83	The temperature variation of interior cement block wall surfaces ...	116
84	The temperature change of northerly aspect exterior and interior cement block wall surfaces	118
85	The temperature change of southerly aspect exterior and interior cement block wall surfaces	118
86	The temperature change of easterly aspect exterior and interior cement block wall surfaces	119
87	The temperature change of westerly aspect exterior and interior cement block wall surfaces	119
88	The temperature variation of exterior autoclaved aerated concrete wall surfaces	121
89	The temperature variation of interior autoclaved aerated concrete wall surfaces.....	121

LIST OF FIGURES (CONT.)

Figures		Page
90	The temperature change of northerly aspect exterior and interior autoclaved aerated concrete wall surfaces	123
91	The temperature change of southerly aspect exterior and interior autoclaved aerated concrete wall surfaces	123
92	The temperature change of easterly aspect exterior and interior autoclaved aerated concrete wall surfaces	124
93	The temperature change of westerly aspect exterior and interior autoclaved aerated concrete wall surfaces	124
94	The temperature variation of exterior brick house wall surfaces	126
95	The temperature variation of interior surface of brick house wall ...	126
96	The temperature change of northerly aspect exterior and interior brick wall surfaces	128
97	The temperature change of southerly aspect exterior and interior brick wall surfaces	128
98	The temperature change of easterly aspect exterior and interior brick wall surfaces	129
99	The temperature change of westerly aspect exterior and interior brick wall surfaces	129
100	Comparison of northerly aspect exterior wall surface temperature of the 4 houses	131
101	Comparison of northerly aspect interior wall temperature surface of the 4 houses	131
102	Comparison of southerly aspect exterior wall surface temperature of the 4 houses	132
103	Comparison of southerly aspect interior wall surface temperature of the 4 houses.....	133
104	Comparison of easterly aspect exterior wall surface temperature of the 4 houses	134

LIST OF FIGURES (CONT.)

Figures		Page
105	Comparison of easterly aspect interior wall surface temperature of the 4 houses	134
106	Comparison of westerly aspect exterior wall surface temperature of the 4 houses	135
107	Comparison of westerly aspect interior wall surface temperature of the 4 houses	136
108	Heat flux Comparison of easterly aspect wall surface of the 4 houses.....	138
109	Heat flux Comparison of westerly aspect wall surface of the 4 houses.....	138
110	Comparison of room temperature of the 4 houses.....	140
111	Comparison of interior relative humidity of the 4 houses.....	140
112	Variation of temperature and solar radiation.....	141
113	Variation of relative humidity and solar radiation	142
114	Variation of relative humidity and temperature	142
115	The temperature variation of exterior improved autoclaved aerated concrete wall surfaces	143
116	The temperature variation of interior improved autoclaved aerated concrete wall surfaces	144
117	The temperature change of northerly aspect exterior and interior improved autoclaved aerated concrete wall surfaces.....	145
118	The temperature change of southerly aspect exterior and interior improved autoclaved aerated concrete wall surfaces.....	146
119	The temperature change of easterly aspect exterior and interior improved autoclaved aerated concrete wall surfaces.....	146
120	The temperature change of westerly aspect exterior and interior improved autoclaved aerated concrete wall surfaces.....	147
121	The temperature variation of exterior cement block wall surfaces ..	148

LIST OF FIGURES (CONT.)

Figures		Page
122	The temperature variation of interior cement block wall surfaces ...	148
123	The temperature change of northerly aspect exterior and interior cement block wall surfaces	150
124	The temperature change of southerly aspect exterior and interior cement block wall surfaces	150
125	The temperature change of easterly aspect exterior and interior cement block wall surfaces	151
126	The temperature change of westerly aspect exterior and interior cement block wall surfaces	151
127	The temperature variation of exterior autoclaved aerated concrete wall surfaces.....	152
128	The temperature variation of interior autoclaved aerated concrete wall surfaces.....	153
129	The temperature change of northerly aspect exterior and interior autoclaved aerated concrete wall surfaces	154
130	The temperature change of southerly aspect exterior and interior autoclaved aerated concrete wall surfaces	155
131	The temperature change of easterly aspect exterior and interior autoclaved aerated concrete wall surfaces	155
132	The temperature change of westerly aspect exterior and interior autoclaved aerated concrete wall surfaces	156
133	The temperature variation of exterior brick house wall surfaces	157
134	The temperature variation of interior surface of brick house wall ...	157
135	The temperature change of northerly aspect exterior and interior brick wall surfaces	159
136	The temperature change of southerly aspect exterior and interior brick wall surfaces	159

LIST OF FIGURES (CONT.)

Figures		Page
137	The temperature change of easterly aspect exterior and interior brick wall surfaces	160
138	The temperature change of westerly aspect exterior and interior brick wall surfaces	160
139	Comparison of northerly aspect exterior wall surface temperature of the 4 houses	161
140	Comparison of northerly aspect interior wall temperature surface of the 4 houses	162
141	Comparison of southerly aspect exterior wall surface temperature of the 4 houses	163
142	Comparison of southerly aspect interior wall surface temperature of the 4 houses	163
143	Comparison of easterly aspect exterior wall surface temperature of the 4 houses	164
144	Comparison of easterly aspect interior wall surface temperature of the 4 houses	165
145	Comparison of westerly aspect exterior wall surface temperature of the 4 houses	166
146	Comparison of westerly aspect interior wall surface temperature of the 4 houses	166
147	Heat flux Comparison of easterly aspect wall surface of the 4 houses.....	169
148	Heat flux Comparison of westerly aspect wall surface of the 4 houses.....	169
149	Comparison of room temperature of the 4 houses.....	170
150	Comparison of interior relative humidity of the 4 houses.....	171
151	Impact assessment of the improved AAC	180
152	Impact assessment of the improved AAC	182

LIST OF FIGURES (CONT.)

Figures		Page
153	Impact assessment of the improved AAC in the each procedure	184
154	Impact assessment of Insee superblock AAC	186
155	Impact assessment of Insee superblock AAC	188
156	Impact assessment of Insee superblock AAC in the each procedure.....	190
157	Impact assessment of average AAC in Thailand.....	192
158	Impact assessment of average database of AAC in Thailand.....	194
159	Impact assessment of average AAC of the each procedure in Thailand	196
160	Impact assessment of average AAC of the each procedure in Thailand	199
161	Impact assessment of the improved AAC	200
162	Impact assessment of the improved AAC	202
163	Impact assessment of the improved AAC in the each procedure	204
164	Impact assessment of Insee superblock AAC	206
165	Impact assessment of Insee superblock AAC	208
166	Impact assessment of Insee superblock AAC in the each procedure.....	210
167	Impact assessment of average AAC in Thailand.....	212
168	Impact assessment of average database of AAC in Thailand.....	214
169	Impact assessment of average AAC of the each procedure in Thailand	216
170	Impact assessment of average AAC of the each procedure in Thailand	219