INFLUENCE OF LANDSCAPE IN OUTDOOR THERMAL COMFORT

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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By

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JUNE 2014

CERTIFICATE

Certified that report entitled **"Influence of Landscape in Outdoor Thermal Comfort"** which has been submitted by **Ms. Shatabdi Mahanta**, for partial fulfilment of the requirement for the award of the post graduate degree in Masters of Architecture, in the Department of Architecture and Planning, Indian Institute of Technology Roorkee, Roorkee is the student's own work carried out by her under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree of this or any other institute.

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CANDIDATE'S DECLARATION

I hereby declare that the work, which is being presented in the dissertation, entitled **"Influence of Landscape in Outdoor Thermal Comfort**" in partial fulfilment of the requirement for the award of the degree of Masters of Architecture, submitted to the Department of Architecture and Planning of the Indian Institute of Technology Roorkee is an authentic record of my own work carried out during the period from July 2013 to June 2014, under the supervision and guidance of Dr. Mahua Mukherjee, Department of Architecture and Planning, Indian Institute of Technology, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree of this or any other institute.

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This is to certify that the above statement made by the candidate **Ms. Shatabdi Mahanta** is correct to the best of my knowledge and belief.

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EXECUTIVE SUMMARY

In an outdoor space, people are involved in many activities, like sitting, standing, playing, etc. They experience various sensations (Thermal Sensation, Humidity Sensation, Wind Sensation) while carrying out these activities. In order to continue these activities, they need to feel comfortable. To understand the behaviour of people in these spaces and in order to design comfortable outdoor spaces, it is very important to understand the microclimate of that place in detail.

For that, it is necessary to understand two important factors as follows:-

1. Aspects of Outdoor Thermal Comfort
2. Landscaping elements that influence the microclimate of any place

Both the factors work together to modify the microclimate of an outdoor space. To control different elements of the microclimatic parameters, like the Air Temperature, Relative Humidity, etc, landscaping elements can be used. Hence, with the help of these factors successful and comfortable outdoor spaces can be designed.

The aim of this research is to review the influence of landscape in outdoor spaces and suggest landscape design strategies for the outdoor cafeterias in IITR (Alpahar and Bru) for comfortable thermal conditions. The cafeterias will be redesigned according to the derived strategies.

To achieve this aim, the following objectives have been framed:

- To identify Outdoor Thermal Comfort (OTC) parameters and Indices
- To carry out evaluation of users' response on OTC and to review influence of landscaping elements specifically for cafeterias in IIT Roorkee (Alpahar and Bru)
- To appraise OTC of selected areas through simulation (RayMan and Envi-Met) :-

- Physiological Equivalent Temperature (PET) index calculation
- Thermal environment of (Bru and Alpahar) cafeterias

- To develop landscape design strategies for comfortable outdoor cafeteria
- To redesign selected Cafeterias spaces from the derived strategies
- To appraise the modified scenarios through Simulation

The above objectives were achieved in the following chapters.

The Research Methodology followed consisted of Identification of Problem, Literature Review, Case Studies, Field Studies in IITR (Alpahar, Bru, Lawn Main Building, LHC Parking and Students Club Front yard), Calculation of PET and simulation in Envi-Met, Development of Interventions and Packages, New and modified design for Alpahar and Bru, Appraisal of Modified Scenario with the help of simulation.

Literature Review-

Several research papers on Outdoor Thermal Comfort (OTC) evaluation methods and Influence of Landscape in Microclimate were studied. Previously thermal comfort conditions in indoors were only studied in details. It is only in the past decade that valuable researches were carried out for outdoor conditions also (Hoppe, 2002; Givoni et al., 2003; Ahmed, 2003; Spagnolo & De Dear, 2003; Stathopoulos, Wu, & Zacharias, 2004; Cheng & Ng, 2006; Gulyas, Unger, & Matzarakis, 2006; Nikolopoulou & Lykoudis, 2006; Cheng, Ng, Chan, Ali-Toudert & Mayer, 2006; Tseliou, Tsiros, Lykoudis, & Nikolopoulou, 2009 & Givoni, 2010). After understanding the outdoor thermal comfort evaluation methods, the OTC Indices were identified. The suitable index, PET (Physiological Equivalent temperature) was selected for further carrying out OTC evaluation in the cafeterias of IITR. Amongst the literature studied, it was found that PET is suitable for diverse climatic conditions like India. PET can be calculated from software like RayMan which is very easily available online. Simulation software like Envi-Met can also assist in outdoor thermal comfort assessment. The ENVI-met has been adapted mainly to simulate surface-plant-air interactions in any microclimate of outdoor spaces and to predict climatic consequences of different urban design options.

Landscaping elements can be grouped into hard landscaping elements and soft landscaping elements. Soft landscaping elements refer to vegetation while the hard landscaping elements are all other elements including simple structures, steps, paving, garden furniture, walls and fences. Landscaping can be used to control several aspects of the microclimate. The climatic variables that can be regulated include solar radiation (sol-air temperature), air temperature, wind speed and direction, relative humidity and glare.

Case Studies-

The case studies studied were basically research work and field studies on the influence of landscaping elements in the microclimate of outdoor spaces, which have been done in various parts of the world. Each case study was unique and dealt with research methods on evaluation of OTC and how landscape influences the microclimate of an outdoor area. It was from the case studies, the use and application of simulation software like RayMan and Envi-Met were learnt. From the various Case Studies, it is found that Landscape plays a major role in influencing the microclimate of an outdoor space. Soft Landscaping elements like the trees can be the best measure to achieve outdoor thermal comfort in an outdoor space. The Mean Radiant Temperature (T_{mrt}) value is stable under Tree Shade. Also, in the field study, along with microclimatic data, subjective evaluation of people is a necessary tool to understand the thermal sensation of the people of that place.

Field survey on OTC and Influence of Landscape Elements: Evaluation

Outdoor Thermal Comfort evaluation was carried out in the cafeterias (Alpahar and Bru) through field studies for both summer and winter for the current year 2014. Each field study consisted of two major parts:-

i. Subjective Evaluation (personal factors, sensation, etc through Questionnaire Survey)

ii. Microclimatic Data Evaluation (measurement of microclimatic parameters like Air Temperature, Humidity, Solar Radiation, Wind Speed and Direction, etc through instruments)

Also, Physiological Equivalent Temperature (PET) index of selected neutral thermal sensation samples from the Questionnaire Survey was calculated in RayMan for the two cafeterias.

Alpahar and Bru are the main study area (base cases) where design will be implemented later. Some contrasting cases were also selected to find out the differences. Lawn Main Building was selected because of the maximum amount of Vegetative area present (Soft Landscaping Element). On the other hand, LHC Parking and Students Club frontyard were selected because of the maximum amount of paved area (Hard Landscaping Element) present. This is to show how microclimatic parameters vary with the different outdoor spaces.

The influence of landscaping elements for the 5 different outdoor spaces (Alpahar, Bru, Lawn Main Building, LHC Parking and Students Club Front yard) in IIT Roorkee campus was observed. Landscaping elements was grouped into:-

i. Soft Landscaping Elements (Vegetation like trees, grass, etc)
ii. Hard Landscaping Elements (e.g., pavement, walls and fences, garden furniture, etc)

A table was prepared for the 5 different outdoor spaces showing the different landscaping elements present and their area in percentage. Also ratio of Building:Pavement:Vegetation was calculated. It has been observed with the different landscaping elements present in these outdoor spaces, the microclimatic parameters and comfort level also varies.

Also existing thermal environments of the 5 outdoor spaces were simulated in Envi-Met mainly for summer scenarios. This is because in Roorkee, summer is longer and more challenging and winter exists for hardly 3 months. Visible difference of temperature is seen while comparing the different simulations.

Redesign of Cafeteria spaces

1. Selection and description

Alpahar and Bru in IITR were selected as the Base cases because -

- Famous Outdoor Activity areas in IITR
- Used by almost 80% of the people in IITR

Each of the sites was analyzed on the basis of landscaping elements present and the outdoor thermal comfort conditions. The outdoor thermal comfort evaluation in these outdoor spaces was a very necessary tool for designing and recommending better design solutions. Hence the influence of landscape for achieving maximum Outdoor Thermal Comfort in these outdoor activity areas has been studied and analyzed.

2. Intervention and Packages

The Landscaping Elements for controlling the microclimate was achieved through various landscaping techniques and elements. Interventions and Packages were developed for the cafeterias (Alpahar and Bru) according to the site requirements for better outdoor comfort conditions.

Redesign of the cafeterias (Alpahar and Bru) was done from the derived strategies.

3. Appraisal through simulation

The modified design scenarios of the cafeterias were simulated in Envi-Met and comparison was done with the existing scenarios. The T_{mrt} (Mean Radiant Temperature) value, which plays a major role in determining the outdoor comfort conditions, was evaluated for both the scenarios. It is observed that in the modified scenario, the thermal comfort conditions are better than the existing scenarios. The T_{mrt} value has been decreased by atleast 2^0 C in the new design.

Conclusion

It has been observed that

- Increasing the soft landscaping elements in a particular site can improve the thermal comfort conditions of that place in summer. But on the contrary, in winter, hard landscaping elements create more comfort by absorbing more heat. So a balance is required to design any outdoor space.
- By channelling the wind to form Venturi Effect and creating wind breakers when required can also increase comfort conditions in any outdoor area.
- It has been proved that it is only under Tree Shade, Tmrt (Mean Radiant Temperature) remains constant throughout the day and maximum comfort is achieved during summers.
- With the help of instruments and software, it was easier to evaluate the microclimate of an outdoor space.
- Hence, the Outdoor Thermal Comfort evaluation methods and understanding the Landscape of any outdoor space not only helps us to know the microclimate of that area but also how to modify and create new and better design solutions so that people can use all times of the year.

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1. INTRODUCTION

1.1 GENERAL

For designing outdoor spaces, microclimate of that area plays the most important role. An outdoor space with the most beautiful landscape and eye pleasing design will also have few people admiring and enjoying it if the microclimate of that place is in extremely hot or cold conditions than desired. Also all living things, both plants and animals need an appropriate microclimate for their survival. But to understand these outdoor spaces and microclimate is a very difficult and challenging task.

1.2 IDENTIFICATION OF THE PROBLEM

Due to the rapid urbanization, it has been observed that both population and buildings are increasing at an alarming rate. Also along with that, increase of the hard surfaces too created problems like the urban heat island (UHI) effect. The use of vegetation can help to mitigate this problem. In the past decade, the role of good and proper landscape in moderating the urban microclimate has been explored in almost all parts of the world.

1.3 NEED FOR THE STUDY

In an outdoor space, people are involved in many activities, like sitting, standing, playing, etc. They experience various sensations while carrying out these activities e.g., Thermal Sensation, Humidity Sensation, Wind Sensation, etc. In order to continue these activities, they need to feel comfortable while carrying out these activities. In urban areas, with the variety of different surfaces, shelter and shading devices, it produces distinct microclimate systems. Therefore, to understand the behaviour of people in the outdoor spaces and in order to design comfortable outdoor spaces, it is very important to understand the microclimate of that place in detail.

For that, it is necessary to understand the factors that influence the microclimate of that place. They are as follows:-

3. Landscaping elements
4. Outdoor Thermal Comfort evaluation methods

Both the factors work together to modify the microclimate of an outdoor space. To control different aspects of the microclimatic parameters, like the Air Temperature, Relative Humidity, etc, various landscaping elements can be used. Hence, with the help of these factors successful and comfortable outdoor spaces can be designed. Hence, outdoor thermal comfort evaluation for the two cafeterias in IITR (*Alpahar* and *Bru*) is necessary. It is also necessary to understand and analyze the influence of Landscaping elements in these outdoor spaces. This will further help in developing landscape design strategies and redesigning these outdoor spaces.

1.4 AIM AND OBJECTIVES

Aim

The aim of this research is to review the influence of landscape in outdoor thermal comfort and suggest landscape design strategies for the outdoor spaces.

Objectives

- To identify Outdoor Thermal Comfort (OTC) parameters and Indices
- To carry out evaluation of users' response on OTC and to review influence of landscaping elements specifically for cafeterias in IIT Roorkee
- To appraise OTC of selected areas through simulation (RayMan and Envi-Met) :-
  - Calculation of Physiological Equivalent Temperature (PET) index
  - Thermal environment of (Bru and Alpahar) cafeterias
- To develop landscape design strategies for comfortable outdoor cafeteria
- To redesign selected Cafeterias spaces from the derived strategies and appraise the modified scenarios through Simulation

1.5 SCOPE

Scope

- The scope of work is focused on OTC evaluation methods through field studies in IITR.
- "Cafeteria" has been selected as the base case where design will be implemented.
- Calculation of PET index by RayMan for selected samples (Neutral Thermal Sensation) of both the cafeterias for both summer as well as winter.
- Develop landscape design strategies for comfortable outdoor cafeteria spaces through Interventions and Packages.
- Redesign selected Cafeterias spaces from the derived strategies
- Simulating existing scenarios of the cafeterias (*Alpahar* and *Bru*) and appraising the modified design scenarios through Envi-Met.

Limitations

Due to limitation of time, the scope of the present work will be limited to Composite Climate, IIT Roorkee Campus and two cafeterias only (Alpahar and Bru). The work is based on the summer and winter microclimatic data of the current year 2014.

1.6 RESEARCH METHODOLOGY

The Research Methodology followed consisted of first identification of the problem followed by literature review, case studies, field studies in iitr (alpahar, bru, lawn main building, lhc parking and students club front yard), calculation of pet and simulation in envi-met, development of interventions and packages, re-design alpahar and bru cafeterias and finally appraisal of modified scenario with the help of simulation. The research methodology that has been followed is shown in fig.1.1 below.

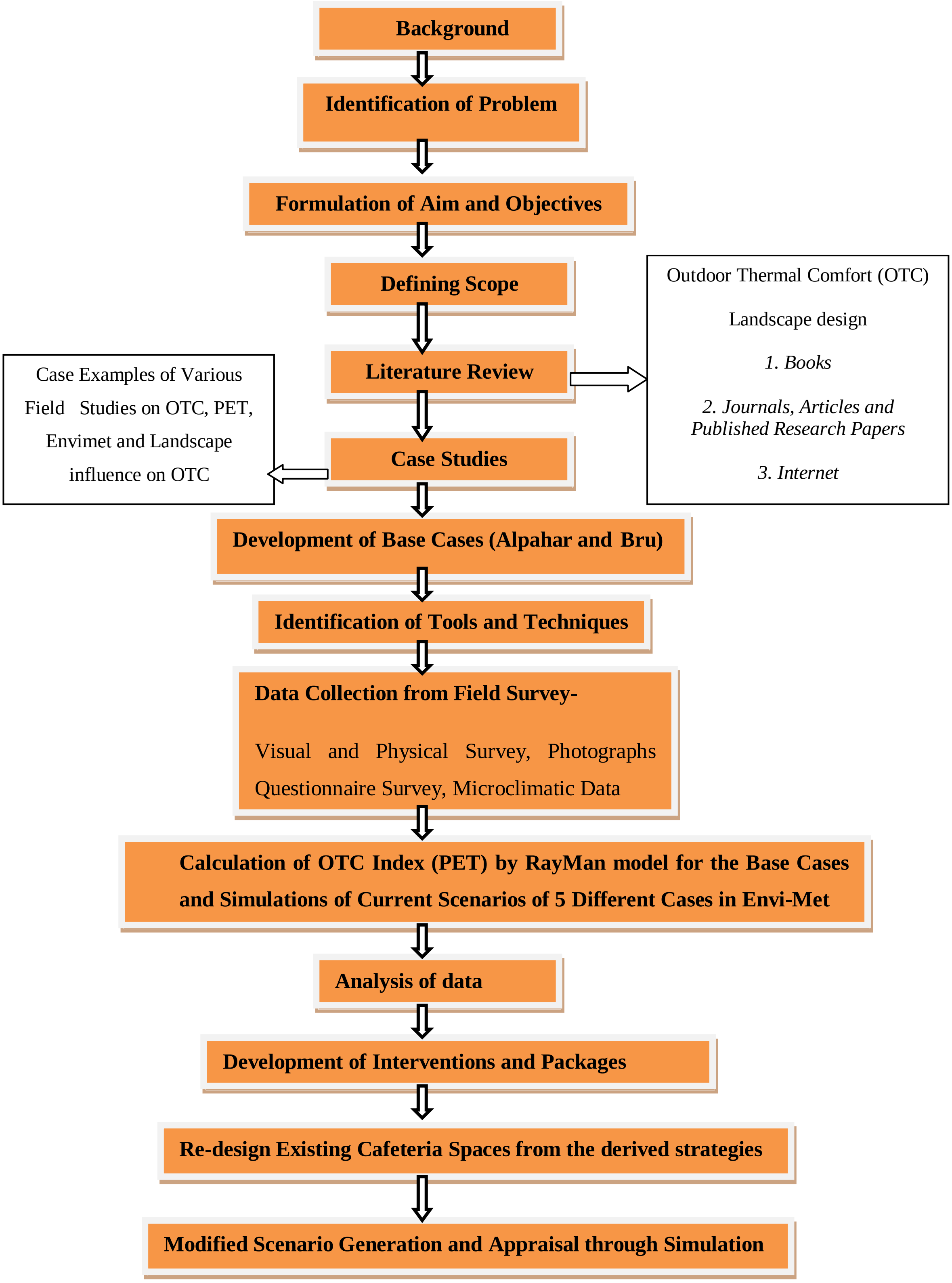


Fig. 1.1 Research Methodology Flow Chart

2. LITERATURE REVIEW

2.1 GENERAL

The built environment mostly influences the outdoor thermal environment. The anthropogenic heat, shading by trees, shading by man-made objects, ground surface cover (natural grass or artificial paving) modifies and determines the microclimate of outdoor environment. Comfortable and well designed outdoor spaces produce better thermal comfort conditions for people and hence improve the standards of urban living. It is only in the past decade that knowledge got transferred from bio meteorological and climatological studies to architectural and urban design (Akbari, Davis, Dorsano, Huang, & Winnett,1992; Brown,1995; Dessi,2002; Katzschner,2006;Ochoa De la Torre J. M. ,1999)(Scudo,2005). The literature review of this study consisted of understanding the microclimate of outdoor spaces for which it is required to study - Landscape Design and Outdoor Thermal Comfort evaluation methods.

2.2 LANDSCAPE DESIGN

2.2.1 Basic Concepts in Landscape Design

The design of Landscape is a complex procedure which combines the realistic with the skilful in a combined and functional composition. Landscaping plays a significant role in modifying the outdoor temperature. Vegetation contributes in improving the urban climate by evapo-transpiration, providing shade and channelling wind, by acting either as wind funnel or as windbreak. The most important characteristic of a tree is to provide shade. A tree provides shade because of its volume, shape and leaf density.

Landscaping can control various elements of the outdoor microclimate like air temperature, relative humidity, solar radiation, wind speed, wind direction and also glare.

Main Concepts:

1. The sun is the main source of heat gained by objects in a landscape. The movement of sun through the sky is very predictable. The amount of heat that warms the various objects of a landscape can be controlled by selecting and placing landscape elements accordingly. In summer, the micro climate can be modified by minimizing the solar radiation absorbed by any object. In winter, it can be modified by reducing the wind speed.
2. The wind acts as the main component of cooling in a landscape.
3. The landscape cannot change Air Temperature and Relative Humidity very much, except in certain circumstances.

Control of Solar Radiation

The sun emits solar radiation that warms the elements of a landscape. The sun rises in the east, moves to its highest position in the southern sky and then sets in the west, describing an arc. The sun's arc is lowest in winter and highest in the sky in summer. In winter, it rises in the southeast and sets in the southwest while in summer; it rises in the northeast and sets in the northwest, while. The sun is usually at the midpoint of the south along its arc, and the southern sun is at its highest point in the sky during summer and at its lowest point in the sky during winter. The difference in height of the mid-noon sun between summer and winter can be quite great. When the sun's rays are directly perpendicular to the surface of any object, it receives the highest amount of radiation. If the colour of the surface is darker, it will absorb more solar radiation. Generally the hotter it will get the less it will reflect solar radiation towards other surfaces. On the other hand, it will absorb less heat and reflect more solar radiation if the object is of light colour and hence will stay cooler.

For reducing the air and surface temperature and for controlling radiant temperature, the shading provided by trees, shrubs and climbers is a important method for controlling the microclimate. To cover surfaces that is exposed to the sun climbers with or without trellis and pergolas can also be used.

Control of Air Temperature

The landscape cannot change Air Temperature and Relative Humidity very much, except in certain circumstances. However, air near the surface in parks will be much cooler than surrounding hard surfaces (concrete and asphalt) in urban areas. Shading by tree canopies is a significant measure in controlling and reducing the air temperature. It is due to evapo-transpiration, a process in which plants collect water from the ground and gives out the water through the leaves by the process of evaporation as shown in fig 2.1 below. This causes cooling and it is similar to the cooling caused by sweating in humans.

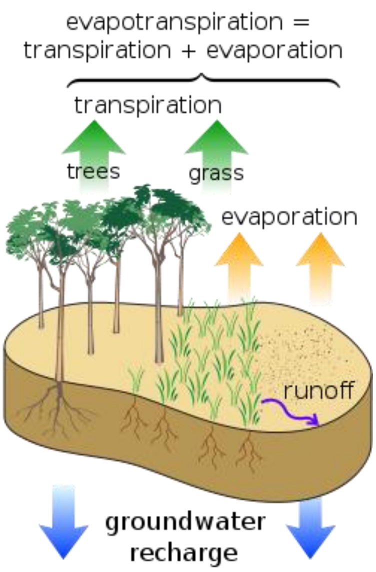


Fig. 2.1 Evapo-transpiration in Plants

Source: Estimation of evapotranspiration (pdf in Greek) from Alexia Tsuni (Athens, June 2003)

Control of Humidity

Generally plants increase the humidity of any site. During hot and dry seasons, they can increase the thermal comfort even though the plants need water regularly. But during this process, the relative humidity increases but it reduces the air temperature. Ponds and pools also behave in a similar manner.

Control of Wind Speed

In a landscape, the most effective mechanism for cooling objects is the wind. It will remove heat from objects until they are the same temperature as the wind. The wind will not make things cooler than itself. However, for an object which is wet, evaporative cooling can lower its temperature to below air temperature. In the landscape, wind can blow from any direction and so it is variable. But usually there are patterns which can be identified and implemented. The prevailing wind often changes with the seasons. Through proper placement of elements the wind can be slowed down in a landscape. Generally in the landscape, vegetation of around 50 percent porosity can be the most successful windbreak.

Vegetation can be used to increase the velocity of slow moving and stagnant air and also to reduce wind speed. A very successful way of filtering dust and reducing wind speed is to create windbreakers in a pattern with rows of trees.

Control of Direction of the Wind

Trees and shrubs help to channel the wind’s direction towards the site or deflect away from the site. Walls, fences, trees and hedges when combined together can be some obstruction which can divert the direction of the wind. On plots which are larger, rows of trees can be used for channelling the wind into a desired direction.

Control of Reflectance (Albedo) and Surface Absorptivity

For controlling the rate in which surfaces absorb and also reflect solar radiation**,** landscaping elements can be used. For controlling the ratio of solar radiation that is absorbed to that which is reflected, the plants, lawns, colour and proper selection of pavement materials can be helpful.

Seasonal shading

In different seasons, the selection of plants can be made for controlling the quantity of shading.

Glare Control

By using trees with large canopies, direct glare can be blocked while by using shrubs, flowers and grass on surfaces which normally reflect light, indirect glare can be avoided.

2.2.2 Landscaping Elements

Generally Landscape elements consist of the following:

◆Vegetation

◆Land Forms

◆Water Features

◆Pavement Materials

◆Site Amenities

◆Lighting

◆Signs

The outdoor space that surrounds buildings has living materials and inert materials. The living materials are known as soft landscaping elements while the inert materials are known as hard landscaping elements. Soft landscaping elements includes the vegetation (like the trees, shrubs, grass) and hard landscaping elements includes the other remaining elements like the simple structures, garden furniture, walls and fences, paving and steps . The fig 2.2 shown below classifies the elements of landscape in a broader classification.

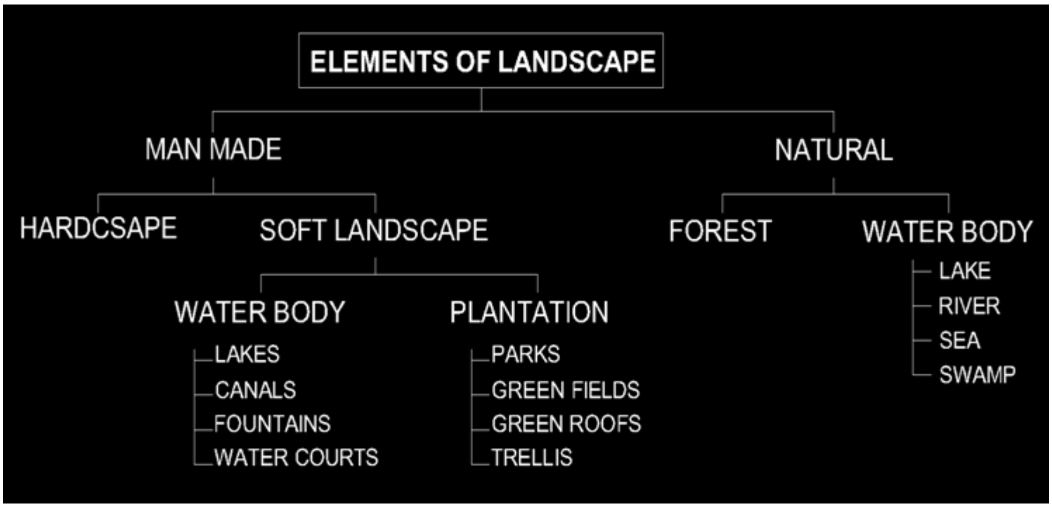


Fig. 2.2 Elements of Landscape

2.2.2.1 Hard Landscaping Elements

It includes all the non-plant materials that are used for a landscape development. Examples are walls, steps, driveways, patio, walkways, decks, fences, pergolas, furniture, containers for potted plants, landscape lightings, water fountains, ponds, etc. All these features, individually and combined together, makes the overhead planes, ground and vertical planes amongst a landscape and thus define outdoor spaces.

The Function of Hard Landscaping Elements is as follows:

- To create links between buildings
- To enclose space
- To create a theme in a development
- To define private areas
- To give security to private areas
- To cater for vehicular and pedestrian movement
- To deter vehicular or pedestrian movement
- To assist people (Universal Design)
- To visually link a development with its surroundings

Hard Landscaping Elements should be used not only for the appearance but also for its function. They are as follows:

Steps and paving

The construction of paving, steps and the material of selection of the finishing of the surfaces helps in reducing temperature of the ground. It is a major source of discomfort when without any shade, asphalt is used in parking lots.

Walls and fences

Walls help deflect the wind and are made up of solid. The fences are generally made from wire, rails, netting, stakes, etc. Hence even when climbers are used in fences, some wind can easily flow through them. Bollards are the man-made structure that creates a feeling of separation even though not separated actually.

Slopes and barriers

On the sites with some variations in topography, slopes and barriers can be used for directing airflow which will be very much effective.

Stones and boulders

To provide shade and direct airflow, both stones and boulders can be used.

Ponds and Pools

The water bodies can be used for evaporative cooling and humidification.

2.2.2.2 Soft Landscaping Elements

It includes the plant components of landscaping (herbaceous plants, trees, shrubs, grasses, etc) that are natural in a landscape. They are as follows:

Trees

Trees can play various roles in urban areas including:

- aesthetic quality
- visual screening and shelter
- solar access
- habitat for wildlife
- street trees
- screening and wind breaks
- vertical scale against other urban elements

Evergreen and Deciduous Trees:

(a) Evergreen trees have the following advantages:

(i) Places requiring shade throughout the year,

(ii) Strong visual screening

(iii) Part of windbreak or shelter planting, and

(iv) Can be used for areas where leaf lifter needs to be discouraged.

(b) Deciduous trees have the following advantages:

(i) Greater visual variety,

(ii) Partial visual barrier,

(iii)Areas where under-planting is to be encouraged (for example grass)

(iv) Emphasis on branching and flowering pattern, and

(v) Areas where shade is not required throughout the year.

Shrubs

Shrubs form a major part in the development of landscapes. They can serve different functions if properly designed, and also if they are properly maintained, they will provide quality and amenity to the space. Their functions are similar to those of trees. For better functioning, shrubs can be used along with trees for creating shelter belts, noise barrier, enclosures, etc.

Trees and shrubs together are very useful for the providing shade and for controlling the relative humidity and movement of air. Their contribution for achieving outdoor thermal comfort cannot be compared with the other elements of the landscape.

There are a variety of tree shapes which gives maximum shade when required. Oval and round shape trees are best for effective shading if they are planted in large quantities. Pyramidal shape provides the minimum effective shading.

Hedges

Hedges provide barrier, which are either visual or physical. Barriers are required for different situations like for defining space, or for security and hence need to be necessarily impenetrable.

Groundcover

Groundcover includes those which naturally grow at a very low height like grasses.

Climbers

Some climbers for their spreading habits can be used as ground cover (for example Asparagus spp.) Climbers can be useful for shading the exposed walls from the direct sunlight. They can also be used for the stabilization of soil on embankments (for example, ficus stipulate, Ipomea biloba).

Lawns

Flowerbeds and Lawns can be used for reducing the temperature of the ground and hence to stop glare.

Mulches

Mulches are protective covering which are used above the roots of trees and bushes for retaining moisture. It also kills weeds. It includes plastic sheeting or fallen leaves straw, rotting leaves gravel, grass and wood chipping. It reduces both the air and the surface temperatures it absorbs heat from the ground.

Trellis and creepers

A trellis is usually a light framework of strips crossing together made up of timber, plastic and is used to support climbers. It is usually fastened to a wall.

Use of colour externally

Absorptivity is the solar radiation that is absorbed by a surface and generally depends upon the surface's colour as shown in table 2.1 below.

Absorptivity of Different Colours

Table 2.1 Absorptivity of Different Colours

Colour	Absorptivity (%)
Perfectly black	100
Ordinary black	85%
Dark green	70
Dark grey	70
Light green	40
Light grey	40
White oil paint	20
New whitewash	12
White emulsion paint	12 – 20

Source: BRE (1974)

The paving and the walls which are in the boundary of a site should always be in dark colours (blue, brown and green) so that they do not reflect the heat. If the paving is of light colours, it is preferred to be broken so as not to reflect heat.

2.2.2.3 Outdoor Furniture

Fig. 2.3 Outdoor Furniture in a Cafeteria

Source: Creative Commons Attribution-Share Alike 3.0 Unported from Rico Shen(June,2007)

These are the structures which are added to the outdoor spaces for enhancing the spaces and making it complete (fig 2.3). They are as follows:

1. Seating
2. planter
3. Dustbin
4. Lighting
5. Signage
6. Telephone booth
7. Focal elements: sculpture, fountain
8. Shelters

2.2.3 Principles of Landscape Design

The principles of landscape design are as follows:

• Colour – Always colours which are complimentary in nature should be used for a garden.
• Line – It is good to use Linear patterns to direct physical movement and also to create attention to spaces.

• Form – Different sizes and shapes of the vegetation can create various forms as shown in fig 2.4.

- Rounded forms are most common in plant materials. They allow for easy eye movement and create a pleasant undulation that leads itself to plant groupings.

- Horizontal and spreading forms emphasis the lateral extent and breath of space. They are comfortable because it corresponds with the natural direction of eye movement.

- Vase-shaped trees define a comfortable “people space” beneath the canopy.

- Weeping forms lead the eye back to the ground. What is below the weeping form often becomes a focal point.

- Pyramidal forms direct the eyes upward, so use sparingly. Grouping pyramidals will soften the upward influence. They will look more natural in the surroundings with foliage to the ground.

Fig. 2.4 Various Shapes of Trees

Source: Principles of Landscape Design, David Whiting and Jeffry de Jong (Nov,2012)

• Texture - Plants with varying textures can add to the atmosphere of the outdoor area (fig 2.5).

Fig. 2.5 Texture as seen from far and near

Source: Principles of Landscape Design, David Whiting and Jeffry de Jong (Nov,2012)

• Scale – The outdoor design should balance the size of the buildings it surrounds, while maintaining a comfortable environment for the individuals who will use the area (fig 2.6).

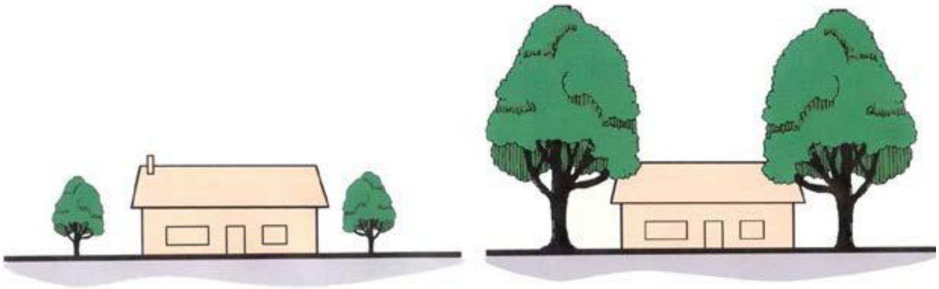


Fig. 2.6 Buildings and Trees in different Scale

Source: Principles of Landscape Design, David Whiting and Jeffry de Jong (Nov,2012)

2.2.4 Influence of Landscape Design

The Landscape has a great influence in modifying the outdoor microclimate. Some of the modifications which can be made are as follows:

A. Planting of deciduous trees because:

   a. It provides shade in summer and allows solar radiation in winter
   b. It has very less effect on wind.

B. Planting of evergreen trees because:

   a. It provides shade year-round, which is a benefit in summer, but a detriment in winter
   b. It can have a substantial effect on wind.

C. Using Trellis because:

   a. It allows solar radiation to penetrate through it in winter and also provides good shade during summer if its orientation is towards the south,
   b. Also it provides a framework for deciduous creepers to grow on, hence creating the similar effect as created by the deciduous trees
   c. But it is not effective if it is oriented toward the north, east or west.

D. Using Fence because:

   a. If it is oriented towards the east or west, it can provide shade in the nearby area for all the seasons (minimum in summer and maximum in winter,)
   b. If it is oriented towards the north or south, effective shading is not possible

c. It can be oriented perpendicular to the wind direction to prevent winter winds

E. Using Light Coloured Surfaces because:

a. it will reflect more solar radiation and hence the surface will remain cool
b. the radiation which is reflected can be absorbed by any other elements of the landscape

F. Using Water elements because when it is sprayed on the ground it cools down the surface and hence reduces the amount of radiation emitted. Also in hot-dry climate with the use of water bodies, the relative humidity can be increased to create more comfort.

G. Using Green Walls because when it is covered with deciduous creepers it will emit less solar radiation and hence remain cool.

2.3 OUTDOOR THERMAL COMFORT

"Thermal Comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55, 2004)." In the past decade, valuable researches were carried out for outdoor conditions (Hoppe, 2002; Givoni et al., 2003; Ahmed, 2003; Spagnolo & De Dear, 2003; Stathopoulos, Wu, & Zacharias, 2004; Cheng & Ng, 2006; Gulyas, Unger, & Matzarakis, 2006; Nikolopoulou & Lykoudis, 2006; Cheng, Ng, Chan, Ali-Toudert & Mayer, 2006; Tseliou, Tsiros, Lykoudis, & Nikolopoulou, 2009 & Givoni, 2010). The parameters of Outdoor Thermal Comfort as derived from these studies are as shown in fig. 2.7 below:-

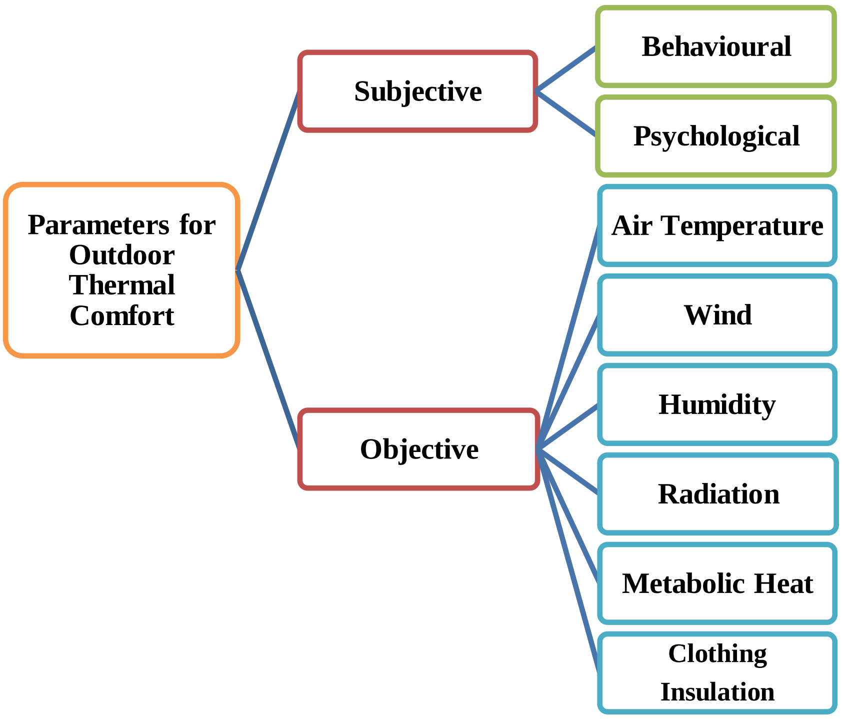


Fig. 2.7 Outdoor Thermal Comfort Parameters

2.3.1 Outdoor Thermal Comfort Assessment Methods

The Outdoor Thermal Comfort Evaluation is carried out by the following two methods simultaneously:

1. Micro-Meteorological Measurement: The four basic microclimatic parameters which influence the outdoor thermal comfort sensation are Air temperature, Relative humidity, Wind and Solar Radiation. In this survey, the microclimatic parameters are measured by the instruments like the portable weather station, thermo-hygrometer, etc.

2. Guided User Questionnaire Survey: During the field survey, a questionnaire survey is carried out where the subjects' comfort condition (e.g. thermal sensation, humidity sensation, etc) are enquired and also record the subjects' personal factors (age, gender, height, weight, etc). The thermal comfort sensation can be recorded in any one of the thermal comfort scale as shown below in Table 2.2.

Table 2.2 Thermal Comfort Scale

ASHRAE SCALE		**BEDFORD SCALE**		**SEVEN POINT**		**NINE POINT**	
Hot	3	Much Too Warm	3	Very Cold	1	Very Cold	1
Warm	2	Too Warm	2	Quite Cold	2	Cold	2
Slightly Warm	1	Comfortably Warm	1	Cold	3	Cool	3
Neutral	0	Comfortable	0	Comfort	4	Slightly Cool	4
Slightly Cool	-1	Comfortably Cool	-1	Hot	5	Neutral	5
Cool	-2	Too Cool	-2	Quite Hot	6	Slightly Warm	6
Cold	-3	Much Too Cool	-3	Very Hot	7	Warm	7
						Hot	8
						Very Hot	9

Source: Nasir et al.,2012

Also external parameters (e.g. Clo value, Metabolic Rate, etc.) that are required for the thermal comfort conditions calculation needs to be obtained from this questionnaire survey.

Activity level: According to nature of activity, the human body converts an amount of food taken into energy. "The amount of energy that is produced per unit of time is called metabolic rate and it is expressed in Watt/ m^2 of body surface." Table 2.3 presents metabolic rate for various activities.

Clothing: It is an intermediate between the human body and the outdoor environment. Different clothing type has different efficiency level which can be expressed by Clo value as shown in table 2.4 and table 2.5.

The subject's personal factors, clothing, activities, outdoor thermal comfort vote and the thermal sensation can be obtained in the field survey from the questionnaire survey. The results of the questionnaire survey and the micro-meteorological data are compared to evaluate the outdoor thermal comfort conditions in that particular place.

Table 2.3 Metabolic Rate of Various Activities

Activity	Metabolic rate (*Met Units)
Sitting	**1**
Eating	**3**
Walking	**2.6**
Playing/exercise	**4**
Standing	**1.2**
Studying and sitting	**1**
Serving	**1.6**

***1 met = 58.2 W/m^2 (18.4 Btu/h·ft^2)**

Source: ASHRAE Handbook of Fundamentals, 1989

Table 2.4 Clo Value Chart for Male

Types	*Clo Values* of various clothes			
Under Garments & Inners	0.05	Briefs		
	0.15	Vest (light)	0.29	Vest (heavy)
Clothing above waist	0.14	Shirt short sleeve	0.22	Shirt long sleeve
	0.25	T-Shirt short sleeve	0.29	T-Shirt long sleeve
Clothing below waist	0.15	Shorts/Half pant		
	0.2	Capris		
	0.3	Jeans		
	0.26	Trouser light material	0.32	Trouser heavy material
Winter Wears	0.3	Inner above waist	0.3	Inner below waist
	0.2	Sweater light	0.37	Sweater heavy
	0.22	Jacket light	0.49	Jacket heavy
	1.5	Overcoat		
Others	0.5	Hat/Cap		
	0.1	Scarf/shawl		
	0.05	Tie		
	0.1	Socks till knee	0.5	Socks till ankle
	0.04	Shoes; 0.02 Sandal / Slippers	0.08	Boots

Based on ASHRAE Handbook of Fundamentals, 1989 and ANSI/ASHRAE Standard 55-201

Table 2.5 Clo Value Chart for Female

Types	*Clo Values* of various clothes				
Under Garments & Inners	0.05	Bras & panties			F E M A L E
	0.19	Slips/Spaghetti			
	0.04	Shape wear			
Clothing above waist	0.14	Shirt short sleeve	0.22	Shirt long sleeve	
	0.25	Tshirt short sleeve	0.29	Tshirt Long sleeve	
	0.25	Short Sleeve Top	0.29	Long sleeve Top	
	0.25	Kurti Short sleeve	0.29	Kurti Long sleeve	
Clothing below waist	0.10	Skirt light	0.22	Skirt heavy	
	0.15	Shorts			
	0.2	Capris			
	0.3	Jeans			
	0.26	Trouser light	0.32	Trouser heavy	
Indian wear/dress	0.7	Dress/Frock			
	0.22	Peticot			
	0.20	Blouse short sleeve	0.30	Blouse long sleeeve	
	0.5	Sari			
	0.2	Kameez/Long Kurta			
	0.2	Salwar/Churidar/Leggings			
	0.15	Dupatta			

Winter Wears	0.3	Inner above waist	0.3	Inner below waist		
	0.2	Sweater light	0.37	Sweater heavy		
	0.22	Jacket light	0.49	Jacket heavy		
	1.5	Overcoat				
Others	0.5	Hat/Cap				
	0.1	Scarf/shawl				
	0.05	Tie				
	0.1	Slacks				
	0.04	Stockings				
	0.1	Socks till knee	0.5	Socks till ankle		
	0.04	Shoes/Pumps	0.02	Sandal / Slippers	0.08	Boots
Any other worn then please specify						

Based on ASHRAE Handbook of Fundamentals, 1989 and ANSI/ASHRAE Standard 55-2010

2.3.2 Outdoor Thermal Comfort Indices

According to outdoor thermal conditions, several indices are available to evaluate and analyze the outdoor thermal condition. These indices can be classified in a number of ways.

(a) According to capability for evaluating hot and cold conditions, they are classified as:-

1. Thermal Stress Model: - Heat stress indices such as Discomfort Index (DI), heat index (HI), Tropical Summer Index (TSI), Humidex, and Wet Bulb Globe Temperature (WBGT) are used for hot conditions. Cold stress indices like Wind Chill Equivalent Temperature (WCET) and Wind chill Index (WCI) are used for cold conditions.
2. Heat Budget Model: - These indices are capable to evaluate both cold and hot and cold conditions like Temperature Humidity Index (THI), Perceived Temperature (PT) and Physiological Equivalent Temperature (PET). The latest index which also comes under this category is called Universal Thermal Climate Index (UTCI) and it is based on the comprehensive heat budget model of human biometeorology,.

(b) Based on their guiding development principles, thermal indices can be classified as follows (Scudo 2002):

1. Empirical Thermal Indices:- Wind Chill Index (Siple and Passel 1945) and Discomfort Index (Thom and Bosen 1959)
2. Psycho-sociological-climatic indexes:- Satisfaction Indexes, Actual Sensation Vote,
3. Energy balance equation indexes based on
    a) Two-node model of the human body **{**Pierce Two-Node model (Gagge, Fobelets, & Berglund, 1986; Gagge, Stolwijk, & Nishi, 1971) treats the human body as two isothermal parts, skin and core **}** eg., OUTSET and on the assessment of all relevant thermal climatic parameters, including the heat balance equation (Hoppe 1999); e.g., PET(Hoppe's MEMI model)

b) One-node model of the human body :- Perceived Temperature (PT) model based on Fanger's (1972) equation and outdoor radiant evaluation model (Jendritzki et al. 1990): PMV index

The general Energy Balance Equation of the human body is as follows (ANSI/ASHRAE Standard 55, 2004) (fig. 2.8):

$$\mathbf{M - W = C + R + E + C_{res} + E_{res} + S}$$

Where, M is metabolic rate (W/m^2),

W is mechanical power (W/m^2),

C is convective heat loss from skin (W/m^2),

R is radiation heat loss from skin (W/m^2),

E is evaporative heat loss from skin ($W/m^{2)}$,

E_{res} is evaporative heat loss from respiration (W/m^2),

C_{res} is convective heat loss from respiration (W/m^2) and

S is the rate of body heat storage (W/m^2)

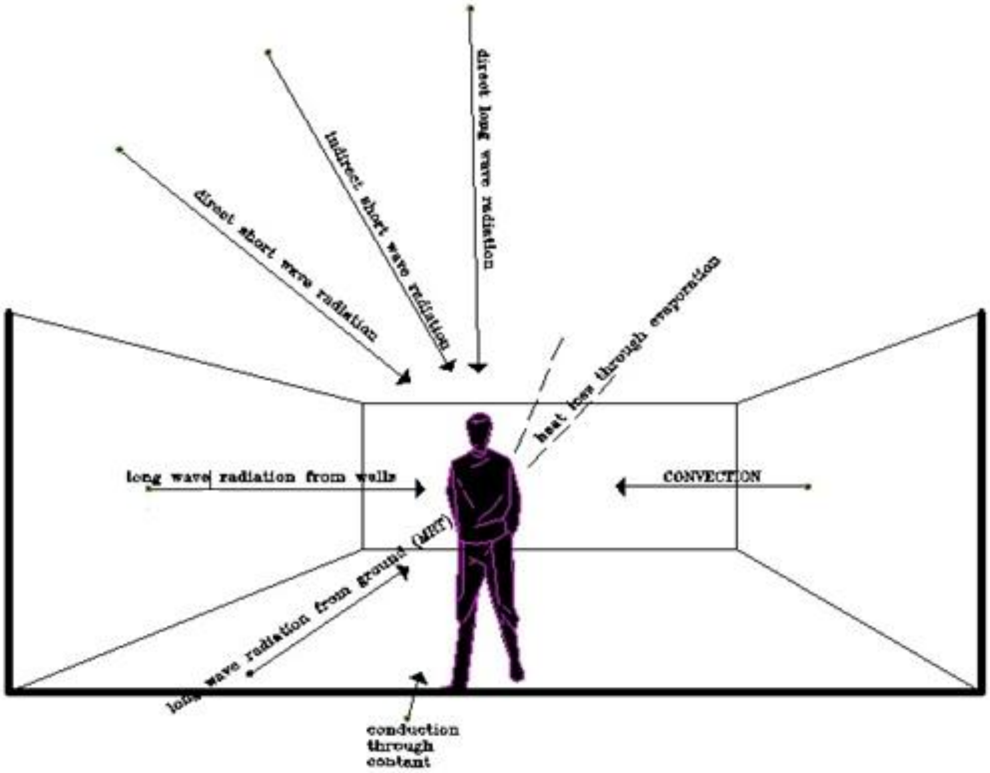


Fig. 2.8 Energy Exchange Diagram of Human Body in Outdoor Environment

Source: Enhancement of Outdoor Thermal Comfort through Adoption of Environmental Design Strategies, Mohammadjavad mahdavinejad, Mahboobe khademi, Golriz Sadeghnejad (2013)

(c) According to assessment methods involved in them, thermal Indices can be classified as follows (Nagano and Horikoshi, 2011):-

1. Steady State Assessment Methods: - According to these models, it is believed that over the years, people's exposure to the outdoor environment has allowed them to reach the thermal equilibrium state and hence numerical solutions can be generated from the energy balance equation which governs the thermo-regulation. E.g. The Index of Thermal Stress (ITS) (Givoni, 1976), Predicted Mean Vote Index (PMV) (Fanger, 1982), Physiological Equivalent Temperature (PET) (Mayer & Hoppe, 1987), , OUT-SET (Pickup & De Dear,1999), COMFA Outdoor Thermal Comfort Model (Kenny, Warland, Brown, & Gillespie, 2009)
2. **Non-Steady Assessment Methods:-** The present studies which are related to non steady assessment methods have been restricted to indoor conditions (Zhang, Huizenga, Arens, & Wang, 2004 ; Foda & Siren, 2010). Hence the evaluation of unstable outdoor thermal comfort conditions has remained as an area of research. (Jendritzky, Maarouf, & Staiger, 2001; Fiala, Lomas, & Stohrer, 2001; Tokunaga & Shukuya, 2011; Shimazaki et al., 2011;).

Important Outdoor Thermal Comfort Indices

(a) Physiological Equivalent Temperature (PET):- PET was developed by Hoppe, 1993, is an OTC index which regulated all the basic thermoregulatory processes. It is based upon the Munich energy balance model for individuals (MEMI) (Hoppe, 1984; 1999). According to Mayer and Hoppe (1987) and Hoppe (1999), "PET is defined as the equivalent air temperature at which, in a typical indoor condition heat balance of the human body exists (work metabolism 80 W of light activity, and clothing of 0.9 clo). The following assumptions are made for the indoor reference climate:

Mean radiant temperature equals air temperature ($T_{mrt} = T_a$).

Air velocity is set to 0.1 m/s. Water vapour pressure is set to 12 hPa (approximately equivalent to a relative humidity of 50% at Ta=20°C)."

PET can be calculated in °C which is the best advantage in terms of applicability. PET and PT (Perceived Temperature) are correlated. PET is applicable to outdoor conditions also. PET has been one of the recommended indices in the new "German guidelines for urban and regional planners" (VDI, 1998). PET can be easily calculated by using the RayMan Software developed by Matzarakis *et al*. (2007).

(b) Predicted Mean Vote (PMV):- PMV (Predicted Mean Vote) has been developed by Fanger (1972) for indoor climates. Jendritzky and Nubler (1981) added complex outdoor radiation for applying the PMV index to outdoor conditions as well. This model is known as Klima-Michel Model (KMM).

(c) Outdoor Standard Effective Temperature (OUTSET):- The new effective temperature (ET) is based on two-node model and human energy balance (Gagge *et al.*, 1971). With ET the thermal conditions can be compared to the conditions in a standardized room with a mean radiant temperature equal to air temperature and a constant relative humidity of 50%. Gagge *et al*. (1986) proposed the new standard effective temperature (SET) by improving ET. SET is used very frequently in indoors and outdoors. Ishii *et al*. (1988) had compared various thermal comfort indices concluding that for evaluating outdoor comfort SET has been one of the best. Kinouchi (2001) too proved the similar thing. Pickup and Dear (1999) developed OUT-SET by improving the SET.

(d) Universal Thermal Climate Index (UTCI):- The Universal Thermal Climate Index UTCI is developed by Hoppe in 2002. It gives an evaluation of the outdoor thermal environment in the bio meteorological applications. The main purpose of the UTCI is to give information to the public about how the weather feels with factors such as wind, solar radiation and relative humidity. UTCI is also in degree Celsius scale so that it becomes easy for the general public. It can also be calculated online.

A comparative analysis has been done for the three important and useful indices (PET, PMV, OUTSET) in table 2.6 below.

Table 2.6 Comparative Analysis Between The Thermal Comfort Indices (PMV, PET and OUTSET)

INDICES / FACTORS	PMV	PET	OUTSET
Introduced	Fanger in 1972	Mayer and Hoppe in 1987,1999	Pickup and De Dear in 1999
Parameters Considered	Clothing and Activity levels as variables.	Earlier, it did not consider Clothing and Activity levels as variables. But in the Rayman Model, these variables are added.	Clothing and Activity levels as variables
Range	Limitations in the range of its upper and lower limits. (Temperature only from 10^0 C to 30^0C) Not suitable for tropical climate (extreme temperature).	Assumes RH=50% in the reference indoor situation which actually changes with T_a in outdoor situations. Hence less accurate.	Assumes Vapour Pressure of 12hPa which is constant water content in the air independent from T_a. Hence more accurate.
Applicability	It does not take into account the thermo-regulations of a human body. Hence not very accurate for extreme conditions (typically outdoors).Thus mainly used for indoor areas.	It takes into account the thermo-regulations of a human body. Hence more accurate for extreme conditions (typically outdoors). Hence better than PMV.	It takes into account the thermo-regulations of a human body. Hence more accurate for extreme conditions (typically outdoors). Hence better than PMV.

Based on Fazia Ali Toudert.,(2005), Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y., Feller, N., & Becker, S. (2003)

2.3.3 Simulation Software for Outdoor Thermal Comfort

For the outdoor thermal comfort assessment, different software can be used for the calculation of the indices as well to carry out simulation in the outdoor spaces. Amongst them, Rayman and Envimet have been very successful and accurate and hence been discussed below briefly.

RayMan Model - RayMan stands for "radiation on the human body". Developed in 2007 by Matzarakis et al., it can be used for the PET calculation. The three thermal indices PET, SET* and PMV can be calculate in the RayMan model. It is also easily available online.

Envi-Met - Envi-met is a three-dimensional grid-based model used for the simulation of surface-plant interaction and also to calculate microclimatic parameters Wind, Surface temperature, Mean Radiant Temperature, etc. It is designed basically for micro-scale simulation with a uniform resolution (0.5 to 10 m) in the horizontal surface and 10 s in time. It includes the key modelling inputs, initial climatic parameters, building structure including site location, plant type and soil type and thermal properties.

2.4 SUMMARY

Outdoor Thermal Comfort is important and significant aspect of quality of living, especially in urban areas. Its assessment can be carried out through different thermal comfort indices and/or using software. Review on basic concepts, parameters and assessment methods to evaluate outdoor thermal comfort through thermal indices throw light on important research initiatives on the same. Also review on scope of software like Envimet and Rayman for evaluating outdoor thermal comfort highlights extension of analytical ability of researchers.

For the evaluation of the outdoor thermal comfort, PET is a more suitable index compared to PMV, OUTSET because of its advantages as discussed. UTCI is a recent index which is also similar to PET but further study is required for its proper appreciation and applicability in Indian scenario. In a tropical climate like India, with diverse climatic conditions, it will be interesting to evaluate PET variations across different climates. PET can be calculated from software like Rayman which is very easily available online. Simulation software like Envimet can also assist in outdoor thermal comfort assessment.

Landscape design is also an important area for designing comfortable outdoor spaces. From the literature reviewed, the various elements of landscape are studied along with their prospects for modifying the microclimate of outdoor spaces. The proper implementation of the landscape elements can help in creating better comfort conditions in the outdoors.

Hence some of the landscape design strategies which can be implemented for better thermal comfort conditions in outdoor spaces are as follows.

- Using shading trees as an overhead canopy
- Using vegetative surfaces instead of paving
- Reducing close shrubs to encourage air circulation
- Encouraging overhead planting, which slows evaporation
- Adding water elements such as fountains
- Using low windbreaks to preserve moisture
- Using natural mulch under plantings
- Increase sky view factor by architectural design
- Increase natural ventilation through open space layout
- Increase vegetation through creating green network in open space
- Attention to the tree types and position of the plants

3. CASE STUDIES

Several case studies were studied and out of them three have been presented here. The case studies were actually field studies done by different researchers from different parts of the world. The case studies helped in understanding how the outdoor thermal comfort evaluation can be done with the help of field surveys, how to evaluate the influence of landscape on OTC in the outdoor spaces, how to use the software for simulation- RayMan and Envi-Met.

3.1 CASE STUDY: "A FIELD STUDY ON THE IMPACT OF VEGETATION ON OTC IN THE NEIGHBOURHOOD OF SAO PAULO- BRAZIL"

Objective of the Research: - The objective was to compare how the different shading devices behave in an outdoor environment.

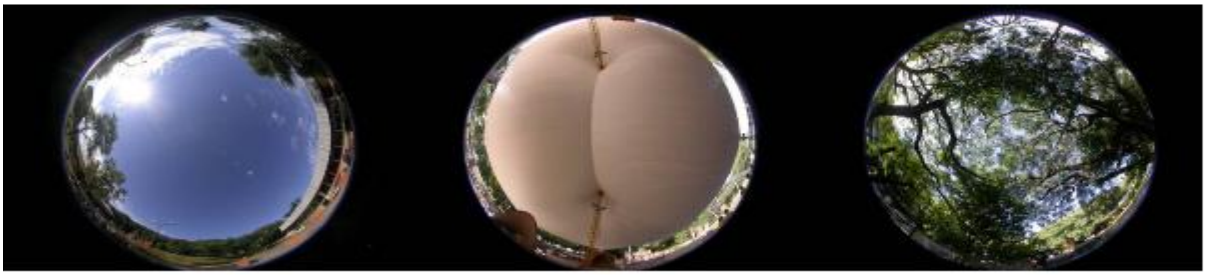
Three sites were selected for the field survey {fig. 3.1 (a), (b), (c)}:

1. Under open sky
2. Shaded by trees
3. Under a processed cover

Methods Used: -

In each of the 3 sites, the microclimatic parameters were recorded with an interval of 1second and a storage interval of 1 minute for the six different hours of a particular day. Also around 150 people answered the questionnaires. Questionnaire contained questions related to acclimatization, personal factors (age, gender, height, weight), and also subjective responses (thermal preference, sensation, tolerance and comfort). Photos were taken for every person for identifying the present activity and clothing. Altogether there were 36 different micro-climatic scenarios and a total of 900 questionnaires were collected during the winter and the summer in the city.

(a) Panoramic view of the Field survey at three different locations



(b) Fish Eye Photographs

1. At this precise moment, I am feeling:

( ) very cold ( ) cold ( ) cool ( ) neutral ( ) warm ( ) hot ( ) very hot

2. I find this:

( ) comfortable ( ) slightly uncomfortable ( ) uncomfortable ( ) very uncomfortable

(c) Part of the questionnaire

Fig. 3.1 {(a),(b),(c)} Field Survey

Observations:-

The results of the survey are shown in fig 3.2.

- Under Tree canopy and processed cover, the neutral thermal situation can be found.

- In a subtropical climate, on a summer day, it is only under tree shade that thermal conditions tend to be cooler and also stable.

Hence tree canopy was a better shading device in an outdoor situation than a processed cover and the worst and harsh scenario is observed under the open sky and it is due to the high amount of solar radiation received.

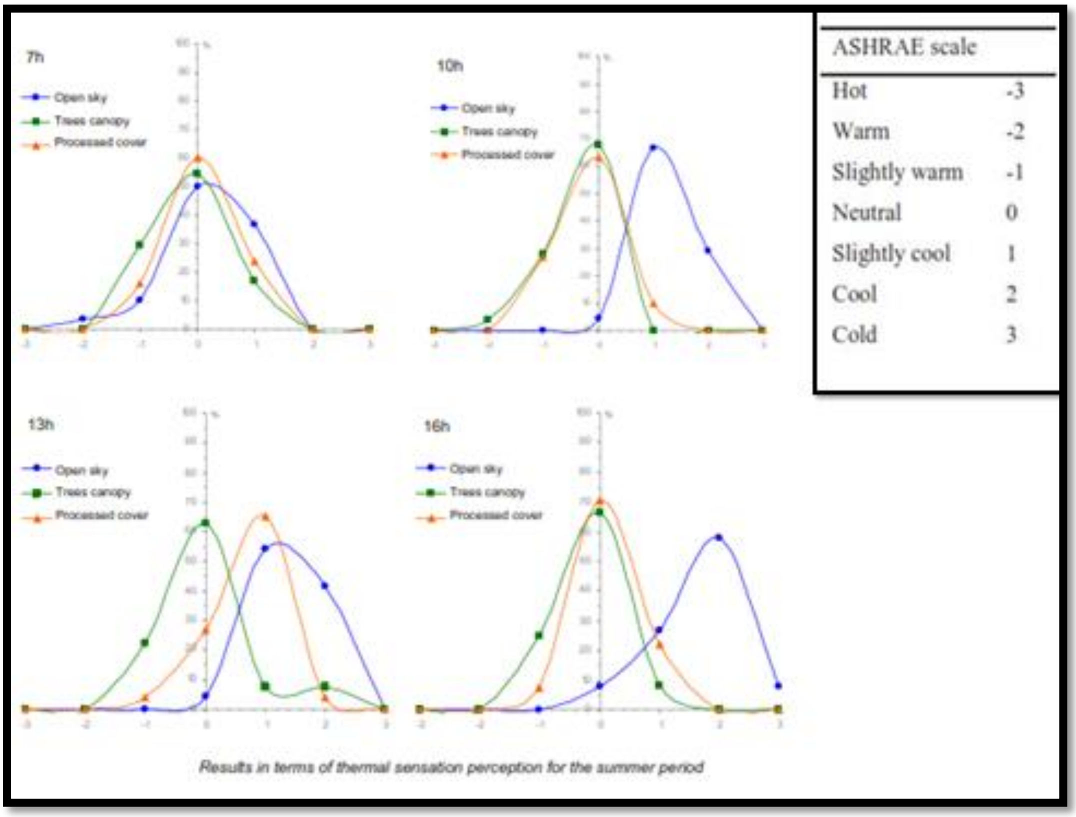


Fig. 3.2 Results of the Survey (Summer)

3.2 CASE STUDY: "A FIELD STUDY ON THE EFFECTS OF PLANTS ON OUTDOOR THERMAL SENSATION UNIVERSITIES OF TAICHUNG CITY, TAIWAN"

Objective of the Research: - The objective of the Research was to review the effect of shading by plants on the thermal condition for outdoor spaces. Analysis was done for two cases (with and without plant shade) (fig 3.3) in Taiwan located in the subtropical zone.

Method: - The scope of the research was focused mainly on the subtropical zone. From April to October 2007, field survey was carried out by taking measurements of the climatic factors and also collecting questionnaire survey in two universities of Taichung City, Taiwan.

Questionnaires: 837 (466 male and 371 female

Time: 8:00 a.m to 6:00 p.m on sunny days

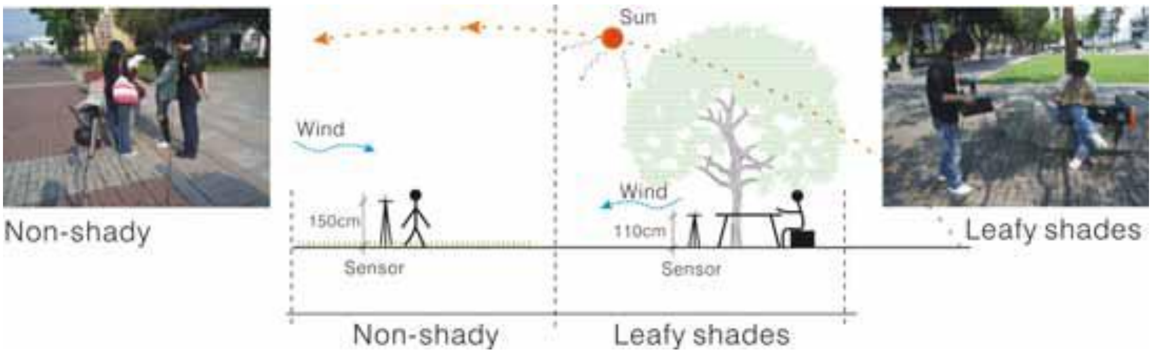


Fig. 3.3 Two Locations of the Survey (Shady and Non-Shady)

Climatic Factor Measurement and Questionnaire Survey:

The study took measurement of the environmental parameters: relative humidity, wind velocity, air temperature, radiant temperature and mean radiant temperatures.

Observations:-

- It was found that planting large trees can influence and improve the outdoor thermal environment.
- Under plant shade, the mean radiant temperature is stabilized and hence brings much higher degrees of comfort.
- A relation between the temperature and the wind sensation was found. The higher temperature led to higher tolerance of wind.

3.3 CASE STUDY: "A FIELD STUDY ON SENSITIVE ANALYSIS OF LANDSCAPING ELEMENTS ON OUTDOOR THERMAL ENVIRONMENT IN A RESIDENTIAL COMMUNITY IN GUANGZHOU, CHINA"

Objective of the Research: - The objective of the Research was to focus on how the landscaping factors affect the outdoor environment qualities. Field studies and Envi-Met analysis were done. Finally, some suggestions and conclusions in landscape design were proposed.

Methods Used: -

Date: From July 19th to 24th in 2007

Place: Guangzhou, China

Time: 10:00 a.m to 5:00 p.m

Several environmental parameters, including wind speed (*v*), relative humidity (*RH*), air temperature (*Ta*) and globe temperature (*Tg*) were measured in various spots with different types of landscaping elements (fig 3.4).

For reviewing the behaviour of different landscaping elements on the outdoor environment, Envi-Met simmulation was done.

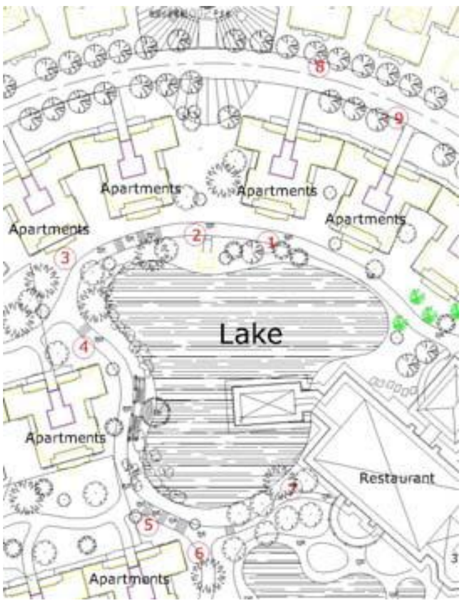


Fig. 3.4 Various Locations of The Survey

Observations:

1) Surface types: Five different types of surface were simulated. It is seen that the different surfaces consisting of various materials have different surface temperatures but air temperature is similar if the location are nearby. As expected, the asphalt has the highest surface temperature.

2) Water depth: Five kinds of lakes with various depths from 0m to 1.75m were simulated. It is found that the depth of water has minimum effects on the air temperature.

3) Vegetation types: Three different kinds of vegetation were simulated. It is observed that grass has very little impact on the air temperature although it has high impact in reducing the surface temperature. It is the trees which can reduce the air temperature to a great extent.

3.4 LESSONS LEARNT

From the various Case Studies, it is found that Landscape has a greater role to play in influencing the microclimate of an outdoor space. Soft Landscaping elements like the trees can be the best measure to achieve outdoor thermal comfort in an outdoor space.

It is identified from the case studies that T_{mrt} (Mean Radiant Temperature) is the most successful parameter in determining the comfort conditions outdoors. It is observed that its value is less and stable under tree shade throughout the day.

Also, along with microclimatic data, subjective evaluation of people is a necessary tool to understand the thermal sensation of the natives of that place. With the help of these data we can determine the PET index in RayMan. Also simulation of different scenarios can be generated by using the Envi-Met tool. This will further help in assessing the outdoor thermal comfort evaluation and in designing better outdoor spaces.

Hence for carrying out the outdoor thermal comfort evaluation and also to review the influence of landscape in the outdoor spaces, the tools and techniques were developed. They are as follows:

- Site Analysis
- Microclimatic Data Collection Survey
- Questionnaire Data Survey
- Calculation of PET index by RayMan model
- Simulation of the thermal environment scenarios through Envi-Met software

All these evaluation techniques are required to analyze in detail for designing comfortable outdoor spaces.

4. FIELD SURVEY IN IITR

4.1 ROORKEE

The climate in Roorkee is composite. The Composite or monsoon climates in India (fig 4.1) usually occur near the tropics of Cancer and Capricorn. The climate characteristics of Roorkee are shown in table 4.1, table 4.2 and table 4.3. The table 4.4 is showing the composite climate of Roorkee in a brief.

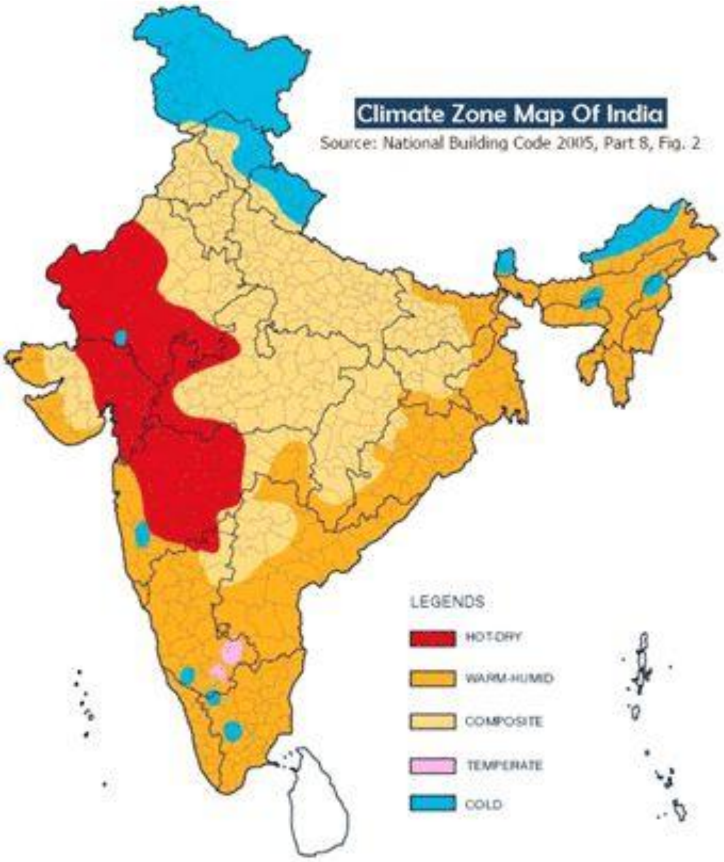


Fig. 4.1 Climatic Zones of India

(Source: NBC, 2005)

Table 4.1 Typical DBT Values of Roorkee

Typical DBT values (^{0}C) are:			
	Hot/dry	Warm/humid	Cool/dry
Day mean max	32-43	27-32	up to 27
Night mean max	21-27	24-27	4-10

Source: Climate and Buildings, Ministry of New and Renewable Energy, Govt. of India

Table 4.2 General Data of Roorkee

Latitude: 29 deg. 51 min. North

Longitude: 77 deg. 53 min. East

Elevation: 274 m above sea level

Average Annual Rainfall: 1032 mm

Average Temperatures:

January: - 13.8^0 C

June: - 32.2^0 C

Annual Temperature difference: 18. 4^0 C

Highest Temperature Recorded: - 45. 5^0 C (on 9th May, 1956)

Lowest Temperature Recorded: - 3. 3^0 C (on 26th January, 1964)

Total area: - 811 Hectare

Average maximum humidity: - 100%

Average minimum humidity: - 30%

Soil: - Alluvial soils of Ganga Plain

Source: Climate and Buildings, Ministry of New and Renewable Energy, Govt. of India

Table 4.3 Historical Average Temperature of Roorkee

	Temperature		
Months	Normal	Warmest	Coldest
January	14.3°C	21.0°C	7.6°C
February	16.8°C	23.5°C	10.1°C
March	22.3°C	29.2°C	15.3°C
April	28.8°C	36.0°C	21.6°C
May	32.5°C	39.2°C	25.9°C
June	33.4°C	38.8°C	27.8°C
July	30.8°C	34.7°C	26.8°C
August	30.0°C	33.6°C	26.3°C
September	29.5°C	34.2°C	24.7°C
October	26.3°C	33.0°C	19.6°C
November	20.8°C	28.3°C	13.2°C
December	15.7°C	22.9°C	8.5°C

Source: Climate and Buildings, Ministry of New and Renewable Energy, Govt. of India

Table 4.4 Composite climate of Roorkee in a brief

Type of climate		**Hot/dry**	**Warm/humid**	**Cool/dry**
Season		Summer	Monsoon	Winter
Months		April, May, June	July, August	Dec, Jan, Feb
Solar radiation	**More Solar Radiation**	West and East	West and East	South
	More Solar Radiation duration	West and South	West and South	West and South
Wind type and direction		Hot and dusty winds	Strong winds from South-East	Dry cold Winds from North East
Wind speed		Highest in May, June (7.4 and 7.2 km/hr)	---	Minimum Wind speed in October (2.6 km/hr)
Sky conditions		Frequently hazy Sky	Overcast and Dull Sky	Clear Sky
Evapotranspiration otential		Maximum in May (198.9mm)	---	Minimum in December (38.5 mm)
Relative Humidity:		Dry Seasons – 20 to 25 %	Wet Seasons – 55 to 95 %	--

4.2 SELECTION OF CASES

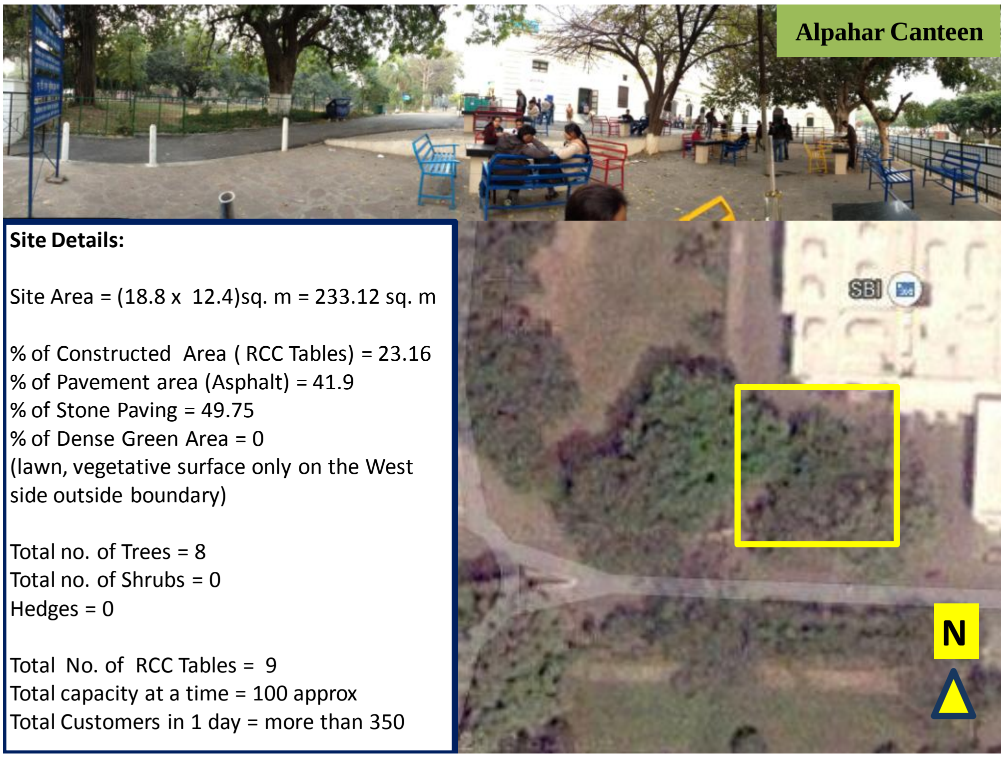
Alpahar and Bru are the main study area (base cases) where design will be implemented later. Some contrasting cases were also selected to find out the differences. Lawn Main Building was selected because of the maximum amount of Vegetative area present (Soft Landscaping Element). On the other hand, LHC Parking and Students Club frontyard were selected because of the maximum amount of paved area (Hard Landscaping Element) present. This is to show how microclimatic parameters vary with the different outdoor spaces.

Alpahar and Bru in IITR were selected as the Base cases because -

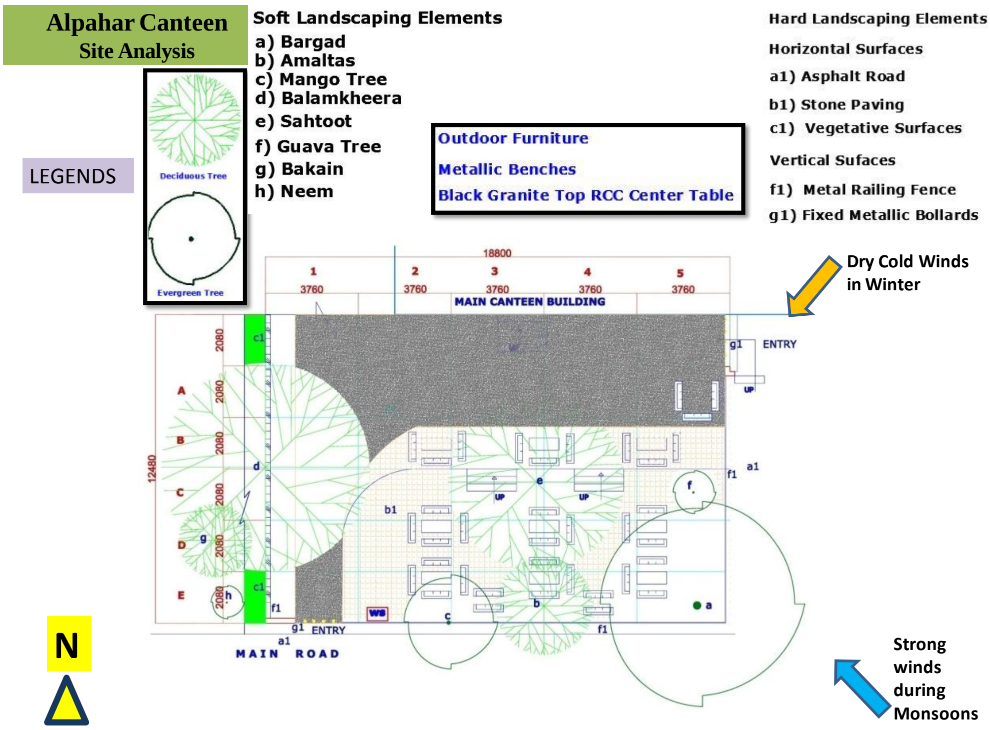
- Famous Outdoor Activity areas in IITR
- Used by almost 80% of the people in IITR
- Many samples (people) can be taken at a particular time (for subjective evaluation of Outdoor Thermal Comfort)
- Comparative analysis can be done between the two as both the spaces are used equally by the people.
- As these spaces concerns the comfortability of many people, the outdoor thermal comfort evaluation is a very necessary tool for designing and recommending better situations if possible. Hence the influence of landscape for achieving Outdoor Thermal Comfort in these outdoor activity areas has been studied and analyzed.

Alpahar Cafeteria

The Alpahar Cafeteria is located adjacent to the SBI IITR. Hence, it is mostly crowded with around 350 customers per day. The customers include students, employees of different age category. It also has indoor seating but the space is very small and because of the shade under the trees, people prefer to sit outside. There is provision of outdoor furniture which includes RCC constructed table with granite finish and metallic benches. Two narrow gates (bollards) and one open access leads to the outdoor cafeteria. Since the customers prefer to have some relaxing time in an outdoor cafeteria, it is very necessary to evaluate the design of these outdoor spaces for better thermal comfort experience. The details of the Alpahar cafeteria site are shown in fig 4.2 {(a),(b)}. The list of trees in Alpahar is shown in table 4.5.



(a)



(b)

Fig. 4.2{(a), (b)} Plan of Alpahar with site details

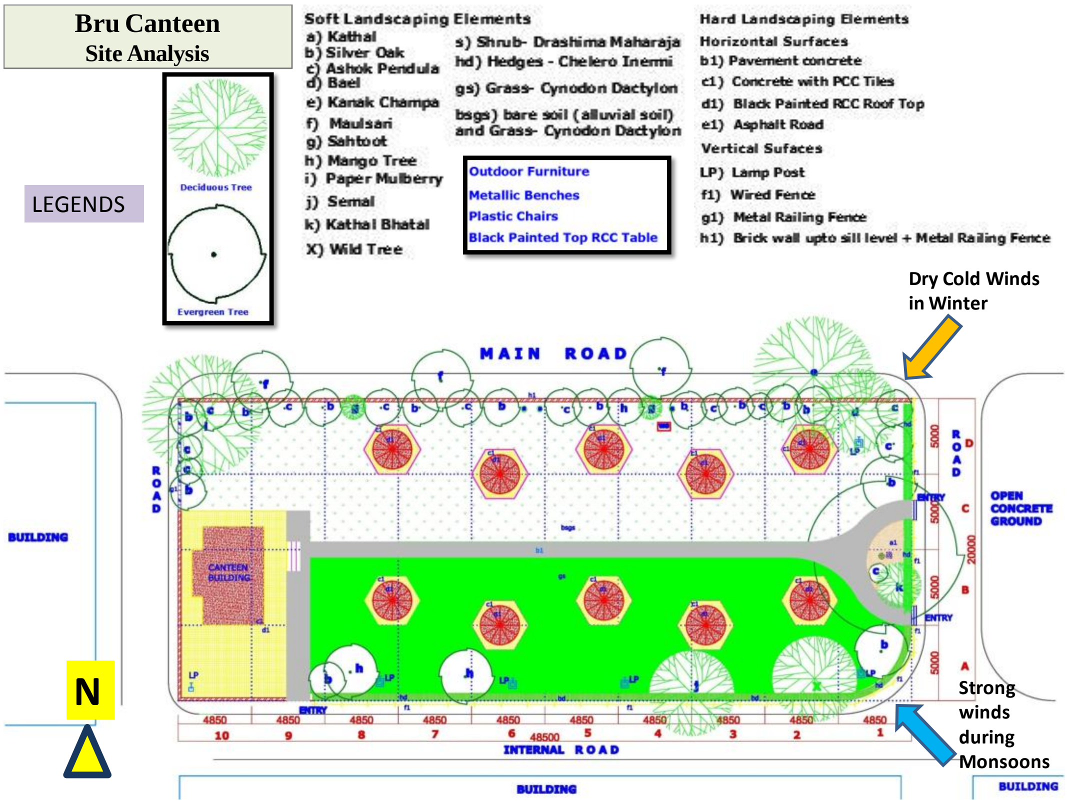
Table 4.5 List of Trees in Alpahar

Total no. Present	Botanical Name	Common Name	Height(m)	Spread(m)	Type	Climate	Soil	Uses
1	Kigelia Pinnata	Balamkheera	10-14	12-15	Sub-deciduous, Maturity- 10 to 15, Life- 80 to 100 yrs	Preferably hot	Alluvial soil, sandy or loamy	Deep shade, good for road side planting
1	Melia Azadiracta	Bakain	10-14	9-13	Deciduous, Life 20 yrs	Varied climate	Any well drained soil	Very good for small parks and roadsides
1	Mangifera Indica	Mango	15-22	12-19	Evergreen, Life-150 to 160 yrs	Warm, moist		
1	Casia fistula	Amaltas	10-20		Deciduous	Dry climate	Well drained soil	
1	Ficus Bengaliensis	Bargad, banyan	Upto 30		Evergreen		Well drained soil	Large Canopy

Bru Cafeteria

The Bru Cafeteria is located adjacent to the Students Club, PNB and Post Office. Therefore, it is mostly crowded with around 350 customers per day. The customers include students, employees of different age category. It has no indoor seating but there are 10 kiosks where there are arrangements for seating. There is provision of outdoor furniture which includes RCC constructed table and metallic benches. Three gates leads to the outdoor cafeteria. Since the customers prefer to have some relaxing time in an outdoor cafeteria, it is very necessary to evaluate the design of these outdoor spaces for better thermal comfort experience. The details of the Bru cafeteria site are shown in fig 4.3 {(a),(b)}. The list of trees in Bru is shown in table 4.6.

(a)



(b)

Fig. 4.3{(a),(b)} Plan of Bru with site details

Table 4.6 List of Trees in Bru

Total no. Present	Botanical Name	Common Name	Height(m)	Spread(m)	Type	Climate	Soil	Uses
1	Artocarpus Integrifolia	Jack Fruit, kathal	9-21 m		Evergreen	tropical	laterite soil	
14	Grevilia Robusta	Silver Oak	18-35	7.62	Evergreen Oval in Shape Maturity- Life-	Warm, sunny	well-drained	
12	Polyalthia Pendula	Ashok Pendula	15-22	7-11	Evergreen Maturity- 6 to 10 yrs Life-150 yrs	Hot, moist	Any well drained soil	Ornamental deep shade
1	Aegle Marmelus	Bael	12-15		Deciduous	subtropical condition with hot dry summer and mild winter	well-drained soil	
2	Morus Indica	Sahtoot			Deciduous		flat, deep, fertile, well drained, loamy to clayey, porous with good moisture holding capacity	
3	Mangifera Indica	Mango	15-22	12-19	Evergreen Life-150 to 160 yrs	Warm, Moist		
1	Broussonetia papyrifera	Paper Mulberry	10-20		Deciduous	many climate types		Ornamental plant, tolerates disturbance and air pollution, so useful as a landscaping plant on roadside
1	Bombax Ceiba	Cotton Tree, Semal	20-60		Deciduous	Grows well in wet tropical climate		
1	Pterospermum acerifolium	Kanak Champa	15-30		Deciduous tree	Moist, full sunlight		Ornamental or shade tree
3	Mimusops Elengi	maulsari/maulshree/bakul	9-18		Evergreen tree			Ornamental or shade tree

4.3 TOOLS AND TECHNIQUES

The Tools and Techniques used are as follows (table 4.7):-

1. Instruments Used for Microclimatic Data
   - (i) Modular Weather Station
   - (ii) Non contact Thermometer
   - (iii) Thermo-hygrometer
   - (iv) Plant Canopy Analyzer
2. Questionnaire Survey
3. Software Used-
   - (i) RayMan Model
   - (ii) Envi-Met Simulation Software

Table 4.7 Tools and Techniques

Tools and Techniques		Parameters
PACKAGE I **Instruments Used in Microclimatic Data**	Modular Weather Station	Air Temperature
		Humidity
		Solar Radiation
		Wind Speed and Direction
	Non contact Thermometer	Surface Temperature
	Thermo-hygrometer	Ambient Temperature
	Plant Canopy Analyzer	Fish Eye Photographs
PACKAGE II **Questionnaire Survey**	Thermal Comfort Scale	Thermal Sensation
		Wind Sensation
		Humidity Sensation
	Clothing Details	Clo Values
	Metabolic Activity	Metabolic Activity Rate
	Thermal Acceptability, Thermal Preference	Comfortable, Not Comfortable Warmer, No Change, Cooler
	Age, BMI	Used for PET calculation
PACKAGE III & IV **Software Used**	RayMan Model	PET Calculation (Comfort Range)
	Envi-Met Simulation Software	Simulate existing scenarios and alternative landscape strategies scenario

4.4 WINTER SURVEY ANALYSIS

Details of Survey

Date of Survey: 6th January 2014 (Peak Winter Data)

Sites selected: Bru and Alpahar simultaneously survey was done.

Methods:

It was carried out by two evaluation methods simultaneously:-

- Microclimatic Data (Objective Evaluation)
- Questionnaire Survey (Subjective Evaluation)

After these two evaluations, further analysis was done with the RayMan and Envi-Met software.

Also Macroclimatic Data was recorded for comparison.

Macroclimatic Data of Roorkee for 6TH January 2014 are as follows:

Maximum Temperature recorded was 22^0C

Minimum Temperature recorded was 7^0C

Clear Sky and plenty of sunshine

Wind Speed- 8 km/hr from the NE

A. Microclimatic Data

For the Microclimatic data, Portable Weather Stations were used where Air Temperature, Solar Radiation, Relative Humidity, Wind Speed and Direction was automatically recorded from 12.30 p.m. to 5.00 p.m. The instruments were located at a height of 1.2m above ground so that the ambient temperature can be recorded. They were placed under open sky not under any shade.

i. Portable Weather Station Data

The data recorded in the two portable weather stations placed in Alpahar and Bru is shown in the fig 4.4.

Microclimatic Data

Bru

DATE	TIME	WS	SR	TP	RH	WD
06-Jan	12:30	0.66	447.19	13.16	68.03	231.65
06-Jan	13:00	0.79	452.38	15.23	59.47	239.18
06-Jan	13:30	0.96	406.25	16.79	52.79	234.25
06-Jan	14:00	0.87	347.94	17.42	49.22	249.46
06-Jan	14:30	0.81	307.5	18.48	44.62	236.31
06-Jan	15:00	0.73	257.69	18.45	42.63	210.31
06-Jan	15:30	0.54	190.81	18.91	40.76	202.26
06-Jan	16:00	0.49	79.69	18.03	41.43	229.65
06-Jan	16:30	0.37	38.81	17.13	43.92	257.4
06-Jan	17:00	0.1	14.75	16.32	47.1	182.35

Alpahar

DATE	TIME	WS	SR	TP	RH	WD
06-Jan	12:30	0.86	49.81	11.64	76.45	194.02
06-Jan	13:00	0.67	60.94	13.85	66.54	206.49
06-Jan	13:30	0.99	80.44	15.39	58.86	202.85
06-Jan	14:00	0.82	141.19	16.48	53.31	228.07
06-Jan	14:30	0.68	115.38	17.33	49.09	236.94
06-Jan	15:00	0.7	150.38	17.85	45.22	229.55
06-Jan	15:30	0.52	165.75	18.5	42.48	215.84
06-Jan	16:00	0.5	90	18.2	41.94	211.84
06-Jan	16:30	0.32	27.12	17.44	43.88	212.18
06-Jan	17:00	0.14	0.38	16.57	46.58	204.6

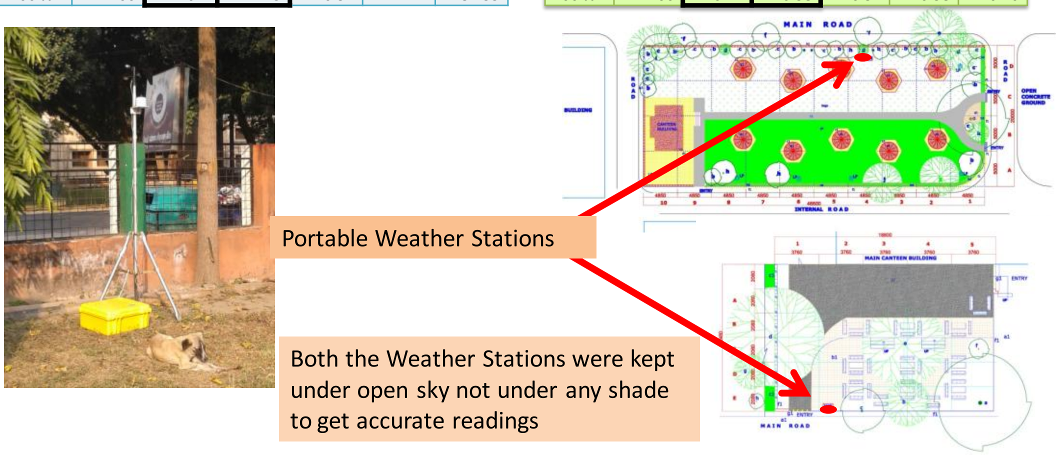


Fig. 4.4 Portable Weather Station in Alpahar and Bru along with locations

ii. Fish Eye Photographs

Fish Eye Photographs are taken for the two sites (Alpahar and Bru) with the help of the plant canopy analyzer (fig 4.5).

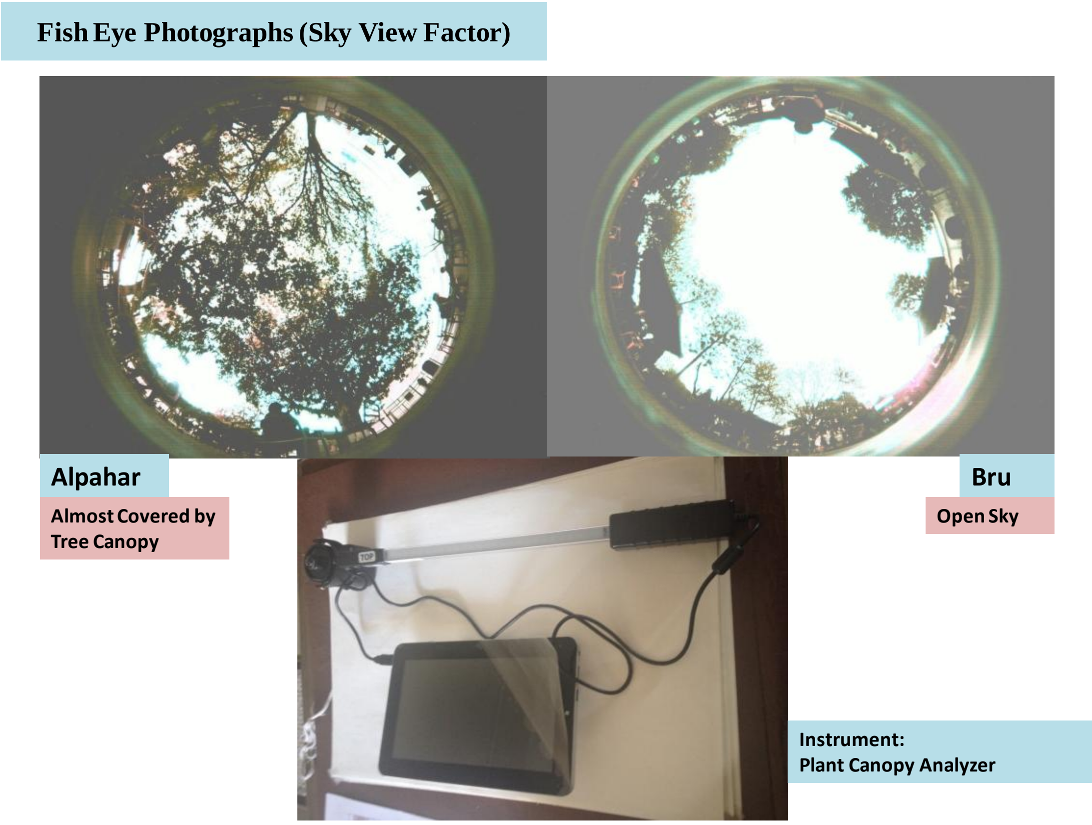


Fig. 4.5 Fish Eye Photographs in Alpahar and Bru and the Instrument used

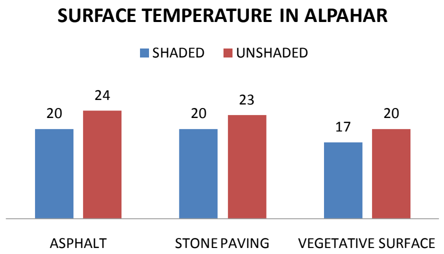
It has been observed from the fish eye photographs that in Alpahar cafeteria, almost all the area is covered by large tree canopies. Hence, it is mostly shaded. On the other hand, in Bru cafeteria, maximum area especially in the center is exposed to the open sky. Hence more sunlight can enter into the spaces.

iii. Surface Temperature

Surface Temperature

Alpahar

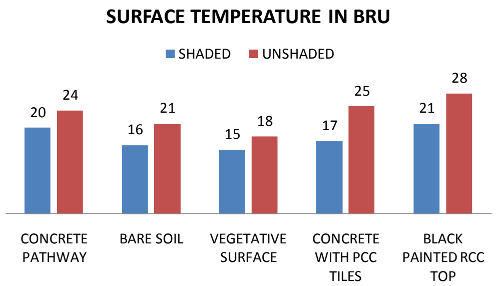
AMBIENT TEMP (⁰C)	16.57
DATE	06.01.14
TIME	5.00 PM



SURFACE TEMP	SHADED (⁰C)	UNSHADED (⁰C)
ASPHALT	20	24
STONE PAVING	20	23
VEGETATIVE SURFACE	17	20

Bru

AMBIENT TEMP (⁰C)	16.32
DATE	06.01.14
TIME	5.15 PM



SURFACE TEMP	SHADED (⁰C)	UNSHADED (⁰C)
CONCRETE PATHWAY	20	24
BARE SOIL	16	21
VEGETATIVE SURFACE	15	18
CONCRETE WITH PCC TILES	17	25
BLACK PAINTED RCC TOP	21	28

Instruments Used

Instrument:
Thermo-hygrometer
(Ambient Temperature)

Instrument:
Non contact Thermometer/
Infrared Thermometer

Fig. 4.6 Surface Temperature Readings and the Instruments used

The surface temperature values are taken from the instrument- Non-Contact Thermometer/ Infra-red Thermometer. The ambient temperature (^{0}C) was recorded by the instrument- Thermo-hygrometer.

The readings and the instrument used are shown in fig 4.6.

Observations:

It is observed that there is a noticeable difference between the surface temperature recorded for the hard landscaping elements (surfaces like Asphalt, stone paving, etc) and the soft landscaping elements (vegetative surface). The surface temperature for the hard landscaping elements is more than the vegetative surfaces.

iv. Microclimatic Data Comparative Analysis

A comparative analysis between Alpahar and Bru was done with the help of the Microclimatic Data obtained from the Portable Weather Station was done. It is shown in fig 4.7.

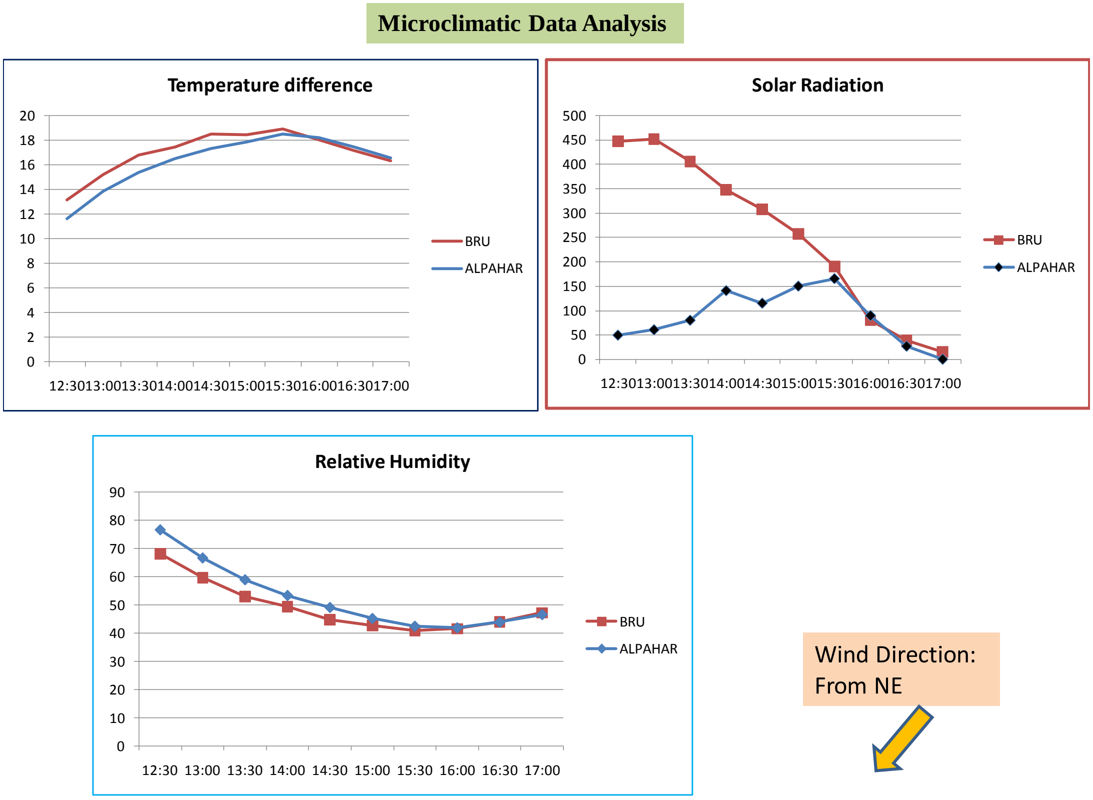


Fig. 4.7 Comparative Analysis of Portable Weather Station Data for Alpahar and Bru

The above graphical comparative analysis shows that-

a) Air temperature in Bru Cafeteria is more than Alpahar Cafeteria of IITR on a particular day during winter.

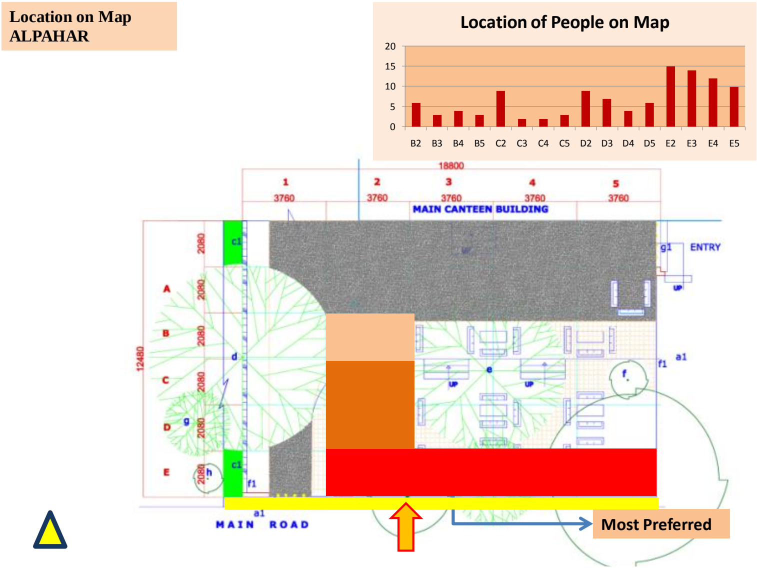
b) Bru Cafeteria receives more solar radiation than Alpahar Cafeteria on a particular day during winter.

c) Relative Humidity in Alpahar cafeteria is more than Bru Cafeteria. This is due to the evapo-transpiration of trees which produces more humidity. In Bru, although there are many trees and shaded areas but there is sufficient amount of open sky where sunlight can come in whereas in Alpahar, almost more than 90% of area is covered by tree canopy.

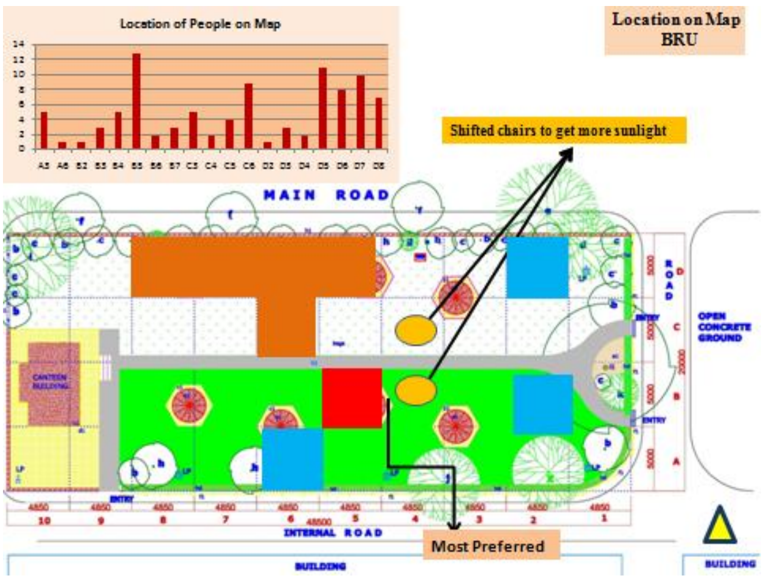
B. Questionnaire Survey Data

i. Sample Location Data of Alpahar and Bru

The sample collected (100 people in each site) were analyzed by the locating them in the plans. The preferred zones and the less preferred zones were identified with the help of number of people present (fig 4.8). It is observed that people preferred the zones where sunlight was maximum during the winter.



(a)



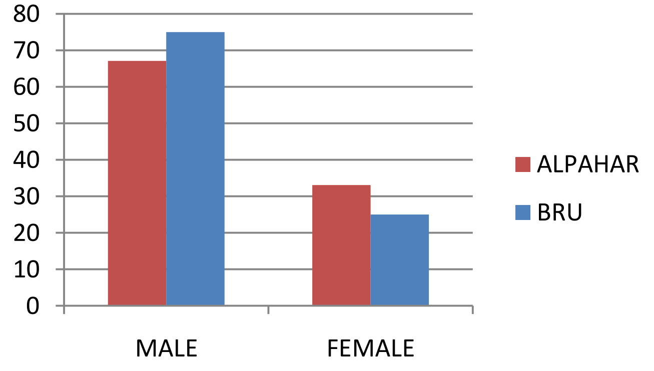
(b)

Fig. 4.8 Sample Location Data in Alpahar and Bru

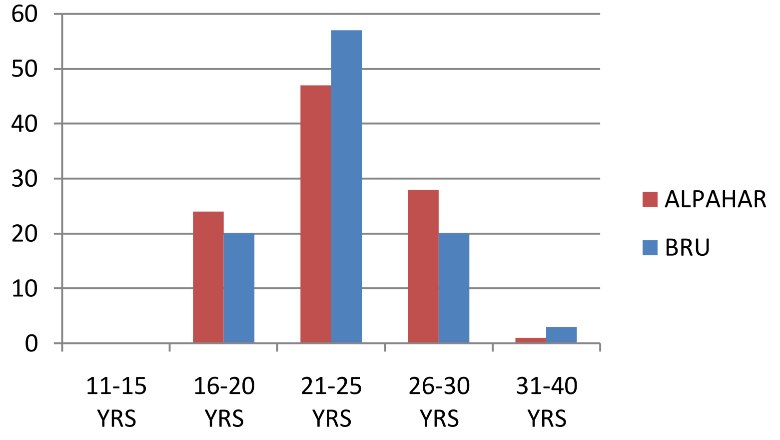
ii. Questionnaire Survey Data Comparative Analysis between Alpahar and Bru

The questionnaire survey was simultaneously started and a total of 100 people were interviewed in each site (fig 4.9). The questionnaire consisted of three distinguished parts where Personal parameters, Perception parameters and also Design Parameters were recorded. The Personal parameters include Gender, Age, Height, Weight, Clothing (Clo values) and Metabolic Activity. The Perception Parameters include Thermal Sensation, Humidity Sensation, Wind Sensation and Comfortability issues. The Design Parameters include preference, suggestions and recommendations of the place. The results are shown in fig (4.10, 4.11,4.12 and 4.13).

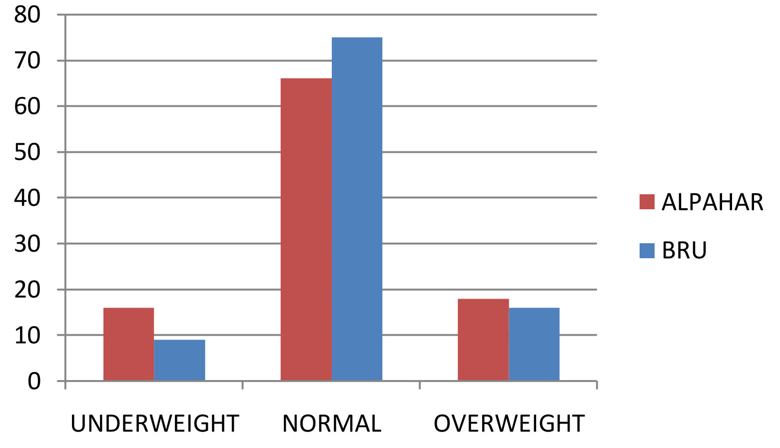
Fig. 4.9 People answering the questionnaire



(a) Gender Ratio

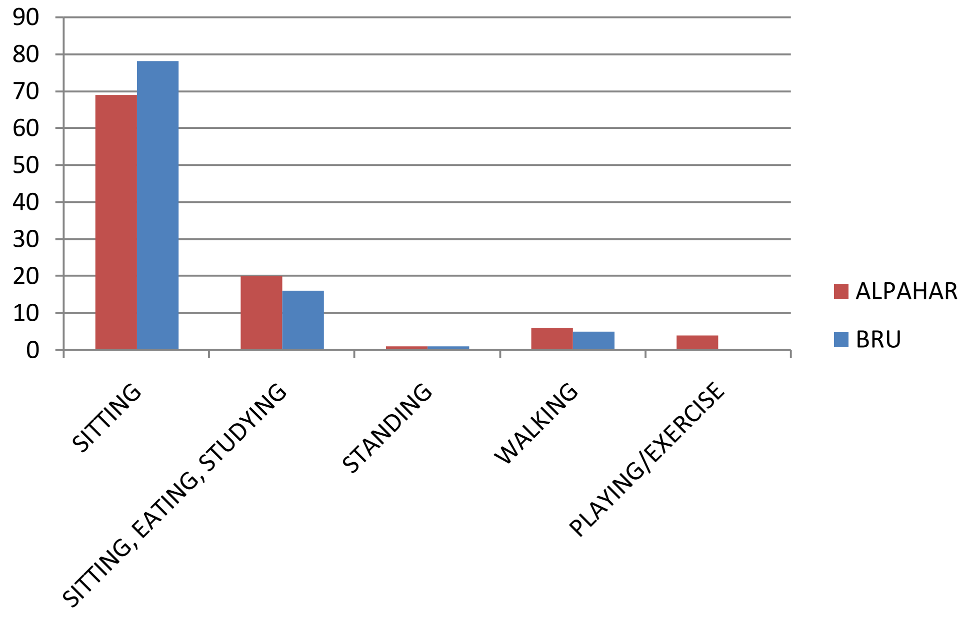


(b) Age

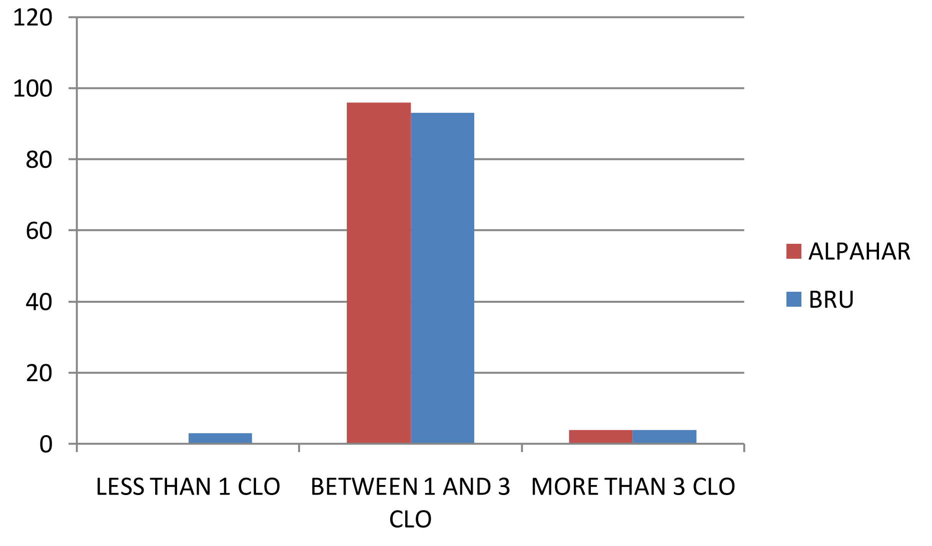


(c) Body Mass Index (BMI)

Fig. 4.10 {(a),(b),(c)}Questionnaire Survey Data (Personal Factors)

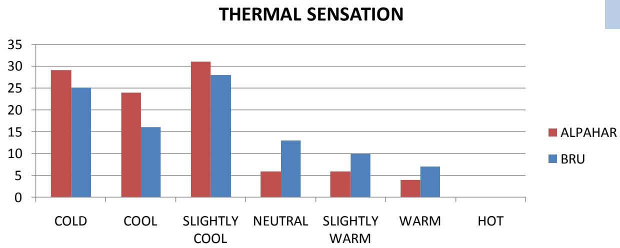


(a) Metabolic activity



(b) Clo Values

Fig. 4.11 {(a),(b)} Metabolic Data and Clo Values (Questionnaire Survey Data)



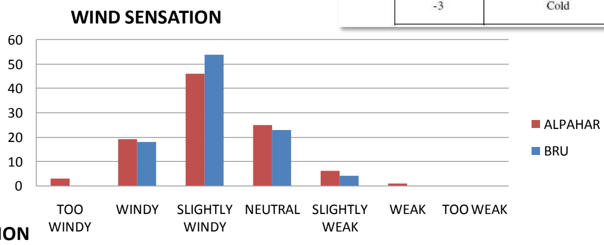
Thermal Comfort Scale (ASHRAE Scale)

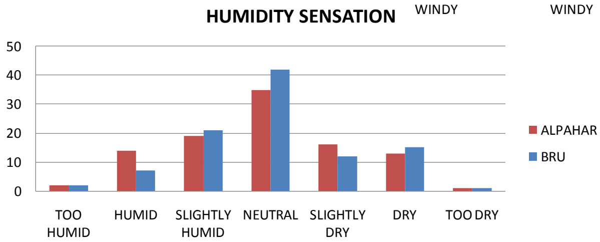
The ASHRAE scale

+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

Observation:

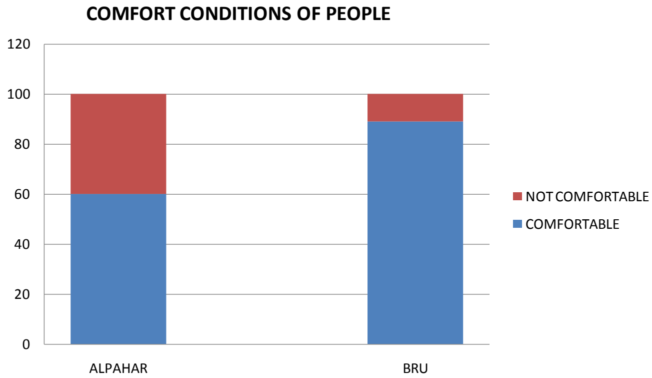
Thermal Sensation: Slightly Cool
Wind Sensation: Slightly windy
Humidity Sensation: Neutral





Microclimatic Data:

Avg Temperature: 18 ^{0}C
Avg Wind Speed: 0.8 m/s
Avg Relative Humidity: 45%



DURING PEAK WINTER SUNNY DAY

Observation:
It is observed that number of people comfortable in Bru is more than in Alpahar during winter.

According to ASHRAE Standard 55, acceptability of a certain thermal condition must be agreed by over 80% of all the subjects.

This is true for Bru but not for Alpahar. Hence in Bru thermal comfort can be achieved during winter but for Alpahar modifications are required in the microclimate design .

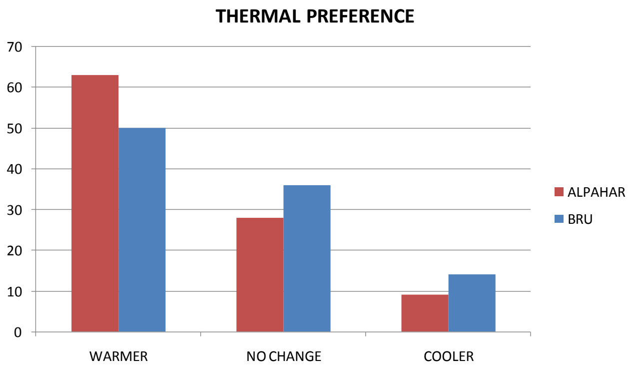
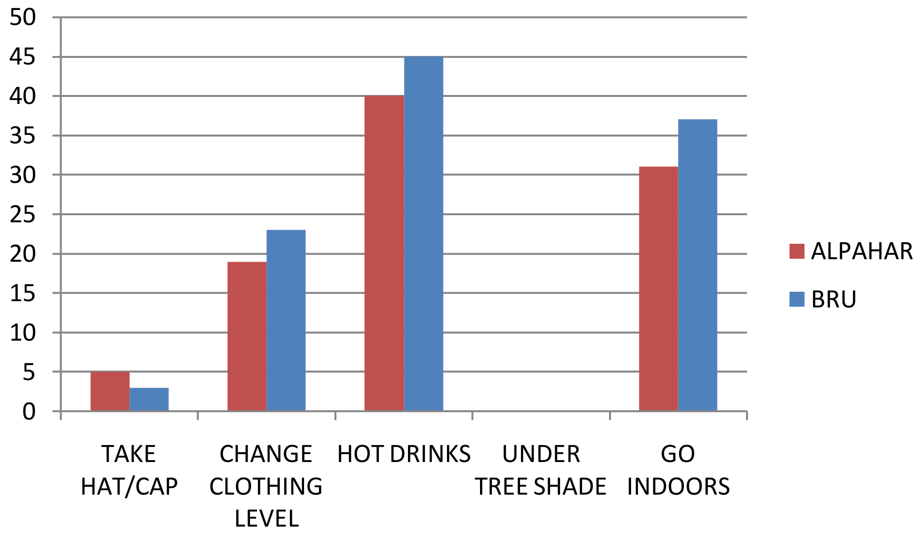
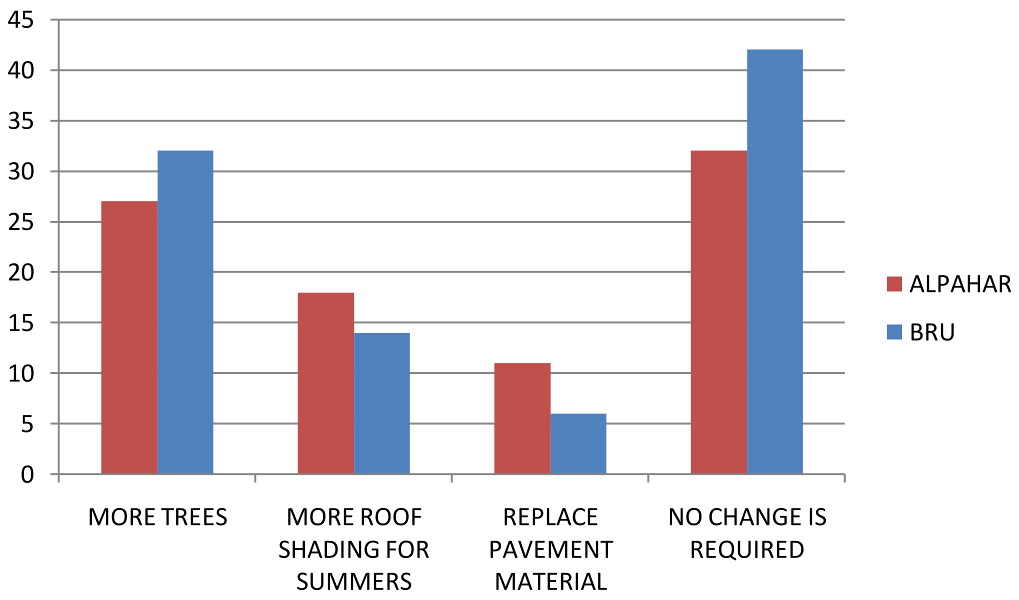


Fig. 4.12 Thermal Conditions of People (Questionnaire Survey Data)



(a) Preference if feeling discomfort



(b) Design suggestions for the place

Fig. 4.13{(a),(b)} Preference and design suggestions (Questionnaire Survey)

iii. Thermal Comfort Index, PET Calculation-RayMan model

PET values and T_{mrt} values were calculated in RayMan model (fig 4.14)

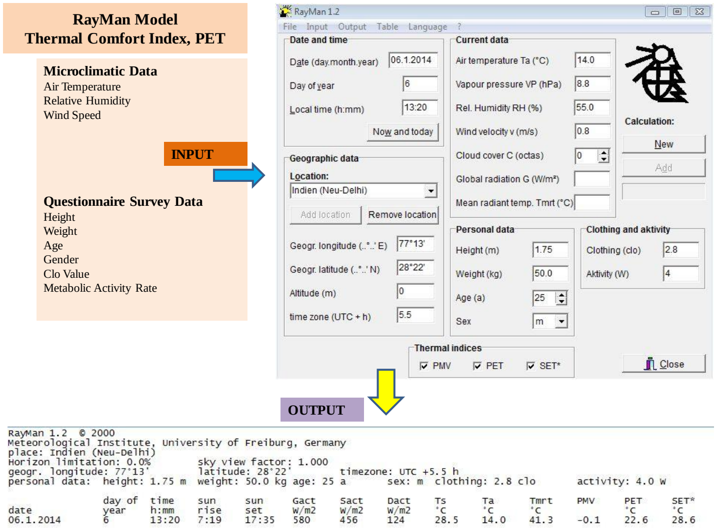


Fig. 4.14 RayMan Model window

The Comfort Range Calculation

Results and observations:

The comfort range of both Alpahar and Bru are calculated. For that PET (Physiological Equivalent Temperature) has been calculated by the RayMan software (fig 4.15).

In the Questionnaire Survey, we have seen that total no. of people comfortable in Bru and Alpahar are more than 60%. But in the real case, only 6 respondents in Alpahar and 13 respondents in Bru are actually considered comfortable as they have responded to the neutral Thermal Sensation in the comfort scale of ASHRAE. Hence, PET of these samples are being calculated in the RayMan software. For calculating the PET, the microclimatic data (Air Temperature, Relative Humidity, Wind, etc) and Questionnaire Survey Data (Personal Parameters like the Height, Weight, Gender, Age, Clo value, Metabolic Rate) are the inputs. In the output we get the PET and T_{mrt} (Mean Radiant Temperature).

ALPAHAR

Comfort Range in Alpahar is from 13.3 to 22.6 (^{0}c).

Total 6 respondents answered neutral thermal sensation which means they are comfortable.

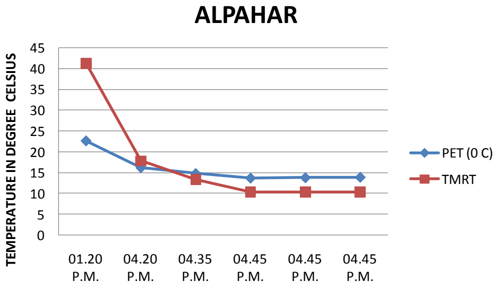
TIME	Neutral TS	PET (0 C)	TMRT
01.20 P.M.	**A54**	22.6	41.3
04.20 P.M.	**A83**	16.2	17.8
04.35 P.M.	**A91**	14.8	13.4
04.45 P.M.	**A94**	13.7	10.3
04.45 P.M.	**A95**	13.8	10.3
04.45 P.M.	**A96**	13.3	9.5

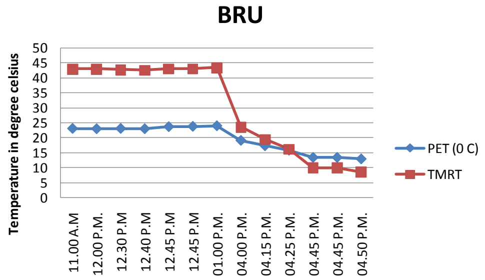
BRU

Comfort Range in Bru is from 12.9 to 23.8 (^{0} c).

Total 13 respondents answered neutral thermal sensation which indicates they are comfortable.

TIME	Neutral TS	PET (0 C)	TMRT
11.00 A.M	**B9**	23.1	42.9
12.00 P.M.	**B14**	23	42.9
12.30 P.M	**B26**	23.1	42.7
12.40 P.M	**B30**	23	42.5
12.45 P.M	**B35**	23.7	43
12.45 P.M	**B38**	23.8	43
01.00 P.M.	**B42**	24	43.4
04.00 P.M.	**B65**	19.1	23.5
04.15 P.M.	**B81**	17.3	19.3
04.25 P.M.	**B88**	15.8	16.1
04.45 P.M.	**B94**	13.4	9.8
04.45 P.M.	**B95**	13.4	9.8
04.50 P.M.	**B97**	12.9	8.4





ALPAHAR

TIME	Neutral TS	VALUES		MICROCLIMATIC DATA				QUESTIONNAIRE SURVEY DATA					
		PET (0 C)	TMRT (0 C)	T_a	RH	WS	SR	H	W	AGE	CLO VALUE	ACTIVITY	G
01.20 P.M.	**A54**	22.6	41.3	14	60	1	80.4	1.7	50	25	2.8	4	M
04.20 P.M.	**A83**	16.2	17.8	17	50	0.7	115	1.6	57	25	2.8	1	F
04.35 P.M.	**A91**	14.8	13.4	17	45	0.3	27	1.8	75	25	2.8	1.6	M
04.45 P.M.	**A94**	13.7	10.3	17	45	0.3	27	1.57	64	30	1.7	4	F
04.45 P.M.	**A95**	13.8	10.3	17	45	0.3	27	1.57	55	25	2.3	1	F
04.45 P.M.	**A96**	13.3	9.5	17	45	0.3	27	1.62	52	20	3.27	1	F

Ta Increasing – PET , Tmrt Decreasing

Solar Radiation, RH, WS decreasing– PET , Tmrt Decreasing

Tmrt is related to SR

Fig. 4.15 PET Calculation (RayMan)

iv. Envi-Met Simulation

Current Scenarios

The current scenarios of both Alpahar and Bru are simulated in Envi-Met.

ENVI-met is a three-dimensional computer model which analyzes micro-scale thermal interactions within urban environments. The software uses both the calculation of fluid dynamics characteristics, such as air flow and turbulence, as well as the thermodynamic processes taking place at the ground surface, at walls, at roofs and at plants. ENVI-met takes into account all types of solar radiation (direct, reflected and diffused) and calculates the mean radiant temperature. In calculating MRT, ENVI-met takes into account all radiation fluxes, direct, diffuse and reflected solar radiation as well as the long-wave radiation fluxes from the atmosphere, ground and walls and is capable of producing MRT values for each cell of the model environment at varying heights above the ground surface (Ali 2005, Emmanuel & Fernando 2007).

The ENVI-met software requires climatic data input for the site being simulated. These inputs were collected during the physical survey.

For the comparison of simulated scenarios, four zones are selected both for Bru and Alpahar (fig 4.16 and 4.17). These zones are simulated for a particular day in winter (6^{th} January 2014) for three different times of the day (12 p.m, 3 p.m, 5 p.m).

Alpahar

Alpahar

Zoning
1. Most Preferred Zone (E2)
2. Under Open Sky (D2)
3. Under Tree Shade and Less Preferred Zone (B3)
4. Hard Landscaping Element, Paved Zone (B5)

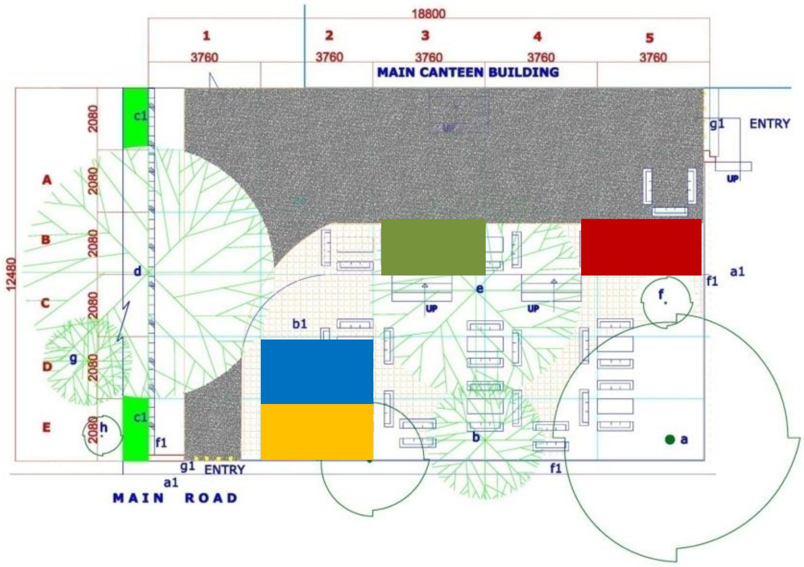


Fig. 4.16 Alpahar Zoning for Envi-Met Simulation

Bru

Bru

Zoning
1. Most Preferred Zone (B5)
2. Under Open Sky (B4)- Shifted Chairs
3. Under Tree Shade and Less Preferred Zone (D2)
4. Hard Landscaping Element, Paved Zone (A10)

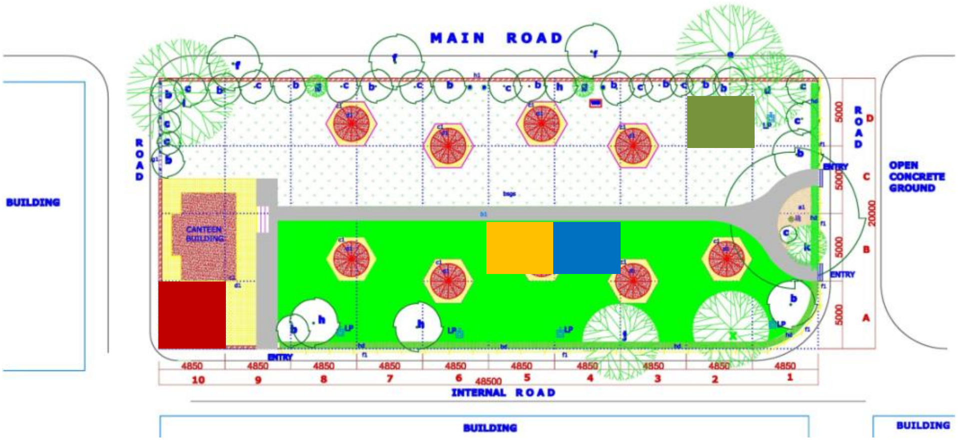


Fig. 4.17 Bru Zoning for Envi-Met Simulation

Results and Observation:

The results are shown in fig 4.18.

From the simulation of the four different zones in each site on a particular day in winter, it is observed that the zone B3 (Alpahar) and D2 (Bru) which are under tree shade has lower values of Mean Radiant Temperature, Air Temperature and Surface Temperature, throughout the day comparative to the other zones.

In Alpahar, it is seen that the Air Temperature in the most preferred zone, E2 is higher than the other zones. That is why people preferred that location and were more comfortable.

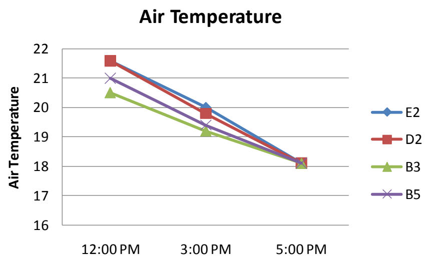
Also it is observed at the site that after noon due to the sun coming from the southernmost part of the day in winter, the solar radiation is actually raising the air temperature. The E2 zone has higher Tmrt values also even though the Surface Temperature values are lower than other zones. The sudden rise in Tmrt values at 3pm in the other zones than the zone B3 shows that under tree shade, T_{mrt} value is stable. On the other hand, in the other zones because of hard surfaces (asphalt, concrete), there is a huge variation in the T_{mrt} values. But in Bru, the T_{mrt} values do not show that huge variation and that is because of the presence of vegetative surface (grass) on the ground.

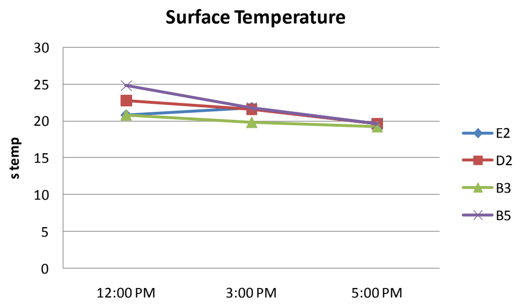
In Bru, the zone A10, which is the paved zone and also exposed to the sun has higher values in all 3 parameters throughout the day and reached its maximum at 12 p.m.

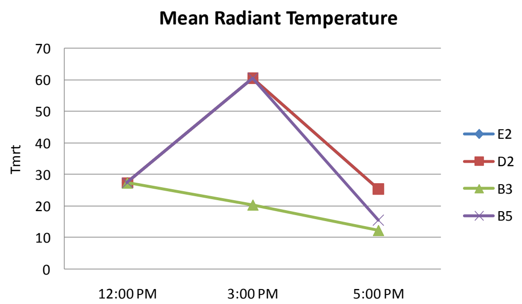
Refer Annexures II for the simulated maps in Envi-Met

Alpahar

LOCATION	Parameters	Surface Temperature 0C			Mean Radiant Temperature (Tmrt) 0C			Air Temperature 0C		
	Time	12 p.m	3 p.m	5 p.m	12 p.m	3 p.m	5 p.m	12 p.m	3 p.m	5 p.m
	E2	20.8	21.8	19.6	27.4	60.5	25.4	21.6	20	18.1
	D2	22.8	21.6	19.6	27.4	60.5	25.4	21.6	19.8	18.1
	B3	20.8	19.8	19.2	27.4	20.4	12.3	20.5	19.2	18.1
	B5	24.8	21.8	19.6	27.4	60.5	15.6	21	19.4	18.1

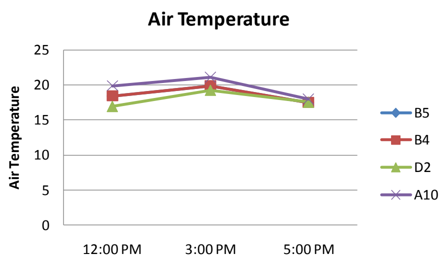


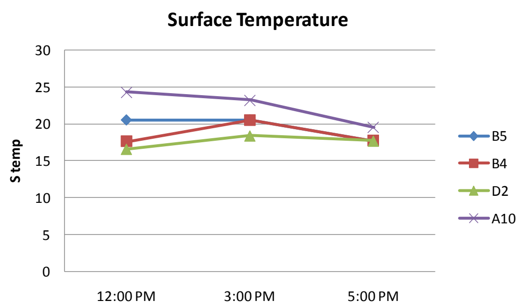




Bru

LOCATION	Parameters	Surface Temperature (0C)			Mean Radiant Temperature (Tmrt) (0C)			Air Temperature (0C)		
	Time	12 p.m	3 p.m	5 p.m	12 p.m	3 p.m	5 p.m	12 p.m	3 p.m	5 p.m
	B5	20.5	20.5	17.7	25.5	20.5	16	18.4	19.9	17.5
	B4	17.6	20.5	17.7	56.6	17.6	16	18.4	19.9	17.5
	D2	16.6	18.4	17.7	20.3	16.6	12.4	16.9	19.2	17.5
	A10	24.3	23.2	19.5	61.7	24.3	26.8	19.9	21.1	18





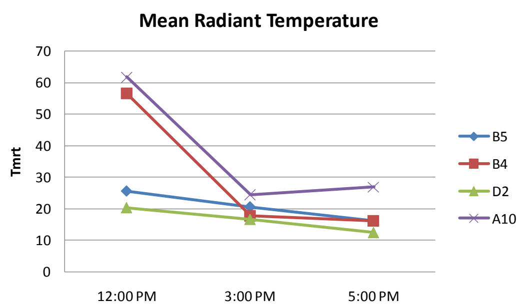


Fig. 4.18 Results of Envi-Met Simulation (Winter)

4.5 SUMMER SURVEY ANALYSIS

It was done in three major parts:

A. Site Analysis
B. Microclimatic Data Survey for Summer
C. Envi-Met Simulation for Summer

A. Site Analysis

Several field studies were carried out in the summer of 2014. It was conducted during the mid of May as we find some of the hottest days of the year in that period. The sites selected were:

1. Alpahar and Bru
2. Lawn Main Building, LHC Parking and Students Club frontyard

Here, Alpahar and Bru are the main study area (base cases) where design will be implemented later. Some contrasting cases were also selected to find out the differences. Lawn Main Building was selected because of the maximum amount of Vegetative area present (Soft Landscaping Element). On the other hand, LHC Parking and Students Club frontyard were selected because of the maximum amount of paved area present.

The area and B:P:V ratio has been calculated based on the ground coverage as shown in table 4.8. Hence the vertical elements like the Trees are not considered. The area of Tree Canopies and hedges have been calculated but not included in the total.

The percentage of area covered by different surfaces in the 5 different sites are shown in the fig 4.19.

Table 4.8 Comparison of the five sites with area calculation and B: P: V Ratio

LAND COVER		ALPAHAR TOTAL AREA (Sq.m) = 234.63		BRU(NESCAFE) TOTAL AREA (Sq.m) = 970		MAIN BUILDING LAWN TOTAL AREA (Sq.m) = 5436.65		LHC PARKING TOTAL AREA (Sq.m) = 2580.56		STUDENTS CLUB FRONTYARD TOTAL AREA (Sq.m) = 1214.13	
		AREA (SQ.M)	% AREA COVERED	AREA (SQ.M)	% AREA COVERED	AREA (SQ.M)	% AREA COVERED	AREA (SQ.M)	% AREA COVERED	AREA (SQ.M)	% AREA COVERED
BUILDING		0	0	29.04	3.0	381.54	7.01	216.04	8.37	71.47	5.80
PAVEMENT (HARD LANDSCAPING ELEMENTS)	OUTDOOR FURNITURE	10	4.20	10	1.03	0	0	0	0	0	0
	ASPHALT	98.33	41.90	0	0	1573.47	28.94	0	0	233.57	19.20
	CONCRETE	91.67	39.07	254.46	26.23	0	0	1468.79	56.91	736.21	60.60
	STONE TILES	0	0	0	0	0	0	0	0	95.60	7.90
	Total	200	85.24	264.46	27.2	1573.47	28.94	1468.79	56.91	1065.38	87.74
VEGETATION (SOFT LANDSCAPING ELEMENTS)	HEDGES	0	0	35.21	3.62	50.76	0.9	0	0	0	0
	SHRUBS	0	0	0	0	0	0	0	0	0	0
	TREES	132.27	56.37	423.58	43.67	344.74	6.34	253.3	9.80	190.96	15.72
	BARREN LAND	0	0	200	20.6	0	0	0	0	77.94	6.4
	VEGETATIVE SURFACES (GRASS)	0	0	476.5	49.12	3427.67	63.04	779.54	30.20	0	0
	Total Horizontal Surfaces			676.5	69.74	3427.67	63.04	779.54	30.20	77.94	6.4
WATER ELEMENTS		0	0	0	0	0	0	0	0	0	0
RATIO OF BUILDING:PAVEMENT:VEGETATION:WATER		0		1:9:23		1:4:9		1:7:3.75		1:17.4:1.2	

Fig. 4.19 Area in % of the 5 sites

Observations:

Though the area of vegetation in square metres for Lawn Main Building is the highest amongst all the cases, but in terms of ratio of Building:Pavement:Vegetation and percentage of area per site, Bru has more % of vegetation (70%) while Lawn Main Building has 64%. Also, Lawn Main Building has more pavement area in terms of square metre. On the other hand, in terms of area in %, Alpahar and than Students Club Frontyard has highest, 100% and 88% respectively.

According to the statistical data of landscaping elements present on the site, Bru should be cooler than Alpahar because of high % of vegetation present in the site. But this part will be observed in the microclimatic data survey whether presence of high % of vegetative surfaces actually change the ambient temperature.

B. Microclimatic Data Survey for Summer

In the Microclimatic Data Survey, the survey was divided into three parts:

I. Comparison of three locations in each of the four different areas (Alpahar ,Bru ,Lawn Main Building and LHC Parking)
II. Comparative Analysis between Alpahar and Bru
III. Comparison between two locations in detail (Under Tree Shade and Under Open Sky) in two contrasting areas on two different days (Lawn Main Building and Students Club frontyard)

I. Comparison of 3 locations in each of the four different areas (Alpahar ,Bru ,Lawn Main Building and LHC Parking)

Date of Survey: 10.05.2014

Time: 12 to 1 pm

Macroclimatic Data of that time of the day for Roorkee as recorded in the Automatic Weather Station (fig 4.20) is as shown in the table 4.9 :-

Table 4.9 Macroclimatic Data recorded

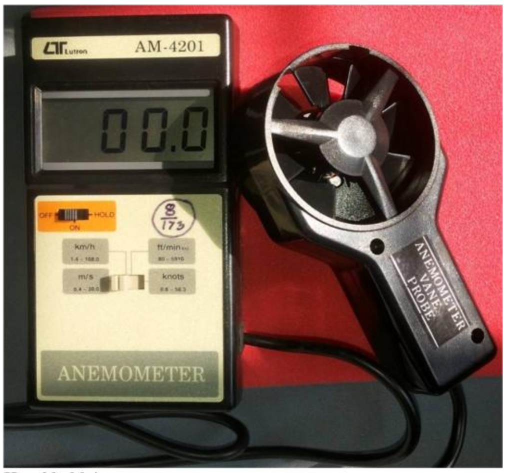
Temp, °C	RH, %	Wind Direction, ø	Wind Speed, m/s	Rain, mm	Solar Radiation, W/m²
37.673	24.5	265.3	1.01	0	870.6

Fig. 4.20 Automatic Weather Station

Instruments Used:

Parameters	**Instruments**
Air Temperature	Hand held Thermo hygrometer
Relative Humidity	Hand held Thermo hygrometer
Wind Speed	Hand held Anemometer
Surface Temperature	Noncontact Thermometer/ Infrared Thermometer
Fish Eye Photographs	Fish Eye Canopy Image Analyzer

Hand held Thermo hygrometer



Hand held Anemometer

Noncontact Thermometer/Infrared Thermometer

Fish Eye Canopy Image Analyzer

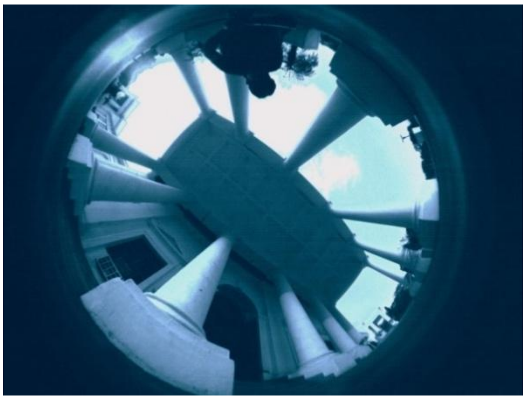
Fig. 4.21 Instruments used in the survey

The instrument used in the survey are shown in fig 4.21.

For the microclimatic data, 3 locations each were selected for the 4 different areas (fig 4.22 and fig 4.23):-

Under Tree Shade

LOCATIONS	
1.	UNDER TREE SHADE
2.	UNDER OPEN SKY
3.	UNDER PROCESSED COVER



Under Open Sky

Under Processed Cover

Fig. 4.22 Fish Eye Photographs and Plans showing the three locations of survey

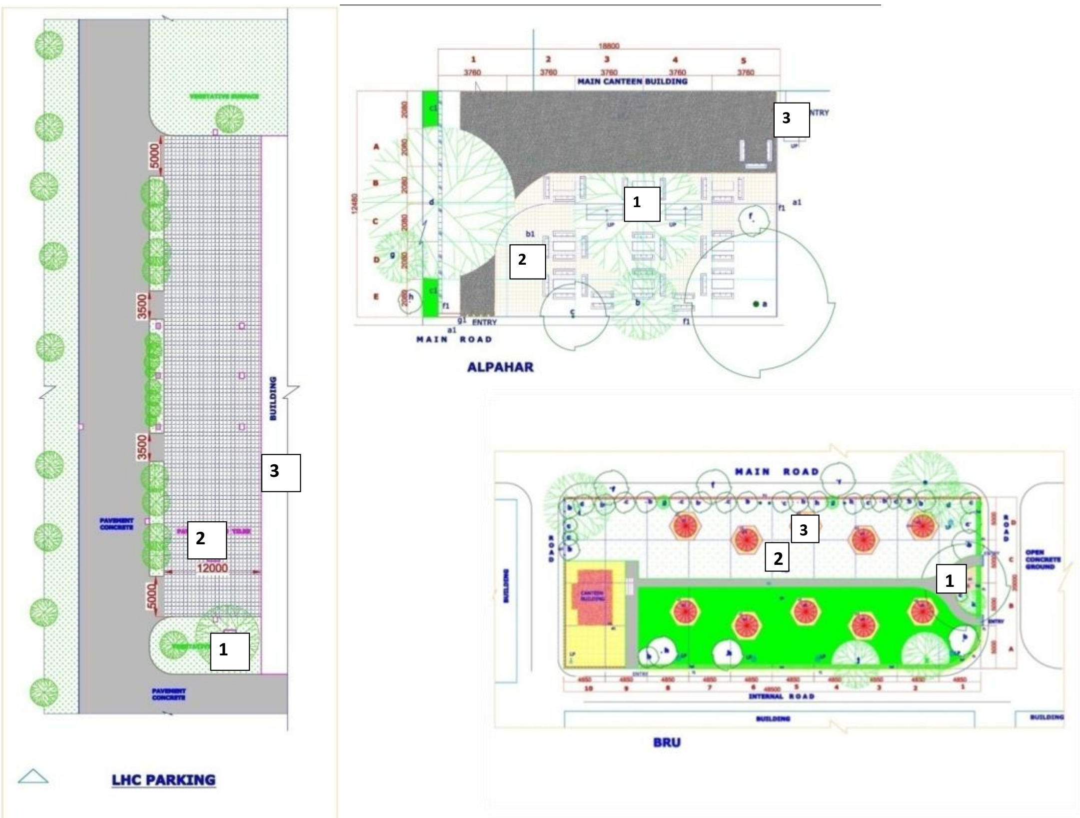


Fig. 4.23 Plans of Alpahar, Bru and LHC Parking showing the three locations

A mobile survey was carried out from 12 pm to 1pm. It started from location 1, Bru and ended in LHC Parking. The time difference between each area was 15 minutes. Hence there was not much time difference as all the readings were taken in almost an hour. The time selected was from 12p.m to 1p.m because at that particular time of the day, the sun is directly above the earth and highest Solar Radiation is achieved at that time. The readings and locations are shown in table 4.10.

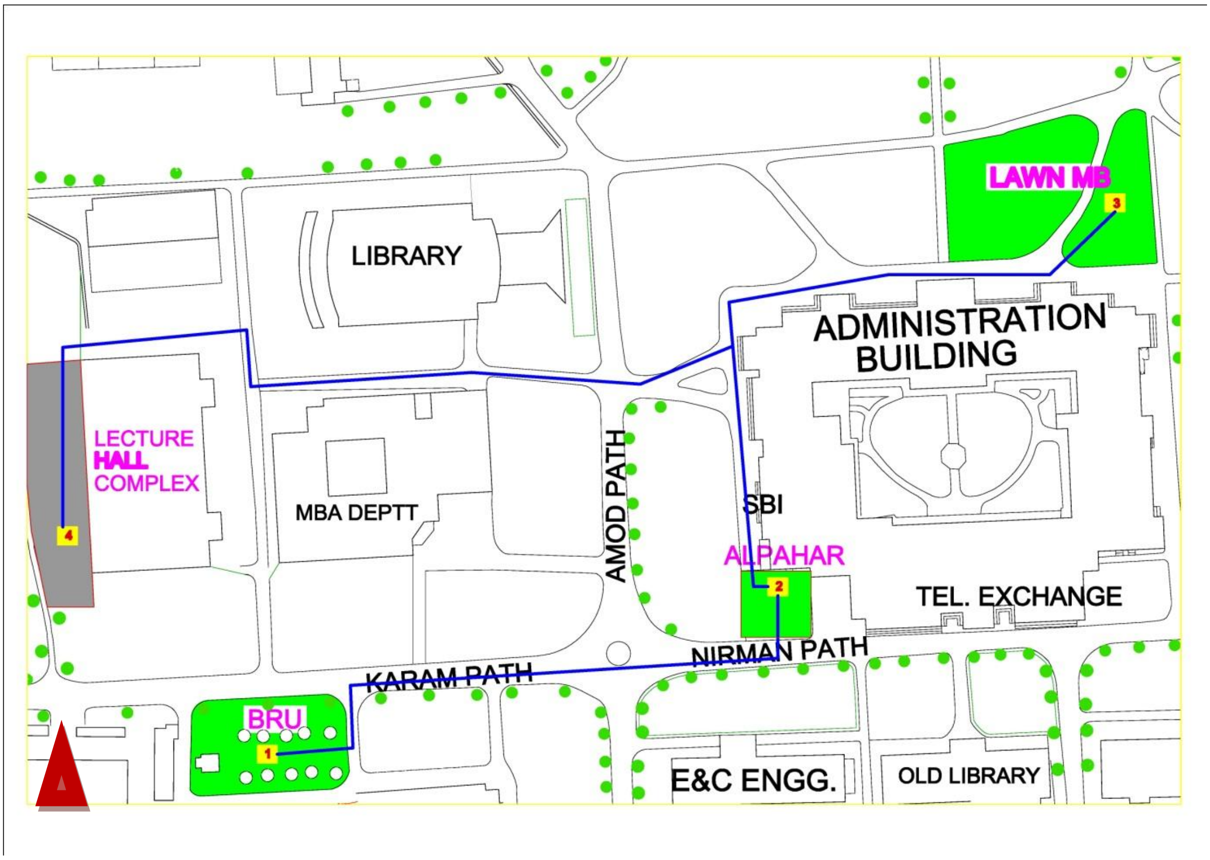


Fig. 4.24 The route of Survey in plan

Route of Survey was as follows:

BRU ALPAHAR LAWN MB LHC PARKING

●---- ----→----------●-------------→---------●----→------------------ ●

Measurement:

Table 4.10 Locations and Readings recorded

LOCATIONS	ALPAHAR	BRU	LAWN MAIN BUILDING	LHC PARKING
1. Under Tree Shade	A1	B1	C1	D1
2. Under Open Sky	A2	B2	C2	D2
3. Under Processed Cover	A3	B3	C3	D3

Parameters	LOCATION											
	ALPAHAR			BRU			LAWN MAIN BUILDING			LHC PARKING		
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3
Air Temperature	35.2	37.4	36.2	36.2	38.2	37.4	33.4	35.2	34	37	39	38
Relative Humidity	21	19.33	20	20	18.9	19	23	20	21	19	17	18
Wind Speed	0.5	0.98	nil	1	0.8	0.3	2.1	1.8	nil	0.7	2.6	0.1

Locations		Under Tree Shade	Under Open Sky	Under Processed Cover
Surface Temperature	**Asphalt**	33.2	64.2	40
	Concrete	30	52	31.4
	Vegetative Surface	22	26	24

Observations:

a) It is observed from the above readings that in all the cases, the Air Temperature is highest in location 2 and lowest in location 1,ie.,

Air Temperature: Under Open Sky > Under Processed Cover > Under Tree Shade

There is a difference of 2^0C between the temperature under tree shade and under open sky.

b) But Relative Humidity:

Under Tree Shade > Under Processed Cover > Under Open Sky

This is because of the evapotranspiration of trees, the relative humidity increases under tree shade.

c) The Surface Temperature readings (fig 4.25) were also taken by the Infrared thermometer. It is found that the Vegetative surfaces has lower surface temperature in all the three locations. The lowest reading is of Vegetative Surfaces under tree shade and highest reading is of Asphalt under open sky.

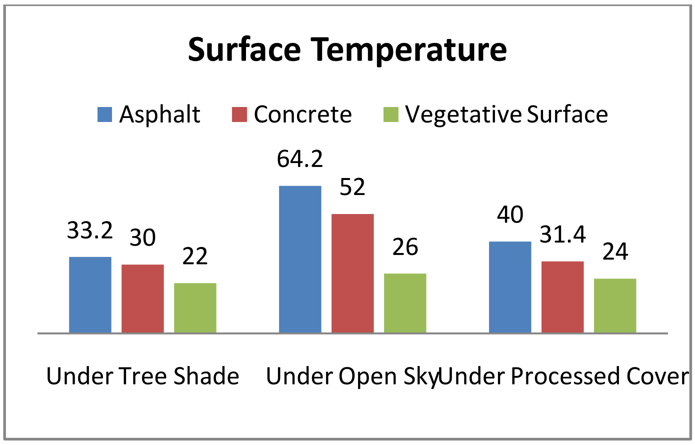


Fig. 4.25 Surface Temperature readings

d) It is also observed that in Lawn Main Building, the temperature is the lowest than all the other areas. Though trees and vegetative surfaces play an important role in minimizing the air temperature, high wind speed observed also contributed to it.

e) In the all the four cases,

Most Comfortable area:

Lawn Main Building > Alpahar > Bru > LHC Parking

Though LHC Parking was the most uncomfortable, because of the high wind speed in the area, it was bearable.

II. Comparative Analysis between Alpahar and Bru

Details of Survey:

Date of Survey: 19th May 2014 (Peak Summer Data)

Sites selected: Bru and Alpahar survey was done simultaneously .

Methods:

It was carried out by two evaluation methods simultaneously:-

a) Microclimatic Data (Objective Evaluation)
b) Questionnaire Survey (Subjective Evaluation)

Also, PET calculation was done for the two cafeterias.

a) Microclimatic Data Survey

For the Microclimatic data, Modular Weather Stations were used where Air Temperature, Solar Radiation, Relative Humidity, Wind Speed and Direction was automatically recorded from 11.00 a.m. to 5.00 p.m.

Instruments Used:

Macroclimatic data for Roorkee was recorded by the Automatic Weather Station. Portable Weather Station (fig 4.26 and fig 4.27) was used in both the sites. WS1 was placed in Bru and WS2 was placed in Alpahar. They were placed under open sky not under any shade. The instruments were located at a height of 1.2m above ground so that the ambient temperature can be recorded.

Fig. 4.26 Portable Weather Station

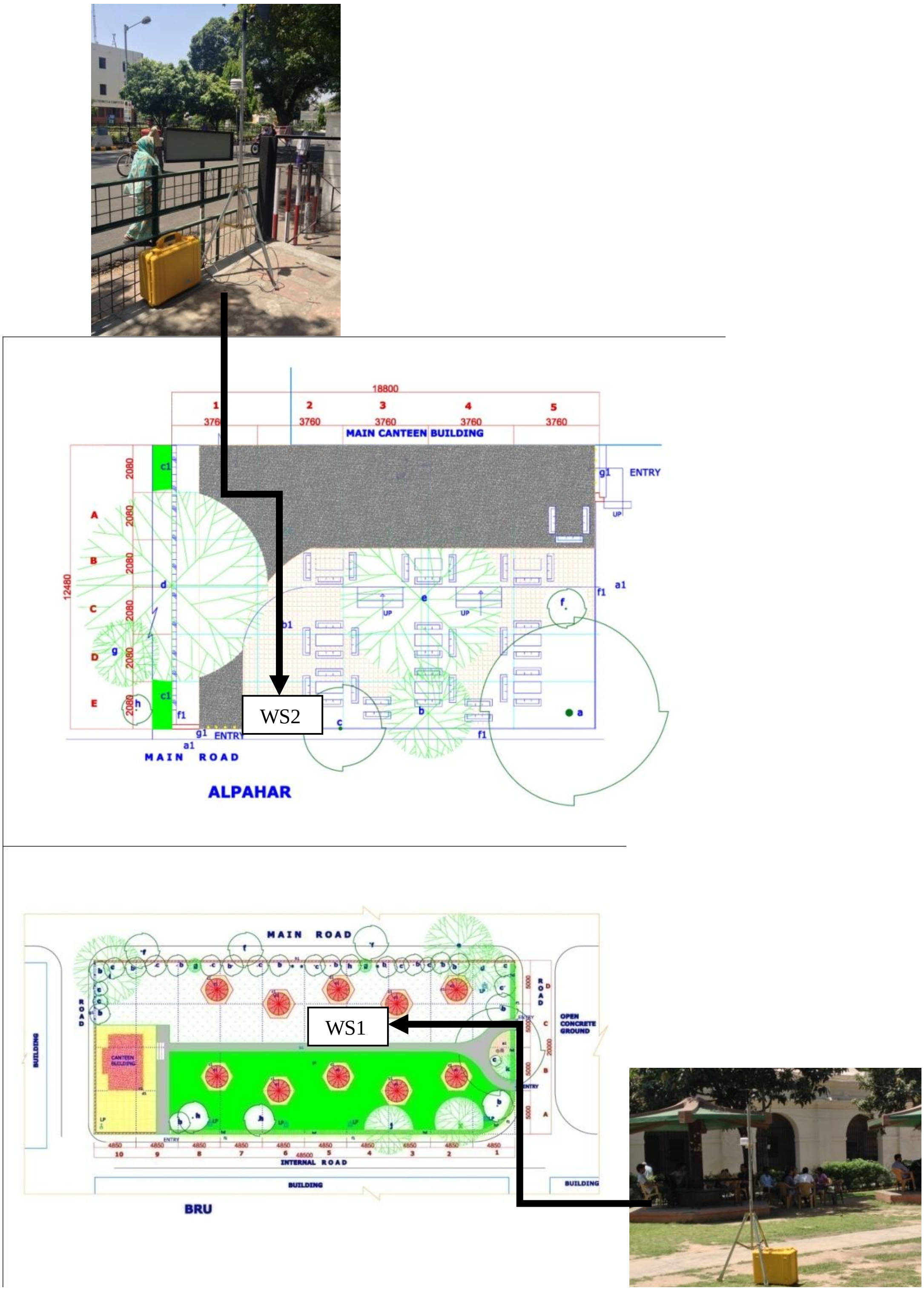


Fig. 4.27 Plans showing Portable Weather Stations placed in the sites

Measurement:

The measurement are shown in table 4.11.

Table 4.11 Readings of the Survey

	Air Temperature (^{0}C)		
TIME	ALPAHAR	BRU	MACRO
11:00	34.51	36.37	36.96
11:30	36.3	37.03	36.933
12:00	36.39	37.35	37.151
12:30	36.93	37.57	36.824
13:00	37	37.65	36.96
13:30	36.49	37.74	37.398
14:00	35.92	37.79	37.866
14:30	36.25	37.93	38.309
15:00	36.11	38.08	38.004
15:30	35.94	37.75	37.48
16:00	35.84	37.52	37.673
16:30	35.76	37.1	37.508
17:00	35.51	35.63	36.606

	Relative Humdity (%)		
TIME	ALPAHAR	BRU	MACRO
11:00	23.98	22.4	31.1
11:30	17.71	17.95	25.3
12:00	16.19	16.01	22.4
12:30	14.99	15.86	21.3
13:00	14.69	15.18	20.1
13:30	18.21	18.16	23.8
14:00	18.5	18.03	23.7
14:30	15.99	14.61	20.9
15:00	16.35	15.3	20.5
15:30	17.81	16.58	22
16:00	18.06	16.45	22.2
16:30	18.55	17.37	22.8
17:00	19.35	19.02	24

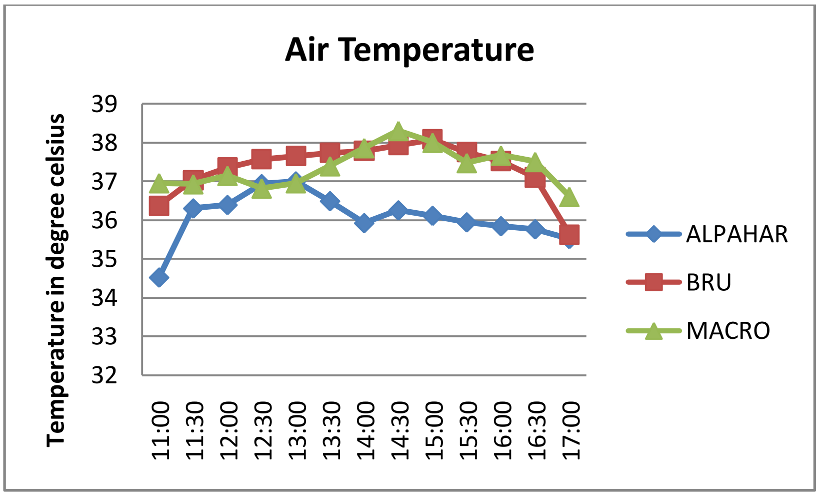


Fig. 4.28 Comparisob graph of Air Temperature

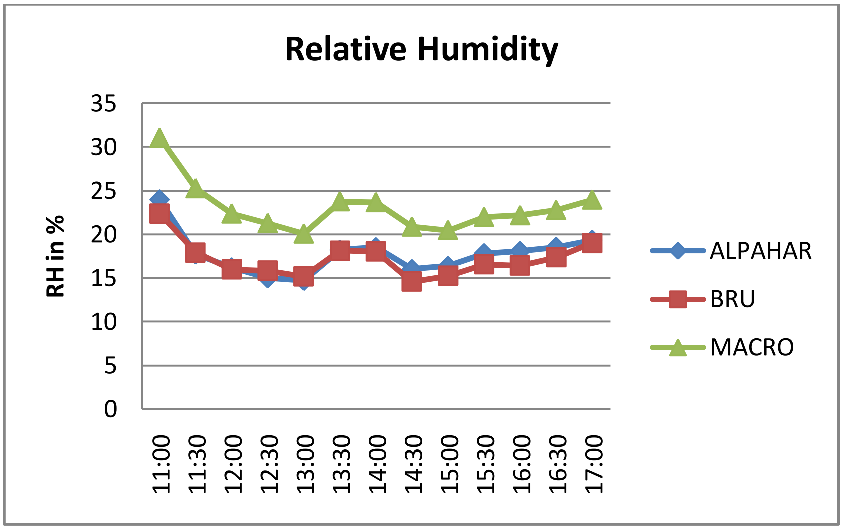


Fig. 4.29 Comparison graph of Relative Humidity

Observations from Microclimatic Data

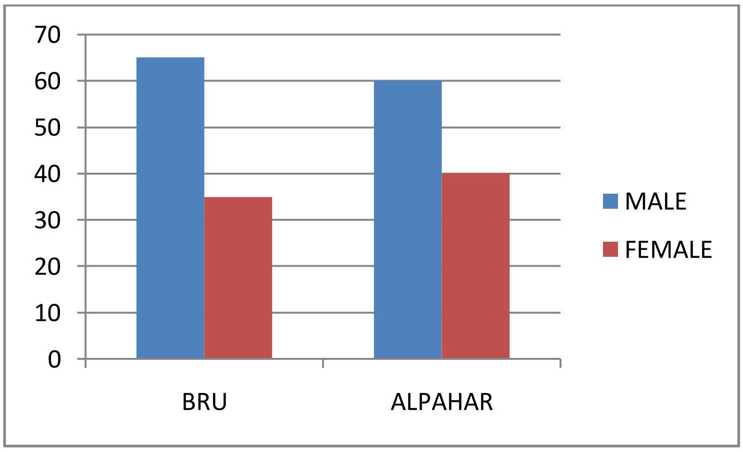
i. From the above comparison of Air Temperature (^{0}C) (fig 4.28) of a hot summer day in 2 different microclimatic sites, it is observed that Alpahar is cooler than Bru. Also, it is clear that the Macroclimatic data is almost similar to the temperature in Bru but it is always higher than Alpahar. At around 12pm, it is observed that the Temperature in macroclimatic data is less than temperature in Bru. This is because the sun is almost above the midpoint of the site at that time of day. Also because there are no trees present at the middle of the site in Bru, the temperature rises and creates discomfort. It is also clear that even though Hard Landscaping Elements like Asphalt and Concrete are present in Alpahar, the ambient air temperature reduces because of the presence of large tree canopies. Hence trees play an important role in reducing the air temperature when the surfaces are paved.

ii. The Relative Humidity (fig 4.29) is little higher in Alpahar than Bru, but it is highest in the macroclimatic data.

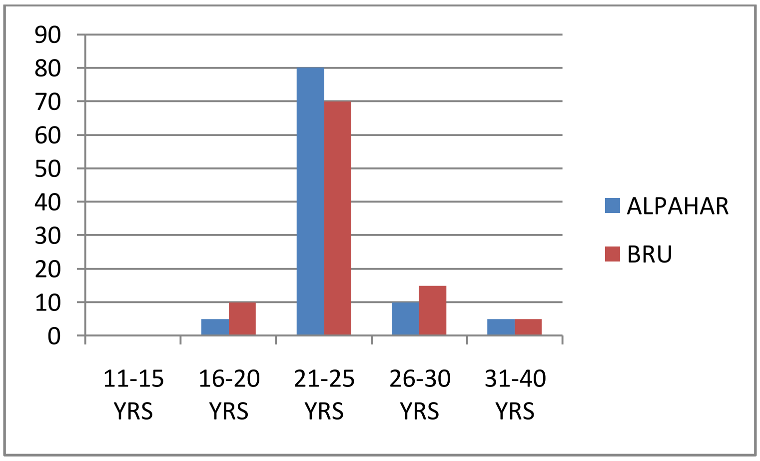
iii. The Wind Direction recorded was from NW. The Wind Speed ranged from 0.45 m/s to 1.47 m/s.

b) Questionnaire Data Survey

The questionnaire survey was simultaneously started and a total of 100 people were interviewed in each site. The questionnaire consisted of three distinguished parts where Personal parameters, Perception parameters and also Design Parameters were recorded. The Personal parameters include Gender, Age, Height, Weight, Clothing (Clo values) and Metabolic Activity. The Perception Parameters include Thermal Sensation, Humidity Sensation, Wind Sensation and Comfortability issues. The Design Parameters include preference, suggestions and recommendations of the place. Questionnaire Survey Data Comparative Analysis between Alpahar and Bru is shown in fig 4.30, fig 4.31, fig 4.32 nad fig 4.33.

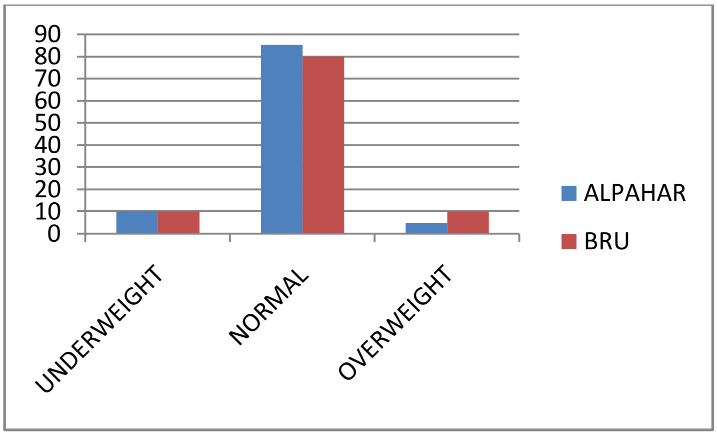


(a) Gender

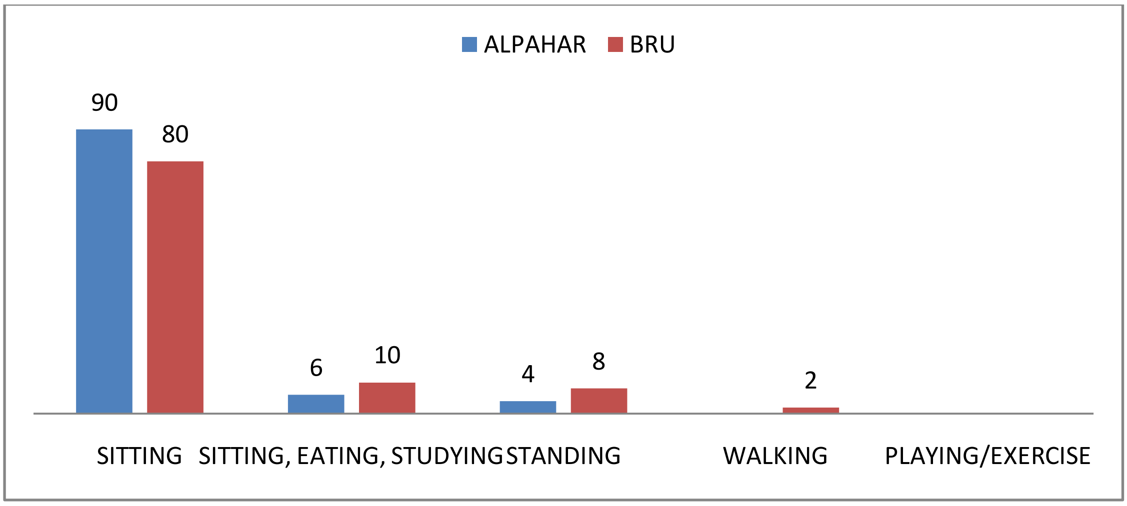


(b) Age

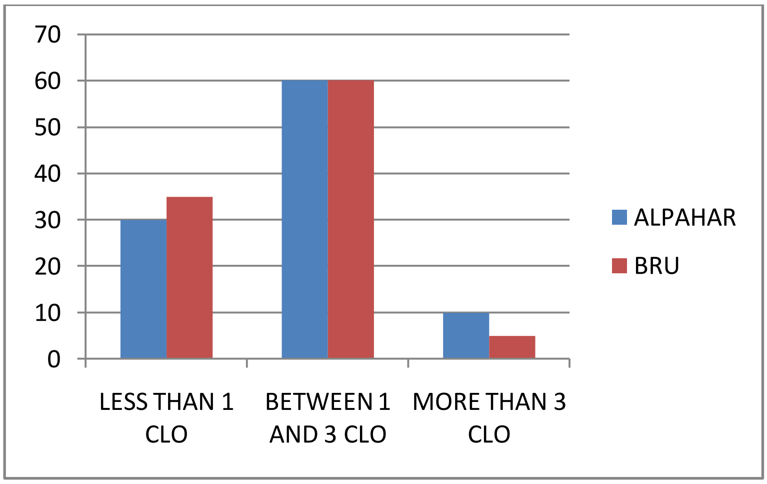
Fig. 4.30 {(a),(b)} Personal factors from the Questionnaire (Gender Ratio and Age)



(a) Body Mass Index (B.M.I)

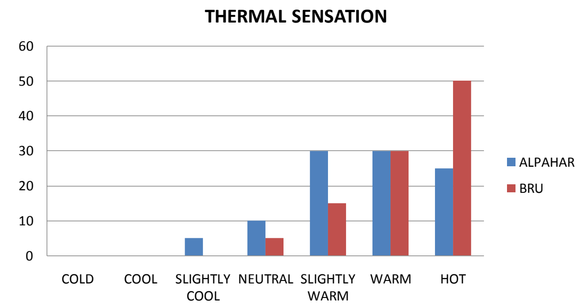


(b) Metabolic Activity



(c) Clo Values

Fig. 4.31 {(a),(b),(c)} Questionnaire Survey data (BMI, Metabolic Activity and Clo Values

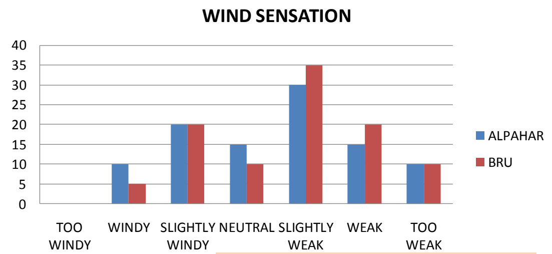


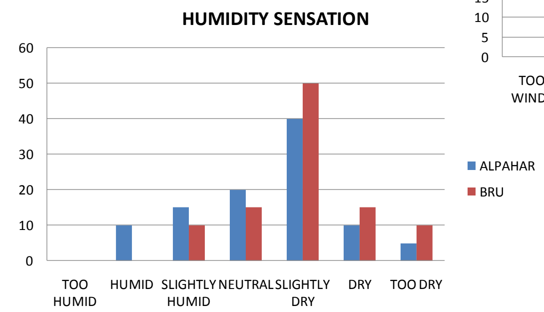
Thermal Comfort Scale (ASHRAE Scale)

+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

Observation:

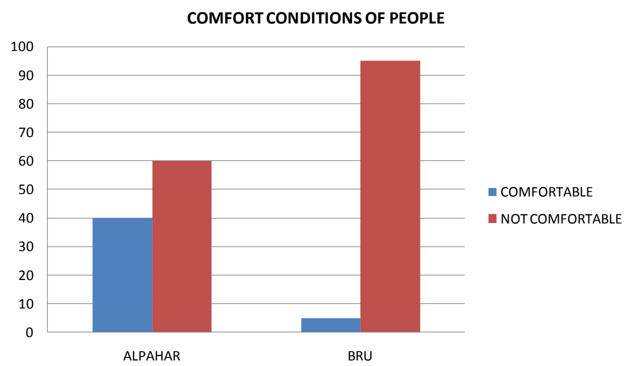
Thermal Sensation: Hot
Wind Sensation: Slightly Weak
Humidity Sensation: Slightly Dry





Microclimatic Data:

Avg Temperature: 37 ^{0}C
Avg Wind Speed: 1.2 m/s
Avg Relative Humidity: 18%



DURING
PEAK SUMMER
HOT SUNNY DAY

Observation:
It is observed that **in both Alpahar and Bru, people are not comfortable.**

Redesign of the Cafeterias is required for Summer.

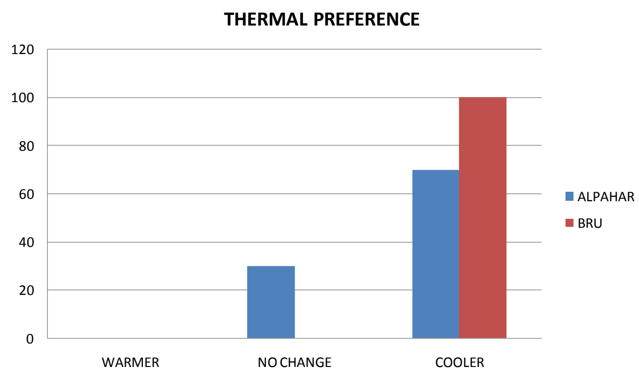
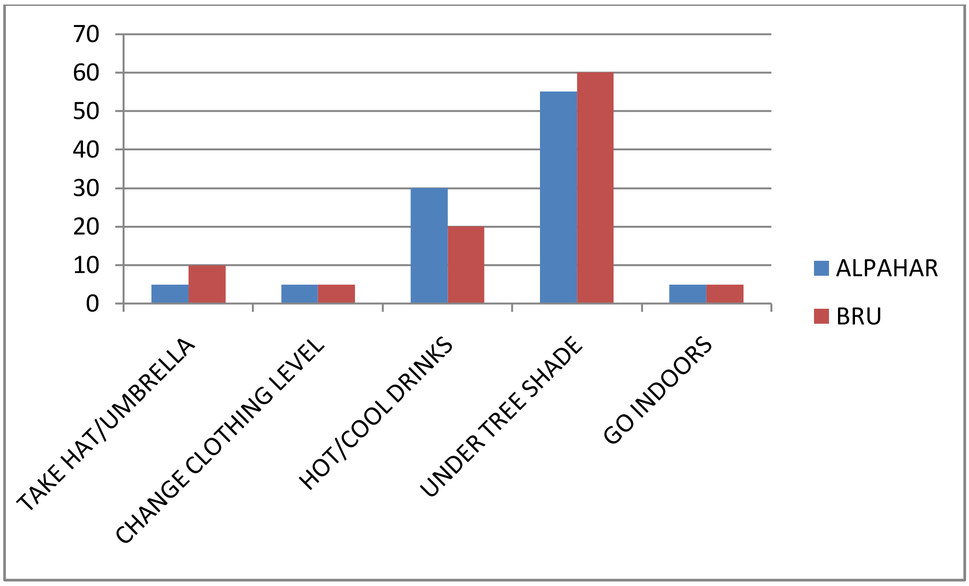
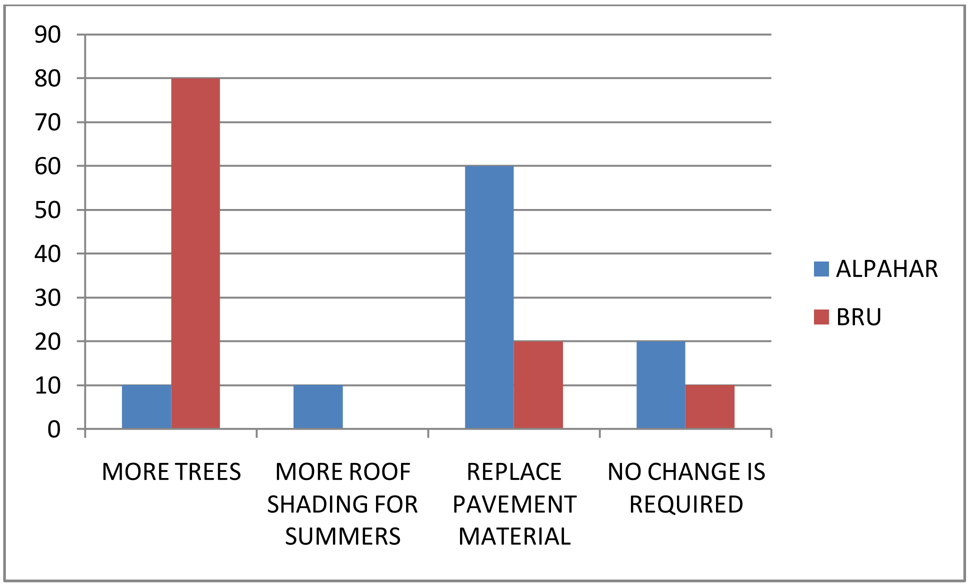


Fig. 4.32 Thermal Comfort Conditions of People



(a) Preference if feeling discomfort



(b) Design suggestions for the places

Fig. 4.33 Preference and Design Suggestions of the people

Observations from the Questionnaire Survey and the Microclimatic Data:

- The number of male respondents was more than female respondents.
- The maximum number of people was in the age category between 21-25 years.
- Maximum of the respondents had normal Body Mass Index (BMI), hence the results are free of error.
- The metabolic activity which was highest was sitting (low metabolic rate) and hence the results are valid and without error.
- Also, clo values between 1 and 3 were the maximum which indicates the average clo values were worn by the respondents. Hence, the results are without error.
- It is observed that
    - Thermal Sensation was Hot (when Average Air Temperature was 37^0 C)
    - The Wind Sensation was Slightly Weak (when Average Wind speed was 1.2 m/s)
    - The Humidity Sensation was Slightly Dry (when Average Relative Humidity was 18%).
- It is also observed that during summer, people were not comfortable in any of the two cafeterias and thermal condition that was preferred was cooler. Hence redesign of these spaces is necessary for summer.

c) Thermal Comfort Index, PET Calculation-RayMan model

The comfort range of both Alpahar and Bru are calculated for summer (table 4.12). For that PET (Physiological Equivalent Temperature) has been calculated by the RayMan software.

Table 4.12 PET Calculation

ALPAHAR

TIME	Neutral TS	VALUES		MICROCLIMATIC DATA				QUESTIONNAIRE SURVEY DATA					
		PET (0 C)	TMRT (0 C)	T_a	RH	WS	SR	H	W	AGE	CLO VALUE	ACTIVITY	G
01.20 P.M.	A23	49.5	64.2	37	18	1.2	953	1.7	75	23	1	1	M
04.20 P.M.	A40	44.2	55.6	36	18	1	427	1.6	57	22	1.5	1	F
04.35 P.M.	A50	42.5	52.2	35	17	0.8	373	1.8	75	25	1	1	M
04.45 P.M.	A74	40.3	47.6	35	18	0.5	282	1.57	64	30	1.2	1	F
04.45 P.M.	A93	40.3	47.6	35	18.5	0.9	282	1.57	55	25	2.3	1	F

BRU

TIME	Neutral TS	VALUES		MICROCLIMATIC DATA				QUESTIONNAIRE SURVEY DATA					
		PET (0 C)	TMRT (0 C)	T_a	RH	WS	SR	H	W	AGE	CLO VALUE	ACTIVITY	G
12.20 P.M.	A10	47.5	64.2	37	15	1	853	1.6	57	18	2.3	1	M
03.20 P.M.	A35	44.2	55.6	38	18	0.7	427	1.57	55	24	2	1	F
04.00 P.M.	A55	42.5	52.2	37	15	1.2	373	1.8	75	20	2	1	M
04.35 P.M.	A73	40.3	47.6	37	16	0.3	282	1.7	75	25	1	1	M
04.45 P.M.	A98	40.3	47.6	37	17	1.3	282	1.7	75	30	1	1	M

Results and observations from PET Calculation in RayMan:

In the Questionnaire Survey, we have seen that total no. of people comfortable in Bru and Alpahar are less than 40%. But in the real case, only 10 respondents in Alpahar and 5 respondents in Bru are actually considered comfortable as they have responded to the neutral Thermal Sensation in the comfort scale of ASHRAE. This means they were not feeling any thermal sensation at that time and were in a comfortable state.

Hence, PET of these selected samples (5 in each site) is being calculated in the RayMan software. For calculating the PET, the microclimatic data (Air Temperature, Relative Humidity, Wind, etc) and Questionnaire Survey Data (Personal Parameters like the Height, Weight, Gender, Age, Clo value, Metabolic Rate) are the inputs. In the output we get the PET and T_{mrt} (Mean Radiant Temperature).

- It is observed that T_{mrt} value depends upon the solar radiation and not on the air temperature. Even if the air temperature is increased, T_{mrt} value will decrease if the solar radiation is decreased too.
- Also, if at the same time of a day, two people of different BMI, different age, gender wears different clothing and involves in different metabolic activity, will not have much variation in the PET and T_{mrt} value because the microclimatic data will be same at that particular time.
- On a hot sunny day of May in Roorkee, it is observed that PET and T_{mrt} values are always higher than the air temperature at that time of the day.

III. Comparison between two locations in detail (Under Tree Shade and Under Open Sky) in two contrasting areas on two different days (Lawn Main Building and Students Club frontyard)

After the first two field studies, it was necessary to understand how two contrasting microclimate behaves. Till now, the harsh microclimate studied was LHC Parking but because of good amount of air circulation due to the high wind speed, the discomfort level decreases in the site. Hence, a more harsh microclimate with presence of more paved area was selected which was the Students Club frontyard.

The field survey was carried out in two alternate days.
Date of Survey: 20th and 22nd May, 2014   Time: 11.00 am to 5 pm
Sites selected: Lawn Main Building and Students Club Frontyard

Instruments Used:

For each area, two locations (fig 4.34 and fig 4.35) were selected and the Portable Weather Stations, WS1 and WS2 were placed. The two locations selected were:

1) Under Tree Shade
2) Under Open Sky

(a) Panoramic View of Students Club Frontyard

(b) Panoramic View of Lawn Main Building

Fig. 4.34 {(a),(b)} Panoramic Views of the two sites (Studens Club Frontyard and Lawn Main Building

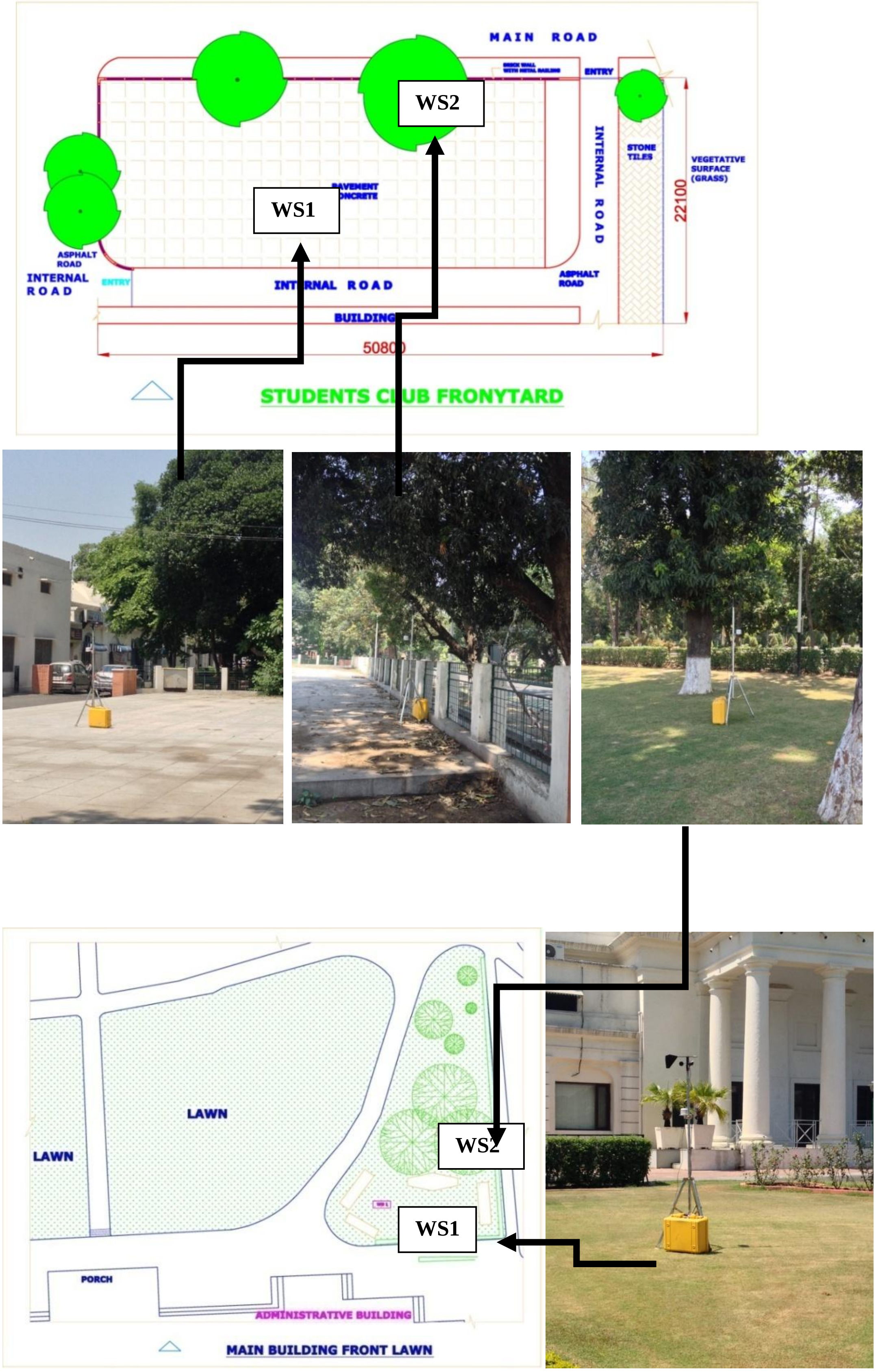


Fig. 4.35 Portable weather Stations in the two locations

Measurement:

The measurement taken from the Portable Weather Stations are shown in the table 4.13.

Table 4.13 Readings taken in the survey

STUDENTS CLUB FRONTYARD UNDER OPEN SKY

DATE	TIME	WS	TP	RH	WD
May-20	11:00	0.54	38	22.69	309.77
May-20	11:30	0.71	38.56	23.43	325.88
May-20	12:00	0.85	39.03	21.49	6.11
May-20	12:30	0.78	39.77	20.46	338.14
May-20	13:00	0.87	39.72	19.83	356.99
May-20	13:30	1.09	39.77	18.22	328.19
May-20	14:00	0.82	40.64	17.82	324.41
May-20	14:30	0.92	40.42	17.73	338.8
May-20	15:00	1.03	40.33	16.62	331.86
May-20	15:30	0.86	40.14	17.03	2.67
May-20	16:00	0.54	40.45	17.28	345.96
May-20	16:30	0.62	39.76	19.15	284.15
May-20	17:00	0.72	38.32	21.91	259.39

STUDENTS CLUB FRONTYARD UNDER TREE SHADE

DATE	TIME	WS	TP	RH	WD
May-20	11:00	0.43	33.72	29.12	298.6
May-20	11:30	0.6	34.48	29.48	313.5
May-20	12:00	0.68	34.94	27.44	339.36
May-20	12:30	0.74	35.56	25.81	329.4
May-20	13:00	0.86	35.83	24.66	301.49
May-20	13:30	0.94	36.22	22.27	298.42
May-20	14:00	0.65	36.7	22.47	302.05
May-20	14:30	0.66	36.96	21.58	323.89
May-20	15:00	0.84	37.07	20.32	330.35
May-20	15:30	0.68	36.91	20.73	289.85
May-20	16:00	0.53	37.04	21.09	328.61
May-20	16:30	0.53	36.76	22.79	292.12
May-20	17:00	0.99	36.24	24.55	230.06

LAWN MAIN BUILDINGUNDER OPEN SKY

DATE	TIME	WS	TP	RH	WD
May-22	11:00	1.9	34.47	28.52	293.61
May-22	11:30	2.51	35.07	27.56	317.34
May-22	12:00	2.67	35.84	25.87	326.76
May-22	12:30	2.92	36.43	23.66	323.17
May-22	13:00	2.63	37.19	22.11	321.96
May-22	13:30	2.8	37.91	18.91	321.8
May-22	14:00	3.09	38.16	15.85	323.25
May-22	14:30	2.65	38.44	15.36	308.8
May-22	15:00	2.61	38.83	14.7	303.77
May-22	15:30	2.91	38.58	15.28	319.55
May-22	16:00	2.53	38.63	15.75	313.66
May-22	16:30	2.44	38.38	16.33	310.01
May-22	17:00	2.07	38.25	16.43	315.52

LAWN MAIN BUILDING UNDER TREE SHADE

DATE	TIME	WS	TP	RH	WD
May-22	11:00	1.97	32.75	31.55	271.7
May-22	11:30	2.37	33.42	30.11	302.3
May-22	12:00	2.49	34.28	27.76	324.76
May-22	12:30	2.73	34.95	25.44	316.95
May-22	13:00	2.57	35.55	24.15	312.99
May-22	13:30	2.72	36.26	19.81	314.77
May-22	14:00	2.69	37.01	16.43	321.84
May-22	14:30	2.4	37.27	16.42	291.41
May-22	15:00	2.44	37.71	15.83	293.89
May-22	15:30	3.18	37.78	15.48	313.89
May-22	16:00	2.45	38.06	16.03	304.3
May-22	16:30	2.4	37.88	16.62	297.06
May-22	17:00	2.19	37.77	16.78	305.3

Observations:

a) It is observed that air temperature is higher under open sky than under tree shade.

   In Students club frontyard that the air temperature is almost 5^0C more under open sky than under tree shade. Also it is almost 2^0C higher than the macroclimatic data for that day.

On the other hand, in Lawn Main Building, the case was different. The air temperature under open sky was 2^0C higher than under tree shade. Also it was less than the macroclimatic data for that day.

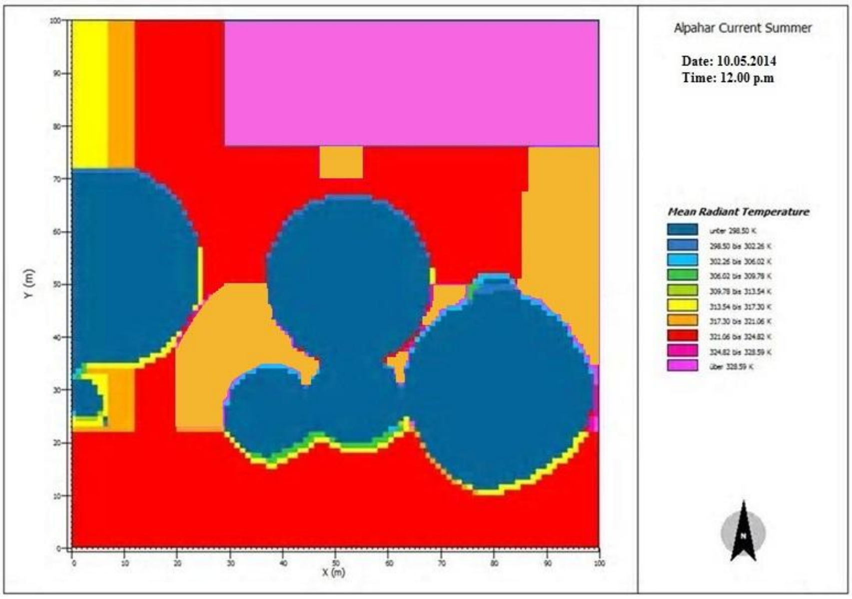
This shows that a site with more hard landscaping elements can increase the air temperature of that microclimate to a greater degree than the air temperature recorded in the macroclimatic data. But with vegetative surfaces, the air temperature reduces. This proves that surface temperature plays a major role in changing the microclimate of that place. Also, with an addition of trees along with the vegetative surfaces, the temperature reduces more.

b) The Relative Humidity was higher in Lawn Main Building than Students Club Frontyard. This was because of the evapo-transpiration of the vegetative surfaces and the large number of trees present in the Lawn Main Building.

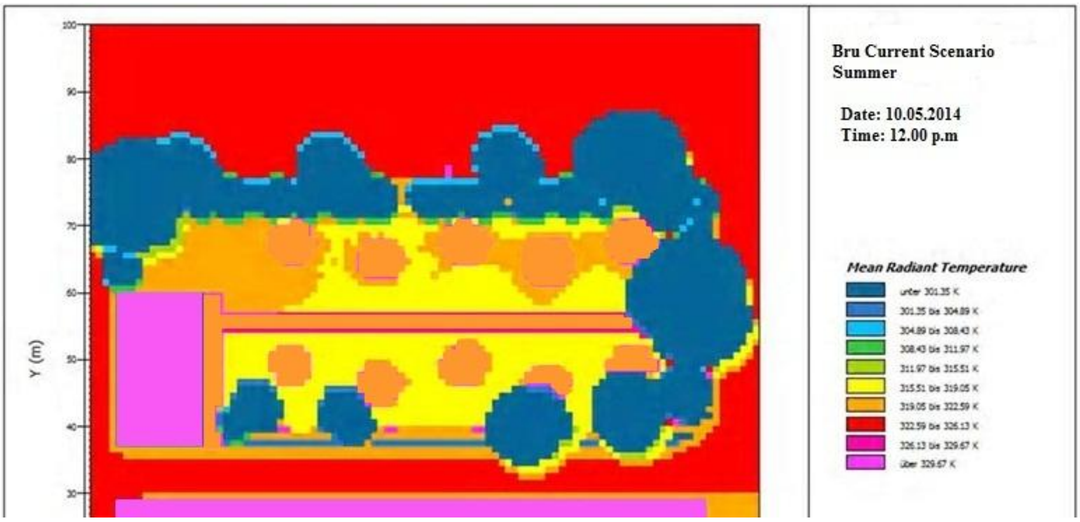
c) The wind speed also plays a major role in reducing the air temperature and creating comfortable surroundings. In Lawn Main Building, wind speed was as high as 3 m/s while in Students Club frontyard, the highest wind speed recorded was 1m/s. Therefore, even though there was higher Relative Humidity in Lawn Main Building, because of the wind speed outdoor thermal comfort is achieved.

C. Envi-Met Simulation for Summer

The existing thermal environments of the 5 outdoor spaces (Alpahar, Bru, Lawn Main Building, LHC Parking and Students Club Front yard) in IIT Roorkee campus were simulated in Envi-Met mainly for summer scenarios (fig 4.36, fig 4.37 and fig 4.38). This is because in Roorkee, summer is longer and more challenging and winter exists for hardly 3 months. Visible difference of temperature is seen while comparing the different simulations.

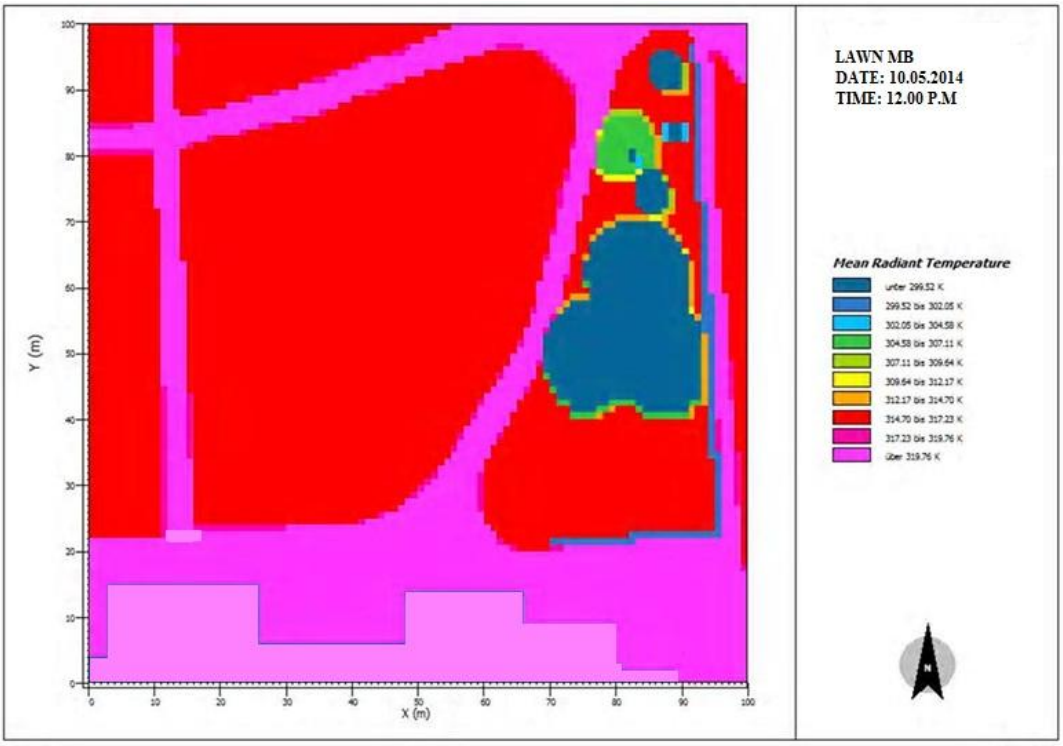


(a)

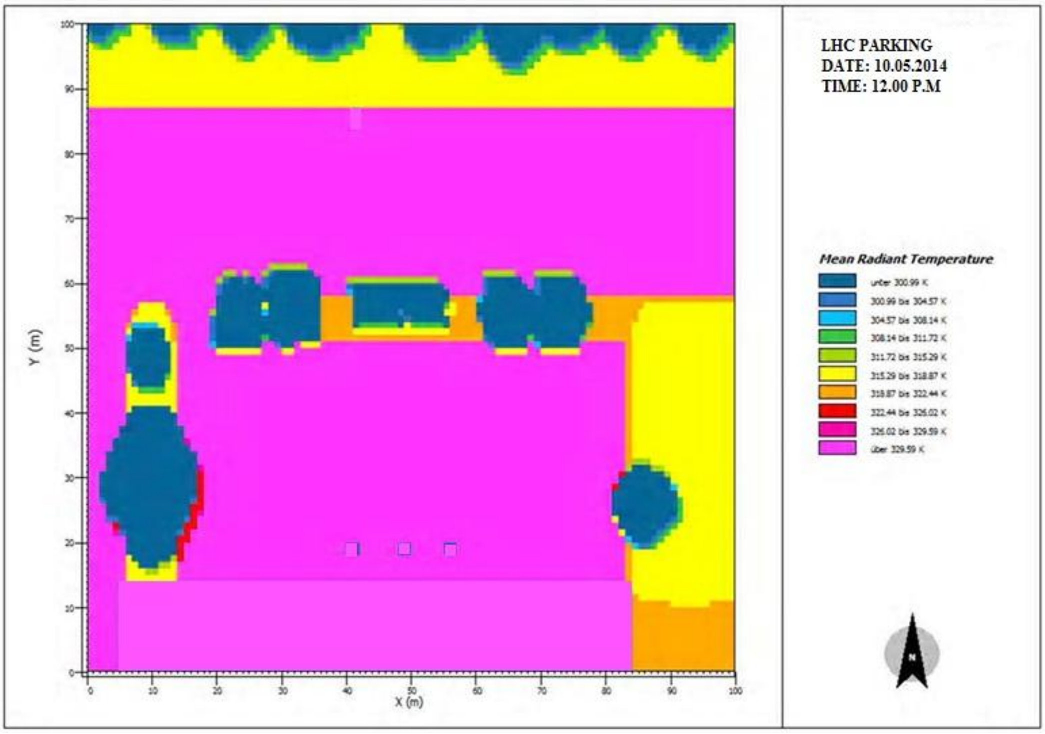


(b)

Fig. 4.36 {(a),(b)} Envi-Met Simulation Graph of Alpahar and Bru



(a)



(b)

Fig. 4.37 {(a),(b)} Envi-Met Simulation Graph for Lawn Main Building and LHC Parking

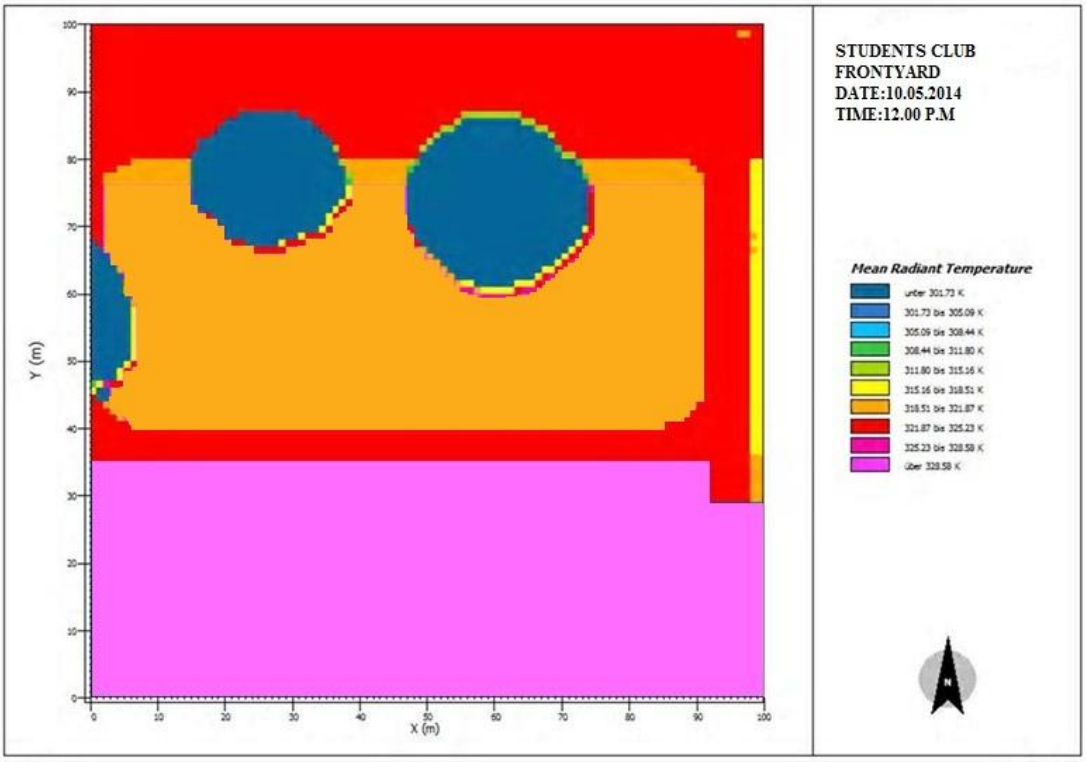


Fig. 4.38{(a),(b)} Envi-Met Simulation Graph for Students Club Frontyard

Observations:

It is found that T_{mrt} values changes with the different zones.It is shown in the following table 4.14.

- The T_{mrt} value is very less under tree shade in all the 5 sites
- The highest T_{mrt} is observed in Asphalt under open sky followed by Paved Concrete, Bare Soil and than Vegetrative Surface (Grass).
- Since in Alpahar, almost the whole site is covered by large tree canopies, T_{mrt} value is lowest under tree shade compared to the other site.
- The highest value of Asphalt is observed in Students Club Frontyard and this may be because it is surrounded by large % of paved surfaces under open sky.

Table 4.14 Tmrt Values of Different Landscaping Elements in the Five Sites

Site	Landscaping Elements	T_{mrt} Values in Kelvin	T_{mrt} Values in ^{0}C
Alpahar	Asphalt	321.06 to 324.82	47.91 to 51.67
	Paved Concrete	317.30 to 321.06	44.15 to 47.91
	Under Tree Shade	298.50	25.35
Bru	Bare Soil	319.05 to 322.59	45.9 to 49.44
	Vegetative Surface (Grass)	315.51 to 319.05	42.36 to 45.9
	Paved Concrete	319.05 to 322.59	42.36 to 45.9
	Under Tree Shade	301.35	28.2
Lawn Main Building	Asphalt	319.75	46.6
	Vegetative Surface (Grass)	314.7 to 317.23	41.55 to 44.08
	Under Tree Shade	299.52	26.37
LHC Parking	Vegetative Surface (Grass)	315.29 to 318.87	42.14 to 45.72
	Paved Concrete	325.02 to 329.59	51.87
	Under Tree Shade	300.99	27.84
Students Club Frontyard	Asphalt	321.87 to 325.23	48.72 to 52.08
	Paved Concrete	317.30 to 321.06	45.36 to 48.72
	Under Tree Shade	301.73	28.58

4.6 SUMMARY

Finally it is seen that even though in Alpahar, there are hard paved surfaces (asphalt and paved concrete), because of the large tree canopies it has the minimum temperature. This proves that trees plays a major role in influencing the microclimate than the ground surfaces.

It is found from the above field studies that minimum temperature is found under tree shade. Also, Tmrt value (which decides the outdoor comfort conditions) remains constant throughout the day under tree shade. Hence, for a good comfortable outdoor design solution, it is required to plant more trees with large canopies and reduce the hard surfaces of the site.

Also along with that it is required to properly analyze the site conditions and the microclimatic data of the outdoor space and finally a good design can be created with the help of proper landscape elements.

5. REDESIGN OF CAFETERIA SPACES

5.1 SELECTION AND DESCRIPTION

From the analyzing of the two cafeteria sites (Alpahar and Bru), it is found that a good design is required for both summer and winter. Since summer period lasts for a longer duration in Roorkee, most of the design strategies will be focused with respect to the summer period.

5.2 SCENARIO GENERATION AND INTERVENTION LEVEL

According to the site analysis and the field survey results, modified scenarios for both Alpahar and Bru are designed with the help of Intervention levels and Packages (table 5.1 and table 5.2).

Table 5.1 Interventions and Packages for modified scenario in Alpahar

Scenario		**Interventions**	
		I	**II**
		Soft Landscaping Elements	**Hard Landscaping Elements**
1.	**Base Case**	N/A	N/A
2.	**Base Case + Package A**	Replace pavement concrete by vegetative surfaces (grass) increasing albedo	High Wired Fences in the Eastern site boundaries (Winter wind)
		Deciduous Creepers in Trellis/Pergolas	
		Green Walls on buildings	Paint Boundary fences in dark colours (brown, green, blue)
3.	**Base Case + Package B**	Replace pavement concrete by vegetative surfaces (grass) increasing albedo	High Wired Fences in the Eastern site boundaries (Winter wind)
		Deciduous Creepers in Trellis/Pergolas	Paint Boundary fences in dark colours (brown, green, blue)
		Green Walls on buildings	
		Shrubs along paved pathway (wind flow)	Asphalt replaced by Grasscrete as pavement material
		Hedges along site boundary as barriers and wind breakers	

Table 5.2 Interventions and Packages for Modified Scenarios in Bru

Scenario		**Interventions**	
		I	**II**
		Soft Landscaping Elements	**Hard Landscaping Elements**
1.	**Base Case**	N/A	N/A
2.	**Base Case + Package A**	Vegetative Surface (Grass)	Remove Solid Walls on North (visual barrier)
		Deciduous Creepers in Trellis/Pergolas	Use Wired Fences in the site boundaries.
		Green Walls	Paint Boundary fences in dark colours (brown, green, blue)
3.	**Base Case + Package B**	Vegetative Surface (Grass)	Remove Solid Walls on North
		Deciduous Creepers in Trellis/Pergolas	Use Wired Fences in the site boundaries.
		Green Walls	Paint Boundary fences in dark colours (brown, green, blue)
		Evergreen Trees on North perpendicular to wind direction	
		Deciduous Trees on South, East and West	Grasscrete as pavement material
		Trees and Shrubs arranged on South East to create Venturi Effect (Monsoon Wind)	Trellis/Pergolas in the paved pathway for shade in summer and in SE for channelling wind
		Shrubs along paved pathway (enhance wind flow)	Sprinkler system for the grasses (Summer)
		Hedges along site boundary as barriers and wind breakers	

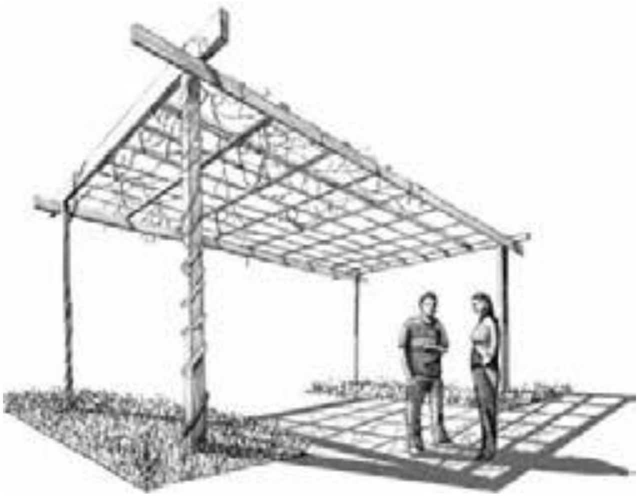
The Interventions Levels (I and II) are the two divisions of Soft Landscaping Elements and Hard Landscaping Elements respectively. First is the Base Case which is the reference and then modified scenario is created by adding or reducing some landscaping elements. The Base case + Package A deals with the minimum or least expensive techniques while Base case + Package B is an addition of techniques with the first which will further help in redesigning the outdoor cafeterias.

5.3 THE DESIGN FEATURES IMPLEMENTED

The design features implemented includes some natural and some artificial techniques. The artificial techniques used are as follows:

i. Deciduous Creepers in Trellis and Pergolas

(a) Summer



(b) Winter

Fig. 5.1 {(a),(b)} Deciduous Creepers used in Trellis

Source: Design with microclimate, Robert D. Brown (2010)

A trellis (fig 5.1) oriented to the south with a deciduous vine growing on it will

(a) Provide shade during the summer

(b) But allow solar radiation to pass through in winter, improving the thermal comfort of people in both seasons.

Hence trellis with deciduous creepers is used in both the sites.

ii. Sprinkler System

A Sprinkler system (fig 5.2) helps to keep a lawn or special plants watered especially during the summer months. It also helps to cool down the surface temperature of the ground. This feature is used in Bru because of the large area of grass (vegetative surface).

Fig. 5.2 Sprinkler System used in Lawns

Source: Sprinkler System Design & Installation (Web Article)

iii. Grass-crete pavement

Grass-crete (fig 5.3) is used replacing the asphalt and the paved concreate. This helps to reduce the surface temperature.

Fig. 5.3 Grass-crete used instead of Paved Concrete or Asphalt

Source: Soil Retention: Plantable Concrete, Zahid Sardar (August 2, 2009)

Both the cafeterias are redesigned (fig 5.4 and fig 5.5) accordingly.

Fig. 5.4 Alpahar Re-design Plan

Fig. 5.5 Bru Redesign Plan

5.4 SIMULATION OF MODIFIED SCENARIOS

Envi-Met is a computer model which helps in analyzing the micro-scale thermal interactions for urban environments. The software uses both the calculation of fluid dynamics characteristics, such as air flow and turbulence, as well as the thermodynamic processes taking place at the ground surface, at walls, at roofs and at plants. ENVI-met takes into account all types of solar radiation (direct, reflected and diffused) and calculates the mean radiant temperature. In calculating MRT, ENVI-met takes into account all radiation fluxes, direct, diffuse and reflected solar radiation as well as the long-wave radiation fluxes from the atmosphere, ground and walls and is capable of producing MRT values for each cell of the model environment at varying heights above the ground surface (Ali 2005, Emmanuel & Fernando 2007).

The ENVI-met software requires climatic data input for the site being simulated. These inputs were collected during the physical survey.

The Envi-Met Simulation for both the sites, Alpahar and Bru was done for summer. The existing scenarios of both the sites were first simulated in the Envi-Met model 3.1 for the day on which field survey was carried out (10^{th} May 2014).

At first, the plans of the existing sites were given the specific characteristic of all the landscaping elements present. The soft landscaping elements (trees, grass, hedges) and the hard landscaping elements (asphalt, paved concrete) were specified on a 100 x 100 x 20 grid model.

Then the whole scenario was simulated for the particular day specifying the microclimatic parameters recorded for that day (Air Temperature, Relative Humidity, etc). In the software Leonardo 3.75, the simulated files with the desired output were received. The T_{mrt} (Mean Radiant Temperature) which is the most effective measure for the thermal comfort state can be calculated for every zones of the site.

5.4.1 Alpahar (Current and Modified Scenarios)

With the new landscape design strategies and Interventions, a new and modified design for Alpahar (fig 5.6 and fig 5.7) has been made. Both the current and the modified scenarios were simulated in the Envi-Met software and comparison was done based on the derived results.

Some of the major changes in the site are as follows (table 5.3):

Table 5.3 Alpahar (Current and Modified scenarios)

Alpahar Current Scenario	**Alpahar Modified Scenario**
Pavement Concrete	Replaced pavement concrete by vegetative surfaces (grass)
Asphalt	Replaced by Grass-crete
	Pergola with deciduous creepers above Grass-crete
	Shrubs along paved pathway (wind flow)

Results and Observations:

The results of the Envi-Met Simulation are shown in table 5.4. It is observed that there is a difference of T_{mrt} values in both the scenarios. It is reduced by almost 2^0C in the modified scenario.

Table 5.4 Tmrt values in Alpahar (Current and Modified Scenario)

Landscape Elements	**Tmrt (Mean Radiant Temperature)**	
	Alpahar Current Scenario	**Alpahar Modified Scenario**
Pavement Concrete to Vegetative Surface (grass)	(317.30K to 321.06K) 44.15^0C to 47.91^0C	(315.42K to 318.99K) 42.27^0C to 45.84^0C
Asphalt to Grass-crete	(321.06K to 324.82K) 47.91^0C to 51.67^0C	(318.99K to 322.56K) 45.84^0C to 49.41^0C

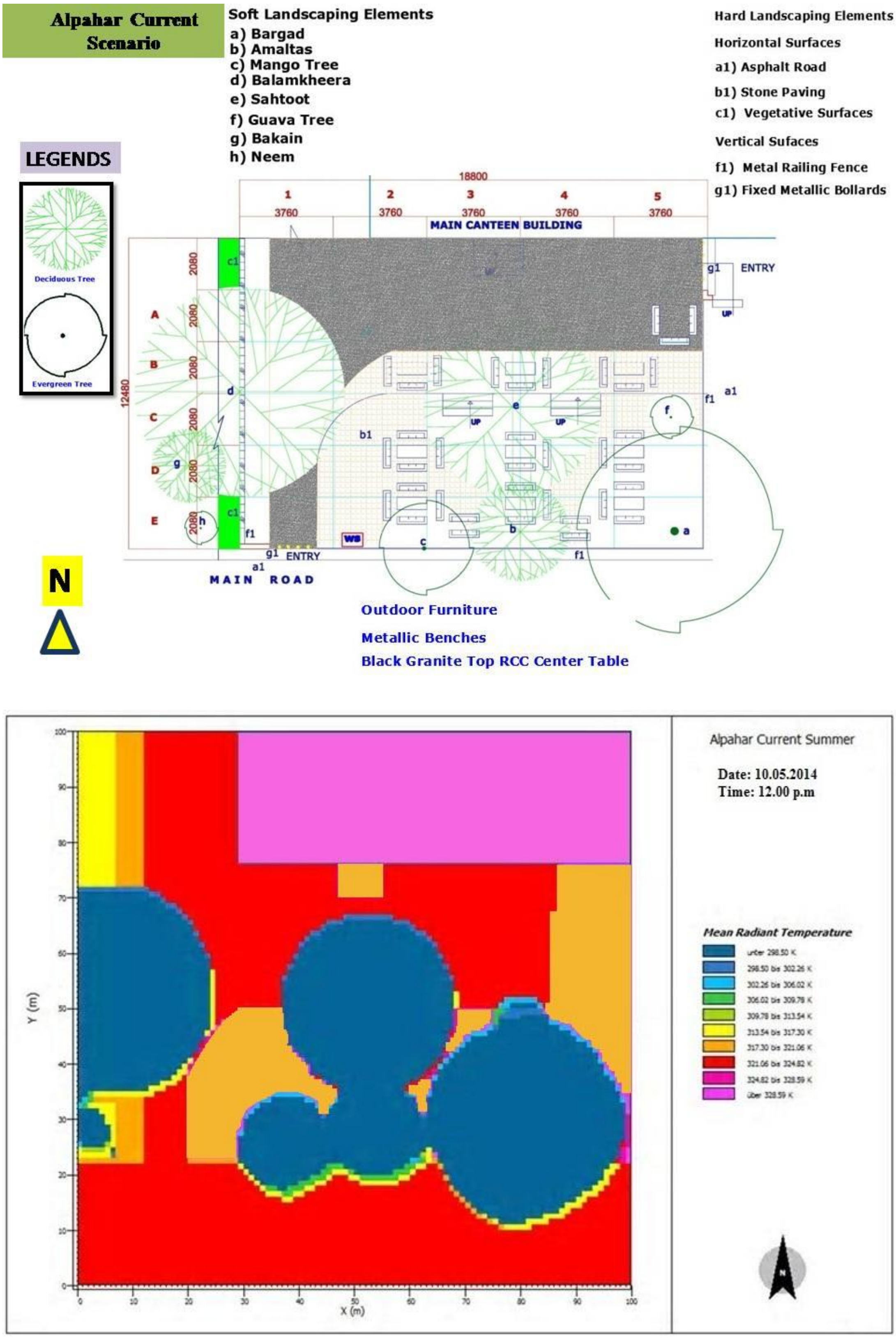


Fig. 5.6 Alpahar Current Scenario plan and Envi-Met Simulation

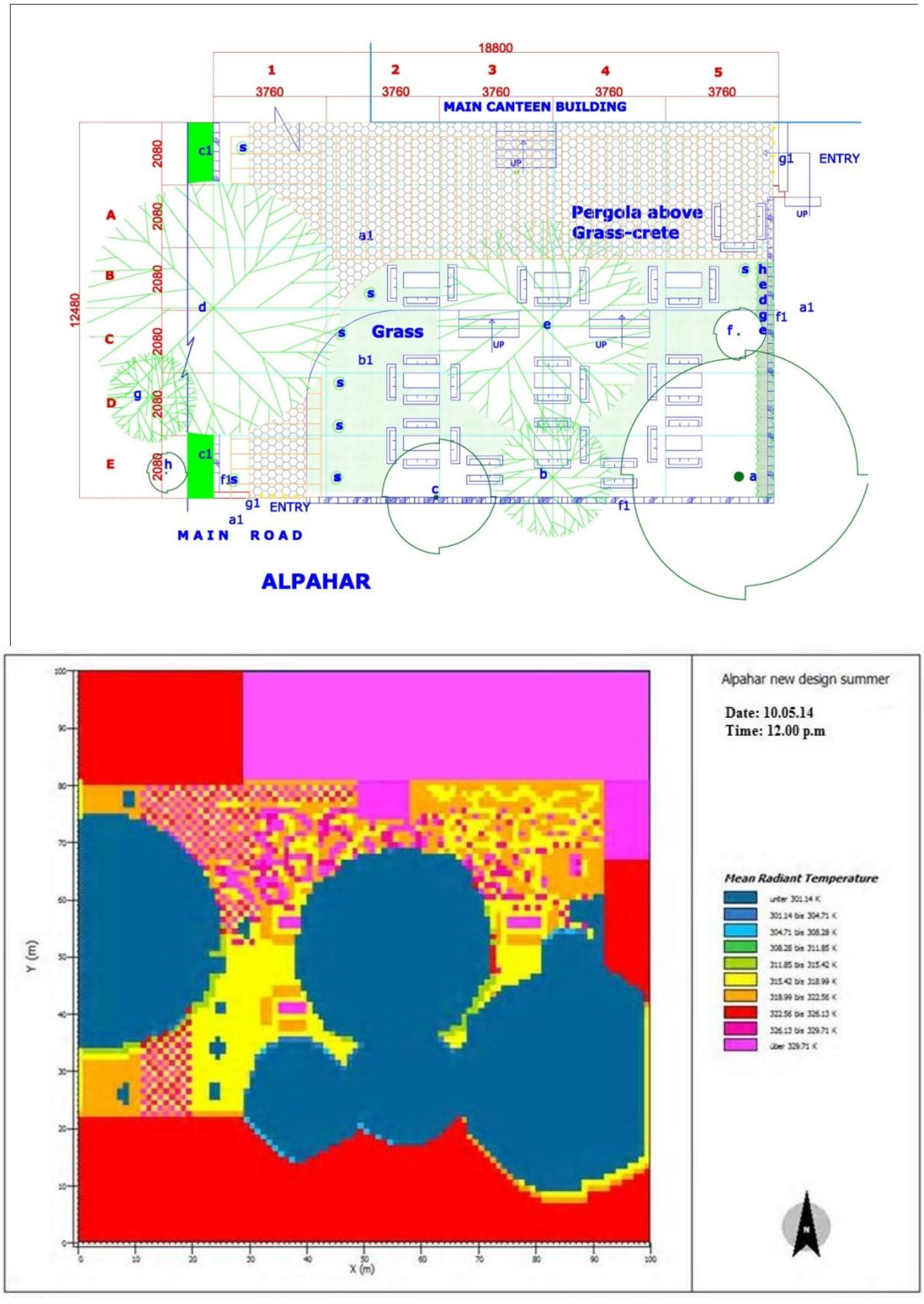


Fig. 5.7 Alpahar Modified Plan and Envi-Met Simulation

5.4.2 Bru (Current and Modified Scenarios)

With the new landscape design strategies and Interventions, a new and modified design for Bru (fig 5.8 and fig 5.9) has been made. Both the current and the modified scenarios were simulated in the Envi-Met software and comparison was done based on the derived results.

Some of the major changes in the site are as follows (table 5.5):

Table 5.5 Bru (Current and Modified Scenario)

Bru Current Scenario	**Bru Modified Scenario**
Bare soil	Replaced by vegetative surfaces (grass)
Pavement Concrete	Replaced by Grass-crete
	Pergola with deciduous creepers above the Grass-crete pathway
	Shrubs along paved pathway (wind flow)
Others	4 Evergreen Trees added on North side
	Deciduous Trees and shrubs arranged on South east side to create Venturi effect
	Hedges along site boundary as barriers and wind breakers

Results and Observations:

The results of the Envi-Met Simulation are shown in table 5.6. It is observed that there is a difference of T_{mrt} values in both the scenarios. It is reduced by almost 20^0C in the modified scenario which is very much effective because of all the strategies implemented.

Table 5.6 Tmrt Values in Bru (Current and Modified Scenario)

Landscape Elements	**Tmrt (Mean Radiant Temperature)**	
	Bru Current Scenario	**Bru Modified Scenario**
Bare soil to Vegetative Surface (grass)	(319.05K to 322.59K) 45.9^0C to 49.4^0C	(297.29K to 298.62K) 24.14^0C to 25.47^0C
Pavement Concrete to Grass-crete	(319.05K to 322.59K) 45.9^0C to 49.4^0C	(298.62K to 299.94K) 25.47^0C to 26.79^0C

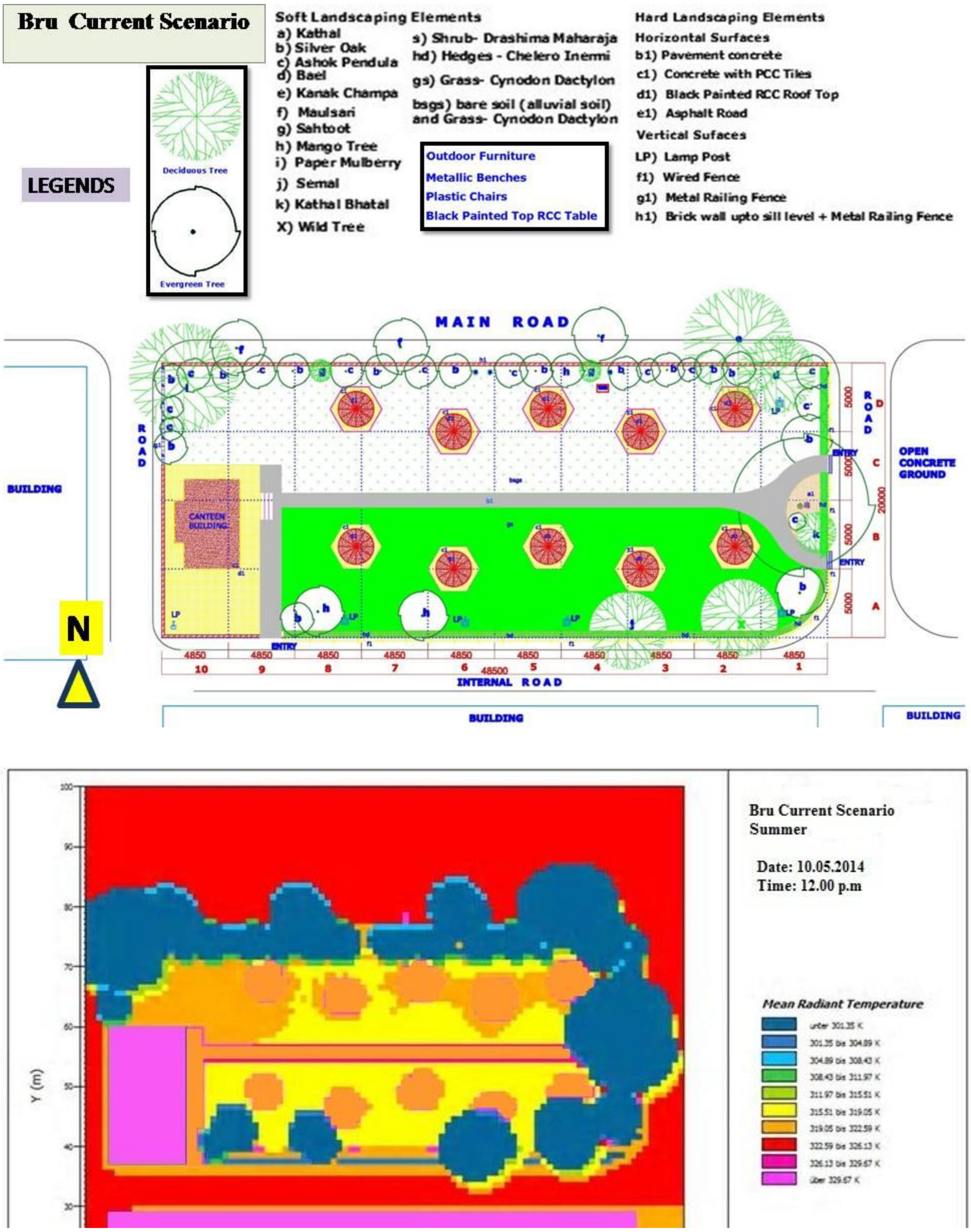


Fig. 5.8 Bru Current Plan and Envi-Met Simulation

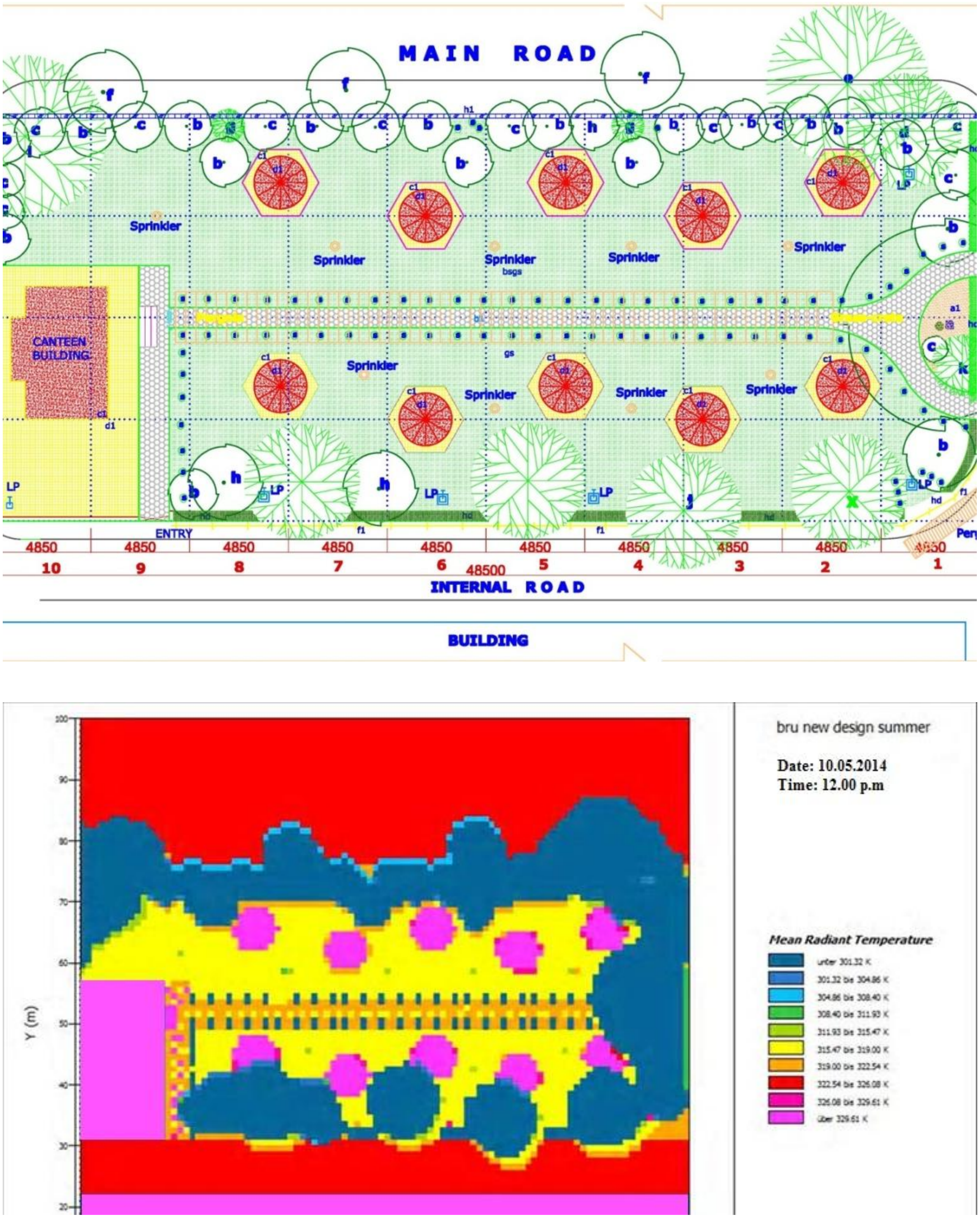


Fig. 5.9 Bru Modified Plan and Envi-Met Simulation

5.5 SUMMARY

The modified design scenarios of the cafeterias were simulated in Envi-Met and comparison was done with the existing scenarios. The T_{mrt} (Mean Radiant Temperature) value, which plays a major role in determining the outdoor comfort conditions, was evaluated for both the scenarios. It is observed that in the modified scenario, the thermal comfort conditions are better than the existing scenarios. The T_{mrt} value has been decreased by 2^0 C to 20^0C in the new design.

6. CONCLUSION

6.1 CONCLUSION

The Outdoor Thermal Comfort parameters and indices were studied in detail. The suitable index, PET (Physiological Equivalent temperature) was selected for further carrying out OTC evaluation in the cafeterias of IITR. Amongst the literature studied, it was found that PET is suitable for diverse climatic conditions like India. PET was calculated from RayMan software.

Outdoor Thermal Comfort evaluation was carried out in the cafeterias (Alpahar and Bru) through field studies for both summer and winter for the current year 2014. Each field study consisted of two major parts:-

iii. Subjective Evaluation (personal factors, sensation, etc through Questionnaire Survey)

iv. Microclimatic Data Evaluation (measurement of microclimatic parameters like Air Temperature, Humidity, Solar Radiation, Wind Speed and Direction, etc through instruments)

Alpahar and Bru are the main study area (base cases) where design will be implemented later. Some contrasting cases were also selected to find out the differences. Lawn Main Building was selected because of the maximum amount of Vegetative area present (Soft Landscaping Element). On the other hand, LHC Parking and Students Club frontyard were selected because of the maximum amount of paved area (Hard Landscaping Element) present. This is to show how microclimatic parameters vary with the different outdoor spaces.

The influence of landscaping elements for the 5 different outdoor spaces (Alpahar, Bru, Lawn Main Building, LHC Parking and Students Club Front yard) in IIT Roorkee campus was observed. Landscaping elements was grouped into:-

iii. Soft Landscaping Elements (Vegetation like trees, grass, etc)

iv. Hard Landscaping Elements (e.g., pavement, walls and fences, garden furniture, etc)

A table was prepared for the 5 different outdoor spaces showing the different landscaping elements present and their area in percentage. Also ratio of Building:Pavement:Vegetation was calculated. It has been observed with the different landscaping elements present in these outdoor spaces, the microclimatic parameters and comfort level also varies.

Also current thermal environment of the 5 outdoor spaces were simulated in Envi-Met mainly for summer scenarios. This is because in Roorkee, summer is longer and more challenging and winter exists for hardly 3 months. Visible difference of temperature is seen while comparing the different simulations.

Also, Physiological Equivalent Temperature (PET) index of selected neutral thermal sensation samples from the Questionnaire Survey was calculated in RayMan for the two cafeterias. Simulation software like Envi-Met was also used for the outdoor thermal comfort assessment. The ENVI-met was used mainly to simulate surface-plant-air interactions in the microclimate of the outdoor cafeterias. The existing scenario of all the 5 selected outdoor spaces were also simulated for the summer and compared with each other.

The Landscaping Elements for controlling the microclimate was achieved through various landscaping techniques and elements. Interventions and Packages were developed for the cafeterias (Alpahar and Bru) according to the site requirements for better outdoor comfort conditions. Redesign of the cafeterias (Alpahar and Bru) was done from the derived strategies.

The modified design scenarios of the cafeterias were simulated in Envi-Met and comparison was done with the existing scenarios. The T_{mrt} (Mean Radiant Temperature) value, which plays a major role in determining the outdoor comfort conditions, was evaluated for both the scenarios. It is observed that in the modified scenario, the thermal comfort conditions are better than the existing scenarios. The T_{mrt} value has been decreased by atleast 2^0 C in the new design.

6.2 SCOPE OF FURTHER STUDY

There is a good scope for further carrying out further study in this area of research. The evaluation of outdoor thermal comfort is itself a very complicated task. In outdoors, the microclimatic parameters like the Air Temperature, Relative Humidity, Wind Speed, etc are constantly changing and each of them depends upon each other for the evaluation of the comfort conditions. In indoor conditions, a stable microclimate can be achieved by controlling these physical parameters. But this is not possible in case of outdoors. Hence, there is a need to constantly observe the behaviour of the microclimate of an outdoor space. For that to happen, it may require field studies which will continue for years.

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ANNEXURES

ANNEXURE 1 OUTDOOR THERMAL COMFORT FIELD STUDY QUESTIONNAIRE

Name: .... **Date:** ....

Gender: ☐ Male ☐ Female **Time:** .... (A.M/P.M)

Height :..................................(feet) **Weight :**...............................(kg)

Age: Please tick (✓) below

- ❒ 11 – 15 years
- ❒ 16-20 years
- ❒ 21-25 years
- ❒ 26-30 years
- ❒ 31-40 years
- ❒ 41-50 years
- ❒ 51-60 years
- ❒ Above 60 years

Physical Activity at present: ....
Example: Sitting, Standing, Playing, Eating, Walking, etc

Duration of the activity: .... (time in minutes)

If duration is less than 5 minutes in the above activity then

The immediate physical activity you did before coming here?
....

Example: Walking, Playing, Eating, Cycling, Driving, etc

Tick (✓) the Clothing you are wearing now in the dark empty boxes from the list below accordingly:

MALE

Types	Tick here	Name of the clothes			No. of layers (If more than 1)
Under Garments & Inners		Briefs			
		Vest (light)		Vest (heavy)	
Clothing above waist		Shirt short sleeve		Shirt long sleeve	
		T-Shirt short sleeve		T-Shirt long sleeve	
Clothing below waist		Shorts/Half pant			
		Capris			
		Jeans			
		Trouser light material		Trouser heavy material	
Winter Wears		Inner above waist		Inner below waist	
		Sweater light		Sweater heavy	
		Jacket light		Jacket heavy	
		Overcoat			
Others		Hat/Cap			
		Scarf/shawl			
		Tie			
		Socks till knee		Socks till ankle	
		Shoes		Sandal / Slippers ☐ Boots	
Any other worn then please specify					

THANK YOU FOR SHARING YOUR PRECIOUS TIME AND VALUABLE COMMENTS

ANNEXURE 1 OUTDOOR THERMAL COMFORT FIELD STUDY QUESTIONNAIRE

FEMALE

Types	Tick here	Name of the clothes			No. Of layers (If more than 1)
Under Garments & Inners		Bras & panties			
		Slips/Spaghetti			
		Shape wear			
Clothing above waist		Shirt short sleeve		Shirt long sleeve	
		Tshirt short sleeve		Tshirt Long sleeve	
		Short Sleeve Top		Long sleeve Top	
		Kurti Short sleeve		Kurti Long sleeve	
Clothing below waist		Skirt light		Skirt heavy	
		Shorts			
		Capris			
		Jeans			
		Trouser light		Trouser heavy	
Indian wear/dress		Dress/Frock			
		Peticot			
		Blouse short sleeve		Blouse long sleeeve	
		Sari			
		Kameez/Long Kurta			
		Salwar/Churidar/Leggings			
		Dupatta			
Winter Wears		Inner above waist		Inner below waist	
		Sweater light		Sweater heavy	
		Jacket light		Jacket heavy	
		Overcoat			
Others		Hat/Cap			
		Scarf/shawl			
		Tie			
		Slacks			
		Stockings			
		Socks till knee		Socks till ankle	
		Shoes/Pumps		Sandal / Slippers; Boots	
Any other worn then please specify					

PART I

How do you feel about the surrounding environment?

THANK YOU FOR SHARING YOUR PRECIOUS TIME AND VALUABLE COMMENTS Page 2

ANNEXURE 1 OUTDOOR THERMAL COMFORT FIELD STUDY QUESTIONNAIRE

Please tick (✓) the right option below:

1. Thermal Sensation (TS): (Tick only 1)

☐ Cold ☐ Cool ☐ Slightly cool ☐ Neutral ☐ Slightly warm ☐ Warm ☐ Hot

2. Wind Sensation (WS): (Tick only 1)

☐ Too windy ☐ Windy ☐ Slightly windy ☐ Neutral ☐ Slightly weak ☐ Weak ☐ Too weak

3. Humidity Sensation / Sweating (HS): (Tick only 1)

☐ Too humid ☐ Humid ☐ Slightly humid ☐ Neutral ☐ Slightly dry ☐ Dry ☐ Too dry

4. Thermal acceptability: (Any 1)

- ☐ Not comfortable
- ☐ Comfortable

5. Thermal Preference: (Any 1)

- ☐ Warmer
- ☐ No change
- ☐ Cooler

PART II

If you are feeling discomfort presently what would you prefer?

Please tick (✓) the right option below: (Only 1)

- ☐ Take Hat/Umbrella
- ☐ Change Clothing level
- ☐ Hot/Cool drinks

or

Move to another location (Any 1):

- ☐ Under Tree Shade
- ☐ Go Indoors

PART III

Do you have any suggestion for this place? (Tick Any 1)

- ☐ More trees
- ☐ More Roof Shading
- ☐ Replace pavement material
- ☐ No change is required

Any Suggestion / Comment:

....

....

....

....

....

Signature

THANK YOU FOR SHARING YOUR PRECIOUS TIME AND VALUABLE COMMENTS Page 3