

LB/DON/31/09

PERFORMANCE OF INSULATED ROOF SLABS ON BUILT ENVIRONMENTS IN TROPICAL CLIMATES

BY

R. U. HALWATURA,

LIBRARY
UNIVERSITY OF MORATUWA, SRI LANKA
MORATUWA

THESIS SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING IN THE FULFILLMENT OF THE REQUIREMENT FOR THE DOCTOR OF PHILOSOPHY IN ENGINEERING



Research supervised

By

PROF. M. T. R. JAYASINGHE

624 "08"

624 (043)

TH

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MORATUWA
SRI LANKA
SEPTEMBER 2008

92927

University of Moratuwa



92927

92927

ABSTRACT

The countries located close to the equator generally have tropical climatic conditions, where temperatures remain relatively high with humid conditions. Thus, the climatic conditions are usually identified as warm humid. With the rapid urbanization, two different solutions are adopted to meet the housing needs. One is the construction of medium to high rise apartment buildings which has become popular in many large cities located closed to the equator. Another option have been to pursue residential developments with a large number of detached houses located on small blocks of lands.

The energy consumption for buildings is becoming higher and high energy demand and the associated green house gas emission is another critical issue that needs attention in the long run. Global warming can also become a key factor in near future due to environment and climatic changes that are associated with it. This emphasise the need to develop and promote new passive techniques to achieve thermal comfort in built environment. The use of insulated roof slabs provide an alternative that may enable the creation of green cover at roof level. This can also become an alternative solution to the traditional roofs since insulation can be effective in creating desirable indoor conditions needed by free running spaces and the flat slab on top of the building can solve many environmental and social problems arising out of high density residential developments to a certain extent. In addition, this can be an ideal alternative to traditional roofs considering the better cyclone resistance that can be offered due to the self weight.

Considering all these facts, reinforce concrete solid slabs were considered as an alternative. With detailed experimental programmes on small scale models and prototypes, it is shown that a minimum insulation thickness of 25 mm with a material having a conductivity of about 0.03 W/mK can retard the heat flow significantly. In order to ensure that roof slabs have unrestricted access, an innovative solution was proposed and used as the insulation system for the experimental programme. Since it is practically difficult to predict the effect of insulated roof slabs on built environments such as houses using actual model based experiments, simulations have been used with computer software validated for tropical climatic conditions to predict the trends. Since there are strong indications of changing climatic patterns due to global warming, the performance of insulated roof slabs under such future scenarios have also been predicted using appropriately modified climatic files.

In order to emphasise the need to rely on carefully planned micro climate in future, thermal comfort models have been developed considering the climatic acclimatization that is expected from people gradually facing the global warming scenarios over a long period of time. With all these studies, it is highlighted the importance of adopting insulated roof slabs as a solution to combat the heat island effect in built up areas by creating roof top gardens. Since these slabs can be successfully adopted in air-conditioned commercial buildings, life cycle costing approach was used to predict the desirable insulation thickness for air conditioned spaces. With this multi-disciplinary approach, the usefulness of insulated roof slabs as an alternative to traditional roofs have been highlighted.

Key words: Tropical climates, flat roof, heat island effect, global warming, thermal comfort, roof insulation, computer simulation, life cycle cost.

ACKNOWLEDGEMENT

The author is immensely grateful to the research supervisor, Professor M. T. R. Jayasinghe of the Department of Civil Engineering for his invaluable guidance and support throughout the research period.

Author wishes to extend his sincere gratitude to McBerton Polymer Ltd for funding the experimental programme for first two years of the research work.

Author wishes to thankfully acknowledge the excellent support given by Dr. A. A. D. A. J. Perera, Dr Mrs. C. Jayasinghe and Dr. L. L. Ekanayake of Department of Civil Engineering and Professor R. A. Attalage of Department of Mechanical Engineering.

Author would like to thanks Mr. R. M. J. S. B. Rathnayake and Mr. J. M. C. G. Jayasinghe, who have supported in numerous ways to complete the questionnaire surveys. Sincere gratitude is also due for all those who participated in the questionnaire survey.



University of Moratuwa, Sri Lanka.
Electronic Thesis & Dissertations
www.lib.mrt.ac.lk

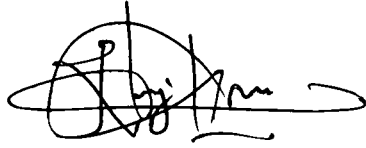
The support given by Prof. W. P. S. Dias (Head, Department of Civil Engineering), and Prof. S. A. S. Kulathilake (Research Coordinator, Department of Civil Engineering) is acknowledged gratefully. All the other lectures and research students are thanked for the positive attitude they adopted in promoting research at Civil Engineering Department.

The technical officers of the Department of Civil Engineering, Messrs S. P. Madanayake, S. L. Kapuruge, H. P. Nandaweera, G. V. Somarathna and laboratory assistants Mr. L. Perera and Mr. H. N. Fernando assisted the detailed experimental programme very much. Mr. J. M. Gunasekara helped in many ways with the apparatus manufactured.

Finally, the author wishes to thank all those who contributed to the completion of this project successfully.

DECLARATION

I, Rangika Umesh Halwatura, hereby declare that the content of this thesis is the output of the original research work carried out over a period of 45 months at the Department of Civil Engineering , University of Moratuwa. Whenever any work by others is included in this thesis, it is appropriately indicated as a reference.

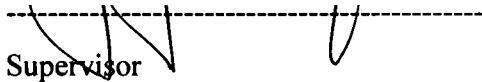


Eng. R U Halwatura
Department of Civil Engineering
University of Moratuwa
Sri Lanka



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

UOM Verified Signature _



Supervisor
Prof. M T R J ayasinghe
Department of Civil Engineering
University of Moratuwa
Sri Lanka

Contents

Abstract	i
Acknowledgement	ii
Declaration	iii
Contents	iv
List of Figures	viii
List of Tables	xii

1	INTRODUCTION	1
1.1	General	1
1.2	The objectives	3
1.3	The methodology	4
1.4	The main findings	5
1.5	The arrangement of the report	5
2	LITERATURE REVIEW	7
2.1	General	7
2.2	Thermal comfort in tropical climates	7
2.2.1	Human body responses to environment conditions	8
2.2.2	Thermal comfort	10
2.2.3	The climate	11
2.2.4	Tropical climatic conditions	11
2.2.5	Climate in Sri Lanka.....	13
2.2.6	Psychrometric chart and comfort zone	16
2.3	Energy crisis and global warming	23
2.3.1	High energy demand.....	23
2.3.2	Energy demand in Sri Lanka	28
2.4	Use of passive techniques	32
2.4.1	Thermal comfort standard for passive buildings	32
2.4.2	Thermal insulation	33
2.4.3	Factors that affect the choice of insulating materials	35
2.4.4	Natural ventilation	38
2.5	Use of roof top garden	40
2.5.1	Solid slab as roofs.....	40
2.5.2	Vegetation and their effects on micro-climate	43
2.5.3	Roof top vegetation	46
2.6	Need for disaster resistance	50

2.6.1	Tropical cyclones.....	50
2.6.2	Earthquake	53
2.7	The effects of anticipated climate change.....	57
2.7.1	The reasons for climate change	58
2.7.2	The activities responsible for greenhouse gases.....	59
2.7.3	The effects of climate change.....	59
2.7.4	The global warming.....	60
2.7.5	Heat Island effect.....	61
2.7.6	Factors Contributing to the Heat Island Effect.....	63
2.8	Life cycle cost	64
2.8.1	Service life.....	66
2.8.2	Inflation	66
2.9	Summary	67
3	ROOF SLAB INSULATION SYSTEM.....	70
3.1	General	70
3.2	The insulation system	71
3.2.1	The arrangement.....	71
3.2.2	The reinforcement for the covering concrete	73
3.2.3	Concrete mix.....	74
3.2.4	Effect of Silica fume on concrete	76
3.2.5	Thickness of resistive insulation.....	77
3.2.6	The experimental setup.....	77
3.2.7	The load testing	78
3.2.8	Durability of concrete.....	80
3.2.9	Thermal characteristics.....	83
3.3	Results of experimental studies on models.....	86
3.4	Summary	90
4	PERFORMANCE OF LARGE BUILDINGS.....	91
4.1	General	91
4.2	Large model.....	91
4.3	Thermal measurements.....	94
4.4	Possibility to use vegetation cover.....	97
4.5	Computer simulation for predicting the performance.....	100
4.6	Validation of simulation results.....	106
4.7	Temperature comparison with different insulation thickness	109
4.8	Insulated roof slabs with global warming effect.....	110
4.9	Thermal performance with insulated roofs.....	115

4.10	Summary	119
5	A COMPARISON WITH TRADITIONAL ROOFS	121
5.1	General	121
5.2	Comparison with traditional roofs.....	121
5.2.1	Different roofing types	121
5.2.2	Computer simulations.....	122
5.2.3	Data used for the simulations	123
5.2.4	The computer model	126
5.2.5	Effect of ceiling type	128
5.2.6	Effect of roofing material without insulation	129
5.2.7	Effect of roofing material with insulation	132
5.2.8	Findings of computer simulations	134
5.3	Social acceptability	135
5.3.1	The details of the participants.....	136
5.3.2	The details related to thermal comfort.....	138
5.3.3	Response to thermal discomfort	141
5.3.4	The preferred type of neighbourhood	144
5.3.5	Findings from the questionnaire survey	144
5.4	Summary	146
6	LIFE CYCLE COSTING	147
6.1	General	147
6.2	The need for life cycle costing.....	148
6.3	Life cycle cost with free running buildings	148
6.4	Air conditioning load in multi storey buildings	149
6.4.1	General information on questionnaire survey	150
6.4.2	The details related to thermal comfort.....	151
6.4.3	The details related to the air condition loads	154
6.4.4	Findings from the questionnaire survey	157
6.5	Life cycle with air conditioning	158
6.5.1	Initial cost	158
6.5.2	Service life.....	159
6.5.3	Discount rate.....	159
6.5.4	The model used.....	159
6.5.5	Life cycle cost analysis.....	160
6.6	Life cycle cost comparison with global warming.....	166
6.7	Disaster resistance	173
6.7.1	The possibility for uplifting of roof slabs	176
6.7.2	Other advantages	176
6.8	Summary	177

7	CONCLUSIONS AND FUTURE WORK.....	178
7.1	The main conclusions	178
7.2	Future work.....	180
	REFERENCES	182
	Appendix	193
	Appendix A: The design calculation for the covering concrete	193
	Appendix B: About DEROB-LTH.....	193
	Appendix B: About DEROB-LTH.....	194
	Appendix C: Climatic Data Files.....	195
	Appendix D: Detail results on computer simulations with tree shadings.....	198
	Appendix E: Questionnaire survey format I.....	207
	Appendix F: Detail tables of computer simulation on free running buildings	210
	Appendix G: Questionnaire Survey Format II	219



University of Moratuwa, Sri Lanka.
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Figure

Figure 1.1: The main climatic zone of the world	1
Figure 2.1: Body heat loss and air temperature	8
Figure 2.2: Heat exchange of the body (from Rosenlund, 2000)	9
Figure 2.3: Map of world's climate.....	13
Figure 2.4: Mean monthly temperatures in different parts of Sri Lanka for January to June .	14
Figure 2.5: The Psychrometric chart	18
Figure 2.6: Comfort Zone for low altitudes of Sri Lanka.....	20
Figure 2.7: Comfort Zone for Colombo, Sri Lanka.....	22
Figure 2.8: Population Living in Urban Areas	24
Figure 2.9: Urban and Rural Populations, 1950-2030.....	25
Figure 2.10: Predicted electricity demand for Sri Lanka.....	29
Figure 2.11: Existing and Proposed power generation capacities	29
Figure 2.12: Deferent categories of the end uses for electrical energy	30
Figure 2.13: Energy consumption for different type of applications	31
Figure 2.14: CEB load profile for small commercial and industry by end use	31
Figure 2.15: Typical houses in Indonesia.....	39
Figure 2.16: Sections of the different tested roofs.....	41
Figure 2.17: Definitions of 'cold' and 'warm' materials.....	42
Figure 2.18: Usefulness of trees	45
Figure 2.19: Greenery on buildings in the forms of rooftop garden, podium garden, balcony planting, fac-ade greenery. (http:// www.nparks.gov.sg/gardencity/skyrise.shtml).....	46
Figure 2.20: Typical tropical cyclonic tracks	51
Figure 2.21: The typical cyclonic belt and the usual cyclonic paths.....	52
Figure 2.22: Three wind zones in Sri Lanka and its comparison with values recommended for South India.....	52
Figure 2.23: Typical anchor arrangement.....	53
Figure 2.24: Typical roof bracing detail	53
Figure 2.25: A world map showing the tectonic plates	54
Figure 2.26: Reassembly of Sri Lanka in Gondwanaland and subdivisions in Madagascar and South.....	56
Figure 2.27: Global atmospheric concentration of CO ₂ with changes occurred in recent times	58
Figure 2.28: Annual temperature trends for the period 1901 to 1996	61
Figure 2.29: Urban heat island effect	61
Figure 2.30: Economic thickness of insulation	65
Figure 2.31: Inflation rate in Singapore.....	67
Figure 3.1: Detail arrangement of the insulation system proposed over reinforced concrete slabs	72
Figure 3.2: Arrangement of small scale models	78
Figure 3.3: Sample panel for strength testing.....	79
Figure 3.4: Loading arrangement of the sample panel	80
Figure 3.5: The sorptivity testing specimen	82
Figure 3.6: Plan view of the insulation arrangement.....	85

Figure 3.7: Soffit temperature distribution for different insulation thicknesses.....	87
Figure 3.8: Heat flow values for different insulation thicknesses	88
Figure 3.9: Surface temperatures for 25 mm insulation system	89
Figure 4.1: Large scale model	92
Figure 4.2: Laying of insulation panels.....	92
Figure 4.3: Resistive insulation panels with reinforcement mesh placed on cover blocks	93
Figure 4.4 : Proposed flashing arrangement.....	93
Figure 4.5: Sample parapet wall.....	94
Figure 4.6: Temperature distribution before installation.....	95
Figure 4.7: Temperature distributions after installation	96
Figure 4.8: Temperature comparison for before and after insulation.....	96
Figure 4.9: Heat flow through the slab	97
Figure 4.10: The model with an insulated roof slab provided with isolated plants.....	99
Figure 4.11: The temperature measurements with and without the roof top garden.....	100
Figure 4.12: Plan views of the model.....	103
Figure 4.13: Simplified floor plans of the house used for the computer simulations.....	103
Figure 4.14: Computer model of two storey houses with an insulated roof slab	105
Figure 4.15: The indoor and slab soffit temperatures for April and December	105
Figure 4.16: The outdoor and slab top temperatures with difference levels of transmittance through shading screens as indicated in brackets	106
Figure 4.17: Large scale models.....	107
Figure 4.18: Three dimensional computer models for the selected buildings.....	107
Figure 4.19: Temperature measurement for the model with flat slab.....	108
Figure 4.20: Temperature measurement for the model with sloping roof.....	108
Figure 4.21: Slab soffit temperatures for different insulation thicknesses	109
Figure 4.22: Indoor temperature comparison for different insulation thickness	109
Figure 4.23: Volume 4 indoor temperature variation with global warming.....	111
Figure 4.24: Upper floor slab soffit temperature variation with global warming	111
Figure 4.25: Upper floor volume temperature variation with global warming	112
Figure 4.26: Slab soffit temperature variation with global warming	113
Figure 4.27: Slab top temperature variation with global warming.....	113
Figure 4.28: Upper floor volume temperature variation with global warming for 25 mm, 38 mm and 50 mm insulation thickness	113
Figure 4.29: Upper floor slab soffit temperature variation with global warming for 25 mm, 38 mm and 50 mm insulation thickness	114
Figure 4.30: Upper floor slab top temperature variation with global warming for 25 mm, 38 mm and 50 mm insulation thickness	114
Figure 4.31: Modified comfort zone for tropical low lands	116
Figure 4.32: Modified comfort zone when the outdoor temperature increase by 2 °C	117
Figure 4.33: Modified comfort zone when the outdoor temperature increase by 4 °C	119
Figure 5.1: Plan views of the model.....	127
Figure 5.2: Simplified floor plans of the house used for the computer simulations.....	127
Figure 5.3: Three dimensional view of computer models.....	128
Figure 5.4: Ceiling soffit temperatures for different ceiling types	129
Figure 5.5: Volume temperatures for different ceiling types	129
Figure 5.6: Temperature variation in the upper floor room(Volume 4).....	130



Figure 5.7: Temperature variation in the ground floor room(Volume 1).....	131
Figure 5.8: Temperature variation in the ceiling soffit (Volume 4)	131
Figure 5.9: Temperature variation in the slab soffit (Volume 1).....	132
Figure 5.10: Temperature variation in the upper floor room (Volume 4) with insulations...	133
Figure 5.11: Temperature variation in the ground floor room (Volume 1) with insulations	133
Figure 5.12: Temperature variation in the ceiling soffit (Volume 4) with insulation	134
Figure 5.13: Temperature variation in the slab soffit (Volume 1) with insulation.....	134
Figure 5.14: An indication of gender of those who participated	136
Figure 5.15: Percentages from seven districts selected	136
Figure 5.16: Age group of the participants.....	137
Figure 5.17: Occupation of the participants	137
Figure 5.18: Type of house that they occupy at present.....	138
Figure 5.19: Number of occupants in a house	138
Figure 5.20: Material used for wall construction	139
Figure 5.21: Colour of the external surfaces	139
Figure 5.22: Colour of the interior walls	139
Figure 5.23: Colour of the floor.....	140
Figure 5.24: Type of roofing materials used	140
Figure 5.25: Type of ceiling	141
Figure 5.26: Colour of roof or ceiling facing the occupants	141
Figure 5.27: Colour of the roof facing sun	141
Figure 5.28: Whether the house was considered too warm.....	142
Figure 5.29: The response to the thermal comfort.....	142
Figure 5.30: Number of fans usually used.....	143
Figure 5.31: Type of heat barriers used over the roof	143
Figure 5.32: Availability of a roof top garden.....	143
Figure 5.33: Preferred type of neighborhood	144
Figure 5.34: Preferred type of house	144
Figure 6.1: The selected participants from different districts.....	150
Figure 6.2: Type of building.....	151
Figure 6.3: Different roof types.....	151
Figure 6.4: Different ceiling types.....	152
Figure 6.5: External wall covering material	152
Figure 6.6: External wall appearance	153
Figure 6.7: Internal wall appearance	153
Figure 6.8: Floor appearance	153
Figure 6.9: Protection for windows	154
Figure 6.10: Type of the air conditioning machine	154
Figure 6.11: Availability of roof top garden.....	155
Figure 6.12: View about the environmental pollution.....	155
Figure 6.13: Dry bulb, wet bulb and A/C machine temperatures.....	156
Figure 6.14: Psychrometric chart with extended comfort zone.....	156
Figure 6.15: Computer models of three storey buildings	160
Figure 6.16: Life cycle cost with 50% land regaining for Rs. 100,000/= per perch	164
Figure 6.17: Life cycle cost with 50% land regaining for Rs. 200,000/= per perch	164
Figure 6.18: Life cycle cost with 100% land regaining for Rs. 100,000/= per perch	165

Figure 6.19: Life cycle cost with 100% land regaining for Rs. 200,000/= per perch	165
Figure 6.20: Life cycle cost without any land recovery factors for 2 °C increase (Case 1)..	167
Figure 6.21: Life cycle cost with 50% land regaining for Rs. 100,000/= per perch for 2 °C increase (Case 1).....	168
Figure 6.22: Life cycle cost with 50% land regaining for Rs. 200,000/= per perch for 2 °C increase (Case 1).....	168
Figure 6.23: Life cycle cost with 100% land regaining for Rs. 100,000/= per perch for 2 °C increase (Case 1).....	169
Figure 6.24: Life cycle cost with 100% land regaining for Rs. 200,000/= per perch for 2 °C increase (Case 1).....	169
Figure 6.25: Life cycle cost without any land recovery factors for 4 °C increase (Case 2)..	170
Figure 6.26: Life cycle cost with 50% land regaining for Rs. 100,000/= per perch for 4 °C increase (Case 2).....	171
Figure 6.27: Life cycle cost with 50% land regaining for Rs. 200,000/= per perch for 4 °C increase (Case 2).....	171
Figure 6.28: Life cycle cost with 100% land regaining for Rs. 100,000/= per perch for 4 °C increase (Case 2).....	172
Figure 6.29: Life cycle cost with 100% land regaining for Rs. 200,000/= per perch for 4 °C increase (Case 2).....	172
Figure 6.30: Three wind zones in Sri Lanka	174
Figure 6.31: Typical single storey house.....	175



University of Moratuwa, Sri Lanka.
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Tables

Table 2.1: Annual mean temperature and neutrality temperature for various towns in Sri Lanka	21
Table 2.2: The average occurrence of earthquakes of different magnitudes.....	55
Table 2.3: Earthquakes in the vicinity of Colombo (Abayakoon 1998).....	57
Table 3.1: Initial mix proportions used for initial investigations	75
Table 3.2: The average compressive strength of concrete at 7 days and 28 days for defferent concrete mixes	75
Table 3.3: Concrete mixes with 5% Silica fume	76
Table 3.4: Average compressive strength of concrete with Silica fume	76
Table 3.5: Different mixes considered for sorptivity test.....	81
Table 3.6: Sorptivity test results of the mixes	83
Table 3.7: Thermal conductivity of material used.....	84
Table 3.8: Surface resistance values used for the calculation	85
Table 3.9: Thermal expansion over 10 m length for 125 mm slab with the proposed insulation system	89
Table 4.1: Material Properties used for the computer simulation	101
Table 4.2: Absorptance and admittance of building elements used for the computer simulation	101
Table 4.3: Building elements used for the computer simulation.....	102
Table 4.4: Average climatic data applicable to Colombo, Sri Lanka.....	104
Table 5.1: Roofing materials used in houses in Sri Lanka.....	122
Table 5.2: Climatic data used for the computer simulation.....	123
Table 5.3: Material Properties used for the computer simulation	124
Table 5.4: Building elements used for the computer simulation.....	124
Table 5.5: Absorptance and admittance of building elements used for the computer simulation	125
Table 6.1: The individual cost component for different roofing arrangements.....	158
Table 6.2: Air conditioning load for different options	162
Table 6.3: Air conditioning cost for different options.....	162
Table 6.4: Life Cycle Cost per square meter the simulations.....	163
Table 6.5: Pay back time for all the cases expressed in years	166
Table 6.6: Pay back time for all the cases expressed in years for 2 °C increase (Case 1).....	170
Table 6.7: Pay back time for all the cases expressed in years for 4 °C increase (Case 2).....	173
Table 6.8: Maximum uplift forces for a slopping roof (kN/m ²).....	175
Table 6.9: Maximum uplift forces for a flat slab (kN/m ²).....	176