A Study of the Effect of Building Designs on Climate Change: Mitigation and Adaption

Repaul Kanji, Sonam Sahu, and Robin Agarwal

Abstract—**Urbanization and development are the inevitable consequences of economic growth. With urbanization, various issues of climate change are cropping up. Urban Heat Island (UHI) is a significant phenomenon to manifest the changes in climate of a region. The present research attempts to establish the presence of this phenomenon in Roorkee, India on one hand. And, to study change in architectural styles of the buildings in the course of time as the possible reasons of these climatic differences on the other hand. Finally, the research concludes with recommendations and suggestion to mitigate and adapt to climate changes through the implementation of an indigenously designed algorithm.**

Index Terms—**Uhi, surface transformation, land surface temperature, minimum u-value algorithm.**

I. INTRODUCTION

Urbanization has lead to transformation of natural surfaces to urban land. Construction of buildings and infrastructure has made undue unavoidable changes in land surface properties. One important property is the land surface temperature (LST). LST is responsible for the change in air temperature of a region [1]. Anthropogenic activities like use of vehicles and air conditioners, and emission of gases is also responsible for the same. But urban development plays a major role. The type of building material used and the percentage of natural land transformed to urban land are solely responsible for the change in land surface properties. This further result in change of local weather conditions and eventually leads to climate change. The construction of buildings, roads and other impervious surfaces leads to increase of temperature of that region as compared to the surrounding rural area. This phenomenon is known as Urban Heat Island (UHI) [2]. UHI is a significant manifestation of climate change. The present study aims to investigate the presence of UHI in Roorkee, India. 268 meters from mean sea level, Roorkee has an extreme and erratic continental climate. The paper also studies the architectural and construction styles of the various buildings in the study area to empathize the causes of UHI.

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II. METHODOLOGY

A. Phase I

Inspired by the work in some UHI studies [3], the first phase of the study is to investigate the existence of UHI in Roorkee. For this, the air temperature of Roorkee needs to be compared with a rural area. The selected rural area is Dhanauri, 13 kilometres away from Roorkee. Specific days of summer and spring season of the year 2013 have been used for the comparison. Hourly data for the time stretch of 16th – 25th April, 2013 and 20th – 29th May, 2013 has been archived from the Meteorological stations for the analysis of UHI. Analyzing nine days, each of spring and summer season, when the climate of Roorkee is in extremes, provided the basis for the proper determination of UHI in the campus.
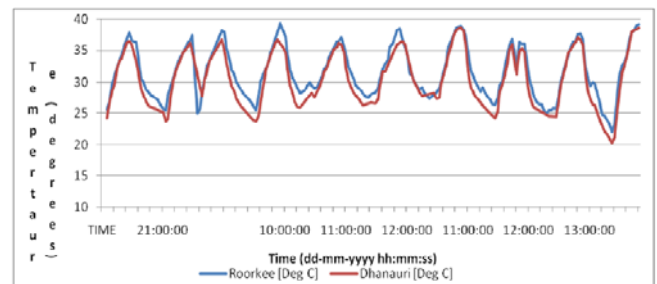

Fig. 1. Graph showing temporal variation of air temperature in summer season in urban and rural sites.
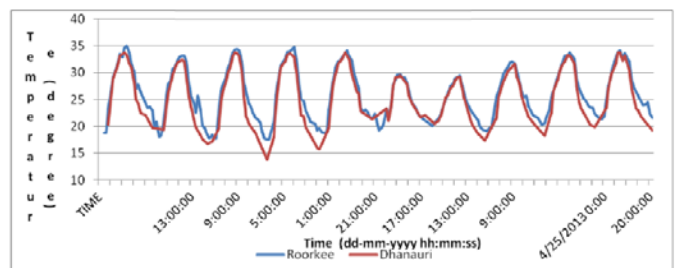

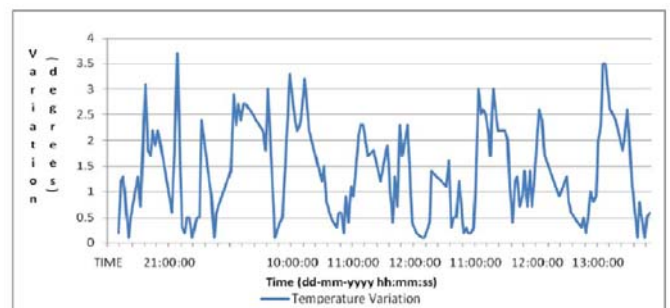Fig. 2. Graph showing temporal variation of air temperature in spring season in urban and rural sites.

Fig. 3. Temperature variation ($t_{u\text{-}R}$) in summer season.

B. Results of Phase 1

The graphs above (Fig. 1 and Fig. 2) are showing the weather profile of the two selected stations Roorkee and Dhanauri (urban and rural respectively). Fig. 3 and Fig. 4 show the temperature variation (T_{U-R}) in summer and spring seasons. There is at most around 3.5 degrees variation in the temperature from the nearby rural area in the summer season ranging from 0.1 to 3.5 degrees, and about 3.8 degrees in the springs ranging from 0.2 to 3.8 degrees.

TABLE I: RESULTS OF CAMPUS DOCUMENTATION

Sr. no.	Site description	Structure	Surroundings	Tree cover	Pollution	Building Height	Distance from nearest building (approx)	Roughness class[1]	% open/ built[2]	Category
Site 1 (Hoste)	residential	RCC	commercial/ residential	Medium	medium	9 mtrs	8 mtrs	0.5	30-70	U
Site 2 (Lecture Comple)	educational	RCC	public/ educational	Low	high	20 mtrs	12 mtrs	1	20-80	U
Site 3 (Management Building)	educational	RCC	educational	Low	high	8 mtrs	12 mtrs	1	20-80	U
Site 4 (Hill View apartments)	residential	RCC	residential/ educational	Low	high	24 mtrs	9 mtrs	1	20-80	U
Site 5 (Shivalik Apartments)	residential	RCC	residential/ educational	Low	high	21 mtrs	6 mtrs	1	20-80	U
Site 6 (Department)	educational	RCC	educational	Medium	medium	10 mtrs	25 mtrs	0.5	40-60	S
Site 7 (Nescafe)	public	RCC	commercial/ educational	Medium	high	2.5 mtrs	8 mtrs	0.25	50-50	S
Site 8 (Residence)	residential	brick masonry	residential	High	low	3 mtrs	12 mtrs	0.25	40-60	S
Site 9 (Residence)	residential	brick masonry	residential	High	low	3 mtrs	22 mtrs	0.25	60-40	S
Site 10 (Residence)	residential	brick masonry	educational	High	medium	6 mtrs	12 mtrs	0.25	60-40	S
Site 11 (Main Building, Academic Institute)	administrative building	brick masonry	public/ educational	Medium	low	8 mtrs	15 mtrs	0.5	40-60	S
Site 12 (Workers residences)	residential	sun dried bricks	residential	Medium	low	2.5 mtrs	3 mtrs	0.25	40-60	R

Roughness class allotted according to Classification of Effective Terrain Roughness (Revised 2000), Source: Davenport *et al.*, (2000) [4] in Oke (2006)[5], Average percentage of ground covered with impermeable material to permeable material, U-Urban, S- Suburban, R-Rural

C. Phase 2

The second phase is the documentation of buildings belonging to different architectural and construction styles in the study area. Surveys were conducted to cover almost all the varied typologies, based on certain parameters which generally contribute to UHI. Parameters like building material, percentage built/open space, tree-cover, pollution, building geometry were noted. The outcomes are presented in Table I in the *Appendix*.

D. Results of Phase 2

The sites 2, 3, 4 and 5 respectively are recently built structures and which are profusely modern. These are designed not according to the existing climate, but for artificial heating and cooling. The structures witness 80% transformed surfaces. The construction of asphalt and concrete roads, extensive use of building materials like concrete and glass on building skin is responsible for increasing the temperature at micro level. The absence of tree cover further ads to the issues of heat gain as there is no evapo-transpiration allowed. Absence of permeable surface hampers the humidity level of the area, allows more solar radiation to get absorbed, and reduces the expected precipitation. On the other hand there are other sites which show highly distinguishable lineament. Site 6, 7, 8, 9, 10 and 11 are suburban. Out of these, the Site 6 and 7 are built up of RCC, but the percentage of human intervention in changing the character of land is appreciably less. The softscape is mostly natural and undisturbed. The play of nature has not been interfered with; it has been kept safe and untouched. All what has been done is the addition of few gathering spaces for utilization and leisure. So there has been least intervention in the natural setup. Next are the sites 8, 9 and 10. These are typical examples of vernacular in Roorkee showing

assemblage of the brilliantly designed arrangement of the built and open spaces. These buildings have brick masonry structure and slab made up of layers of tiles plastered with lime mortar. This thoughtful system of planning and design holds the essential weather factors under assurance, being designed for the local climate; no artificial cooling required. The other location is the site 11 is the main building of an educational institute in Roorkee. The structure made up of brick masonry holds a magnificent look and does not need any high order modern material range. With a noticeable part belonging to green spaces the structure has very little harm to make to the climate of the region even though it has a huge amount of ground coverage. The thick brick walls and the slab made up of reinforced brickwork are good for high insulation and low heat gain are responsible for less energy consumption for cooling the interiors. Site 12 is a residential area belonging to the lower income group. The buildings are made up of sun dried bricks. The space is categorized as rural [4], [5] because of the material used for construction and the untouched surroundings.
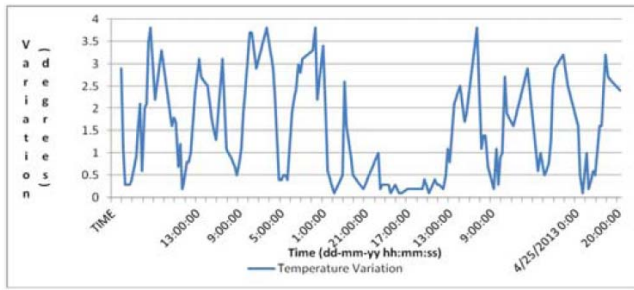

Fig. 4. Temperature variation (T_{U-R}) in spring season.

III. CONCLUSION

While at this, it was perceived that the trend is to gradually move towards modern architectural style. So step should be taken not to stop the progress but to ensure the steps are taken carefully. Hence, the research work suggests an algorithm to select appropriate building materials and components with the lowest U-value or thermal conductivity value. Based on ASHRAE Handbook of Fundamentals [6] and Scottish Governments resource document [7], an inventory can be created of the design U values or thermal conductivities of all the probable and commonly used materials and styles. The algorithm suggests a connected graph, G, to be constructed from a source vertex, say A. From A, edges would link to vertices which are probable options of construction types, with each edge weighing the U value of the material in the vertex it leads to. In turn, every vertex should be connected to every other vertex finally leading to convergent vertex, say B, thus creating a connected, weighted graph of probable options of material or building style. Finally, the following algorithm is run on the graph, G.

```
MinU(G, uvalue, A)
{for (each u belongs to V)
        {
        cuvalue[u]=infinity
        color[u]=white
```

```
        }
cuvalue[A]=0; pred[A]=NIL
Q=(queue with all vertices)
    while (Non Empty (Q))
        {
        u=Extract-Min(Q)
    for (each v belonging to Adj[u])
    if (cuvalue[u]=uvalue(u,v)<d[v])
        {
cuvalue[v]=cuvalue[u]+uvalue(u,v)
    Decrease-Key (Q, v, cuvalue[v])
        pred[v]=u
        }
    colour[u]=black
        }
```

The result optimizes the possibility with the least design U value or thermal conductivity whichever is fed in uvalue[]; cuvalue gives the total calculated uvalue for the specific graph G. The graph is implemented using priority queue and hence typical queue operations can be found. Thus, an optimal algorithm is ready to be implemented to help designers adapt and in a way mitigate the obvious climate changes.

In this context the important strategies that can be listed to ensure the least impact on the climate can be:

1) Innovation in technology and construction process and minimum use of materials with undesirable thermal properties
2) Identifying materials with low carbon footprints and improved thermal properties
3) Using indigenous materials, and manpower instead of heavy machinery
4) Designing and planning for local weather conditions using passive solar design features instead of creating artificial indoor climate and using HVAC.
5) Reducing anthropogenic activities and artificial surface transformation to minimum.

With these schemes, understanding of vernacular technologies and knowledge of material science, it can be possible to build an integrated and successful environment conscious design for the city which will portray its connectivity to the locale, ties with the history & culture and be a solution for the climatic changes to come in the near future.

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