International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 3 No. 1 Jun. 2014, pp. 27-39

http://www.ijisr.issr-journals.org/

INFLUENCE OF STREET GEOMETRY ON URBAN MICROCLIMATE – A COMPARISON OF TRADITIONAL AND MODERN STREETS OF SRIRANGAM

D.Kannamma[1] and Dr.A.Meenatchi Sundaram[2]

[1]Assistant Professor, Department of Architecture,
National Institute of Technology,
Tiruchirappalli, Tamil Nadu, India

[2]Associate Professor, Department of Architecture,
National Institute of Technology,
Tiruchirappalli, Tamil Nadu, India

ABSTRACT: Urban microclimate is very much influenced by the various anthropometric factors like pollution, population growth, scarce vegetation, lack of significant open spaces and so on. Built environment also in a very significant manner contributes in this influence. Considering the building environment of the city, factors like building layout, street geometry contribute a key role in altering the urban micro climate. The comfort of the interior spaces can be improvised with either of the active or passive techniques. Outdoor comfort is seldom thought of .Though there are many aspects of the built environment considered as factors in influencing outdoor thermal comfort, this paper focuses on the contribution of street geometry.
To understand the influence of street geometry on outdoor thermal comfort traditional and the modern streets layout are documented and analyzed. The outcome of this paper is to establish the relationship between the elements of street geometry and the outdoor thermal comfort index PET.

KEYWORDS: Street geometry, outdoor thermal comfort, PET, RAYMAN.

1 INTRODUCTION

The world is undergoing the largest wave of urban growth in history. Since 2008, for the first time more than half the worlds' population is living in towns and cities. By 2030 this number will swell to almost five billion or an estimated 61 percent of global population [1].Cities has the ability to modify their climates. These modifications include changing cloud cover, precipitation patterns, wind speeds, solar irradiance, and increasing air temperatures [2]. The most significant modification is the creation of Urban Heat Islands. The term Urban Heat Island (UHI) refers to an urban area with temperatures that are elevated relative to its less developed surroundings. While the physical mechanisms causing UHIs are well documented [3], they continue to be the most studied phenomenon in urban climatology [4], [5].

The urban research has taken very serious concern over this increase in city temperature and the various factors contributing to these phenomena are analyzed to bring out possible solutions to enable the urban planners, designers, developers and regulation authorities to work out strategies to minimize the heat island impact.

2 URBAN MICROCLIMATE

The impact of the urban heat island is basically the cumulative effect of the various factors on the climate [6] carried out a detailed statistical analysis of UHI characteristics in Athens and concluded that the appearance of high air temperatures was reinforced by increased urbanization and industrialization coupled with the increased anthropogenic heat flows and the lack of vegetation. Urban elements play a major role in the development of UHI. Some studies [7] showed the various impacts of land use on urban temperature. The factors that influence the urban microclimate can be classified as the climatic factors and the physical factors. These factors operate together in establishing cycles in the existing climate of cities and increase the outdoor temperature.

2.1 CLIMATIC FACTORS

2.1.1 SOLAR RADIATION

Solar radiation reach the earth’s surface as direct (short wave radiation) or heat up the atmosphere first and then be directed towards the earth’s surface and immediately reflected back or stored and then lost to the atmosphere (long – wave radiation).More over energy may be lost due to convective flow (called the turbulent flow) and all these factors contribute in heating up the urban system and is then convected out (sensible heat) [3].

2.1.2 HUMIDITY

The percentage of moisture present in air is also influenced by the components of urban canyon. The extent to which humidity is raised depends on either vegetated area or presence of water body. The larger the extent of wet surfaces relative to dry surfaces such as bare soil, paving and walls the larger is the proportion of incoming solar energy. At the same time the increase in humidity at pedestrian head height is ultimately limited by the mixing of humidified air with dry air from outside the canyon. This depends on intensity of air flow in the canyon, which is affected by physical factors (Aspect Ratio and orientation) [1].

2.1.3 WIND

The urban wind field is complicated. Small differences in topography can cause irregular air flows. As the air flows from the rural environment to the urban environment, it must adjust to the new boundary conditions defined by the cities [8]. This adjustment results from the higher level development flow field and the uniqueness of local effects such as topography, building geometry and dimensions, streets, traffic and other local features like trees [9].Oke, 1987 [3] characterized the wind variation with height over cities by defining two specific sub layers, the obstructed sub layer or urban canopy sub layer which extends from the ground surface up to the height of the buildings and the so called free surface layer or urban boundary layer which exists above roof tops. The obstructed or canopy sub layer has its own flow field driven and determined by the interaction with the local features [10].The impact of wind is felt very significant particularly in the high density pockets of the urban area as the wind movement is obstructed by the closely packed buildings and lack of open spaces.

2.2 PHYSICAL FACTORS

The presence of buildings modify in a different degree all the energy balance terms in an urban context [11]. The physiological thermal stress that is imposed on a pedestrian in an urban canyon is an integral expression of the radiating and convective exchanges which is impacted in some way by the physical properties of the canyon [1].

2.2.1 URBAN CANYON

The urban geometry of a city is characterized by a repetitive element called the Urban Canyon. Urban Canyon is defined as the three dimensional spaces bounded by a street and the buildings that abut the street [12].

Urban Canyons restrict the view of the sky dome (characterized by the sky view factor SVF), cause multiple reflections of solar radiation, and generally restrict the free movement of air (Fig 1). For long urban canyons it is customary to specify the geometry by its height of the building/width of the street (H: W) ratio, also known as Aspect Ratio.

- Canyon Geometry for long canyons = height of building (H)/width of street (w)
- Sky View Factor (SVF) = fraction of sky visible at middle of Street
- For infinitely long canyon (SVF) = Cosβ

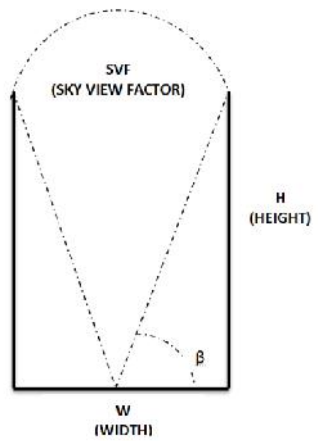

Fig 1: Urban Canyon

Fig 1 shows the urban canyon profile

2.2.2 SOLAR ENVELOPE

The concept of solar envelope was initiated by Knowles [13],[14].was a first attempt to resolve the problem of handling potential solar irradiation in the urban context. In urban areas the solar access is controlled predominantly by the shapes, form and materials [13].

2.2.3 URBAN GEOMETRY

Many experiences of urban design illustrate a real concern and consciousness in designing with the climate, either by taking advantage from the potential of natural energy or by protecting the living spaces from adverse climatic conditions. These can be verified through history [15], in the traditional built heritage [13],[16],[17],[18] as well as in contemporary urban projects [19],[20],[21],[22]. The street as climate regulator is one aspect within a whole urban design methodology [23]. The aspect ratio(height of the building to the width of the street ratio) and solar orientation are the basic components in determining street microclimate, along with the details of the street design like – galleries, vegetation, shading , façade treatment, material finish)[3].

3.0 METHODOLOGY

The aim of the study is to compare the outdoor thermal comfort of pedestrian users in the traditional streets of Srirangam with that of the newly developed streets. The index of comfort used in this study for calibrating outdoor thermal comfort is PET (Physiological Equivalent Temperature) . It can be calculated by using the Software 'RayMan' which is currently made freely available by its author. The street geometry factors considered for the analysis include the street orientation and the aspect ratio for five different time periods (7.00 Am, 10.00 Am, 1.00 Pm, 4.00Pm, 7.00Pm, 10.00Pm).The values of PET enable the understanding of the influence of street orientation and aspect ratio of the outdoor thermal comfort of the pedestrians. The study also enabled the role played by other components of the street geometry like (galleries, vegetation, shading, façade treatment, material finish) on the microclimate modification of the urban canyon. Hence this enable in deriving design solutions to modify the existing urban canyon in achieving a better outdoor thermal comfort conditions for the pedestrian users.

4.0 PET (Physiological Equivalent Temperature)

The physiological equivalent temperature (PET) is put forward by a German research group headed by Peter Hoppe [24] and is already included in the new VDI guidelines (German guidelines for urban and regional planners) for assessing the thermal component of microclimate. PET is defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed.

The advantages of using PET are:

- It is a universal index and is irrespective of clothing (clo values) and metabolic activity (met values).
- It has a thermo physiological background and so it gives the real effect of the sensation of climate on human beings.
- It is measured in °C and so can be easily related to common experience.
- It does not rely on subjective measures
- It is useful in both hot and colder climates.

5.0 Study Area

Tiruchirappalli is the fourth largest city of Tamil Nadu State in India (10°44′46″N to 10°52′46″N latitude, 78°39′11″ to 78°44′13″E longitude) and is situated on the banks of River Cauvery. It acts as a nodal point for communication from North through South and East through West within the state. Tiruchirappalli City has a population of 8,46,732 as per 2011 census. Tiruchirappalli Corporation consists of four zones namely Srirangam, Ariyamangalam, Abishekapuram, and Ponmalai zone (Golden Rock), with each zone having 15 wards [25].

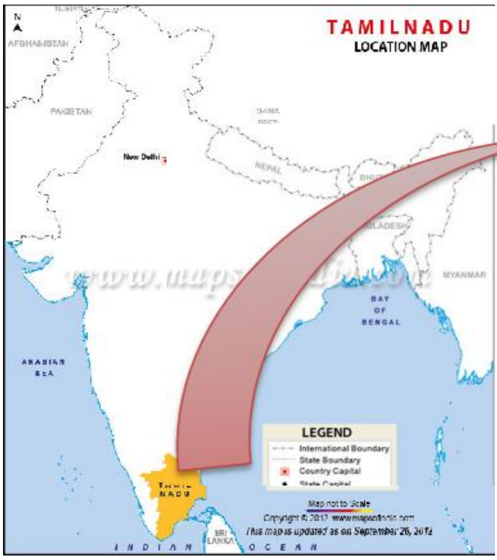

Fig 2: Tamil Nadu location Map

Figure 2 shows the location of Tamil Nadu in India

Fig 3: Tiruchirappalli location

Figure 3 shows the location of Tiruchirappalli in Tamil Nadu

5.1 SRIRANGAM CITY

The Srirangam town is located at the geographical coordinates of 10° 52' 0" N, 78° 41' 0" E in between rivers Cauvery and Kollidam. The average climate of Srirangam is Humid and the temperature range in summer is maximum of 36.9 degree centigrade and minimum of 26.3 degree centigrade. In winter maximum of 30.3 degree centigrade and minimum of 20.6 degree centigrade.

The study was carried on the 24th of April 2013 and the weather was with the following attributes: Average temperature 37 degree centigrade, Wind :4.83 km/h, N 0°,Humidity :44 %,Visibility :6 km, Pressure :982.05 mb.(Weather station , Tiruchirappalli).

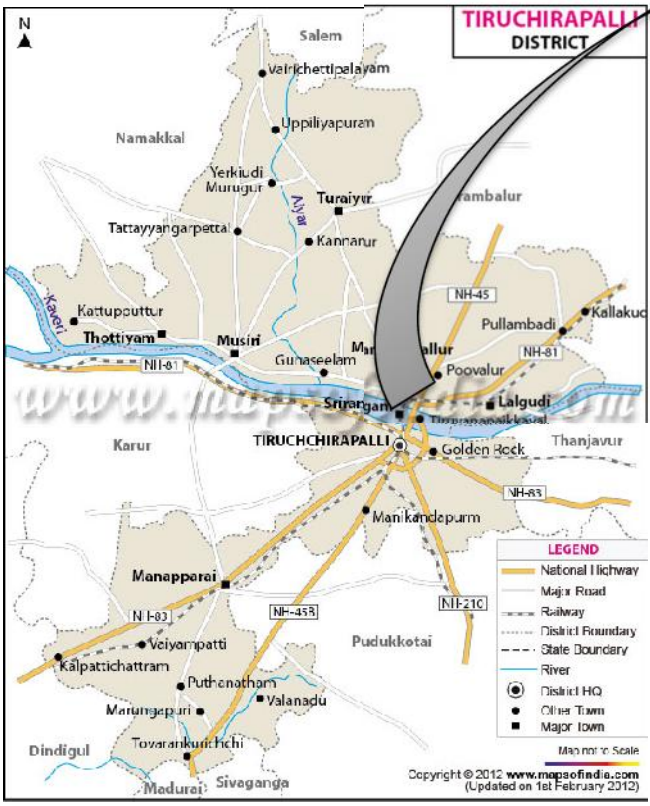

Fig 4: Srirangam district Map

Fig 5: Srirangam location Map

Fig 4 shows the district map of Tiruchirappalli

Fig 5 shows the location of Srirangam

5.2 SRIRANGAM CITY PLANNING

The town has originated and developed only on account of the great Sri Ranganathar Swami temple that covers an enormous area on the island and is the foremost center of all the religious activities in the town. This temple town has a concentric street layout where the streets are located around the temple complex. There are overall seven streets around the temple, of which four are inside the temple (the temple praharams/processional pathways) complex and three of them are located outside the temple they are , Uthara Street, Chitra Street and Adayavalanjaan Street. The streets are predominantly occupied by people who have their employment in the temple. All these seven streets are visually enclosed by the huge wall of the traditional town.

Due to the increase in population and to accommodate more people the temple town grew organically on the southern direction due to its connectivity to the Tiruchirappalli City. The northern part of Srirangam is still undeveloped because of poor infrastructure services like roads and other basic facilities.

For the purpose of this study the two distinctly varying street typologies are chosen.

(1) TYPE A streets: Streets inside the temple wall.
(2) Type B streets: Streets that were developed outside the temple wall.

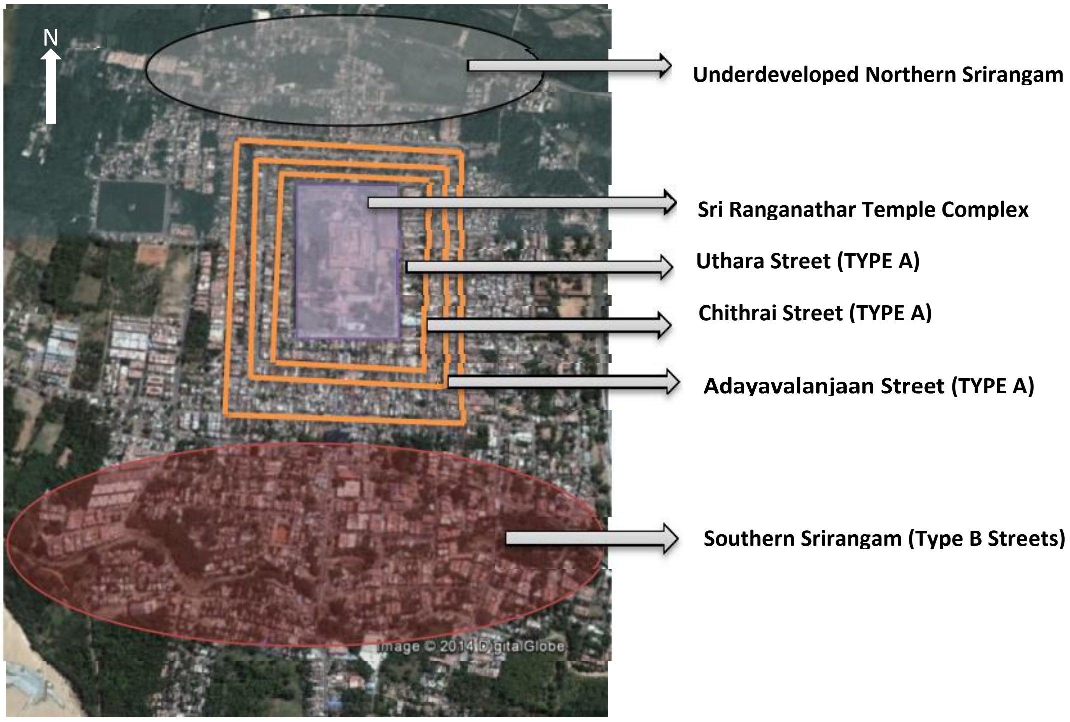

Fig 6: TYPE A and Type B Street locations – Srirangam

Figure 6 shows the location of the Temple, Temple streets (TYPE A), Type B streets Southern and Northern Srirangam.

5.2.1 TYPE A STREETS - Traditional Town character:

The streets that belong to **TYPE A** are the Uthara Street, Chitra Street and Adayavalanjaan Street. They are located outside the temple but within the traditional town wall. These threes streets have the following characteristics:

- The streets are low density residential.
- The widths of the streets are more (12m to 15m) basically to accommodate the movement of the temple car and the huge population who gather to view the festivals.
- The buildings are low rise even after some alterations.
- The streets have the common Aspect Ratio (Height of the building/Width of the street) – 0.3, 0.5.
- Though the streets of the traditional town are wide enough to have greenery, only few of the spots have vegetation and the rest lack.

Fig 7: The temple car festival along the traditional

Figure 7 shows the wide traditional streets to accommodate the crowd during temple car festival

5.2.2 TYPE B STREETS – New development outside the Traditional Town.

The streets that belong to **TYPE A** are the Uthara Street, Chitra Street and Adayavalanjaan Street. They are located outside the temple but within the traditional town wall. These threes streets have the following characteristics:

- The streets are high density residential and low density commercial and mixed use.
- The width of the streets are less (3m to 7m) and the streets are enclosed by tall buildings.
- The buildings are high rise.
- The streets have the following Aspect Ratio (Height of the building/Width of the street) – 1.3,2, 3, 4, 5.For the purpose of study I have considered the maximum and minimum value i.e 1.3 and 5.
- Since the width of the streets in new developed are of Srirangam are less, seldom greenery is observed.

Fig 8: Type B street with more Aspect Ratio.

Figure 8 shows the narrow streets on the southern part of Srirangam City

6.0 STREET CANYON TYPOLOGIES

To calculate the PET (Physiological Equivalent Temperature) and compare the traditional streets with that of the streets in new developed area following canyon typologies are derived based on the common aspect ratios. The canyons are also analyzed on the two different orientations (N-S and E-W).

The varying permutations and combinations of the canyons were studied for five different time period on the 20th of April 2013.

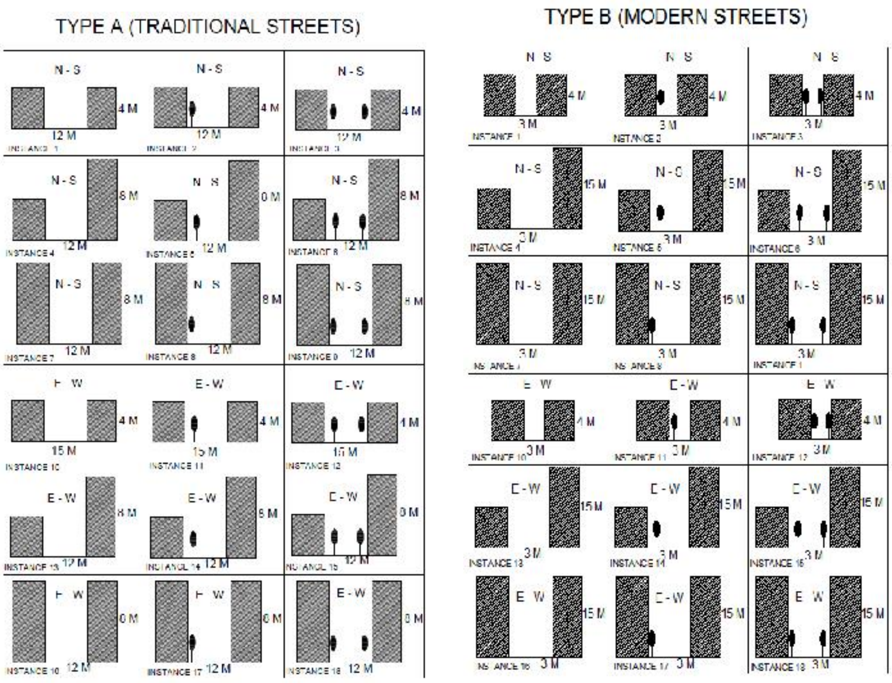

Fig 9: the 18 different canyons of the TYPE A Street and TYPE B

Figure 9 shows the 18 different canyon profiles for TYPE A (traditional streets) and Type B (Modern streets of Srirangam)

7.0 DATA FOR ANALYSIS

PET (Physiological Equivalent Temperature) can be calculated simply by the software RAYMAN, which is made freely available by its author. It avoids all the complications of the two node model and takes simple inputs in the form of data files, topography, sky view factor etc. [26].

The RAYMAN software requires the climatic Data (Air temperature, Humidity, Vapor Pressure, Wind Velocity, Cloud Cover, Surface Temperature, Sky View Factor), Personal Data (Height, Weight, Age, Sex, Clothing value, activity, and position)

The PET value for all 18 instances in both TYPE A streets and TYPE B streets are calculated. The study was based on ten samples chosen with different personal data for all the instances in TYPE A and TYPE B.

8.0 RESULTS AND DISCUSSIONS

8.1 INFERENCES – STREET GEOMETRY ELEMENTS

When the PET values within TYPE A and Type B were analyzed to find out the important geometric feature that influence the microclimate of pedestrians in street level, following observations were made:

1. Influence of vegetation contribute to a difference in microclimate: Values of PET were plotted against the five different period for the instances with similar orientation and Aspect Ratio with difference in landscape for both TYPE A street instances and Type B street Instances and it was observed that the presence of landscape contributes to microclimatic difference.

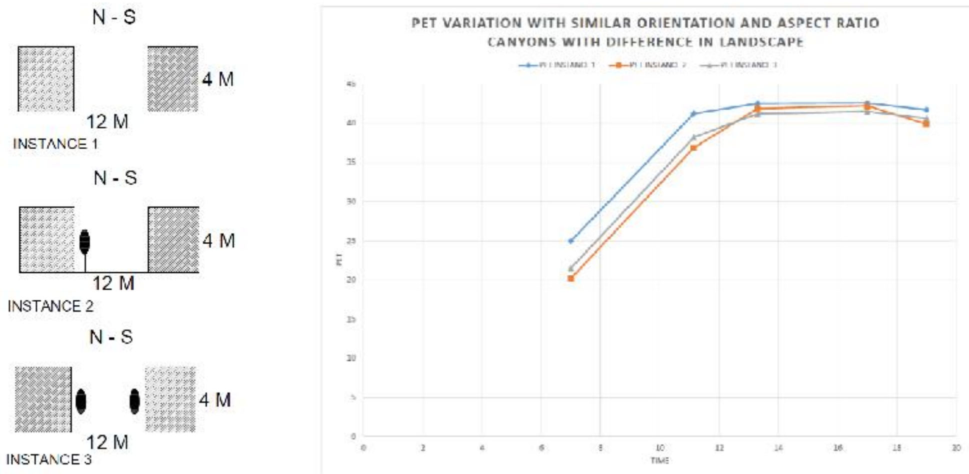

*Fig 10: PET variation with alteration in landscape – **TYPE A street***

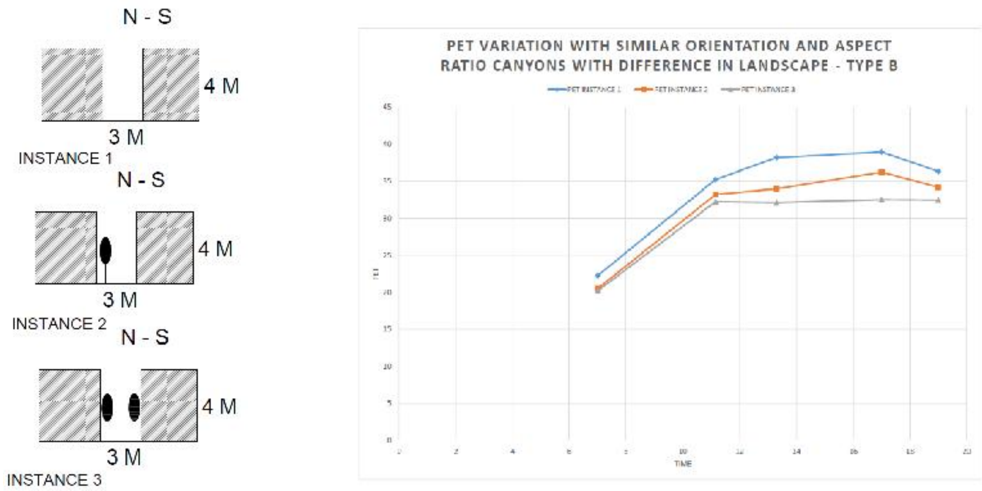

*Fig 11: PET variation with alteration in landscape – **Type B street instances**.*

Figure 10 and Figure 11 show the impact of landscape on the urban microclimate of street canyons irrespective of Orientation and Aspect Ratio.

2. The influence of orientation on the urban microclimate of streets was evident in both TYPE A (Traditional Street) as well as Type B (Modern Streets).This inference was made possible after plotting the values of PET against the five different time period on the instances with similar aspect ratio and landscape but different orientation. When the results were compared in both TYPE A and Type B it was observed that the negative impact in East – West orientation was more compared to the North – South orientation.

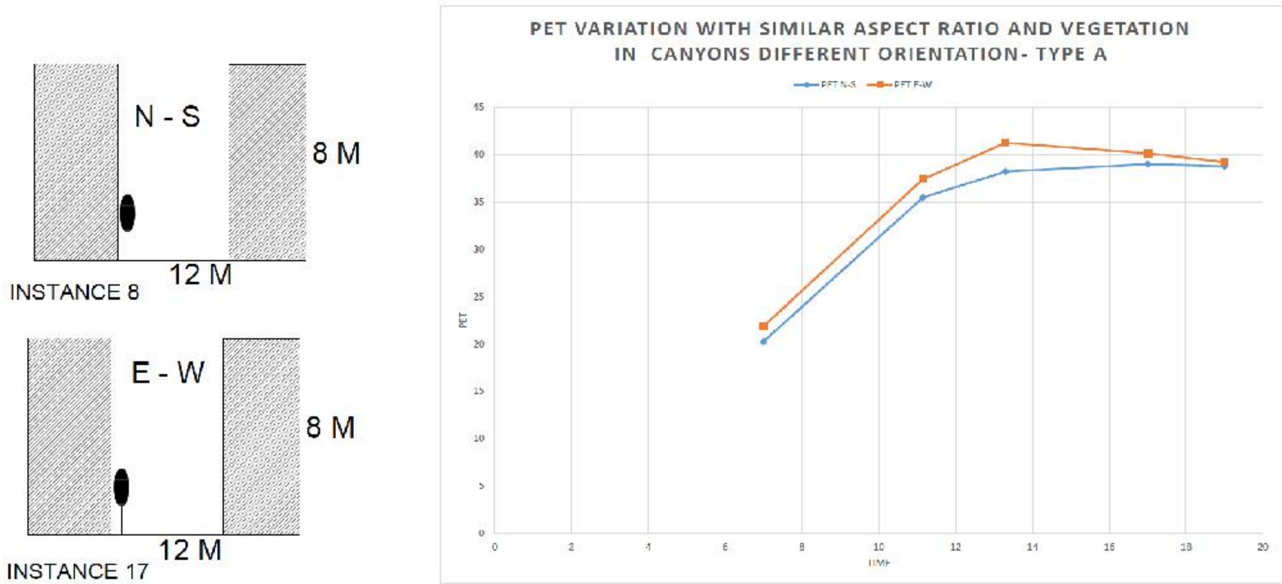

*Fig 12: PET variation with alteration in orientation – **TYPE A street***

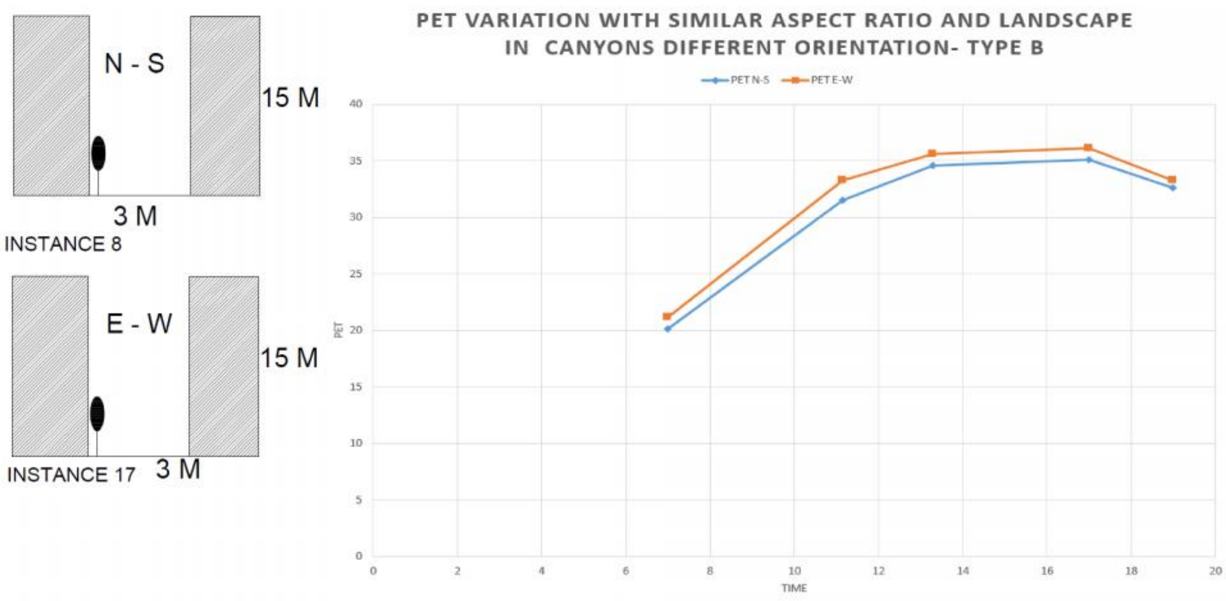

*Fig 13: PET variation with alteration in orientation – **Type B street***

Figure 12 and Figure 13 show the impact of orientation on the urban microclimate of street canyons irrespective of Orientation and Aspect Ratio.

3. The role of Aspect ratio is very critical in any urban canyon .The canyon with different aspect ratio but with same orientation and landscape was analyzed in both TYPE A and Type B. The canyons with more aspect ratio had less range of PET values. Since the Type B (modern Streets) of Srirangam are narrow with high density buildings, the PET value were comparatively less than the TYPE A (traditional streets) that had wide streets and less Aspect Ratio.

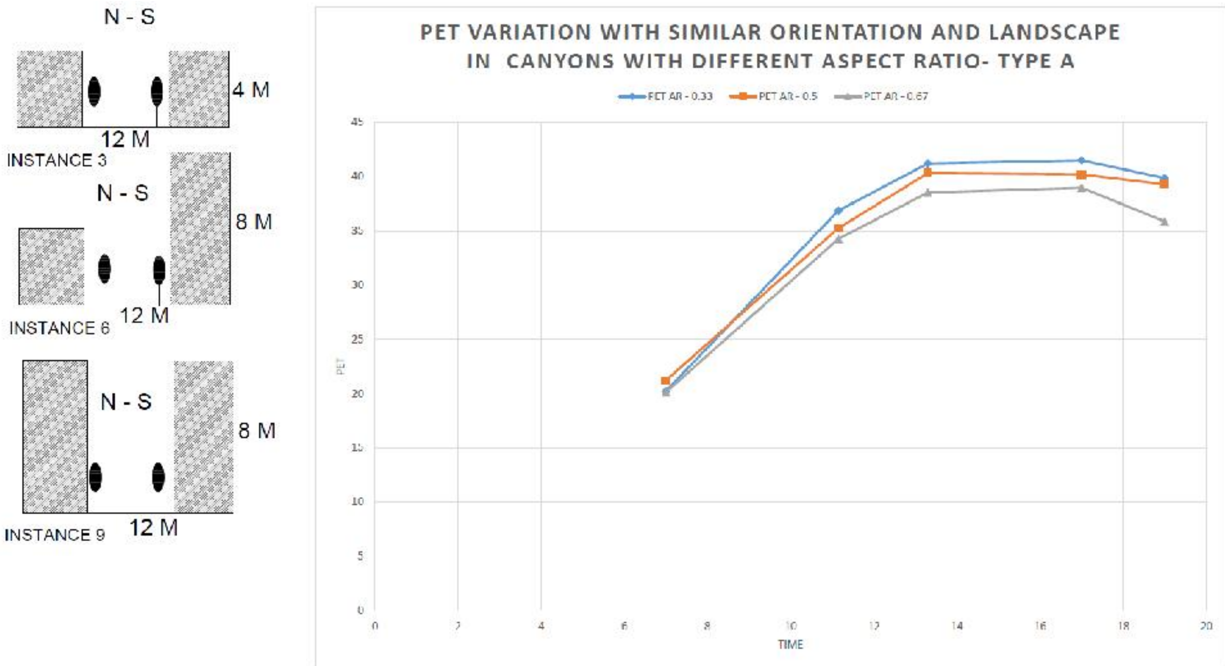

*Fig 14: PET variation with alteration in Aspect Ratio – **TYPE A street***

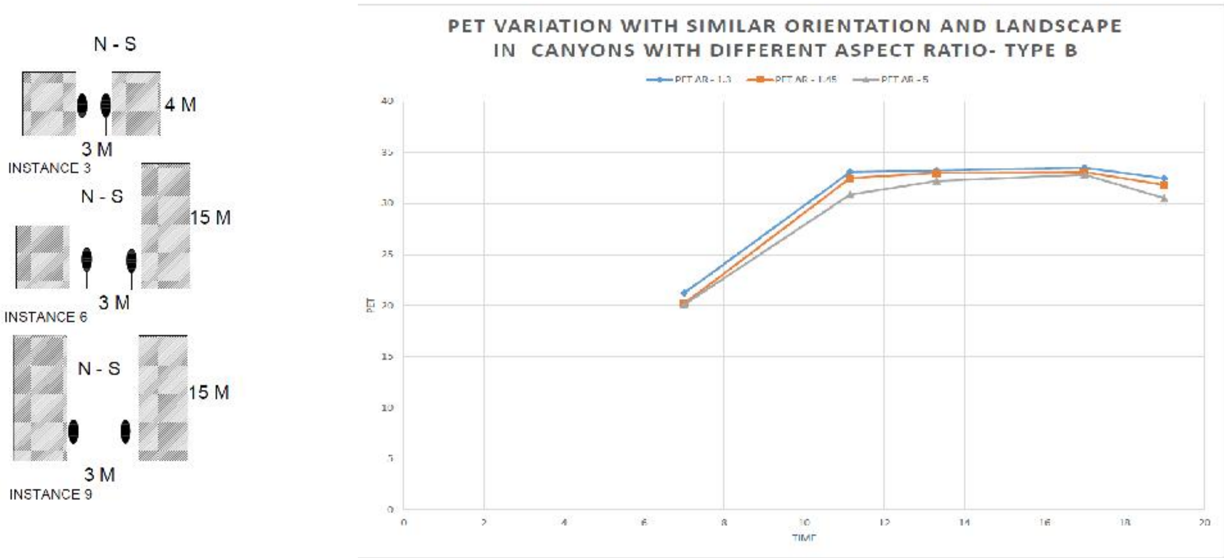

*Fig 15: PET variation with alteration in Aspect Ratio – **Type B street***

Figure 14 and Figure 15 show the impact of Aspect Ratio on the urban microclimate of street canyons irrespective of Orientation and Landscape.

8.2 Inference and Observations – Factor of Comparison

It was observed from the inferences and results of street geometrical elements **8.1** (Orientation, Aspect Ratio, and Landscape) that between TYPE A and Type B streets, **ASPECT RATIO** plays an important role. It is found that the PET (Physiological Equivalent Temperature) range for TYPE A (Traditional Streets) found to be 22.1 °C – 42.7 °C and the PET (Physiological Equivalent Temperature) for Type B (Modern Streets) found to be 21°C - 37°C.

The difference in the minimum range of PET between TYPE A and Type B is 1.2°C and the difference in the maximum range is 5.7°C between the types, which is significant to a pedestrian user in the street canyon. The most important factor which contributes to this change is the **ASPECT RATIO**.

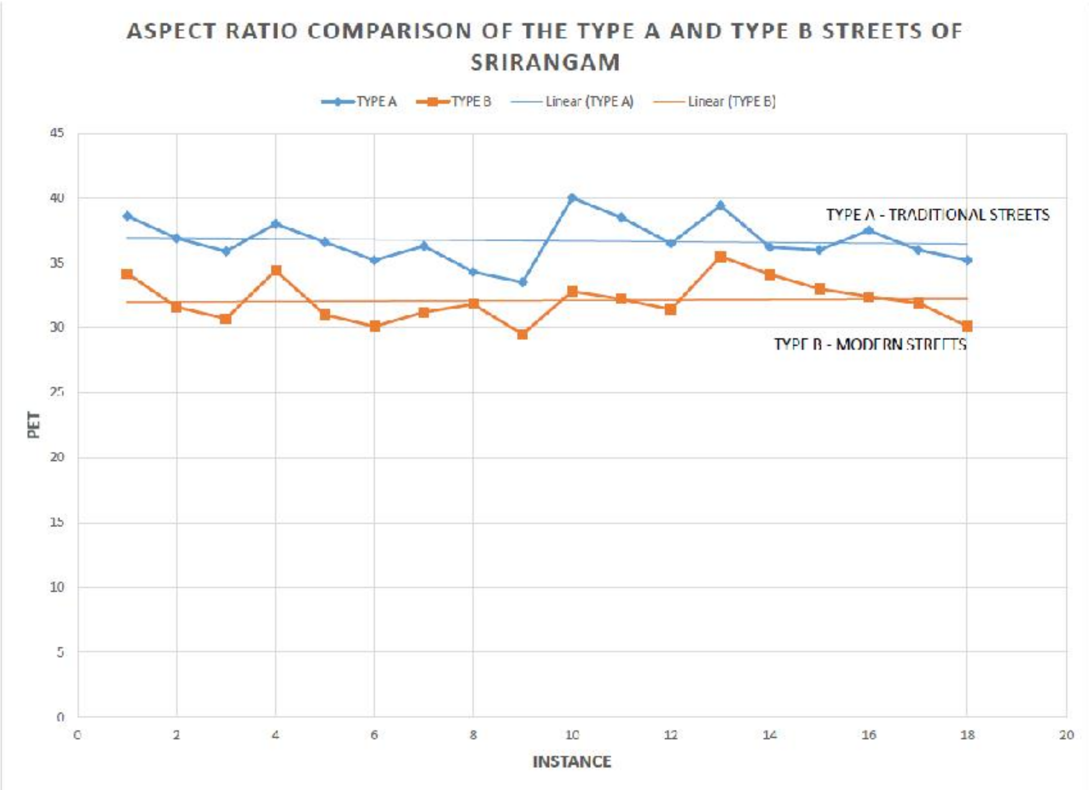

Fig 16: PET value comparison between TYPE A & TYPE B streets.

Figure 16 show comparative PET value between TYPE A street instances with TYPE B street instances.

From the observation of the graph it is evident that the factor that contributes to the significant difference between instances of TYPE A canyons and Type B canyons is the **ASPECT RATIO**. In TYPE A the Aspect Ratios (0.33, 0.45, 0.5) are less compared to the range of Type B (1.33, 1.15, 5.0). The huge value of Aspect ratio in Type B streets enable the mutual shading of building surfaces. This enables the building surface to radiate less heat, hence the PET value is also less compared to streets with less or no shading.

9.0 Recommendation

The suggested recommendation for the TYPE A streets in order to have better outdoor thermal comfort condition of its pedestrian users is that the possibility of enhancing shading. The shading can be either through landscape as well through projections from the building surfaces (balconies, galleries, simple slab projection).

10.0 Conclusion

- The PET (Physiological Equivalent Temperature) value that is calculated with the help of RAYMAN software enables in identifying the factors that contribute to the urban microclimate modification in specific to the pedestrian users. When the PET (Physiological Equivalent Temperature) values for different Orientation, Landscape and Aspect Ratio within the typologies (TYPE A and Type B streets) following aspects were observed:

1. The PET (Physiological Equivalent Temperature) values of N-S orientation was less compared to the E-W orientation.
2. The streets with landscape on both sides had less PET (Physiological Equivalent Temperature) value compared to the canyons with one sided landscape followed by canyons with no landscape.
3. The canyons with more aspect ratio had less PET (Physiological Equivalent Temperature) value.

- When the street canyons between the streets of TYPE A and TYPE B were compared it was observed that the TYPE B canyons (Modern Streets) had less PET (Physiological Equivalent Temperature) value than the TYPE A Streets (Traditional Streets). The factor that enables the change is the **ASPECT RATIO.**

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