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Performance of Insulated Roofs with Elevated Outdoor Conditions Due to Global Warming

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Abstract

Global warming is a serious condition when it comes to analyzing how to achieve thermal comfort by natural means. With the predicted rise of temperature from 2-4 ^{0}C, the probability of people turning to alternative thermal comfort options such as air conditioning would increase creating energy crises. Therefore, it is necessary to investigate building construction methods that increase thermal comfort. This study was aimed at evaluating the effect of expected global warming on thermal comfort related expectations of people and to develop strategies that can assist to minimize the energy needed for thermal comfort especially in tropical climates. The results suggest that construction of multi-storey houses with small foot print and insulated concrete slab as roof has the possibility of creating desirable micro–climates. The concrete slab roof provides the possibility of creating roof top vegetation which can significantly reduce the indoor temperature.

Keywords: Global warming, Insulated concrete slab, Roof top vegetation, comfort zone, Indoor temperature

1 Introduction

Global warming initiated by various human activities is a serious concern when considering the possibility of gaining thermal comfort through natural means in tropical climatic conditions [1]. It is likely that most of the tropical climates, where passive houses can perform reasonably satisfactorily for a major portion of the year, may become too warm and persuade people to install more energy consuming active means such as air conditioning [2, 3 and 4]. Since the electricity generation for higher air conditioning loads can be an additional source of green house gas emission, it would be necessary to find suitable options that would rely less on energy consuming active means [5].

Climatic acclimatization is one of the ways available to face climatic changes associated with global warming i.e. people adapting to climates that they have lived for a long period of time. Another way to face climatic changes is creation of more conducive environments that may be able to create micro-climates with slightly lower temperatures than the usual. This paper critically evaluates many solutions that can be adopted as an integrated approach to face the threat of global warming in countries with tropical climatic conditions [6].

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2 Objective

The main objective of this research is to predict the effect of expected global warming on thermal comfort related expectations of people and to develop strategies that can assist to minimize the energy needed for thermal comfort especially in tropical climates.

3 Methodology

The research was based on the following methodology. 1. The thermal comfort model that is being widely used at present was critically reviewed

2. The changes that can be expected for such models with future temperature rises were investigated
3. The strategies that can be adopted to create more desirable micro climates were evaluated as planning provisions and changes to structural forms.
4. These findings are presented as an integrated approach for wider adaptation in regions with tropical climatic conditions.

4 Critical review

4.1 Effects of global warming

The effects of global warming are of speculative nature. It may vary between 1.2 ^{0}C to 5.8 ^{0}C in the next 100 years [7]. However, due to various positive measures adopted such as creation of carbon sinks and controlling of green house gas emissions, it may be reasonable to assume a temperature rise of about 2 ^{0}C to 4 ^{0}C in the next 50- 100 years. Such temperature rises would be likely to change the somewhat favorable conditions of tropical climates to a situation that needs special attention [8]. For example, the maximum temperature of a tropical city such as Colombo, Sri Lanka (Latitudes of 7^0 and longitude of 79^0) generally remains at about 30 ^{0}C due to many cloudy days that are often experienced almost every month [2]. Such conditions are expected to gradually change with global warming where the average monthly maximum temperature may rise to about 32 ^{0}C to 34 ^{0}C despite the associated intensities of solar radiation remaining approximately the same. Such rise in temperatures is likely to affect the average daily temperatures. It may be reasonable to expect that average annual minimum temperatures may also to rise by the same margin as the average maximum temperatures. This means that the average monthly temperature is likely to changes by about 2 ^{0}C – 4 ^{0}C while the solar radiation intensities are likely to remain approximately the same.

4.2 Thermally comfortable conditions

The ability to provide acceptable level of thermal comfort is an essential feature expected from built environments. The most desirable temperatures for indoors can be identified as neutrality temperature [9]. It can be calculated by using $T_n = 0.31\ T_{mean} + 17.6$ [10]. For example, for the month of March, 2013 in Colombo, Sri Lanka, the mean monthly temperature is 27.2 ^{0}C. The corresponding T_n will be about 26.0 ^{0}C. The mean annual temperature is 26.9 ^{0}C and the corresponding T_n is 25.9 ^{0}C. This means that a neutrality temperature of about 26 ^{0}C would be a reasonable value irrespective of the month under consideration since tropical climatic conditions would not indicate substantially distinct seasons. The climatic data and neutrality temperatures for Colombo, Sri Lanka are given in Appendix A.

In tropical climatic conditions, it is difficult to experience temperatures as low as neutrality values except during night time. However, people tend to have reasonable tolerance and according to Sokolay [10], a variation of $\pm$ 2 ^{0}C is acceptable. The studies done by de Dear and Brager [11] indicate a variation of $\pm$ 3.5 ^{0}C. The adaptation of the suggestions by Dear and Brager [11] would result a comfort zone as shown in Figure 1 where the indoor air velocity can be taken as less than 0. 25 ms^{-1}.

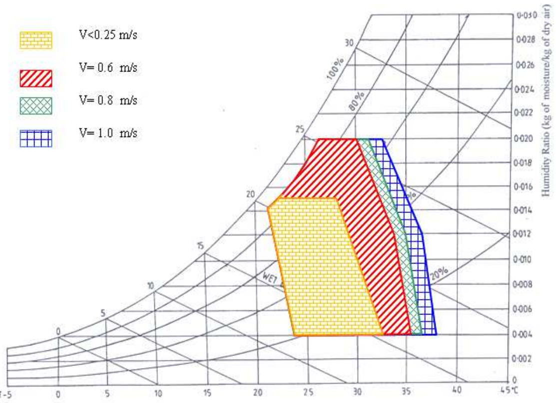

Figure 1: Modified comfort zone for tropical low lands

The strategy that is often used in tropical climatic conditions is physiological effects of cooling by having enhanced air velocities close to the people either with natural or artificial means such as fans. This is taken into account when expanding the comfort zone by an amount equal to $6V-V^2$ where V is the average air velocity. The extended comfort zone is also shown in Figure 1. When global warming occurs gradually over the years, it is likely to have climatic acclimatization by people who live in tropical regions. This may be coupled with adapting to climatic changes by changing the clothing to a certain extent and also changing the expectation to a certain extent. It is reported [12] that people consider changes as of dynamic nature and respond to them by using weather forecast, which may directly influence their perception and expectation for a particular day.

When global warming shifts the average temperature by 2 ^{0}C to about 4 ^{0}C, the neutrality temperature will increase only by about 0.6 ^{0}C. This indicates that climatic acclimatization will be of much smaller scale than the temperature change that may occur due to global warming. The corresponding comfort zones are shown in Figure 2 where the neutrality temperature was considered as 26 ^{0}C.

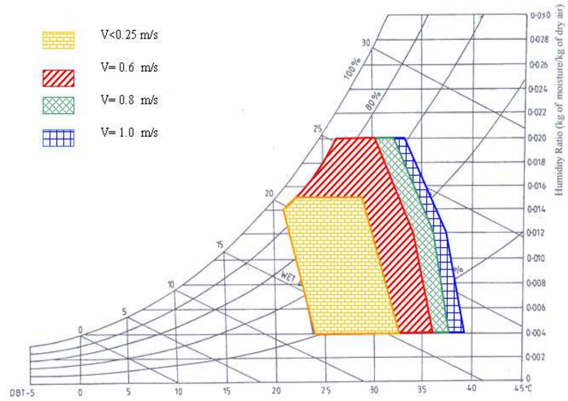

Figure 2: Modified comfort zone when the outdoor temperature increase by 2 ^{0}C

The comfort zone corresponding to a temperature rise of 4 ^{0}C is shown in Figure 3. The neutrality temperature correspond to 4 ^{0}C rise in annual average temperature is about 27.2 ^{0}C.

The three comfort zones corresponding to present climatic conditions and possible scenarios that can be expected in future due to global warming indicate that special strategies will be necessary with free running built environments that will not use energy intensive means such as air conditioning.

4.3 Creation of desirable micro–climates

Built environments consisting of walls and roofs have a tendency to absorb and store heat. Thus, built environments created with high densities on small blocks of land in tropical climates have a tendency to promote heat island effects. The only source that can reduce the occurrence of heat island effect is vegetation. However, the use of conventional roof will not allow the creation of such vegetation with adequate density especially with high density developments consisting of detached houses. One possible strategy is the construction of multi-storey houses with small foot print and then to have insulated concrete slab as roof. An insulation system that can allow unrestricted access is shown in Figure 4 and the proposed roof slab insulation system consists of a 25 mm insulation layer and a screed on top to protect it, which is supported by 40mm thick strips of concrete in 500mm spacing. the reinforced concrete covering slab can be considered as a continuous slab, which is supported at every 500mm intervals due to the strip arrangement around the insulation panel. Several aspects were considered while designing the system. Panel size was decided based on the strength of covering concrete and panel size that can be achieved with minimum wastage. Among two sizes considered, 1m x 1m and 0.5m x 0.5m, it was found that the latter could perform better.

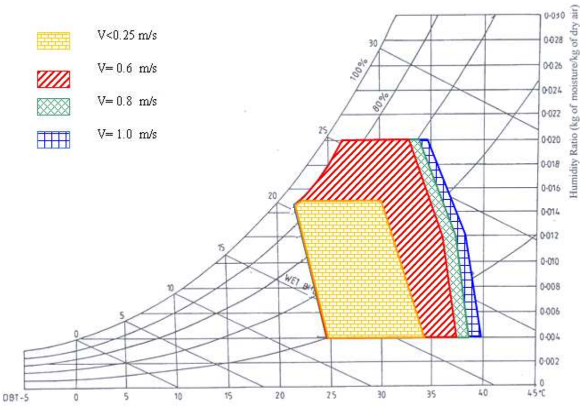

Figure 3: Modified comfort zone when the out door temperature increase by 4 ^{0}C

the reinforced concrete covering slab can be considered as a continuous slab, which is supported at every 500mm intervals due to the strip arrangement around the insulation panels. This arrangement can provide very effective support to the covering concrete of 40 mm thick. Thus, the strength is not derived from the strength of the resistive insulating material. This will be extremely useful for creating a roof top space, which will not have any restrictions for access. The thermal expansion also could be confined primarily to the covering concrete and hence has the potential to minimize the serviceability problems [13]. The small foot print of multi-storey construction could allow greater spaces for creating green environment around the houses. This can be coupled with vegetation at roof top level.

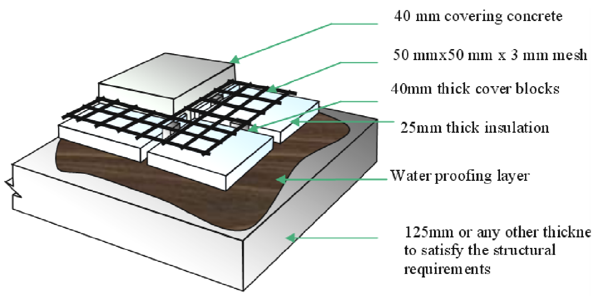

Figure 4: Detailed arrangement of the insulation system proposed over reinforced concrete slabs

4.4 Computer simulations

Global warming can increase the outdoor temperature without a significant increase in solar intensities. DEROB-LTH models can be used to predict the situation that would arise in such a scenario [14, 15 and 16]. The scenarios considered can be 2 ^{0}C and 4 ^{0}C rise. The comparisons can be made with roof top temperatures, soffit temperatures and indoor temperatures. The roof slab insulation was considered with insulation thicknesses of 25 mm, 38 mm and 50 mm. Such a comparison will shed light on strategies that would be needed on long term basis with respect to insulation thicknesses.

The effect of anticipated temperature increase can be introduced to the simulations by increasing the outdoor temperatures in the climatic files by 2 ^{0}C and 4 ^{0}C respectively. The climatic files used for the simulations are presented in Appendix B.

Two-story house was considered for the simulations. It consists of four bed rooms, living area, dining room, kitchen, verandah, two toilets and an open balcony. Building elements have been designed with commonly adopted passive techniques as described in literature for tropical climates. The walls facing east or west were not provided with any openings, since they open up the indoor volumes to the direct sun. Thicker walls were considered to reduce the heat transfer through the walls into the building [17]. Such passive features generally have the potential to reduce the indoor air temperature by about 3 ^{0}C bellow the outdoor temperature [18]. The plan views of the buildings are shown in Figure 5. **Error! Reference source not found.** highlights the three dimensional view of the two-storey building considered.

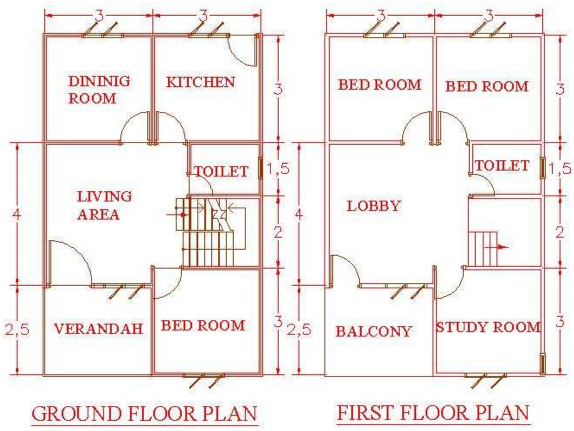

Figure 5: Plan views of the model

Three insulation thicknesses of 25 mm, 38 mm and 50 mm were considered with the above mentioned insulation system. Three cases were analyzed separately for future climatic changes

Figure 7 represents the upper floor indoor temperature variation with different outdoor conditions. The upper floor slab soffit temperature distribution is presented in Figure 8. Both the ground floor and the upper floor temperatures are highly influenced with the outdoor temperature hick due to global warming. The insulation thickness has a marginal effect on ground floor condition, while there is a considerable effect on the upper floor temperature distribution, especially at peak times. However, still the reduction is not enough to achieve the favorable conditions inside. Even though 25 mm has identified as the most effective insulation thickness [5 and 13], there is a requirement for going up to 50 mm to accommodate the possible extreme outdoor conditions, which can be present due to global warming in the near future.

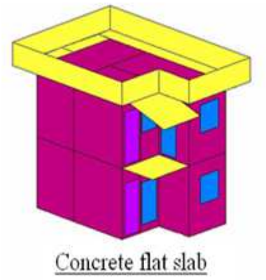

Figure 6: Three dimensional view of computer models

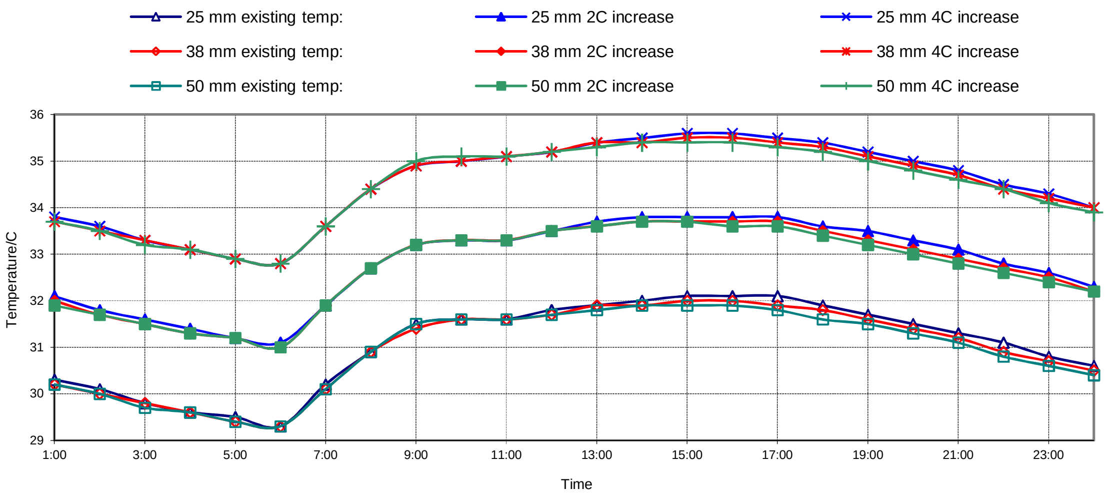

Figure 7: Volume 4 indoor temperature variation with global warming

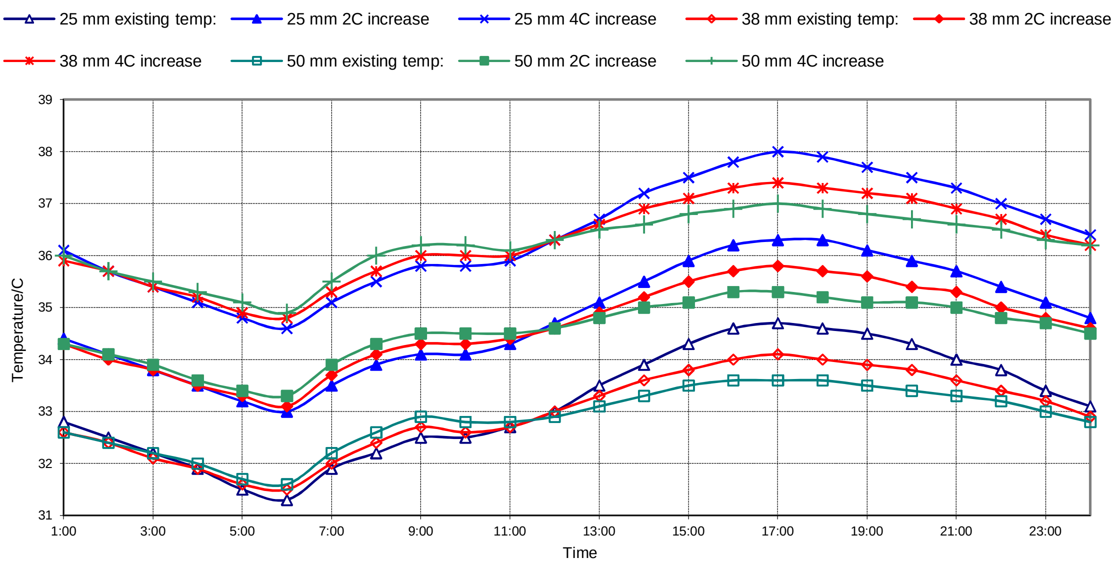

Figure 8: Upper floor slab soffit temperature variation with global warming

5 Conclusion

Due to high heat transfer through the slab, the soffit temperature of the un-insulated roof slab will be higher than the body temperature; the reinforced concrete roof slab without insulation will not be suitable for tropical countries. Further, due to the long wave radiation, which is emitted by the slab soffit, the occupants will feel thermal discomfort. Therefore, Insulated roof slabs can be identified as a better way to mitigate the effects due to expected climatic changes. With the present climatic condition, it was found that even 25 mm insulation can create the required comfort conditions at the top floor. Even though the outdoor temperature increases by 2 -4 ^{0}C due to global warming, the corresponding increase in the comfort zone is marginal. Therefore, the presence of higher insulation thicknesses is highlighted with the expected climatic changes. The presence of roof slabs instead of traditional sloping roof let creating green roof over the building. These roof top gardens can drop the slab top temperature by about 10 ℃ – 15 ℃ due to the reduction in solar radiation gains [2]. That can reduce the heat transfer through the slab and also help to mitigate the heat island effect. Further, it is essential to rethink of a green outdoor to keep favourable outdoor conditions [19 and 20]. This can minimise the effect of global warming and even with lesser extra cost, it will be possible to achieve favourable conditions inside. Such favorable conditions will be extremely useful in the face of global warming predicted in the future where temperature is predicted to rise from 2 ℃ – 5 ℃ within a century.

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Appendix A: Climatic data and Neutrality temperature for Colombo, Sri Lanka [2]

Month	Sunshine (hours per day)	Average Rainfall (mm/month)	Mean daily temperature (^oC)		Minimum & maximum relative humidity (%)		Monthly mean temperature, T_o	Monthly neutrality temperature, T_n
			Max (around 14.00 hours)	Min (around 6.00 hours)	Min (around 14.00 hours)	Max (around 6.00 hours)		
Jan	7. 5	87. 9	30. 3	22. 2	58	90	26.3	25.7
Feb	8. 2	96.0	30. 6	22. 3	59	92	26. 5	25. 8
Mar	8. 8	117.6	31.0	23. 3	64	94	27. 2	26.0
Apr	7. 9	259.8	31. 1	24. 3	68	95	27.7	26. 2
May	6. 2	352.6	30. 6	25. 3	72	92	28.0	26.3
Jun	6. 6	211.6	29. 6	25.2	73	93	27. 4	26. 1
Jul	6.1	139.7	29. 3	24. 9	70	90	27. 1	26.0
Aug	6. 5	123. 7	29. 4	25.0	65	90	27. 2	26.0
Sep	6. 4	153.4	29. 6	24. 7	67	91	27. 2	26.0
Oct	6. 2	354. 1	29. 4	23. 8	70	92	26. 6	25. 8
Nov	6. 8	324. 4	29. 6	22. 9	67	93	26.3	25.7
Dec	6. 9	174.8	29. 8	22. 4	61	91	26.1	25.7

Appendix B: Climatic Data Files

B1: Climatic data file for typical April with existing data.

C	Climate data file for DEROB-LTH program								
C									Site: Colombo
C									Latitude: 7
C									Longitude: 80
C									Time Meridian: 82
C									Standard Time is used
C									Altitude: 100
C									1:st day: 2007.04.15
C									Last day: 2007.04.15
C	Y	M	D	H	t out	X	IdH	IN	t sky
C					DegC	kg/kg	W/m2	W/m2	DegC
	2013	4	15	1	25.7	0	0	0	7. 1
	2013	4	15	2	25.1	0	0	0	6. 4
	2013	4	15	3	24.6	0	0	0	5. 8
	2013	4	15	4	24.4	0	0	0	5. 4
	2013	4	15	5	24.4	0	0	0	5.2
	2013	4	15	6	24.3	0	52	18	5.1
	2013	4	15	7	24.4	0	137	528	5
	2013	4	15	8	24.8	0	175	680	5.2
	2013	4	15	9	26	0	200	741	5.6
	2013	4	15	10	28	0	216	771	6.7
	2013	4	15	11	29.7	0	226	786	8.8
	2013	4	15	12	30.6	0	229	790	10.5
	2013	4	15	13	31	0	226	786	11.3
	2013	4	15	14	31.1	0	216	771	11.7
	2013	4	15	15	31	0	200	741	11.8
	2013	4	15	16	30.8	0	175	680	11.8
	2013	4	15	17	30.5	0	137	528	11.5
	2013	4	15	18	30.1	0	52	18	11.2
	2013	4	15	19	29.6	0	0	0	10.8
	2013	4	15	20	29.1	0	0	0	10.3
	2013	4	15	21	28.4	0	0	0	9.8
	2013	4	15	22	27.7	0	0	0	9.1
	2013	4	15	23	27	0	0	0	8.4
	2013	4	15	24	26.3	0	0	0	7.7

B2: Climatic data file for typical April with 2 ^{0}C increase due to global warming.

C		Climate data file for DEROB-LTH program							
C									Site: Colombo
C									Latitude: 7
C									Longitude: 80
C									Time Meridian: 82
C									Standard Time is used
C									Altitude: 100
C									1:st day: 2107.04.15
C									Last day: 2107.04.15
C	Y	M	D	H	t out	X	IdH	IN	t sky
C					Deg C	kg/kg	W/m2	W/m2	Deg C
	2113	4	15	1	27.7	0	0	0	7.1
	2113	4	15	2	27.1	0	0	0	6.4
	2113	4	15	3	26.6	0	0	0	5.8
	2113	4	15	4	26.4	0	0	0	5.4
	2113	4	15	5	26.4	0	0	0	5.2
	2113	4	15	6	26.3	0	52	18	5.1
	2113	4	15	7	26.4	0	137	528	5
	2113	4	15	8	26.8	0	175	680	5.2
	2113	4	15	9	28	0	200	741	5.6
	2113	4	15	10	30	0	216	771	6.7
	2113	4	15	11	31.7	0	226	786	8.8
	2113	4	15	12	32.6	0	229	790	10.5
	2113	4	15	13	33	0	226	786	11.3
	2113	4	15	14	33.1	0	216	771	11.7
	2113	4	15	15	33	0	200	741	11.8
	2113	4	15	16	32.8	0	175	680	11.8
	2113	4	15	17	32.5	0	137	528	11.5
	2113	4	15	18	32.1	0	52	18	11.2
	2113	4	15	19	31.6	0	0	0	10.8
	2113	4	15	20	31.1	0	0	0	10.3
	2113	4	15	21	30.4	0	0	0	9.8
	2113	4	15	22	29.7	0	0	0	9.1
	2113	4	15	23	29	0	0	0	8.4
	2113	4	15	24	28.3	0	0	0	7.7

B3: Climatic data file for typical April with 4 ^{0}C increase due to global warming.

C		Climate data file for DEROB-LTH program							
C									Site: Colombo
C									Latitude: 7
C									Longitude: 80
C									Time Meridian: 82
C									Standard Time is used
C									Altitude: 100
C									1:st day: 2107.04.15
C									Last day: 2107.04.15
C	Y	M	D	H	t out	X	IdH	IN	t sky
C					DegC	kg/kg	W/m2	W/m2	DegC
	2113	4	15	1	31.7	0	0	0	7.1
	2113	4	15	2	31.1	0	0	0	6.4
	2113	4	15	3	30.6	0	0	0	5.8
	2113	4	15	4	30.4	0	0	0	5.4
	2113	4	15	5	30.4	0	0	0	5.2
	2113	4	15	6	30.3	0	52	18	5.1
	2113	4	15	7	30.4	0	137	528	5
	2113	4	15	8	30.8	0	175	680	5.2
	2113	4	15	9	32	0	200	741	5.6
	2113	4	15	10	34	0	216	771	6.7
	2113	4	15	11	35.7	0	226	786	8.8
	2113	4	15	12	36.6	0	229	790	10.5
	2113	4	15	13	37	0	226	786	11.3
	2113	4	15	14	37.1	0	216	771	11.7
	2113	4	15	15	37	0	200	741	11.8
	2113	4	15	16	36.8	0	175	680	11.8
	2113	4	15	17	36.5	0	137	528	11.5
	2113	4	15	18	36.1	0	52	18	11.2
	2113	4	15	19	35.6	0	0	0	10.8
	2113	4	15	20	35.1	0	0	0	10.3
	2113	4	15	21	34.4	0	0	0	9.8
	2113	4	15	22	33.7	0	0	0	9.1
	2113	4	15	23	33	0	0	0	8.4
	2113	4	15	24	32.3	0	0	0	7.7