ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE, ENGINEERING AND TECHNOLOGY

ASSESSMENT OF OUTDOOR THERMAL COMFORT IN A SUBURBAN UNIVERSITY CAMPUS WITH THE USE OF ENVI_MET PROGRAM

M.Sc. THESIS

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Mujesira Bakovic, a M.Sc. student of ITU Graduate School of Science Engineering and Technology student ID 519151012, successfully defended the thesis entitled "ASSESSMENT OF OUTDOOR THERMAL COMFORT IN A SUBURBAN UNIVERSITY CAMPUS WITH THE USE OF ENVI_MET PROGRAM", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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FOREWORD

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Urban Planner

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ABBREVIATIONS

ASHRAE **:** American Society of Heating, Refrigerating and Air-Conditioning Engineers
PMV **:** Predicted Mean Vote
PET **:** Physiological Equivalent Temperature
UTCI **:** Universal Thermal Climate Index
ITS **:** Index Thermal Stress
OUT-SET **:** Standard effective temperature
SVF **:** Sky View Factor

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ASSESSMENT OF OUTDOOR THERMAL COMFORT IN A SUBURBAN UNIVERSITY CAMPUS WITH THE USE OF ENVI_MET PROGRAM

SUMMARY

Open spaces where people spend their leisure time and engage in various activities have always been considered as a part of a successful environment. However, the conditions of open spaces have been extremely important for people to use and further enjoy these open spaces. In a suburban university campus, where the high population spending all day within the campus has been considered, the importance of open spaces rises. Yet, understanding the issues affecting open spaces has been crucial; in accordance with that the characteristics of urban microclimate and outdoor thermal environment offer new opportunities for the improvement of open spaces. Modeling of an urban microclimate has been fundamental at this point, as it allows understanding the present and future microclimate dynamics of open spaces. Although there have been numerous tools and indices developed for assessment of outdoor thermal comfort, due to the complex frame of parameters included, their use has been disregarded during the preliminary/post design process.

For this reason, the aim of the thesis is to propose a model in order to inquiry the impacts of the parameters on outdoor thermal comfort and create an assessment methodology for open spaces. Further, the proposed model has been applied on a suburban university campus with the use of a simulation program, ENVI_met. Outputs obtained have been used for evaluation of meteorological and physical environmental parameters over open spaces. In addition, outdoor thermal comfort perception has been simulated with the use of BIO_met tool embedded in ENVI_met program, according to PMV index. The effect of user-related parameters, such as clothing, activity and height-to-weight ratio has been examined. As an essential "tool" in urban design, the impact of vegetation, specifically tree, on thermal comfort perception has been investigated, as well.

With simulation results, the effect of environmental and user related parameters on outdoor thermal comfort has been determined. Air temperature and exposure to solar radiation have been affecting the outdoor thermal comfort to a significant extent. Wind direction and speed also affect the outdoor thermal comfort. As highlighted through literature review, not only the meteorological parameters, but the physical environment affects the outdoor thermal comfort remarkably. The geometry of the buildings, surface materials and tree presence has verified their impact on outdoor thermal comfort. The geometry of buildings has been affecting the wind pattern and solar radiation access; as a consequence, the PMV values have been changed according to the building geometries. Additionally, the presence of trees has the crucial role in the summer season and again has positive effects in the winter season if used in a proper way. Surface materials tend to affect solar radiation reflection and the perception of outdoor thermal comfort.

This study provides a link between the theoretical background on outdoor thermal comfort and the planning or design processes. The proposed model can be used as a

tool for the urban designer in order to assess the effect of design strategies on outdoor thermal comfort and creation of successful open spaces and urban environment at all. The outdoor thermal comfort can be achieved by implementing appropriate design strategies, previously simulated with assessment tools and minimizing the possible discomforts that would occur.

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ÖZET

Kentsel alanlar, son birkaç yılda nüfus enflasyonu ve buna bağlı olarak artan talepler nedeniyle önemli sorunlarla karşı karşıyadır. İnsanların boş zamanlarını geçirdikleri ve çeşitli aktivitelerde bulundukları açık alanları sağlamak, ve bu alanlarda kullanıcılar için rahat ve keyifli bir ortam yaratmak en önemli konulardan biri olarak görülmektedir.. Ancak, kentsel açık alanların çeşitli süreçlerden ve faaliyetlerden etkilenmesi nedeniyle, rahat bir ortamın oluşturulması çok boyutlu bir yaklaşım gerektirmektedir. Açık alanları etkileyen hava sıcaklığı, nem, rüzgâr hızı ve radyasyon gibi atmosfere bağlı süreçler aslında faaliyetler ve davranışlar açısından insan günlük yaşamını doğrudan etkilemektedir. İnsanlar dışarıdaki hava koşullarına göre davranmaya eğilimlidirler; örneğin, kıyafetlerini seçerler, zamanlarını dışarıda geçirirler vs. Fakat açık alanları etkileyen tek etken hava koşulları değildir. Bina geometrisi, binaların yüksekliği ve uzunluğu, bina hizalaması, sokağın yönlendirilmesi gibi fiziksel değişkenler, bitki örtüsünün ve hatta yüzey malzemelerinin çeşitliliği kentsel yapılaşmış ortamı etkilemektedir. Tüm bu değişkenler, kullanıcıların açık alanlardaki dış mekân ısıl konforunu bir diğer deyişlekişinin içinde bulunduğu ısıl ortamdan memnuniyetini belirten zihinsel bir süreci (ASHRAE, 1981) etkilemektedir.

Bu nedenlerden dolayı, açık alanlar için mikro-iklim ve fiziksel değişkenlerin önemini belirtmek oldukça önemlidir. Teknolojinin hızlı bir şekilde gelişmesine ve kentsel tasarım süreçleri için pek çok iyileştirme getirilmiş olmasına rağmen, mikro-iklim ve fiziksel değişkenlerin birarada ele alınmasına çok sık rastlanmamaktadır. Örnek vermek gerekirse tasarım sürecinde bilgisayar yazılımlarının kullanılmaması hala söz konusudur. Oysa yaşanabilir ve kaliteli kentsel mekânları tasarlamak için, mikro-iklim ve açık alan arasındaki ilişkilerin niceliksel ve niteliksel olarak anlaşılmasını sağlayan bilgisayar programları kullanılabilmektedir. Bu programlar yardımıyla ön tasarım sürecinde hataların azaltılması ve başarıdan faydanabilmesi mümkündür.

Yaşanabilir ve konforlu açık alanlar tasarlamak, başarılı kentsel çevre için en önemli ölçütlerden biri olmuştur. Ancak, çeşitli konulardan etkilenerek, kentsel yapılaşmış çevre tasarımı sürecinde sadece çevresel etkiler değil, aynı zamanda kullanıcı memnuniyeti de dikkate alınmalıdır. Bu nedenle, dış mekânda ısıl konfor kentsel çevreyi değerlendirirken hem çevresel hem de kullanıcı ile ilgili değişkenleri birleştiren konulardan biri olarak önem kazanmaktadır. Her kentsel çevre, bina konfigürasyonları, bitki örtüsü, açık alanların boyutu ve kullanıcıların profili gibi farklı özelliklerden oluşur. Her ortam çeşitli değişkenlerden etkilenir veya aynı değişkenin iki ortam üzerinde farklı bir etkisi olabilir. Bu nedenle, çalışmanın hipotezi, yalnızca mikro-iklim değil, aynı zamanda fiziksel çevre ve kullanıcı ile ilgili değişkenlerin dış mekân ısıl konforunu etkilediği görüşüne dayanmaktadır.

Mikro-iklimin kentsel açık alanlardaki büyük etkisi, dış mekân ısıl konfor sorunlarına olan ilgiyi artırmıştır. Son birkaç yılda, değişkenlerin, sonuçların ve bunun faydalarının araştırıldığı dış mekân ısıl konforu konusunda bir dizi çalışma yapılmıştır. Güneş ışınımı, hava sıcaklığı, nem ve rüzgâr hızı/yönü gibi mikro-iklimsel değişkenlerin dış mekân ısıl konforunu etkileyen değişkenler olduğu bilinmesine rağmen; topoğrafya, yapı formu ve hizalama, zemin yüzey örtüsü ve yeşil altyapı gibi fiziksel değişkenler de büyük bir etki yaratmaktadır.
Bu noktada, tezin amacı, yukarıda sıralanan değişkenlerin dış mekân ısıl konforu üzerindeki etkilerini araştırmak ve açık alanlar için bir değerlendirme yöntemi oluşturmak amacıyla bir model önermektir. Daha sonra önerilen model bir kent dışı üniversite kampüsünde bir bilgisayar programı (ENVI_met) kullanılarak uygulanmıştır. Program çıktıları ile bina yerleşiminin ve geometrisinin, bitki örtüsü ve diğer fiziksel değişkenlerin dış mekân ısıl konforu üzerindeki etkisi değerlendirilmiştir. Ayrıca, mikro-iklimi ve PMV düzeyini geliştirmek için ağaç veya gölgeleme elemanları, rüzgâr koridorları vb. pasif çevre kontrol stratejilerinin uygulanması önerilmektedir.
Son on yılda İstanbul, üniversite kampüslerinin de yer aldığı hızlı bir nüfus ve altyapı büyümesi ile karşı karşıyadır. Kent merkezlerindeki yüksek fiyatlar ve yer eksikliği nedeniyle, yeni kurulan üniversitelerin çoğu kampüslerini kent dışı alanlarında kurmuşlardır; kampüsler sadece eğitim değil aynı zamanda mekânsal kalite ve sosyal hizmetler de sunabilecek potansiyele sahiptir. Bu üniversitelerden biri olan ve İstanbul Anadolu yakasında Çekmeköy İlçesi'nde bulunan Özyeğin Üniversitesi; 136.000 m^2 alana sahip ve 10.000'den fazla öğrenci ve akademisyeni barındırmaktadır. Yüksek nüfusu ve çok işlevli binaları, yayalar tarafından kullanılan rekreasyon ve açık alanları içerdiği için kentsel bir ortam olarak düşünülebilecek böyle bir kampüs alanında, dış mekân ısıl konforunun önemi göz ardı edilmemelidir.
Literatür taraması ile konunun önemi vurgulanmıştır. Hipokrat (2004), doğanın insan sağlığı üzerinde olumlu etkileri olduğunu belirtirken, Vitruvius (2001), sokakların ve binaların düzeninin güneş ve rüzgâra göre biçimlenmesi gerektiğini önermektedir. Günümüzde ise iklim değişikliği meseleleri planlama ve tasarım ilkelerinin yeniden gözden geçirilmesine yol açmıştır. Mikro-iklimsel koşulların, planlama ve tasarım sürecinin bir parçası olması gerektiği vurgulanmıştır (Nikolopolou ve Steemers, 2003; Nikolopoulou ve Lykoudis, 2007).
Açık alanlar ile mikro-iklim arasındaki ilişki kaçınılmaz olarak dış mekân ısıl konforunun önemini vurgular. Dış mekân alanlarını etkileyen iklim koşulları aslında kullanıcıların belirli bir çevreye olan algısını doğrudan etkilemektedir. Ancak, sadece iklim değil, bina düzeni ve geometrisi, bitkisel ve su elemanlarının varlığı vb. dış ortamlarda iklim koşullarının nasıl algılanacağını etkilemektedir (Santamouris, 2001; Meir et al., 1995; Berkovic et al., 2012).
Dış mekân ısıl konforunu etkileyen değişkenlerin kullanıcıya bağlı ve çevreye bağlı olarak ayrılması, değerlendirme ve uygulama yöntemlerinin belirlenmesinde yardımcı olmuştur.
İlk olarak, dış mekân ısıl konfor değerlendirmesi için bir model geliştirmeye yönelik teorik altyapıoluşturulmuştur. Modelde hangi değişkenlerin değerlendirilebileceği, hangi değerlendirme araçlarının ve değerlendirme endeksinin kullanılabileceği açıklanmaktadır.
İkinci olarak, teorik model kent dışı üniversite kampüsünün dış mekânlarını değerlendirmek için uygulanmıştır. Bitki örtüsü ve yüzey malzemesi gibi fiziksel değişkenlerin yanı sıra mevsimsel değişikliklere bağlı mikro-iklimsel etkiler ile aktivite ya da giysi türü gibi kullanıcı ile ilgili değişkenlerin etkileri araştırılmıştır.

Bu değişkenlerin etkilerini analiz etmek için bu amaca yönelik olarak geliştirilmiş ENVI_met bilgisayar programı seçilmiştir. İlk adım olarak, doğrulama çalışması yapılmıştır. Saha ölçümleri ile mikro-iklimsel veriler belirli noktalar için toplanmış ve kullanıcı ısıl konfor değerlendirme anketleri ile programdan alınan çıktıların doğrulanması sağlanarak programın geçerliliği onaylanmıştır. Ayrıca, kampüs dış mekânlarının mevcut ortamı benzetilmiş ve elde edilen sonuçlar dış mekân ısıl konfor açısından değerlendirilmiştir. Isıl konfor açısından sorunlar ile karşılaşılan alanlar tespit edilmiş ve iyileştirilmeye yönelik öneriler geliştirilmiştir.

Tez "Giriş" bölümü dâhil olmak üzere beş ana bölümden oluşmaktadır. "Literatür taraması", iklim, üniversite kampüsü ve açık alanlar gibi konuların yanı sıra, dış mekân ısıl konfor konu başlıklarını içermektedir. Kapsamlı bir biçimde sunulan literatür taraması, kullanıcılarına başarılı bir kentsel ortam sunmak için dış mekân tasarımının öneminin altını çizen bu çalışmayı destekleyen tez, kitap, makale ve ilgili yeni yayınlanan çalışmalardan oluşmaktadır.

Tezin üçüncü kısmı çalışmada kullanılan "Yöntemi" açıklamaktadır. Dış mekân ısıl konforunu etkileyen değişkenleri belirleyebilmek için çalışma alanı olarak bir üniversite kampüsü seçilmiştir. İyileştirme önerileri belirlemek ve dış mekân ısıl konfor sorunlarını azaltmak amacıyla bir değerlendirme modeli oluşturulmuştur. Bununla birlikte, geliştirilen metodoloji, incelenen değişkenler farklılaştırılarak veya kullanılan değerlendirme metodolojisi ile başka herhangi bir kentsel alanda uygulanabilir niteliktedir. Bu bölümde çalışma alanı için geliştirilen metodolojinin "Uygulama modeli" de anlatılmıştır. İstanbul'un çevresinde yer alan bir kent dışı üniversite kampüsüuygulama alanı olarak seçilmesinin nedeni , öğrencilerin ve çalışanların tüm zamanlarını kampüs sınırı içinde geçirmeleri nedeniyle bu tür kampüslerde dış mekânların öneminin daha da artmasıdır. Ayrıca, üniversite kampüsünü çevreleyen arazininormanlık ve düşük yoğunluklu yerleşim alanları ile çevrelenmesi, kampüs içindeki dış mekân mikro-iklim koşullarının kentsel yapılaşmış bir çevrenin etkisi olmaksızın doğrudan gözlemlenebilmesine olanak sağlamaktadır. Bu bölümde uygulama metodolojisi, ele alınan değişkenler, değerlendirme aracı ve kullanılan ısıl konfor endeksi açıklanmıştır. Çevresel ve kullanıcı ile ilgili değişkenleri dâhil etmek için ENVI_met bilgisayar programı araç olarak seçilmiştir. Programın kabiliyetleri incelenmiş ve belirlenen değişkenlere göre değerlendirme ölçütleri ve değerlendirme endeksi (PMV) belirlenmiştir. Ayrıca, doğrulama (validation) için yapılan pilot çalışmanın uygulama adımları anlatılmıştır.

Program çıktıları ve elde edilen bulgular, ana konuların da vurgulandığı dördüncü bölüm olan "Bulgular" da tartışılmıştır. Dış mekân ısıl konforu etkileyen değişkenler belirlenmiş olup çalışma alanındaki sorunlara özgün öneriler geliştirilmiştir. İlk olarak, güneş ışınımı ve hava sıcaklığı, daha sonra da rüzgâr yönü ve hızı ısıl konfor üzerinde etkisi olan önemli değişkenlerdir. Kaynak taramasından elde edilen bilgilerle benzer şekilde fiziksel çevrenin de dış mekân ısıl konforu büyük ölçüde etkilediği tespit edilmiştir. Elde edilen sonuçlar binaların geometrisi, yüksekliği, ağaç ve bitki örtüsü çeşitliliğinin dış mekân ısıl konforu etkilediğini kanıtlamaktadır. Bina geometrisi rüzgâr dağılımı büyük ölçüde etkilemektedir. Avlu yapılı binaların önünde bulunan dış mekânda rüzgâr dağılımı değişim göstermektedir. Onun yanı sıra güneş ışınımı da binanın geometrisine bağlı olarak mevsimsel ve saatlik olarak değişmektedir. Bunun sonucunda PMV endeksi bina geometrisine bağlı olarak değişim göstermekteedir. Ağaçlar, dış mekânda ısıl konforu iyileştirme aracı olarak büyük rol oynamakta; yazın gölgeli alanlar sağlayarak PMV endeksinde iyileştirme sağlarken, kışın ise yüksek rüzgârları engelleyip düşük PMV endeksini arttırma potansiyele sahiptir. Fakat ağaç türü ve dış mekân içindeki konumu dikkatle seçilmelidir. Yüzey kaplama malzemelerin ısıl konfora etkisi de gözlemlenmiştir. Yaz mevsiminde yeşil malzeme ile kaplı alanda sert yüzeylere göre düşük PMV değerlerine ulaşılmıştır. Kış mevsiminde ise farklılık gözlemlenmemiştir. Son olarak, kullanıcıya bağlı değişkenlerin dış mekân ısıl konfora etkisinin olduğu tespit edilmişse de, dış mekan ısıl konfor üzerinde fiziksel çevre bu değişkenlerden daha önemli etki göstermiştir.

Son olarak, çalışmanın önemi ve bulguları özetlenmiş ve ileriki çalışmalar için öneriler yapılmıştır. Doğru planlama ve tasarım kararlarıyla dış mekân ısıl konfor sağlanabilmektedir. Bu noktada bilgisayar programlarının planlama ve tasarım sürecinde kullanılması önemli rol oynamaktadır.

1. INTRODUCTION

Urban environment has been facing significant issues in the last few decades, due to the increase in population and its demands. As one of the most important issues, the urban built environment lean towards providing a comfortable and pleasurable environment for its users. With open spaces, where people spend their leisure time and perform various activities, the goals of successful environment start being achieved to some extent. However, as the open spaces are being affected by various processes and activities take place in the urban environment, the creation of comfortable environment requires multi-dimensional approach. The processes affecting open spaces being related to atmosphere, such as air temperature, humidity, wind speed and radiation are in fact directly affecting human daily life in terms of daily activities and behaviors. People tend to behave according to the outside weather, for instance, choose their clothes, spend their time outside etc. But the weather is not the only determinant in the use of open spaces. The physical parameters, such as building geometry, height and length of the buildings, building alignment, street orientation and width to height proportion, the existence of vegetation and even surface materials are considered to affect the urban built environment as well. All these parameters are affecting users' outdoor thermal comfort at open spaces, that is usually described as a state of satisfaction with the thermal environment a person is found at (ASHRAE, 1981).

For these reasons, it is reasonably significant to express the importance of microclimate and physical parameters for open spaces. Although the technology develops fast, and many enhancements are brought to improve the urban design processes, the effect of microclimate and physical parameters at once is lowly integrated into. There is still lack of usage of simulation software during the design process. On the contrary, the importance of pre-design simulations is inevitable as merits and demerits can be determined and reconsidered again in order to decrease the faults and benefit from the success.

In order to design livable, vital and pleasurable urban space that will be occupied by the people designers are in advance for having an opportunity to use a simulation tool that can provide them quantitative as well as the qualitative understanding of the relationship between microclimate and outdoor thermal comfort.

1.1 Problem Definition- Hypothesis

Designing comfortable and pleasurable open spaces has been one of the major criteria for the successful urban environment. Yet, being affected by various matters, urban built environment design process should take into consideration not only the environment but also user satisfaction. For this reason, the outdoor thermal comfort gain importance as it is one of the topic integrating both environmental and user related parameters when evaluating the urban environment. Hence, every urban environment consists of differen-t characteristics, such as building configurations, vegetation, size of open areas as well as a profile of the users. Each environment is affected by various parameters or the same parameter can have a different effect on different environments. For this reason, the hypothesis of the study depends on the argument that “not only microclimate but the physical environment, as well as user-related parameters, affect outdoor thermal comfort”.

1.2 The Aim of the Study

The great influence of microclimate on urban open spaces has led to an interest in outdoor thermal comfort issues. In the last few years, a number of studies have been done on outdoor thermal comfort investigating the parameters, consequences as well as benefits of it. Although the microclimatic variables such as solar radiation, air temperature, humidity and wind speed/direction are known to be the parameters that affect the outdoor thermal comfort; the physical parameters including topography, building form and alignment, surface materials and green infrastructure are having great influence as well. At this point, the aim of the thesis is to propose a model in order to inquiry the impacts of the parameters on outdoor thermal comfort and create an assessment methodology for a built-up area and its open spaces. Afterward, the proposed model has been applied on a suburban university campus with the use of a simulation program, Envi_Met. With the simulation outputs, the impact of the layout and geometry of the building, vegetation and other physical parameters on outdoor thermal comfort can be evaluated. Moreover, the passive environmental control strategies such as trees or shading elements, wind corridors etc. are proposed to be implemented in order to improve the local microclimate and PMV level as well. The scope of the study is seen in Figure 1.1.

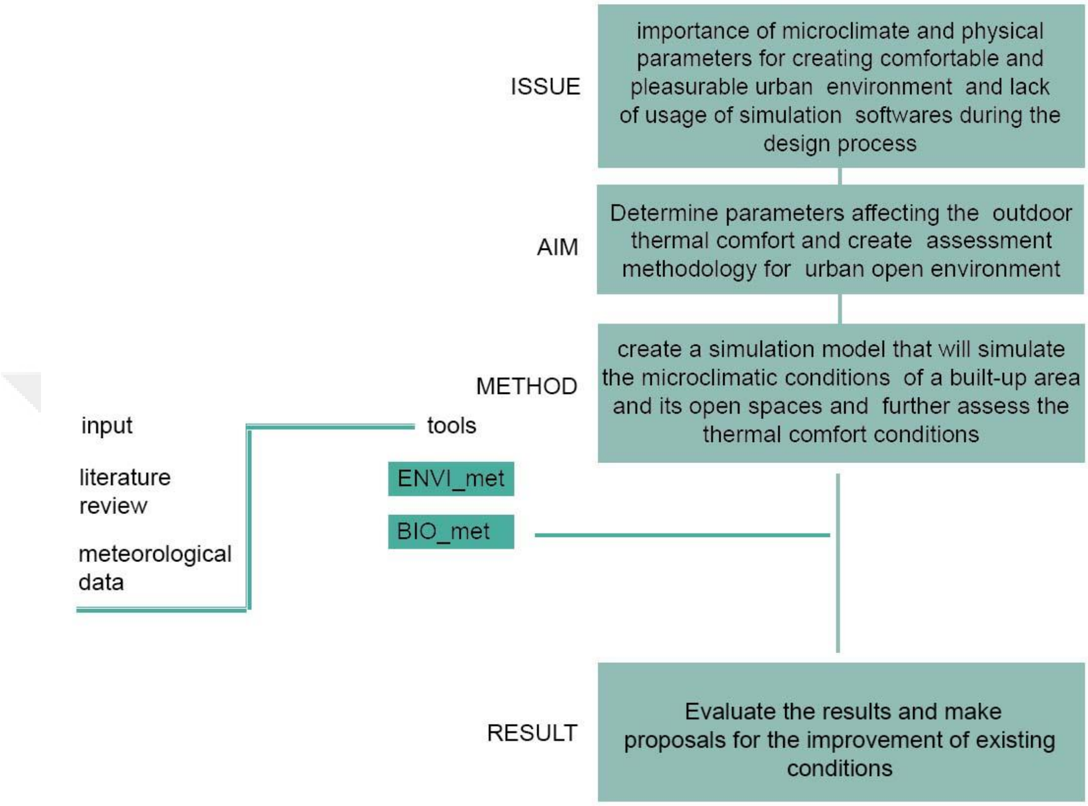


Figure 1.1: The scope of the study.

1.3 Selection of the Site

In the last decade, Istanbul is facing a rapid population and infrastructure growth, where university campuses take their places as well. Due to the high prices and lack of spaces in the city centers, many of the newly established universities have decided to build their campuses in suburban areas, where they would be able to provide not only educational but also spatial quality and services as well. One of these universities is Ozyegin University, being settled at the periphery of the Anatolian part of Istanbul, Cekmekoy District, populating with more than 10,000 students and academics, with the area of 136 000 m^2. Within a campus area that can be considered as an urban setting due to the fact that it includes high population and variety of multifunctional buildings, open and recreation areas occupied by pedestrians, the importance of outdoor thermal comfort should not be disregarded.

1.4 Methodology

With a literature review, the significance of the topic is emphasized. From the Hippocrates (2004), stating that natural elements are having positive effects on human health, through Vitruvius (2001) affirming that layout of the streets and buildings should be arranged according to sun and wind, coming to nowadays where climate change issues led to reconsidering the planning and design principles, it is highlighted that microclimatic conditions should be a part of planning and design process and used as not limiting but a supplementing tool (Nikolopolou and Steemers, 2003; Nikolopoulou and Lykoudis, 2007).

The relationship between open spaces and microclimate being inevitable impulses the significance of outdoor thermal comfort. Climatic conditions affecting the open spaces are in fact directly affecting the users' perception of a certain environment. However, it is not only the climate but the physical environment, such as buildings layout and geometry, street orientations, trees and their canopies that affect how the climatic conditions will be perceived in an open space (Santamouris, 2001; Meir et al. 1995; Berkovic et al., 2012).

The division of parameters affecting outdoor thermal comfort into user related and physical environment, as well as explanations of assessment methodologies, assists in determining application methodology.

Firstly, a theoretical background has been used to develop a model for outdoor thermal comfort assessment. The model explains the related parameters of outdoor thermal comfort, the appropriate assessment tools and the index used in the study.

Secondly, the theoretical model has been implemented to a case study, in this case, open spaces of a suburban university campus in Istanbul. The effects of physical parameters, such as vegetation and surface material, as well as microclimate effects in accordance with seasonal changes and user related parameters, such as activity and clothing level have been investigated. In order to analyze the effects of these parameters simulation software improved for microclimate model design has been selected, in this case, ENVI_met. As the first step, the validation study has been conducted. Validating the results with field measurements and thermal comfort survey results the accuracy of simulation software has been approved. Additionally, the existing environment of the campus open spaces has been simulated and obtained results have been assessed from the viewpoint of outdoor thermal comfort. The areas facing thermal discomfort are outlined and proposal for improving environmental conditions has been done.

1.5 Scope and limitation of the study

The thesis consists of five main parts, including “Introduction”. “Literature review” explains main issues of the topic such as climate, university campus and open spaces, further emphasizing the outdoor thermal comfort. A comprehensive literature review consists of the recently published studies involving thesis, books, articles and proceedings which support this study underlining the significance of the open areas for its users for a successful urban setting.

The third part of the thesis explains “Methodology”. A model, in order to determine the parameters affecting on outdoor thermal comfort, is created for a university campus in order to determine the main issues, opportunities for improvement and to reduce the discomfort at open areas. Developed methodology, however, can be implemented in any other urban area with changes in parameters examined or assessment methodology used. In addition, “Application model” of the developed model on a case study, in this case, University Campus has been explained in this chapter. Being a suburban campus, located at the periphery of Istanbul, emphasize the significance of open spaces for students as they are obligated to spend the day within the border of the campus. Moreover, natural land use surrounding the university campus (forest and low-dense settlement) provides a chance to directly observe the impacts of the physical environment on microclimatic conditions over open spaces within the campus, without an effect of urban built environment. In this part, applied methodology, assessed parameters, assessment tool and index have been explained. In order to include environmental as well as user-related parameters, simulation tool ENVI_met has been selected. The capabilities of the software have been examined and in accordance, parameters to assess and assessment index (PMV) determined. Further, validation pilot study and application steps of this study have been described.

The outputs and results have been discussed in the fourth part "Findings" where the main issues have been emphasized as well. The impact of microclimate and physical parameters has been determined. Results assessing the vegetation and surface material impact on outdoor thermal comfort have been explained. Similarly, the influence of user-related parameters has been investigated. Following these, the proposals for improvements of the outdoor thermal comfort have been defined.

As a "Conclusion", the significance of the study as well as its findings has been outlined and suggestions for further work are made. Implementation of appropriate design strategies and ability to simulate physical environment during the preliminary/post design process have been underlined as of great significance for outdoor thermal comfort.

2. LITERATURE REVIEW

This part of the study attempts to briefly explain the term of “outdoor thermal comfort” in urban open areas and the related main parameters of outdoor thermal comfort, emphasizing the impact of microclimatic conditions, building layout and geometry, and user-related factors under four sections.

In the first part of literature review, briefly review on climate, climate zones and its components are given. Besides, the impact of climate and climatic conditions on urban open areas is discussed. In the second part, the campus as an urban settlement is explained with look upon historical context and the first campus developments, planning and design concerns they occurred. Examples of possible campus systems and layouts are explained briefly as well. The significance of open areas in the campus, from the very first beginning, is discerned what has made campus to be a settlement with urban characteristics even though it can be settled on the peripheries of the city. The third part emphasizes the importance of open spaces, its advantages and general use. Yet, it is explained how microclimatic conditions affect the use of the open spaces and as a consequence importance of creating a pleasurable and comfortable environment for its users as one of the main goals of the sustainable urban design.

Outdoor thermal comfort is explained in the fourth part of the chapter. This part explains the parameters affecting outdoor thermal comfort, assessment methodologies, tools and indices.

2.1 Climate and Urban climatology

When all of the meteorological factors on the earth are having long-term impacts on a particular region it is considered as “climate”. Climate is one of the significant factors that affect the design of indoor and outdoor built environment, human lifestyles and behavior. Its conditions are known to shape our residential areas, lifestyles and many other daily life decisions (Kocman, 2002). There are examples of vernacular designs where the local population designs its areas according to the occurring climate conditions. For instance, the color of the buildings in hot and arid climate zones are preferred to be white in order to reduce absorption of the sun rays during the hot summer days and in that way reduce the inner temperature of the buildings (width of streets, the height of the buildings, vegetation etc.). Moreover, people daily activities change according to the climatic conditions, such as choosing their clothes, how and where to spend their day, which public transport to use etc. These decisions further affect the formation of natural and socio-cultural processes which is determined by climate conditions as they affect the geographical environment, where the natural and socio-cultural processes occur (Çetin et al., 2010).

A region is having its climate defined according to the interactions of the meteorological elements in it, such as air temperature, wind, humidity, solar radiation etc. These elements are collected and analyzed to have a better understanding of climatic conditions of a certain region, city, area etc. Still, the regional data is used in the evaluation of specific climate elements of a certain area (Koch-Nielsen, 2002).

2.1.1 Climate, climate zones and types

At the end of the 19th century, Wladimir Koppen (1936) classifies the climates around the world according to the different type of vegetation found there. In 1936 he refined his classification that is used nowadays. This classification is modified by Ahrens (2000) and Bailey (1996, 1998) as being classified into five major climate zones below:

1. Humid Tropical Climate is determined as a zone where temperatures are warm throughout the year. There are two types of climate within it: Rainforest climate and tropical savanna. The first one occurs where rainfall is plentiful, while the second one is in the dry season.
2. Dry Climate is a zone with deficient precipitation throughout the year and can be divided into semi-arid and arid climates, depending on moisture.
3. Moist Subtropical Mid-Latitude Climate zone is in regions with distinct summer and winter seasons. Here, summers are warm to hot and winters are mild. The Mediterranean, humid subtropical and marine zones are three subzones within it.

4. Moist Continental Climate has large seasonal variations in temperature where summers are moderate to cool and winter cold. It is divided into warm summer and cool summer regions.
5. Polar Climate has extremely cold winters and cold summers. This climate experiences the coldest temperatures on Earth.

However, climate elements or climatic variables can be examined in three main groups: macroclimate, mesoclimate and microclimate.

Macroclimate can be explained as atmospheric conditions covering large areas around the world including land, sea, sun and air flows. Basically, the climate types that cover wide areas of the earth are called macroclimate. It can be grouped as following: Equatorial climate, Savannah climate, Monsoon climate, Desert climate, Mediterranean climate, Step climate, Continental climate, Mild oceanic climate, Tundra climate and the Pole climate.

Mesoclimate is the climate of small areas of the earth's surface which may not be representative of the general climate of the one. It is formed by the effects of water, topography, vegetation and structured environmental characteristics, covering the regional areas of macroclimate. It has variables in altitude, soil types and the distance from a water source.

Microclimate is basically the climatic characteristics of a certain local area which differs from the meso and macro climate of that region. The climatic changes caused by the protection and utilization decisions taken for the existing macro and mesoclimate create the microclimate (Arslanoğlu, 2008). The reason why microclimate is having different climatic characteristics from the climate of the area located in is that microclimate is affected not only by natural components (air temperature, air flow, radiation, moisture) but also by the characteristics of physical and built environment as well such as topography, vegetation and urban geometry. Knowing the basic forces acting on the atmosphere gives an opportunity to comment on the effects of the designs made on the microclimate or the microclimate on the designs (Gülbay Tuğaç, 2003).

According to these factors, microclimate can be classified into four main categories: highland microclimate, coastal microclimate, forest microclimate and urban microclimate. This study focuses on urban microclimate which is directly affected by the existing environmental and physical factors beyond the built environment characteristics.

2.1.2 Climate components

Climatic elements or components are air temperature, humidity, wind speed and direction, solar radiation and in some cases fog or rainfalls can be considered as well (De Wall, 1993). These climate components are briefly explained in below:

2.1.2.1 Air temperature (^{0}C)

Air temperature is the component affecting the geographical conditions and daily life of human beings. The sun, heating up the atmosphere and the earth causes a diverse range of conditions where air temperature rises or falls.

2.1.2.2 Air humidity (gr/kg)

Air humidity is known as the amount of water vaporized into the air. It can vaporize from various sources on the earth. Relative humidity (%) is used for expressing the level of moisture in the air. Different surfaces allow or slow down the evaporation process in an urban environment; for instance, concrete and asphalt surfaces absorb the sun rays and block water pass to the inner layers of the earth what further causes lower humidity level in the air (Kadıoğlu, 2007).

2.1.2.3 Wind speed and direction (m/s)

Wind can be defined as a natural movement of air at any velocity. So, the direction and speed of air flow are determining the wind. Wind speed is known to be slower near the ground level, while it increases when the distance from ground level increases as well.

2.1.2.4 Solar radiation (W/m^2)

Solar radiation is a climate component that depends on the length of the day, the angle of the rays falling from the sun, the distance of the earth from the sun as well as air quality of the atmosphere through which the sun rays pass (Koch-Nielsen, 2002). It can be direct, diffuse and reflected and it significantly affects the surface temperature.

2.1.3 Urban climatology

The processes of urbanization led urban environments to decline in terms of vigorous urban climate. With population increase the need for dwelling units and other services raises, further affecting the creation of a sustainable urban environment. This issue causes the deprivation of green and open areas and construction of high-density buildings that are the main heat absorbers, what further lead to the creation of urban heat island effect. Similarly, the air flows and wind speeds are affected by urban built environment, as seen in Figure 2.1. The building geometry and its dimensions, the length and width of the streets, trees and their canopies affect the air flows (Santamouris, 2001).

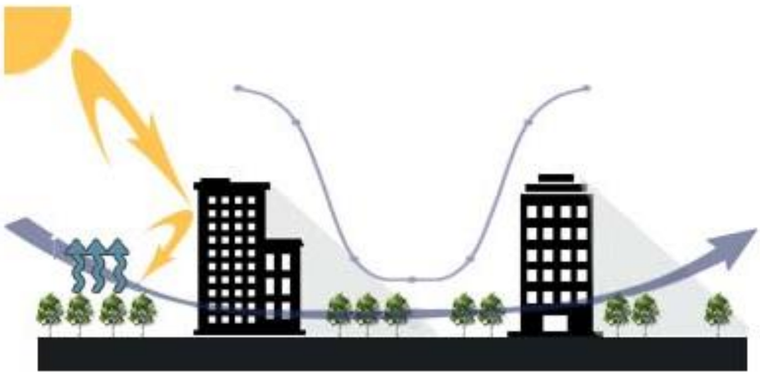


Figure 2.1: Air flows and solar radiation within the urban environment.

As Oke (1987) in his theory affirms, it is possible to divide airspace above a city into urban canopy (the space surrounded by the buildings in an urban environment until to their tops) and the boundary urban air dome (boundary layer over the city space).

2.1.3.1 Urban canopy

Urban canopy defined as the space surrounded by the buildings in an urban environment can include a various number of microclimates due to the different urban configurations. The main influence on urban canopy tends to have natural environment and morphology of the built environment as well. The geometry of the buildings, built up materials and vegetation affect the microclimatic conditions occurring within the urban canopy. The height of the buildings determines the upper boundary of the urban canopy.

2.1.3.2 Boundary layer

The upper boundary layer or 'urban air dome' (Oke, 1976) is related to the lower layer (urban canopy) as the characteristics of it affects the conditions happening in the upper layer. The air flow, the temperature distributions, pollution dispersion and other processes are bounded between these two layers, and firstly related to the urban configurations.

Both of these terms (urban canopy and boundary layer) are investigated within the urban built environment, usually within urban canyons. Urban canyons, having similar geometrical forms allow a better understanding of air flows and thermal conditions. As it is familiar, the solar radiation in dense built-up environment rarely reaches the ground level due to the high-rise buildings. Although this can be considered as an advantage in hot summer days by providing the shading areas, it is, in fact, causing solar radiation heats up the roofs and facades of the buildings causing the heat island effect in the upper layer.

The importance of climatology should be emphasized in urban planning and design disciplines. Its impact on urban areas (as well as rural etc.) can be observed through natural processes (wind, sun, rain etc.) affecting the creation of comfortable and pleasurable environment as well as affecting the daily life of human beings. So, it is in the hands of planners and designers to evaluate the climatic conditions and include them in the design process of open spaces in order to achieve the goals of sustainable urban environments leading to a healthy society in prosperity.

2.2 Campus as an Urban Settlement, Campus Historical Context and Design Principles

Having primary aim to become an institution where quality and innovative education is given, universities became independent settlements, increasing in their size and power, called a campus. Deriving its meaning from the Latin word "campus" (Oxford Dictionary English, 2018), it can be described as a land or plain with all buildings and structures settled in it and making up a physical environment. In this chapter, it is explained how first campuses emerged, the main aims of planning throughout the history and how first "campus" settlement occurred. Additional, the systems and layouts of campus are given and discussed in terms of creating open spaces that provide students with the space to relax and experience natural phenomena.

2.2.1 Historical context

Educational institutions although having a long history and being considered as descendants of Sumerian schools, or according to some approaches Ancient Greece, numerous studies show that universities started with feudalism and its framework for the positivist understanding of history (Charle and Verger, 1994). According to the authors, if by term university place where students and teachers come together with an aim to learn and teach a variety of disciplines is meant, then this institution is firstly born at the beginning of 13th century in Italy, France and England respectively. They emerged as a consequence of higher population where the number of students and teachers linked to cathedral raised as well. Following, some of the teachers started carrying out their educations by renting the places within the city (Timur, 2000). Usually, these medieval European universities were known by the name of the city they were settled in (Bologna, Oxford etc.). Although they were designed in order to teach and educate the students, universities started contributing to urban life in terms of making cities as well as its economies livable (Timur, 2000). As for example, students were renting rooms and lived with the local population. By the time, they started renting whole building together (Turner, 1990) what became stepping-stone in planning and creating new university model with the main strategy to host dormitories for students and teachers near education buildings.

In the period of Renaissance, universities lost autonomy and were part of the state (Timur, 2000) and in the period of Rationalism universities had a duty to officiate to the state and educate students according to the disciplines needed (Chaunu, 2000). Rationalism affected American Universities in terms of preparing students for the practical life that included strong social relations and civic organizations.

At the beginning of the 20th-century expansion of universities worldwide has led to the growth of academic expertise and specialization, where economic growth provided resource support (Wallerstein, 2000). The period after WW2, known as a time of the significant social reforms, caused universities feel these reforms the most. In the United States, with merging universities and colleges a term of “campus” occurred. At first, they were called “cluster” or “satellite” colleges. They hosted dormitories, faculties and provide main social and retail functions. Lately, this concept was imported to Europe as “Campus University”. The main issue of these types of universities was growth and development as they needed large areas for providing impeccable education as well as social and retail areas. So, together with decentralization aspect emerged new approach of establishing universities outside of city center (although originally they were established in the city, as part of one community), where they could use land and resources according to the needs and do not face scarcity.

2.2.2 Design principles and urban forms of campuses

As previously mentioned, university buildings were originally built in the city centers, a dense urban environment to whom their size and forms (typology) depended on (Bologna, Paris University). Usually, they had a "quadrangle" (middle courtyard) plan, where the main courtyard is surrounded by buildings consisted of faculty, library, dormitories, dining halls etc. This form was mainly used as a “protection from the dangerous urban life” (Lenglart and Vince, 1992). Oxford and Cambridge Universities as well emerged from this type of planning principle; it started with the sprawl of “quadrangle” college buildings all around the city and ended with making those a “University town”. One of the first changes in the rectangular plan of universities done in Cambridge, where one of the sides was kept open and a monument or garden wall used instead, has become an inspirational design principle for further university planning principles (Turner, 1990). It can be stated that although universities main aims were providing education and specialization in various disciplines, from the very beginning they carried on enriching social life, creating open areas for leisure activities etc. (silent and isolated from city crowd). This planning approach continued in America as well, with the main aim to coexist with the natural environment still preserving the college lifestyle and spirit. As so, one side of the courtyard remained open but green areas become wider and in some cases open to public use. Still, they have been planned in a comprehensive way, holding university structure into whole unity, as Harvard University seen in Figure 2.2 (Turner, 1990).

Figure2.2: Harvard University- View from 1936 and nowadays (Wikimedia Commons, 2018).

Formally the first campus designed was Princeton University, established on city peripheries within a wide green area aiming to create a new self-sufficient, ideal prototype for not only universities but cities as well (Campos, 2002). A morphological form of these campuses was strictly grid blocks with large open areas (Muthesius, 2000). Although emerging from one same prototype, university campuses started to vary in systematic terms of keeping buildings together. In correspondence, university campuses can be gathered in six main groups in terms of building form and system: Diffusive, Central, Cross, Nuclear, Linear and Gridiron system (Linde, 1971).

Diffusive system campus has a random distribution of individual building groups within green area, containing low-density buildings. The common areas are separated from the academic building clusters. Due to the building low density, a second center can occur within the campus (Çınar, 1998).

The most important feature of the centrally planned university campuses is that it has a high concentration of buildings (core), which includes management areas, social areas and common facilities. The faculty buildings are located radially around this center (Yekrek, 1999).

In the cross-system campus, the education facilities and common facilities are located on two axes that cross each other in the shape of a cross. The connection between the university campus area and the city is provided by a crossing network on the axis of the cross (Linde, 1971).

The nuclear system mainly provides the gathering, social and recreational facilities in the center of campus and aligns educational buildings according to these areas. The density of buildings is low, but it offers a chance for new built-ins if needed (Türeyen, 2003). One of the best examples where the nuclear system is observed is York University (Figure 2.3).

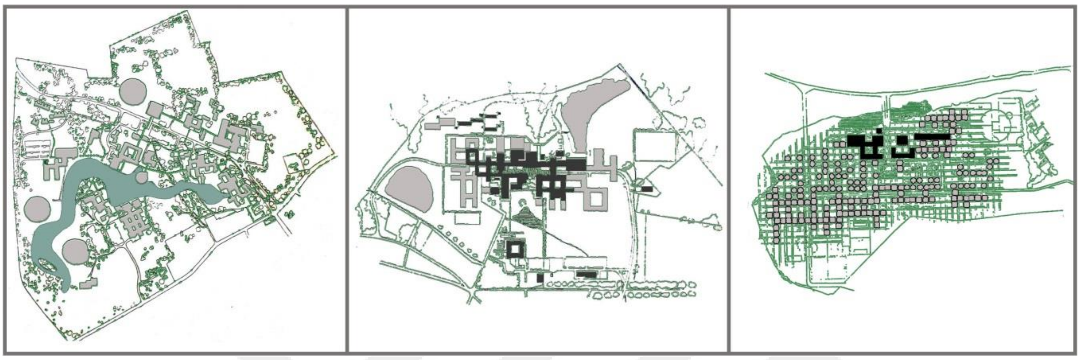


Figure 2.3: Plans of York, University, Bath University and Loughborough University (adopted from Tureyen, 2003).

Linear system creates the main alley to which are other axis connected vertical or perpendicular. The growth of the campus occurs on the head and tails of the main alley and along the short axis. Common facilities such as the library, conference halls and social services are placed parallel to the main alley. Shorten axis host educational buildings (Bath University, METU) (Türeyen, 2003).

Gridiron system although having an aim as a nuclear campus system, to settle common facilities in the center, is systematic and more apparent system divided into grids where the buildings are placed (ITU, Loughborough). The merit of this system is its ability to grow towards open areas in a systematic way (Begeç, 2002).

Being a concept related to various topics, sustainability raised its interest worldwide as so the universities that have made the sustainability a major factor in developing and designing their campuses. When developing a sustainable campus not only buildings and their energy use and waste amount are important, but also a successful design of open spaces should be achieved as well. Moreover, designing open space that provides pleasurable experiences for its users is seen as an important urban design guideline for achieving sustainability goals. Due to climate changes and its effect on open spaces and users, the importance of thermal comfort has increased in open spaces which accommodate various activities and improve the livability of the certain areas used in daily life. In order to determine whether a certain place is pleasurable in terms of thermal comfort, it is necessary to better understand the outdoor thermal comfort itself.

2.3 Open Spaces

This part emphasizes the importance of open spaces, advantages it provides and general use of. Yet, it is explained how microclimatic conditions affect the use of the open spaces and as a consequence its importance of creating a pleasurable and comfortable environment for its users.

The importance of open areas for a university campus is inevitable in terms of providing leisure and recreation areas for students to spend their time. It is noticeable from the very beginning of campus planning that open areas are included and integrated into campus layouts. However, the importance of open spaces as a part of the urban environment is inescapable as well. In this part, significances of urban open spaces, its advantages and contributions to urban environment and issues affecting the use of open spaces are discussed.

2.3.1 Functions and advantages of open spaces

The reasons for open spaces contributing to a sustainable environment are the facts that they accommodate pedestrian traffic and outdoor activities; additionally improve urban livability and vitality (Chen and Ng, 2012). For instance, the spaces those attend to provide a pleasurable thermal comfort experience for its user's area at the same time improving the quality of the urban environment. Because, it is common that as long as people use open spaces and streets the cities tend to benefit in terms of physical, environmental, economic and social aspects which are the main components of sustainability (Hakim et al., 1998; Hass-Klau, 1993; Jacobs, 1972; Whyte, 1998).

The main goals of open spaces in urban areas are improving the quality of life, revitalize city center and host a high number of users of these open spaces. Various stimulant policies were given to developers as a bonus for participating in creating a better environment. One of the examples is in New York, during 1972, developers who would provide plaza would gain extra floor space to get built (Whyte, 1980).

On the other side, public interest for open spaces has increased and the local population has started to protect their rights such as sunlight access in parks, or protection of wind from new developments (Bosselman et al., 1988).

2.3.2 Open space design principles

While planning and designing the cities and buildings, wholeness with open spaces should be created. Because it is the open spaces where people spend their free time, perform recreational and leisure activities, making urban environments pleasurable and preferred to spend time at. Building cities, in fact, mean creating spaces for people, not only buildings. It is the open spaces, parks, squares, alleys and of course the surrounding buildings that create the urban built environment. Although the social benefits of open spaces are familiar, the environmental and economic benefits for a sustainable environment are inevitable as well.

There are various classifications of main parameters that should be considered when designing open spaces. Whyte (1980) in his work states that open spaces should be designed according to the few guidelines that will make it successful: the provision of sitting places and food, access to sun and protection from the wind, as well as including water and vegetation. In another work, Whyte (1988) has conducted direct observation about the social life of the streets and found out that carrying capacity, steps and entrances as well as sun and shadows affect the street life.

Smith et al. (1997) in their study about quality in an urban community refer to livability, character, connection, mobility, personal freedom, diversity as a sign of quality and need for urban community spaces. Within livability, they emphasize the personal health and development, environmental health, comfort, safety and security. Places that provide physiological and psychological comfort are designed in order to provide a comfortable microclimate, protect from the rain and wind while desired activities are performed. Again, they should emphasize the ecological preservation in order to provide the environmental stability. Similarly, Hester (1975) while examining the neighborhood open spaces has highlighted the appropriate activity settings, interaction with the natural environment, convenience, safety, psychological and physical comfort.

According to Lennard (1987), there are ten basic design principles that should be included in the design process. Some of them are designing human-scaled urban spaces, comprising them with natural elements in order to increase sensual enjoyment and locating the seating elements correctly.

Although proposing for better understanding the relationship between architectural form and energy use, Brown (1985) has stated that design should consider sun, wind and light, combine climate, provide comfort and design comfortable open spaces.

According to these principles, it can be concluded that one of the main principles, being mentioned by all authors, is to design comfortable places for its users. This comfort can be physical, psychological and physiological. Both physical and psychological aspects are involved in the term of “comfort”. Physical aspect can be related to the provision of comfortable sitting elements and food services where people would meet their needs. The physiological state of a person in open spaces is related to climatic conditions, as the sun or the cold winds affect the human body temperature what further can cause discomfort and avoidance of the space. From a psychological aspect, it is mentioned the specific involvement of open spaces in providing joy, memorable experiences and pleasure/displeasure for its users. For this reason, the two aspects are highly linked.

2.3.3 Parameters affecting the use of open spaces

According to Whyte (1980), the main parameter for examining open space is its use. As much certain place is used so does its characteristic of being successful rise. Vice versa, if a certain place is not used then it can be categorized as unsuccessful (Marcus and Francis, 1998). Moreover, the variety of activities performed in a certain place make it more attractive and successful (Gehl, 1987).

There is significant number of studies demonstrating that the physical environment noteworthy affects the use of open spaces (Marcus and Francis, 1998; Yildiz and Sener, 2006; Saglar, 1998); for instance, the presence of sitting equipment, vegetation, shading objects, eating or drinking services affect the intensity of using open spaces, and in some cases affect whether open spaces are used at all. The form of a certain place is another factor that affects social interactions, traces and human behavior at that place (Bornberg, 2008).

A human being is regularly exposed to outdoor climate conditions, especially when recreating or performing leisure activities in open areas. For this reason, the thermal conditions of these areas have a direct impact on user satisfaction. Studies emphasizing the correlation between usage of open spaces and users thermal comfort satisfaction (Thorsson et al., 2004; Nikolopoulou et al., 2001; Knez I, et al., 2008) found out that the thermal assessment of an open space influences its use. The most leading microclimatic parameters that influence the use of open spaces are shown to be air temperature and solar radiation; while humidity and wind speed seem to have lower influence. For instance, people displeasure the direct sunlight at high air temperatures and seek for shaded areas. If the air temperature increases significantly, then the use of open areas and overall presence decreases. Nikolopoulou and Lykoudis (2007) also find out that environmental conditions to which are people exposed while using open spaces significantly affect their experiences.

2.3.4 Relationship between microclimatic conditions and open space

The theory and practice of microclimate as a “design” input has a long history whose roots of tradition in Western culture are deep: from Hippocrates’ treatise “Airs, Waters, Places” (2004) to contemporary authors. More than two thousand years ago, the Greek physician Hippocrates described the effects of “airs, waters, and places” on the health of individuals and communities. Later on, The Roman architect Vitruvius (2001) (ca. first century B.C.) described how the layout of streets and the orientation and arrangement of buildings should respond to seasonal patterns of sun and wind.

Architect Leon Battista Alberti’s treatise “On Architecture”, written in the mid-15th century (1988), expanded these recommendations, advocating that the sitting of cities and the design of streets, squares, and buildings should be adapted to the character of their environment so that cities might promote health, safety, convenience, dignity, and pleasure.

But, with industrialization revolution, the mass production, implementation of new technologies rapid urban growth in terms of population as well as built environment occurred. This caused environmental and social aspects of urbanization to be disregarded to some extent for the sake of economic development.

Luckily, in the last few decades, the importance of environment and urbanization, planning and design according to nature have been reborn. As an important thinker in the history of ecological urbanism Jane Jacobs (1972) in her book “The Death and Life of Great American Cities” states that: “human beings are... part of nature” and cities should ‘consist of grass, fresh air and little else” (Jacobs, 1972). She has focused on the city as a human habitat and regarded urban design as a way to support and fulfill human needs. Jacobs advocates an ecological approach to designing and managing cities, arguing that cities are problems of organized complexity, akin to living organisms, and that there are lessons for urban design from the study of systems where “half-dozen or even several dozen quantities are all varying simultaneously and in subtly interconnected ways” (Jacobs, 1972).

With the rise of ecological approach, the consideration of climatic conditions during planning and design process again started to be highlighted. One of the good examples, the city of San Francisco, since 1985 has established design requirements and guidelines in order to control the effects of new constructions on the local microclimate of open spaces, such as limiting wind speed or controlling the shadows that will occur (City and County of San Francisco, 1985).

Similarly, the studies examining the relationship between microclimate and open spaces have been increased. Nikolopolou and Steemers (2003), in their paper, discuss how designing according to microclimate can improve the use of open spaces with the emphasis on how the microclimate is not restricting but complementing the design process.

A quantitative study between microclimate and the use of urban open spaces has been done by Zacharias et al., (2001) was conducted on seven plazas and public squares in Montreal. The aim was to find out the relation between local microclimate and the usage of the space by measuring the presence of people and passive activities occurring at. Hence, they found out that although the presence can be high, the satisfaction and perception of thermal comfort can be low.

Berkovic et al. (2012) has shown the importance of openings of courtyards in hot and arid climate emphasizing that east side openings are creating more comfortable thermal environment instead of west openings. For the same study area, they have proved that galleries are having the better impact on thermal comfort when comparing to trees and openings. Moreover, the fact that correct layout of the building creates shaded areas in courtyards made authors compare the temperature of tree shades and building shaded areas where they found that those areas are having similar PMV values. Similarly, Meir et al. (1995) in their study have concluded that thermal conditions of semi-enclosed open spaces can be improved by correct orientation, vice versa orienting the areas regardless of solar radiation and wind direction might result in thermal discomfort.

Scandinavia, the region having harsh and cold climate is a good example of how microclimate and physical environment affect the use of urban open spaces where there is an obvious seasonal use of open spaces, called "outdoor season", which is demonstrating the role of climatic conditions (Gehl, 1987).

So, it can be stated that starting from the last decades of the 20^{th} century, the goal to create attractive and successfully occupied open spaces has become one of the main issues in urban planning and design fields (Carr et al., 1992; Gehl and Gemzøe, 2004). Due to the mutual interaction of urban design and microclimate, outdoor thermal comfort can be used as a key indicator for assessing whether or not human use and design plans are in fact successful. Additionally, it should be used as a key tool for designing open spaces.

2.4 Outdoor Thermal Comfort

2.4.1 Thermal comfort and outdoor thermal comfort

The thermal environment can be defined as a human thermal comfort determined by physical environment elements in a certain area. According to ASHRAE (1981):

“Thermal comfort refers to that condition of mind expressing satisfaction with the thermal environment.” Although this statement was primarily made for indoor spaces, for the issue of outdoor thermal comfort the same statement is used.

According to Olgyay (1973) physical and psychological reactions arise as a result of the biological equilibrium war between the physical environmental parameters and the human body. People want to spend as little energy as possible to be able to adapt themselves to their surroundings. The conditions under which this can be achieved are called comfort conditions. Thermal comfort is very important in terms of the healthier life of the individual, the ability to enjoy in environment, and the feeling of being psychologically comfortable.

The influence of thermal comfort on open spaces is a complex issue comprising both climatic and behavioral aspects (Chen and Ng, 2012). The thermal comfort topic itself is being investigated from various aspects such as biometeorology and urban climatology where the main aim of the studies is researching the outdoor thermal comfort in various climate zones worldwide (Ahmed, 2003; Ali-Toudert and Mayer, 2006; Cheng and Ng, 2006; Cheng, Ng, Chan, and Givoni, 2010; Givoni et al., 2003; Gulyas, Unger, and Matzarakis, 2006; Höppe, 2002; Nikolopoulou and Lykoudis, 2006; Spagnolo and De Dear, 2003; Stathopoulos, Wu, and Zacharias, 2004; Tseliou, Tsiros, Lykoudis, and Nikolopoulou, 2009). On the other side, there are studies investigating the factors that determine thermal comfort levels (Cheng and Ng, 2006; Spagnolo and De Dear, 2003). Similarly, there are studies researching the modeling and assessment of thermal comfort from a thermo-physiological perspective (Gulyas et al., 2006; Höppe, 2002).

2.4.1.1 Studies on outdoor thermal comfort

The methodology of studies can be grouped as following: (i) survey (Thorson et al., 2004; Nikolopolou et al., 2001), (ii) field measurements (Spagnolo and De Dear, 2003; Kruger et al., 2011), (iii) statistical analysis related to human bio-meteorological principles, (iv) model simulations (Nikolopoulou and Lykoudis, 2006; Lin et al., 2011; Brusse, 2010), and (v) combination of these (Bakovic et al, 2017b; Gulyas et al., 2006). Type of sites studied are usually parks, squares, pedestrian streets, waterfronts, sport fields and residential streets (Johansson et al., 2014).

Thermal comfort studies vary when the time period is about. Some of them focus on seasonal, while other on diurnal changes (Spagnolo and de Dear, 2003; Becker et al., 2003; Yin et al., 2012). Of course, the majority of studies although focusing on seasonal changes has investigated diurnal changes as well (Nikolopoulou and Lykoudis, 2006; Cheng et al., 2012).

Thermal comfort is an important condition for user satisfaction. From the viewpoint of indoor thermal comfort, the desired indoor temperature is the most important factor determining the amount of energy to be spent for conditioning. Under the comfort of the user, the user will try to maintain the thermal comfort conditions with own efforts. This means that the waste of the current system is wasted and more energy is consumed (Roaf et al., 2009). Looking at this factor for open spaces it is familiar that conditioning cannot be implemented, or in other words, it will not have any effect. That is why open spaces should be designed in order to ease the achievement of user thermal comfort via taking into consideration the climate effects.

2.4.2 Outdoor thermal comfort parameters

Outdoor thermal comfort in an urban environment, similarly to the urban environment itself, may be affected by a wide range of parameters such as user related and environmental parameters (Figure 2.4).

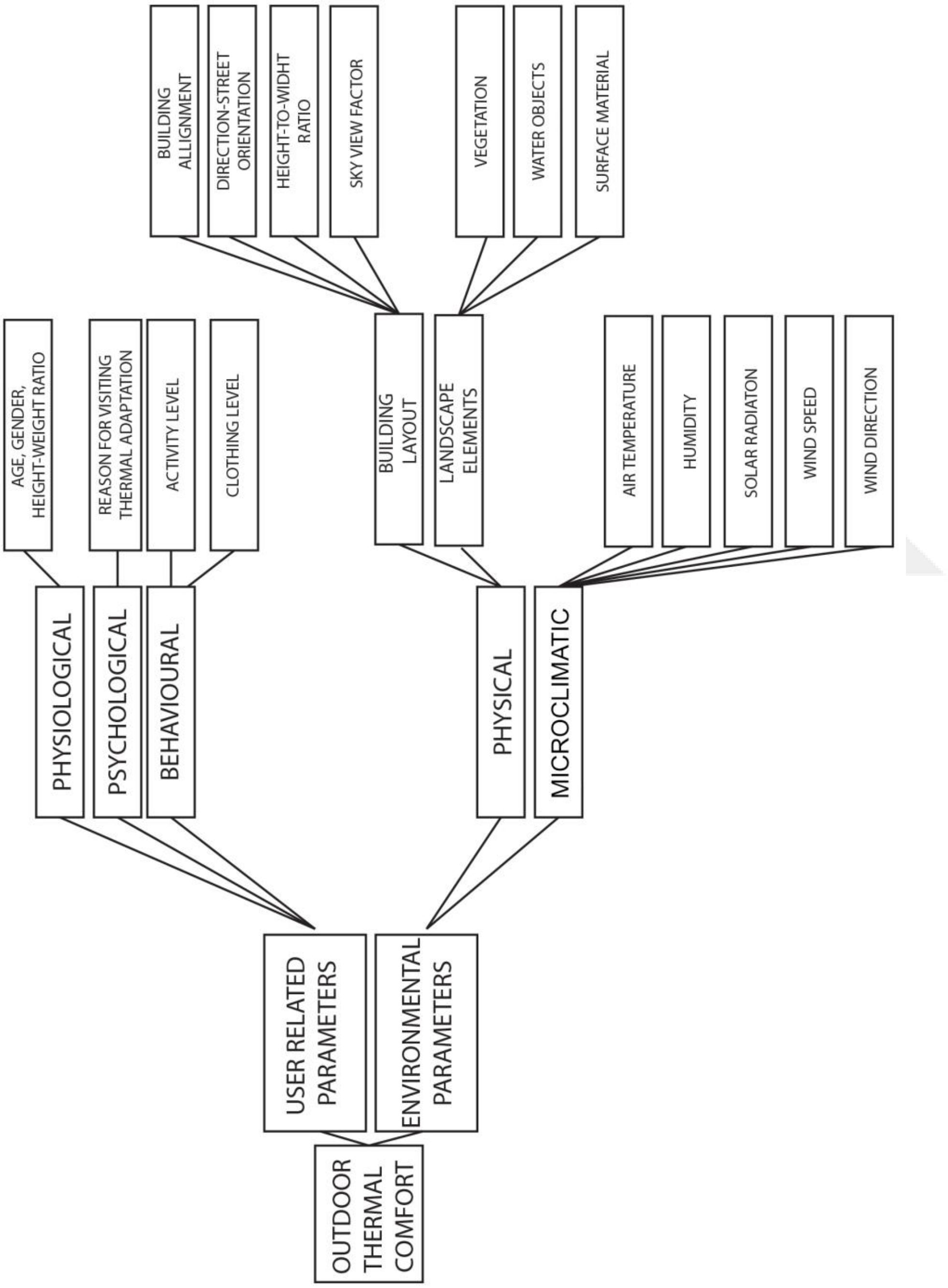


Figure 2.4: Parameters affecting the outdoor thermal comfort.

2.4.2.1 User-related parameters

This group of parameters consists data about users' physiological, behavioral and psychological state. User-related parameters such as user nationality, age, gender, weight/height ratio, activity level, clothing level, the reason for visiting are explained briefly below.

Physiological parameters

Physiological parameters consisting of weight/height ratio, user age and gender are briefly explained below.

Weight- height ratio

The weight height ratio of a person affects the metabolic rate and further the thermal comfort of that person. The height-weight ratio affects how a person perceives the environment. The metabolic rate of an overweighed person cannot be the same as the rate of a fit person. For instance, an overweighed person tends to have higher body temperature and so perceive cold conditions as neutral, but warm conditions as too hot.

Age

Age of the user tends to affect thermal perception as well. The main reason is the metabolic speed that varies according to ages. The perception of the thermal environment is not same for elderly people as it is for young or adults. Usually, younger generations are more adaptable to the thermal conditions, while elderly people need more effort to obtain the balance between their body and environment.

Gender

The gender of users, although not being often considered as a parameter that affects the thermal perception, has been made known to affect general perception of the thermal environment. Oliveira and Andrade (2007), in their study about bioclimatic comfort in open public space in Lisbon, have stated that there is a difference in perception of thermal environment between man and woman. Women tend to be more sensitive to wind and perceive the environment as uncomfortable (44%) when comparing to man (21%).

Behavioral parameters

The activity and clothing levels as consequence of user behavior have been explained.

Activity level

Metabolic rate is highly related to activity level. As activity level rises so does the metabolic rate and vice versa. ISO 8996 (2004) has determined metabolic rates for various activities, such as sitting, standing, walking, running etc. All these activities have value (Figure 2.5) that is further used when the calculation of thermal perception is done (PMV, PET etc.).

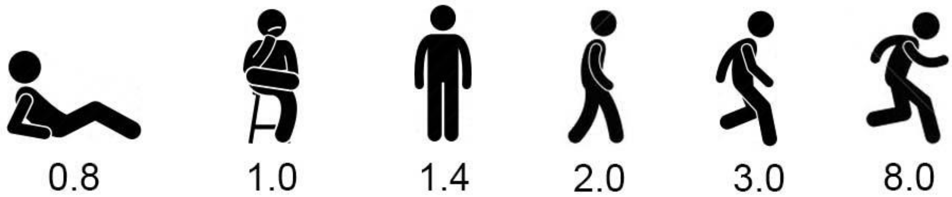


Figure 2.5: Activity level.

Zacharias et al.,(2001) in their quantitative study about microclimate and use of urban open spaces in Montreal examined the relationship between those two. They have found a strong linear relationship between the air temperature and sitting behavior (r=0.920).

Clothing level

According to ISO 9920 (2007) clothing level with respect to known garments has been determined. Similar to activity level, every clothing level has its value (Figure 2.6) being used for further calculations of thermal comfort perception. Besides, the clothing level affects the perception of the thermal state. The same thermal conditions cannot be perceived the same by the person whose clothing levels are different. For instance, a person with low clothing level will feel more comfortable in summer where a person with a higher clothing level will feel uncomfortable; or in winter the vice versa. Moreover, clothing can be used as a tool for thermal adaptation (Lin et al., 2011). As for, people can adjust their clothes to outdoor thermal conditions: take off when for warm or wear on for cold weather conditions.

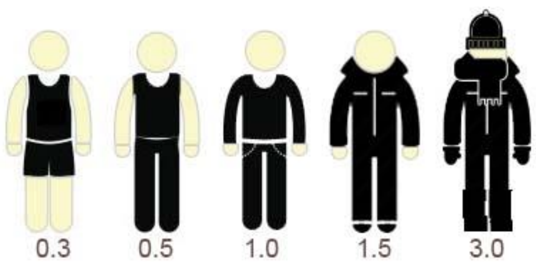


Figure 2.6: Clothing level.

Psychological parameters

Reason for visiting

Nikolopolou and Lykoudis (2006) have found out that there has been a difference in thermal perception in between the person who is a transit and the one that is using the certain place as a recreation area. Because people prefer spending time in places where good and satisfying thermal condition occur. On the other side, transit person neither considers thermal state important (due to the short time he/she will spend there) neither he/she can perceive it subjectively (due to the short time he/she spends there before).

Moreover, there have been dissimilarities in thermal perception for the users who have been visiting places on their own choice (recreation, meeting with friends, food/drink) when compared to the ones that have been forced to spend their time at the same place (waiting for someone/something, merely transit, etc.). So, the psychological state of the user has been one of the significant impacts when perceiving outdoor thermal comfort.

The study of Thorson et al., (2004) about the influence of thermal bioclimatic conditions on human behavior in an urban park in Gothenburg (Sweden) has been conducted with questionnaires, with evaluation on subjective thermal sensation (ASV). The results have been compared to PMV Index, where disagreement occurred. For instance, although PMV predictions have been 23% of users found the environment warm or hot the survey results showed 59%; or PMV prediction for acceptable comfort (26%) has been quite lower than of survey (38%). This has indicated that people who visited the park and exposed them self to directly sunny areas voluntarily brought the results outside the theoretical thermal comfort range. Another similar study (Katzcshner, 2006) conducted in Germany found out the similar results to the previous one: the behavior of people depends on outdoor thermal conditions but the individual expectations affect it as well.

Thermal adaptation

Thermal adaptation, as classified by Nikolopolou and Steemers (2003), can be physical, physiological and psychological. In their study, they have stated that psychological factors such as past experience, time of exposure, environmental stimulation and expectation create differences for thermal adaptation.

Time of exposure

Time needed for a human body to adapt to certain environmental conditions is an important factor in thermal comfort perception. So the perception cannot be expected to be the same for a person who is outside (outdoors) and for the one just being exposed to outdoor conditions. The first one will be accustomed to, while the second one will need a certain time to perceive environment positively. Time of exposure can be assessed with questions about the person being indoor-outdoor before the interview or for how long person has been spending its time in the certain area. Here, the time of residency can be related as well because people from different climate regions adopt different to climate conditions.

Other: Nationality or living in different climate zones

It is familiar that people from different climate zones perceive thermal comfort in different ways. As for example, a person from hot climate zones is more used to high air temperature and solar radiation than a person from cold climate zones and vice versa. This has been revealed by Lin's study (2009) about thermal perception and adaptation in a hot and humid subtropical climate in Taichung city, Taiwan where he has found that thermal acceptable range was 21.3°-28.5° according to PET, what differs from European scale of 18°-23° PET. This indicates that living in different climate zones affects the thermal preferences. Similarly, Knez and Thorsson (2006, 2008) have stated that the cultural norms, rules and values intend to affect the thermal perception.

2.4.2.2 Environmental parameters

Environmental parameters are related to the physical as well as natural environment. For this reason, parameters are divided into two groups: physical environmental and natural (microclimatic) parameters.

Physical environmental parameters

In this category, parameters can be divided into building layout related and landscape elements related parameters. First one includes the direction or street orientation, building configuration such as layout, geometry and height-width ratio.

Direction- street orientation

Street geometry and orientation aspects are examined as the passive cooling tool; for canyon streets in hot and arid climate (Shashua-Bar and Hoffman, 2003). It is shown that geometry and orientation influence ground shading and Sky View Factor (SVF) as well. SVF is the ratio of the spherical field visible from a surface. Kruger et al., (2001) investigate the influence of SVF in urban climate, where the SVF index shows the amount of visible sky from a given point. Yamashita et al (1986) have found out that there is a clear correlation between sky view factor and urban air temperature in some Japanese cities where the study has been conducted. Similarly, Barring et al. (1985) has investigated the correlation between surface temperature pattern and street geometry. They stated that when sky view factor is higher, temperature tends to decrease and when it is lower, due to the direct solar radiation on the surface, temperature tends to increase. Another study demonstrates that some orientations can have higher cooling capacity than others, what is related to the air flows and compactness of urban areas (Fahmy and Shaples, 2009).

The alignment of buildings affects how the open spaces are exposed to direct sun radiation and so increase or decrease the air temperature at the pedestrian level. A study has been conducted for 12 urban canyons in Athens (Santamouris et al., 1997) brought significant findings related to the direction-street orientation and building alignment. They have found out that the south facing buildings had a significantly higher temperature when compared to north facing buildings. It is the alignment of the buildings affects the amount of solar radiation to reach the ground level. Still, authors emphasize that the air temperature within the canyons are influenced by the air-flow processes as well, making building alignment of secondary importance.

Buildings configurations

Buildings limit the sky view of the surface, and therefore emission of solar radiation to space is limited. Building configurations, layouts and alignments provide additional friction to the flow affecting wind speed and intensity. Design studies in the UK demonstrate the decrease in benefits of passive solar design may occur if the layout is inappropriate (Teller and Azar, 2001).

Height-to-width ratio

The importance of height-to-width ratio is underlined due to the air flows and solar radiations blockage/allowance within the open spaces (Figure 2.7). If there is a need for maximizing the solar rays to the ground level than ratio should be lower; as Aida and Gotoh (1982) explain in their work. On the contrary, where the hot weather conditions occur, the ratio can be arranged to provide shade and cool the environment to some extent.

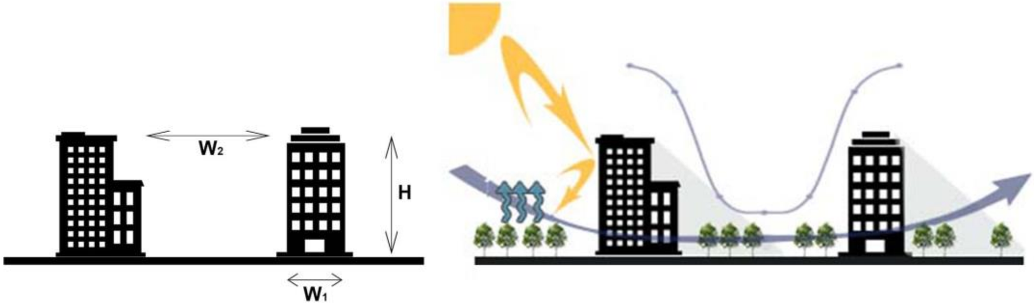


Figure 2.7: Height to Width ratio and air flows within the urban built environment.

Landscape design elements
Presence of vegetation and shading elements

A number of studies (Lin et al., 2010; Lin et al., 2007; Robitu et al., 2006) have found that the ground surface covering, vegetation and man-made shading objects affect the thermal environment. Moreover, the urban trees integrated with built environment are shown to act as cooling elements (Chudnovsky et al., 2004)

Additionally, there is a difference between positioning the trees within a site. Cooling effects of individual trees or trees settled in large intervals are minimal. On the other side, arranging the smaller group of trees is having the better impact (Shashua Bar et al., 2006, Shashua Bar et al., 2010).

Lin's study (2009) emphasizes the importance of shading elements and vegetation for hot seasons because of the fact that 90% of people visiting the square were preferring staying under the shade of trees or shelters. Berkovic et al. (2012) have examined the effect of wind and shading opportunities (galleries, horizontal shading or trees) in an enclosed courtyard. They have found out that the addition of trees to the closed courtyard in a hot arid climate improves the outdoor thermal comfort. Moreover, Robitu et al. (2006) for their study in France have found out that trees and water lower the PMV value. On the other side, Chatzidimitriou et al. (2004) have found that vegetation and trees have the cooling effect during the summer and warming effect during the winter seasons. Because, the trees are providing shading areas during the hot summers what lead to temperature decrease below the tree crown; on the contrary, in the winter they block the cold winds what further lead to temperature increase. Berkovic et al., (2012) also have stated that trees will elevate comfort in the enclosed courtyards during the summer in Israel due to the fact that increased shaded area. Still, they emphasized the importance of the location of the trees as the trees located in North and South of the courtyard create an area that is shaded from both sides (from buildings and from trees).

Quality and location of seating

The existence of seating elements is important for the open spaces where passive activities often occur. For instance, parks and squares are supported by sitting elements in order to keep the user spend more time in calm and contented conditions. Still, these sitting elements should be supported by trees or shading elements in hot climate conditions. Stathopoulos, Wu and Zacharias (2004) have found out that the amount of seating does not affect the presence of people at open spaces. However, a location of the seating has dominant effect for seating occupancy because of the sunlight and air temperature which can be controlled by shading elements.

Water pools or ponds

Water features such as pools or ponds are likely to improve outdoor thermal conditions too. The presence of water elements in an urban environment cools temperature in hot summer days due to the evaporative cooling effect they possess. The number of studies examined the impact of water features on thermal comfort of urban spaces. According to Chatzidimitriou et al. (2004), water pools do have an impact on thermal comfort but trivial in comparison to trees and vegetation. Another study conducted by Nishimura et al. (1998) have found out that water features decrease air temperature only at the points where shading elements are present. Still, Tominaga et al. (2015) have shown how water surfaces can decrease the air temperatures at pedestrian level, up to 2°C. More significant is the study conducted in Athens (Santamouris et al., 1999), where more than 30 stations were recording the temperatures and they found out that there are 5° and 15° higher air temperatures at urban areas when compared to suburban areas, where lakes and rivers occupied the majority of the land.

Ground surface material

Although the pavement materials are used as a tool for creating strong and rich landscape design, the fact that they absorb solar radiation and disperse the accumulated heat to the atmosphere, therefore increase the temperature should be taken into account as well (Santamouris et al., 2011). The albedo index - the reflectance of the surface caused by color, roughness or other radiative properties (Morais et al., 2017) - of ground surfacing material is playing an important role because higher albedo can help in improving the urban climate (Akbari et al., 2001, Bakovic et al, 2017a). Materials having lower albedo are asphalt, brick and stone pavements (0.05, 0.20 and 0.40) while flat and smooth marble or stone tiles have a higher albedo (around 0.91). For this reason, concrete and asphalt have a higher heat capacity than green areas, what limits rapid cooling during the hot periods.

All design details are affecting the outdoor thermal comfort, so they should be considered/ taken into account in accordance with the solutions that will improve it. For instance, as the creation of shadow improves the thermal comfort during the summer in hot or arid climate, the significant number of vegetation or shading elements should be implemented in the design solution. Or if a certain area is windy during the winter, where the air temperature falls below 0°, it will negatively affect the perception of the thermal comfort. As a solution some wind blockades, using trees or portable single walls, can be designed in order to create a comfortable environment.

Microclimatic parameters

Environmental parameters including air temperature, wind direction and velocity, relative humidity and solar radiation are affecting the thermal comfort and a subjective perception of it.

A study about the diurnal use of open space in Athens (Greece) has examined a neighborhood square and a resting area near the sea through interviews and observations (Nikolopoulou and Lykoudis, 2007). The main factors that were affecting the use of both areas tend to be air temperature and solar radiation. So, the presence of people was highly related to the presence of the sun.

Air temperature

Although air temperature differs according to climate regions it differs according to different surface materials, physical forms or alignment in an urban environment. As relation to differences in surface materials or land cover, the difference in air temperature between urban and rural area is worth to mention as well (Figure 2.8), which tend to vary from 2-5°C (Taha, 1997). Rise or falls in temperature degrees can be perceived differently according to the season, thermal preferences or user behavior. While in some climate zones higher air temperature can be preferred during the winter season, in others lower air temperature can be preferred during the hot summers.

Figure 2.8: Air temperature escalation from rural to urban environment.

Humidity

The role of humidity for outdoor thermal comfort is that it affects the perceived thermal comfort. Although it is related to air temperature in a divergent way, it affects how existing air temperature is perceived in a certain urban environment. The same air temperature is likely to be perceived differently if air humidity differs. For this reason, it is important to implement design solutions that will improve the moisture level in the air. In hot dry-climate regions (deserts etc.) moisture increasing solutions and in the hot-humid climate region moisture reducing solutions should be implemented.

Wind speed and direction

Although being difficult to control (in comparison to humidity or solar radiation), it significantly affects the comfort level at open areas. Higher wind velocity is preferred in regions where hot weather conditions occur (Hot-dry or hot-humid climate regions) due to the fact that it has cooling power and in that way improves the thermal conditions (Seçkin, 2007). On contrary, higher wind velocity is undesired in cold climate regions and it causes lower thermal comfort perception. Although prediction of wind flows in urban areas is difficult, their meaning for passive cooling and heating interventions is inevitable. The airflows in an urban environment depend on topography, building geometry, length and width of the street, vegetation and other local features (Santamouris, 2001). For instance, certain building geometries, the height of the buildings blocks entrance of the wind at the same speed as it is above at atmospheric level. In their study about various canyons in Athens, Santamouris et al. (1999) have confirmed that there has been a difference between the wind speed above the urban canyon and within it; 5 m/s and 1 m/s correspondingly.

The use of wind as natural and passive cooling technique is dependent on an adequate justification of data that the design of the buildings and open spaces should be done according to.

Solar radiation

The inevitable fact that solar radiation has an impact on the thermal comfort which can be simply explained with presence or absence of solar radiation in the certain environment, as well as with the fact that the solar radiation increases the air temperature of the surface. For instance, the presence of direct solar radiation in hot climate regions will cause thermal discomfort, while in the cold climate regions the presence of it will be preferred due to the cold and harsh conditions. Vice versa, the absence of solar radiation during the summer season in a hot climate will lead to thermal comfort and creation of a pleasurable thermal environment, while on the opposite it will be considered as a discomfort during winter seasons in cold climate regions.

Mean radiant temperature

Although air temperature is an important parameter for outdoor thermal comfort, the mean radiant temperature is considered as one of the significant variable parameters. It is ‘'uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure" (ASHRAE, 2001) and calculates all the radiation fluxes over human body within a study area. With a measurement of required parameters, it can be calculated or it can be simulated by various simulation models.

2.4.3 Assessment of outdoor thermal comfort

2.4.3.1 Assessment of outdoor thermal comfort according to index

Assessing outdoor thermal comfort or human thermal comfort is usually done with linkage of microclimate conditions and human thermal sensation (Task Committee on Outdoor Human Comfort of the Aerodynamics, 2004).

One of the most common used indices, PMV (Fanger, 1982), is a seven-point scaled index (+3 = hot, +2 = warm, +1 = slightly warm, 0 = neutral, _1 = slightly cool, _2 = cool, _3 = cold) predicting the mean thermal response of a group of people at certain place. Although it is first developed as indoor thermal comfort index, it is as well adapted for outdoor thermal comfort studies for surveys as well as simulations (Nikolopoulou, Baker, and Steemers, 2001; Cheng et al. 2012, Bruse, 2009; Berkovic et al., 2012). It is calculated by using the equation of human body and thermal environment heat exchange:

$$M + W + Q(MRT, v) + Qh(Ta, v) + Ql(e, v) + Qsw(e, v) + QRe(Ta, e) = S \qquad (2.1)$$

"Here, *M* is the metabolic rate; *W* the physical work output; *Q* the radiation budget, a function of mean radiant temperature (*MRT*) and air velocity (*v*); *Qh* is the turbulent heat flux of sensible heat, a function of air temperature (*Ta*) and air velocity; *Ql*, the latent heat flow due to evaporation of moisture diffused through the skin, a function of air humidity (*e*) and velocity; *Qsw*, the latent heat flow from sweat evaporation; *QRe*, the respiratory heat flux (sensible and latent); *S*, the storage" (Berkovic et al., 2012).

PMV is a function of a local climate, so when simulating it can reach -4 or +4 (above or below). Being a stationary value it predicts the value according to a person being at the certain place for some time (not transit).

Another index for thermal comfort assessment is Physiological Equivalent Temperature (PET) defined by Mayer and Höppe (1987) differs from PMV as it interprets the thermal comfort in degrees Celsius (℃) and models the thermal conditions of the human body in a physiological aspect. It is the air temperature at which the energy budget of the human body is sustained by the same skin and core temperature at which outdoor conditions are to be assessed (Höppe, 1999). PET is based on the Gagge-2-node model relating the skin and core temperature generated by the outdoor environment to the indoor air temperature resulting in the same temperatures.

Besides these, there are other analytical tools for assessing human thermal comfort to the outdoor environment such as Index of Thermal Stress (ITS), the OUT-SET (Standard effective temperature) and COMFA outdoor thermal comfort model (Givoni, 1976; Pickup and De Dear, 1999; Kenny et al., 2009). However, these models are not including the dynamics of the human body that affect the thermal adaptation (Chen and Ng, 2012). Although there are some models including these aspects they seem to be unfeasible and unpractical in outdoor environment due to the need for extensive monitoring. Still, these models can be implemented for indoor studies as well as simulation cases (Bruse, 2005, Havenith, 2001; Battista et al., 2016; Lee et al., 2016).

Universal Thermal Climate Index (UTCI) is suggested by EU COST Action 730. The calculation is based on a simplified regression model by Peter Broede. SET value calculates Standard Effective Temperature according to ASHRAE Standard 55-2013. The parameters are defined and fixed: body weight as 69.9kg and Body surface area 1.8258 m^2).

2.4.3.2 Assessment tools: survey, measurements and simulation

According to numerous fields of studies for outdoor thermal comfort being conducted, the main assessment methodologies are survey, measurements, and simulation.

Survey studies are conducted in order to determine users subjective thermal comfort perception, satisfaction or adaptation. Questions usually aim to collect demographic data at first and then current characteristics of the user (activity level, clothing, height to weight ratio, the reasons for visiting, as well as the time of exposure). This data is afterward correlated with the last part of the questionnaire, where questions about thermal comfort perception, satisfaction and preference are taking place.

Field measurements are conducted with measurement devices in order to obtain data about meteorological conditions in open spaces. Usually, a portable mini-weather station is used for measuring the general conditions of the environment. In the study area, the measurement points are marked and with the use of the device, data has been collected from these points. For obtaining the accurate result, measurements are done at every point for a couple of minutes than average value is considered as a current condition. Mini- weather station is usually set to measure at 1.1 m as proposed by Johansson et al., 2014. Data obtained from the device can be used for creating maps about meteorological conditions in the environment. Additionally to this device, measurements can be conducted with portable devices as well. Portable devices are usually used parallel with surveys, in order to measure conditions that user is facing at the certain point or during the certain routes (Klemm, 2015).

Simulation tools are used for numerical determination of outdoor thermal comfort within a certain environment. They offer the assessment of not only existing conditions but the creation of various scenarios in terms of microclimatic conditions as well as physical configurations. For this reason, simulation software can be used as a vigorous tool for pre-design/post-design evaluations.

All of these methodologies are used to investigate the environments according to the study aims. For instance, if studying the impact of outdoor thermal comfort on human metabolic rate then measurements of the environmental conditions, concomitant with the user body measurement is conducted in order to determine the relation in between both. Or if the satisfaction level of users is investigated then survey questionnaire is implemented in order to collect the subjective responses. Similarly, if the impact of urban built environment and microclimatic parameters is investigated then a tool that will provide the best variety for assessing these parameters are simulations tools such as TownScope, Rayman, UrbaWind and ENVI_met.

Simulation tools

TownScope is based on solar access decision making for a sustainable urban design perspective (Teller and Azar, 2001). It contains solar evaluation tools with a three-dimensional urban information system. The scale of the simulations is determined as urban design, examining interactions between urban open spaces and surrounding environment (buildings, roadways, pavement, vegetation etc.). However, the software does not provide the data for other weather parameters (air temperature, wind and humidity), the PMV, PET or any other index assessing the human thermal comfort and does not allow simulations for any other day except June, 15^{th}.

Rayman is a tool for calculating the radiation fluxes within an urban environment by model approaches including air temperature, humidity, cloud cover, air transparency and time and date when the simulation is done. It takes into considerations various aspects. For estimating the radiation flux density the model divides environment into two layers, upper and lower hemisphere, where lower one has a sky view factor covered by solid surfaces and its adjustment can be done easier than upper. Rayman can model the urban environment in two ways. The first one is by using fish-eye photographs, while the second is a detailed design of built environments such as buildings, trees and other obstacles (Matzarakis et al. 2007).

UrbaWind is modeling software for pedestrian wind comfort, specially developed for urban areas. As a tool, it determines discomfort areas and is important in for mitigation of uncomfortable urban environments (Meteodyn, 2018). It calculates the wind characteristics and effects of the buildings on the wind flow. As a result, the coefficient of the mean and gust velocity, turbulence and pressure coefficient can be obtained. With results, evaluation in terms of wind comfort, energy and natural ventilation can be done (Fahssis et al., 2010a; Fahssis et al., 2010 b).

ENVI_met software has been used worldwide as a tool for assessing the outdoor thermal comfort. The increase in interest in climate change and heat island effect has led to widening the scope of outdoor thermal comfort studies assessed by ENVI_met. It is important that ENVI_met can be used for micro as well as macro level studies. There are a number of studies implemented on the urban scale (Battista et al., 2016; Lee et al., 2016; Elnabawi et al., 2015), as well as those implemented for certain open spaces such as squares, parks, courtyards, urban canyons (Lobaccaro, 2015; Salata et al., 2016). Moreover, there are studies assessing the effects of surface finishing materials as well as facades materials on outdoor thermal comfort; or the effects of trees and green areas (Morakinyo et al., 2016). Not only the outdoor thermal comfort, but the energy saving potential of green spaces is examined as well (Kong et al., 2016).

Main capability of simulation tools should be including the air temperature, solar radiation, humidity and wind data because these parameters have been the key factors influencing the outdoor thermal comfort. In simulation tool lack in term of one of these, then the complexity of outdoor thermal comfort issues will not be apprehended enough. As outdoor thermal conditions affect the user, then the tool should include the user related data and track the changes according to the outputs.

As a short preview of the simulation tools including assessment index, capabilities and outputs, limitations and recent studies figure has been created (Table 2.1).

Table 2.1: Preview of simulation tools.

TOOLS	**ENVI_met**	**TOWNSCOPE**	**RAYMAN**	**URBAWIND**
Input	3D model (buildings, vegetation, surface materials) meteorological data, user-related parameters	-	Topography, obstacles, fisheye photographs, sky view factor, data import	CAD files, .stl data Atmospheric boundary data layer
Index	PMV,PET, UTCI,SET	-	PET, PMV	-
Ability	The distribution of heat, air flow, humidity and radiation based on thermodynamic and fluid and then predicts outdoor thermal comfort by solving the interaction between air, plants and buildings.	Thermal comfort related to solar radiation	Radiation fluxes and mean radiant temperature	Wind flows and pedestrian wind comfort
Output	Maps, graph, table The atmosphere, Buildings, Inflow, Pollutants, Radiation, Soil, Solar access, Surface, Vegetation, PMV index	Solar access, sky view factor	Graph, table Polar diagrams, data table, daily data. shade	Maps, graph, table The coefficient of the mean velocity, the coefficient of the gust velocity, turbulence, pressure coefficient, Wind comfort, wind energy, natural ventilation
Drawbacks	Does not allow CAD or shapefile input Work on grid-based modeling Wind distribution is constant	Does not provide the data for other weather parameters and index assessing the human thermal comfort Does not allow simulations for any other day except June, 15th.	Assess thermal comfort by manually entering data on a point (just one point) lack of compatibility with low solar angels inability to account for reflected short-wave radiation	Does not provide the data for other weather parameters (air temperature, solar radiation and humidity),
References	Elnabawi et al,2015; Lobaccaro, 2015; Battista et al, 2016; Lee et al, 2016; Salata et al,2016; Morakinyo et al, 2016; Kong et al.,2016; Wang et al, 2017; Perini et al, 2017; Morakinyo et al, 2017; Zhu et al, 2017; Reinhart et al, 2017; Taleghani et al, 2017; Tsitoura et al,2017; Kolokotroni, 2017; Gobakis et al,2017; Tan et al, 2017; Kyriakodis et al, 2017; Sun et al, 2017; Zha et al, 2017; Kolokotsa et al,2018; Acero et al, 2018;	Teller and Azar, 2001; Marique et al, 2017;Canan, 2017;	Matzarakis et al.,2007; de Abreu-Harbich et al, 2015; Konarska et al, 2014; Fang et al, 2018; El-Ashry et al , 2017; Kwon et al, 2017;	Fahssis et al., 2010a; Fahssis et al., 2010 b; Saquer et al, 2017; Constanzo, 2017; Gedik et al, 2017;

3. METHODOLOGY

With literature review, the main issue of the topic has been outlined. The significance of the microclimate for the urban built environment as well as open spaces has been inevitable. From the very beginning of the settlements planning and design principles, the respect for nature and natural processes have been considered in order to create pleasurable and comfortable living environment. With population growth, especially urban, the establishments of dense urban built environments have enhanced emphasize on economic development to overcome social and environmental developments. Not only the urban built environment has been influenced, but the open spaces where people spend their time and perform leisure activities or just use as a transit area have been confronting social as well as environmental issues. This has been mainly related to the need for new developments (dwelling units, business districts etc.) leading to the lack of provision of qualitative open spaces. But, as one of the indicators for qualitative open spaces is being comfortable and pleasurable, the environmental impact on open spaces should not be disregarded. Environmental impact over open spaces can be observed at every scale; from various climatic conditions (meteorological conditions-mesoscale) to the physical environment configurations (microscale) affecting the creation of various microclimatic conditions in the built environment.

In addition, there is a difference in between urban and suburban built environment due to the variety of building configurations, land use as well as in the integrations within them. These further affect the open spaces and microclimatic conditions shaped in them. For instance, in the dense city centers, open spaces are surrounded by high-rise buildings, the solar radiation and wind corridors are affecting the pedestrian level different from the suburban area open spaces. Due to the dense urban fabric, wind corridors might get blocked and decrease comfort in summer seasons. Or the high-rise buildings might prevent direct solar radiation access the pedestrian level during the cold winters and cause discomfort. On the contrary, the suburban areas although being built-up environment with a determined master plan are facing different effects from surrounding environment. The surrounding environment usually being low-dense settlements or even forest or agricultural areas is having a lower impact on open spaces. In this case, the meteorological effects on open spaces can be observed directly; similarly, the advantages and disadvantages of physical environment configuration facing these meteorological conditions can be observed objectively.

The university campuses, although being located within suburban areas, can be considered as urban settlements, hosting a large number of population and providing not only educational but recreation and leisure services too. Additionally, the significance of open spaces for a university campus is evident in terms of providing a pleasurable environment where users, usually students, can spend their free time, relax during the classes breaks. Moreover, the open spaces of university campus can be considered as learning spaces, where classes are held and students have a direct relationship with nature. Students usually tend to remember the open spaces more than classrooms. Those are the places where they enjoy with friends, join social activities and relax. They tend to do this usually every day, during a long period of their study years. For this reason, it is important to achieve user satisfaction not only in terms of education but in terms of socialization and provision of recreation, relaxation and enjoyable areas.

The impacts over the use of open spaces can be examined under numerous topics such as behavioral mapping and occupation pattern analysis, space syntax analysis, spatial statistical and morphological analysis, user satisfaction evaluation and many others. One of the topics investigating the physical and natural environmental parameters affecting open spaces while taking into consideration user as well is the outdoor thermal comfort. In this study, after a brief explanation of outdoor thermal comfort issue, its assessment principles and methods are given. Within the context of case study area main principles and issues are reviewed and methodology of the study has been obtained.

As previously explained, outdoor thermal comfort issue has been considered as the complexity of climate, physical environment as well as human aspect. Directly affecting the users, that are the indicators for a successful environment, it should be regarded as a guideline for planning and design principles. It is the outdoor thermal comfort that allows us to enjoy in a certain environment. If thermal conditions of the environment are causing discomfort and stress, then people avoid those kinds of places and look for a more comfortable one.

3.1 Assessment Parameters

Although there are a lot of parameters affecting outdoor thermal comfort, they can be clustered into two main groups: user-related parameters and environmental parameters. User-related parameters are containing physical, physiological, behavioral and psychological data about user characteristics. The difference in the background (Lin, 2009), age, gender, metabolic rate and activity (Zacharias et al., 2001), clothing (ISO 9920, 2007), time of exposure all tend to affect the subjective perception of outdoor thermal comfort. To the other extent, the environmental parameters (physical environmental and microclimatic) are having a crucial role in the creation of the microclimate and though on outdoor thermal comfort. Meteorological parameters (air temperature, humidity, wind speed and direction, solar radiation) are affecting the creation of local microclimate (Nikolopoulou and Lykoudis, 2007). These climatic conditions differ regionally as well as seasonally. However, the physical parameters of built environment, such as geometry and layout of buildings, height and widths, surface materials, sky view factor, presence of vegetation or shading elements, as well as water elements are affecting the outdoor thermal comfort too (Shashua-Bar and Hoffman, 2003; Teller and Azar, 2001; Aida and Gotoh, 1982; Kruger et al., 2001; Santamouris et al., 2011; Barring et al., 1985).

3.2 Assessment Methodology

Outdoor thermal comfort can be examined in three different ways: measurements, survey or questionnaires, and simulation. There are studies using more than one method in their study in order to determine and validate one or the other. The meteorological field measurements objectively assess thermal conditions, such as air temperature, wind speed, and direction, humidity or solar radiation. Surveys assess users' subjective perception of thermal environment in terms of comfort or discomfort, collecting detailed data about the user. Simulation, on the other hand, offers to assess thermal comfort in terms of behavioral, physiological and microclimatic parameters. It can be considered as the most inclusive method where a high number of variables affecting each other have been involved in the simulation process.

Assessment method in this thesis has been selected to be the simulation, in order to emphasize the importance of the pre-design/post-design process, where urban designers should use simulation tools during the design process as well as after built for improvements to be done. Because of the fact that microclimatic design affects the thermal comfort at open spaces, it is important to create a pleasurable environment for users. The role of the simulation programs has been vital at this point, as the planned project can be simulated and issues or negative points can be determined and design can be modified using different scenarios before the implementation. Still, for the projects already implemented simulations should be conducted in order to improve the existing conditions. The accuracy of simulation programs plays an important role at this point that is why validation with a pilot study should be implemented in order to determine accuracy.

3.3 Assessment Simulation Tool

There are various tools examining the outdoor thermal comfort, such as TownScope, Rayman, UrbaWind, and ENVI_met. Although the purpose of the tools has been the same (assessing the outdoor thermal comfort), the capabilities and parameters assessed, as well as input included differs. Additionally, the outputs of every tool differ as well. The most comprehensive tool beyond the other programs, ENVI_met, within this context, calculates flows within the environment and solves interactions between air, plants, and buildings. When compared to other simulation tools, it provides a variety of parameters to be determined what is important for creating different scenarios. Likewise, the range of outputs obtained is rich and allows comparing data within the software. For this reason, ENVI_met simulation software has been selected as the assessment tool.

3.4 Assessment Index

In order to describe and determine the outdoor thermal comfort, indices are developed for standardization and better complementation within studies worldwide. The most common one is Predicted Mean Vote (PMV) index used for prediction of the mean thermal response of a group of people at the certain place. Its seven-point scaled assessment index, starting from -3 (cold) to +3(hot). ENVI_met simulation software provides assessing outdoor thermal comfort via PMV, PET, UTCI, and SET. As PMV is being the most common, it has been selected for assessing the outdoor thermal comfort.

To summarize, open spaces of university campus are examined in terms of outdoor thermal comfort. Firstly, a simulation model which integrates user related and environmental parameters to assess the outdoor thermal comfort for an existing open space has been proposed (Figure 3.1).

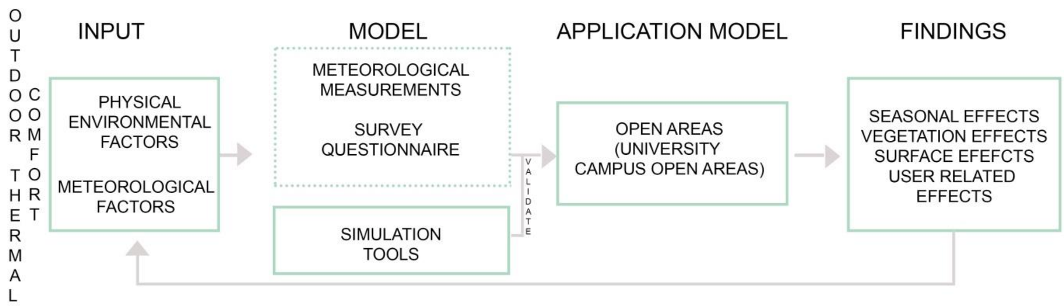


Figure 3.1: The methodology proposed for assessment of outdoor thermal comfort.

An application model has been created for Ozyegin University campus. Additionally, the application model has been run for various scenarios obtained by changing the environmental parameters such as seasonal meteorological condition, vegetation, as well as user-related parameters such as activity level, clothing, and height to weight ratio. The outcomes of the simulation were assessed in accordance with PMV Index.

3.5 Study Area: Ozyegin University

Özyeğin Foundation began its efforts to found Özyeğin University in the autumn of 2005. But, it was officially founded on May 18, 2007, with the mission of contributing to social development by producing creative, original and applicable knowledge through its modern education system, its innovative structure integrated with life and its academic programs focused on the service sector. However, Çekmeköy Campus opened its doors in September 2011 and at that, the university has increased the total area of its campuses to 136,000 m^2. It is located on the peripheries of Istanbul, close to the northern forest areas and 3rd bridge high way (Figure 3.2).

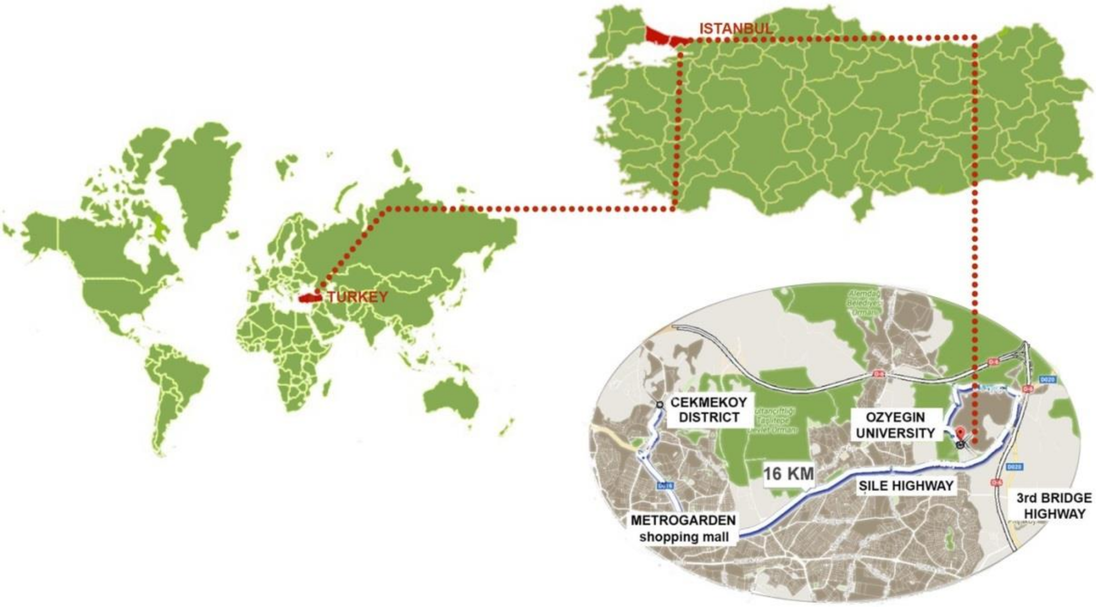


Figure 3.2: Campus location.

Not only each of the first three buildings of the Ozyegin University Cekmekoy campus buildings, Faculty of Engineering, Academic Building 2 and Student Center (Figure 3.3), is awarded LEED-New Construction Gold certification, but also Ozyegin University Cekmekoy campus is considered as one of the firsts in Turkey as the green campus. Many important topics such as stormwater and plumbing systems, mechanical and electrical systems analyzed as a whole in campus and all the work from the design stage up to the selection of materials was planned according to the principle of these three buildings to be interactive with each other as the parts of a whole. With the same principle, the design of green areas works such as site pollution prevention, indoor air quality, and construction waste management was planned and carried out by approaching the campus as a whole.

University has been listed into ISCN and Green Metric ranking list (Greenmetric.com, 2018). In order to achieve enhanced rankings, from the very beginning university settled aims and targets. Buildings and their sustainable impact, minimizing environmental impacts such as energy and water consumption or waste, and moreover producing own energy make campus sustainable. To ensure buildings on campus can meet these goals in the long term campus applied for LEED

Certificate and it has been awarded it. The campus has buildings that have many features enabling energy consumption such as collecting rain to use a source in terms of water or grey water collected from taps will be refined to be used as flush water. There are some methods which are used for energy saving too. Also, the buildings are environmentally friendly and they give tremendous attention not to harm the nature and natural resources in the campus. Some roofs are covered with green areas, while other have solar panels used for producing solar energy that has been further used for campus needs.

One of the evaluation principles for rankings was not only planning the campus as an independent settlement but a settlement that would have integration with the surrounding environment. Caused by the surrounding military forest areas on the west and tilting (sloping) area on the east, the university had to be planned within itself, still benefiting from both of these areas. Having edges of the campus area determined from the beginning happened to be advantage according to which campus has been planned and designed. Hence, within these edges, the alignment of buildings, relations of one to each other and creation of open spaces were the major design principles. The advantage is seen in a way that all the buildings and functions are planned within these borders, so even though new development occurs it will be done within same borders. Otherwise, the matter of campus unplanned development causes abolishment of surrounding forest or agricultural areas (Ilgaz, 2014). Although not benefiting from nearby forest areas directly, the layout and design of open spaces tend to benefits from them in a way that main open areas are confronted to it and users can enjoy in view.

Figure 3.3: The master plan of Ozyegin University Campus.

3.5.1 Campus layout

According to the campus systems and layout explained in the literature review, Ozyegin University at first look can be categorized as a nuclear system campus where the huge open area is located in the middle while dormitories and faculty buildings are built up surrounding this open area. Still, due to the slope separating faculty buildings from the main recreation area, it would be accurate as well to categorize campus as a linear system campus (Figure 3.4). Similar to Bath University and METU, the main alley is designed to hold main faculty buildings and open spaces integrated. The retail and recreation facilities are placed along the main alley as well. There is one main and two small courtyards confronted to nearby forest areas, plus terraces opposed to the campus main recreational areas in the middle. It is obvious that all open spaces are integrated with existing buildings, still benefiting from surrounding natural areas.

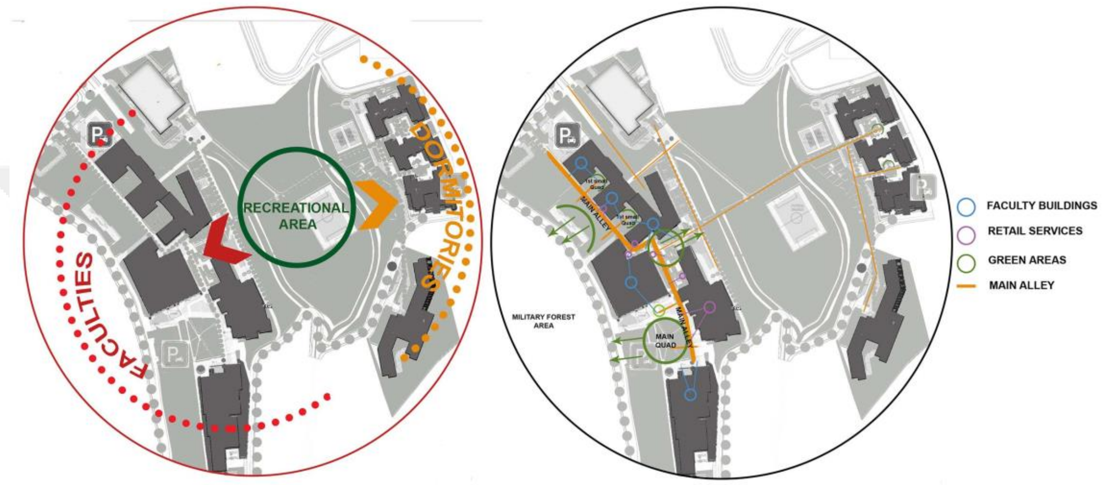


Figure 3.4: Campus layout and system- a) nuclear system b)linear system.

3.5.2 Campus open spaces

In this part, open spaces of case study have been explained. The study area has been divided into five sub-areas, as seen in Figure 3.5, in order to give a brief explanation about open spaces separately. Areas have been subdivided according to physical characteristics or their main use, such as square, courtyard, terraces etc.

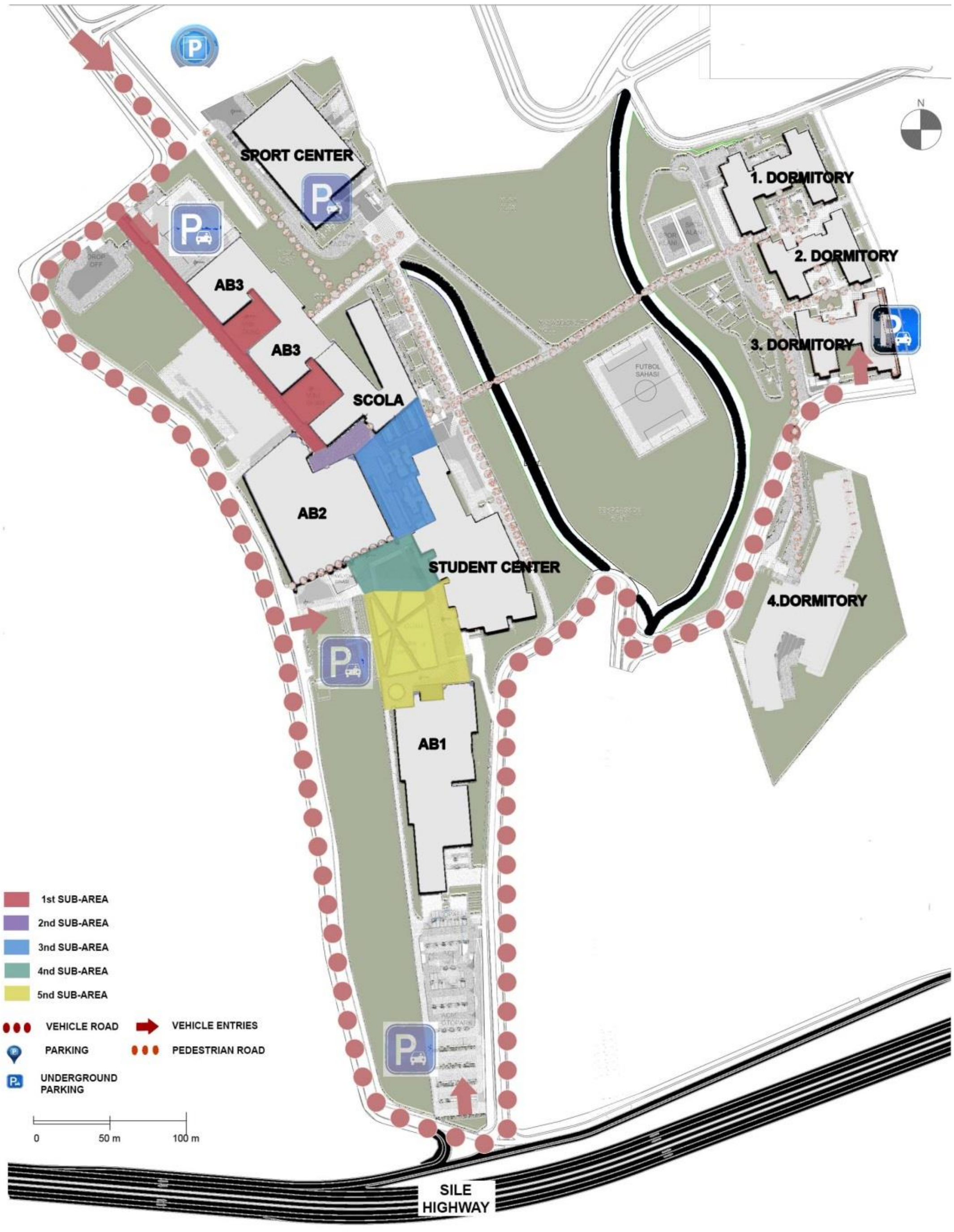


Figure 3.5: Sub-areas of Ozyegin University Campus.

First sub-area (Table 3.1), starting from the northern part of campus begins with the main alley. Two small courtyards are connected to the main alley and provide a recreation area for students during the class breaks. On the western side of the alley, white marble roof of Innovation Centre is located. Here, benches are settled towards the nearby forest in order for users to enjoy the scenery. However, the area still lacks in terms of sitting, shading and lighting elements. For this reason, it is usually used as a transit area. Another demerit is the solar reflection of the white-marble roof during the sunny days, causing pedestrians to avoid this area.

Table 3.1: Merits and demerits of the first sub-area.

Spatial function: Main alley integrated with two courtyard and white marble roof
Green design: shrubs and decoration trees
Major use: Transit

Merits

The beginning of the Main alley

- Two small courtyards connected to the main alley
- The scenery over the nearby forest areas
- Variety in terms of surface materials
- Integrated landscape elements

Demerits

- Lack of sitting, shading and lighting elements
- Used as a transit area
- Lack of food/drink services
- Reflection of white-marble roof

Second sub-area being located between the two buildings (SCOLA and AB2) is having the character of a node where students prefer spending short class breaks. Although connecting 1st sub-area to other areas within campus; the function of the main alley loses its form and has been more perceived as a square (Table 3.2). It usually hosts passive activities such as sitting or standing, occupying the service areas of restaurants. These areas are located under arcades, providing shadow during the sunny days and protection from the rain as well. Yet, the area lack in terms of vegetation and water elements that could improve the environment.

Third sub-area consists of landscaped terraces providing scenery over the recreation areas in the middle of campus. It is rich in vegetation such as sampling trees and shrubs, still not providing shadings (Table 3.3). As connecting the faculty area with dormitories, the area has been intensively used as transit. Although having the potential for passive activities in terms of sitting elements and scenery over the recreation areas, lack of shading elements is the major reason for this area fails to attract long-term passive activities.

Table 3.2: Merits and demerits of the second sub-area.

Spatial function: Node for short breaks **Green design:** Sapling trees **Major use:** Passive activities (Sitting, standing, eat/drink) **Merits** • Providing food/drink services • Connects 1st sub-area to other areas within campus • Having “node” character • Passive activities are taking place • Sitting elements located in shadowed areas under the arcades **Demerits** • Lack of sitting elements • Lack of vegetation and water elements • Lack of landscape and scenery	 

Table 3.3: Merits and demerits of the third sub-area.

Spatial function: Landscaped terraces integrated with the main alley **Green design:** Sapling trees, shrubs, decoration plants **Major use:** Transit **Merits** • Connects faculties with dormitories and recreation areas • High transit use • Variety in terms of surface materials • Integrated landscape elements **Demerits** • Lack of shading elements • Used as transit area only • Lack of food/drink services • Weak passive use (standing and sitting)	 

Although being integrated with the main quad, the fact that forth sub-area has been designed as a square with hard-surface material makes it differs from the main quad. It provides a view over the nearby forest and has integrated landscaped elements around sitting elements. Yet, the trees fail to provide significant shadow during the hot weather conditions, what is the main reason for users to avoid the area for long-term activities. These kinds of activities are usually performed at the eaves of the buildings (Table 3.4).

Table 3.4: Merits and demerits of the forth sub-area.

Spatial function: Square **Green design:** Sapling trees, decoration plants **Major use:** Transit **Merits** • Located at the beginning of Student Centre • Square integrated with the main quad • Potential to host campus crowd • The scenery over the nearby forest areas • Integrated landscape elements **Demerits** • Lack of shading elements • Transit area occasionally hosting passive activities • Building corners preferred for passive activities • No water elements	 

Fifth sub-area is the largest open space in the faculty section and it is located in front of the Student center, AB1 and AB2 (Table 3.5). At the same time, it is the most intensely used area, due to the high number of amenities and services providing. It accommodates passive activities, short-term and long-term as well as transit activities. Passive activities are usually performed at the edges of Student Centre where café provides food and drinking services, as well as sitting and shading elements. During the comfortable weather conditions quad is used for long-term leisure activities, such as lying down, enjoying the landscape etc. But during the hot weather conditions, lack of shading elements affects the use of quad negatively. Although area consists plenty of trees, they fail to provide enough shading due to the size and shape of the canopy. Similarly, during the cold winter conditions, lack of protection from rain and harsh winds causes absence of users. On the other side, active users can be observed during all seasons due to the main alley connecting Student Centre with other faculty buildings.

Table 3.5: Merits and demerits of the fifth sub-area.

Spatial function: Quad connected with the main alley
Green design: Sapling trees, shrubs, decoration plants
Major use: Recreational

Merits

- The main quad is the largest open space in the faculty zone
- The student center, AB1 and AB2 making area crowd
- The scenery over the nearby forest areas
- Variety in terms of surface materials
- Provide drink/food services
- Quad host passive activities
- Continuity of the main alley
- Integrated landscape elements

Demerits

- Lack of sitting and shading elements
- Passive activities are performed at building corners under the shadowed areas
- The path on the western part of the quad is rarely used
- The certain part of the quad is not used due to the lack of shading and sitting elements
- Sitting elements

3.5.3 Microclimate data of study area

According to Ersoy (2009), there are five climate regions in Turkey: Cold climate region, temperate climate region, Mediterranean climate region, Hot and arid climate region and hot humid climate region. Istanbul is having a temperate climate, with hot and cold climate condition being balanced throughout the year. For this reason, the environment should be planned and designed according to different needs for each season.

One of the issues affecting the creation of a microclimate is land use or in other words nearby green or built-up areas. For a positive impact in terms of creating a pleasurable and comfortable climate, forest areas and water surfaces, especially pastures and meadows, agricultural areas have great prospects. Considering the general land cover distribution of Istanbul (Figure 3.6), 20% of Istanbul's land has been constructed, 46% forest areas, 22% agricultural areas, 3% water surfaces and marsh areas (excluding river beds), 2% maqui, 3% are meadow and pasture areas, 1% are mine and 1% are military sites (Onur, 2014). Still, the integration and distribution of these areas are more noteworthy than its presence. If the green and forest areas are not well distributed and integrated into the urban environment, then its impact on creating a comfortable climate- in this case microclimate- is doubtful.

For this reason, the implementation of green areas within the city, even though in small scales can help improving local climatic conditions.

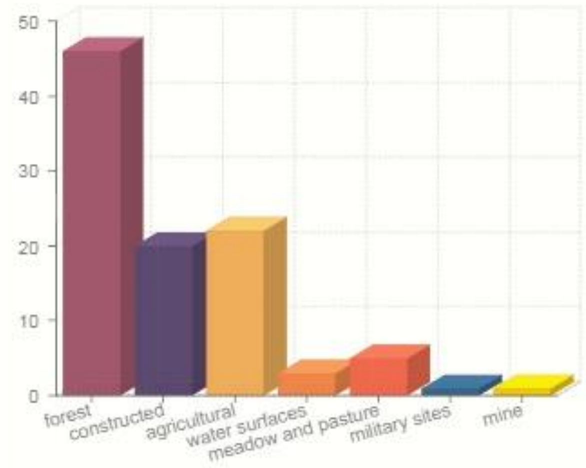


Figure 3.6: Istanbul land distribution (adopted from Onur, 2014).

Additionally, Ersoy (2009) states how cities in this climate region should be planned in harmony with nature; lawn areas should be improved with grouped trees; open spaces and streets should be aligned in a southwest direction in order to be protected from cold winds in winter and offer softly and cool winds in summer. Vegetation can be used as a wind barrier in cold winter, still not impede the air flow in the hot summer period. Coniferous trees can be used for this purpose. On the west and east sides of the buildings, trees providing significant shadow should be implemented. Building forms can be used as a cross, however, if an east-west alignment is used then the length of the buildings should be maximized. In this climate region, east orientation (starting from the south 17.5^0C) balances the heat distribution the best. Colors used in this region should be of medium darkness; at the roofs and terraces, light colors should be used, while dark colors can be used only at the surfaces where the sun does not reach.

Within this context, the evaluation of the campus has been done:

1. The campus is located at the periphery of Istanbul, at the edge of Istanbul North Forest and Sile Highway (Figure 3.7). Surrounding settlements are low-dense buildings, though not affecting the microclimate conditions at the campus as they do not block the wind flows or create any wind corridors. The nearby forest area prevents heat absorption and mitigates the heat island effect.

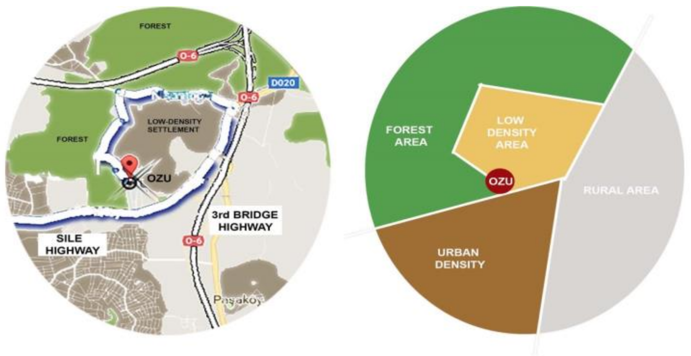


Figure 3.7: Land use of the campus surrounding area.

2. Buildings of the campus have been aligned in the northwest-southeast direction, creating main open spaces to be on the western side, such as main quad and two courtyards. Various bushes and ground vegetation have been used in landscaping the open spaces. Additionally, there are few types of trees used such as Liquidambar styraciflua, Magnolia grandifola, Acer palmatum butterfly, Cupressus macrocarpa goldcrest and Picea abies (Figure 3.8). Although there are plenty of trees in open spaces, they lack in providing any significant shades due to the canopy size and shape. As they are young trees, canopies are still insufficient. On the contrary, as proposed by Ersoy (2009) that trees should be grouped, trees are planted singular or in row lines. At certain points, row lined planting can be considered an advantage used for blocking wind flows.

Figure 3.8: View of the campus vegetation and building facades.

3. The colors of the building surfaces are of medium lightness, still not dark. Predecessor color is grey, with high use of glasses. For this purpose, the sun

blinds over facades facing direct sun rays are used in order to block solar reflection. The roofs of the buildings have been vegetated or covered with the white pebbles and solar panels. Surface materials of open spaces are majorly light colored or green areas. Light colors prevent heat absorption; however, they may cause solar reflection disturbs pedestrians.

3.6 Application Model

3.6.1 Assessment tool

Hence, ENVI_met has been selected as a simulation tool since (i) it allows creating 3D model, (ii) input meteorological data such as air temperature, humidity, wind speed and solar radiation and user-related data such as clothing, gender, activity and height-weight ratio, and (iii) provides outputs of microclimatic data as well as outdoor thermal comfort with assessment indexes.

In this section, the simulation tool has been introduced and the simulation process explained.

3.6.1.1 ENVI_met simulation software

ENVI_met model calculates outdoor thermal comfort by solving the interaction between air, plants and buildings (Bruse, 2009). It is a numerical prognostic model that calculates the distribution of heat, air flow, humidity and radiation in the urban environment based on fluid and thermodynamics.

The model is based on a grid-system of 250x250x25 grid cells. Every grid cell can be determined to be at the required size in meters, such as 1m, 2m for smaller areas or 5m, 10m for large or areas at urban scale (min 0.5m, max 10 m). A 3D model of the study area is created, with opportunities to define the building and façade materials. Soil type is defined as well as the ground surface for which a library of data is provided so that there are options for detailing study areas such as concrete, asphalt, granite and many others. Moreover, there is a database manager allowing a user to create a database for its own case study with exact determination of material values. Similarly, the vegetation type can be determined with a range of tree and plant species. Again, data can be created manually if the required species are not available. The software provides choosing the location of the study area or defining the longitude and latitude at which area is found. Afterward, data about weather conditions of the simulated day, obtained from Alemdag meteorological station has been used as an input. In order to be precise and create real environmental conditions, meteorological data should be obtained from local meteorological stations.

Input data

In the beginning, data used as input of simulation, obtained from Alemdag Meteorological station, for a specific date is the wind flow (m/s) and direction, initial temperature (^{0}C), relative humidity (%). Next step requires defining the minimum and maximum temperature and humidity, with an option to "force temperature and humidity" that distribute values through the day or user can enter data hourly for temperature and humidity. Solar radiation and amount of clouds can be modified as well. Optionally, pollutants or chemical species can be added. Finishing these steps lead to running the simulation. Though, there is an option to first check the simulation file before running. This step eventually provides the details about errors that would disturb the simulation process and allows the user to repair the simulation file and run it afterward.

Simulation process

Simulation process, depending on the computer configuration, size of the area and hours simulated, can last a couple of days. In order to obtain the most accurate results, the simulation should be run at least for a few hours before the selected date for simulation. For instance, if a simulation is run for 5th July and the output used would be for all the day (00.00h – 23.59h) than the starting hour for simulation should be on 4th July.

At the end of the simulation process, hourly microclimatic data is obtained. It is divided into separate folders such as atmosphere, pollutants, radiation, soil, surface, vegetation etc. The most commonly used is data related to atmosphere, as it contains air temperature, wind speed, humidity and radiation data. This data set is further used for obtaining results about the outdoor thermal comfort of the study area.

BIO_met tool

An extension of software, Bio_met, is used for calculating the PMV/PPD, PET, UTCI and SET. The section containing personal human parameters (age, weight/height, gender, clothing parameter and body metabolism rate) can be defined manually or reset to a "Standard Human" according to ISO 7730. Still, if the study area is mostly used by a group of people with similar characteristics then it can be defined manually (university campus- majority profile of users are students around 20 years old; home for elderly- majority profile above 75 years old etc.).

Leonardo extension

Extracting the simulation data and observing the results, as well as creating 2D and 3D maps have been done by Leonardo extension (Figure 3.9). Data layer settings and legend can be modified. Data can be extracted as a color or contour layer. This allows two data (eg. Temperature and wind speed) can be visible at the same time. In case of data comparison during the day (morning and afternoon results), two data layers can be extracted at the same time and then compared. Map extracted show the difference in degrees, according to the reference file.

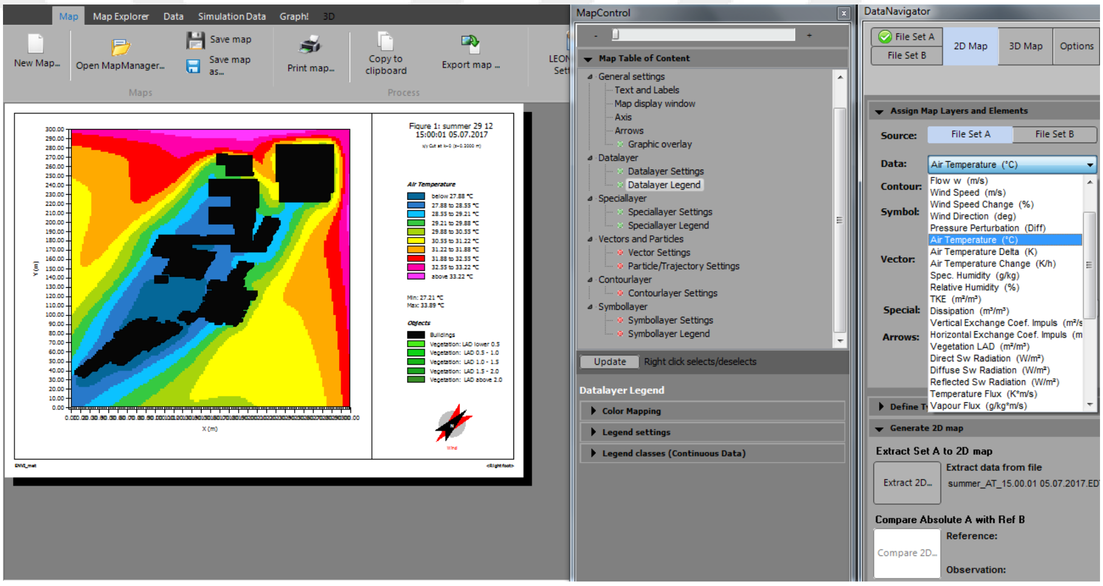


Figure 3.9: View from Leonardo tool

The work flow of simulation software can be summarized as follows: i) 3D model where size of the area, use of materials and vegetation has been created ii) as input to the model meteorological data has been specified iii) model has been checked and if there is no any issue simulation has been run iv) outputs of microclimatic conditions in a case study are obtained v) with use of atmospheric data as a base for BIO_met tool and including personal human parameters PMV Index has been calculated vi) the results have been viewed via Leonardo Tool extension where 2D and 3D maps have been obtained (Figure 3.10).

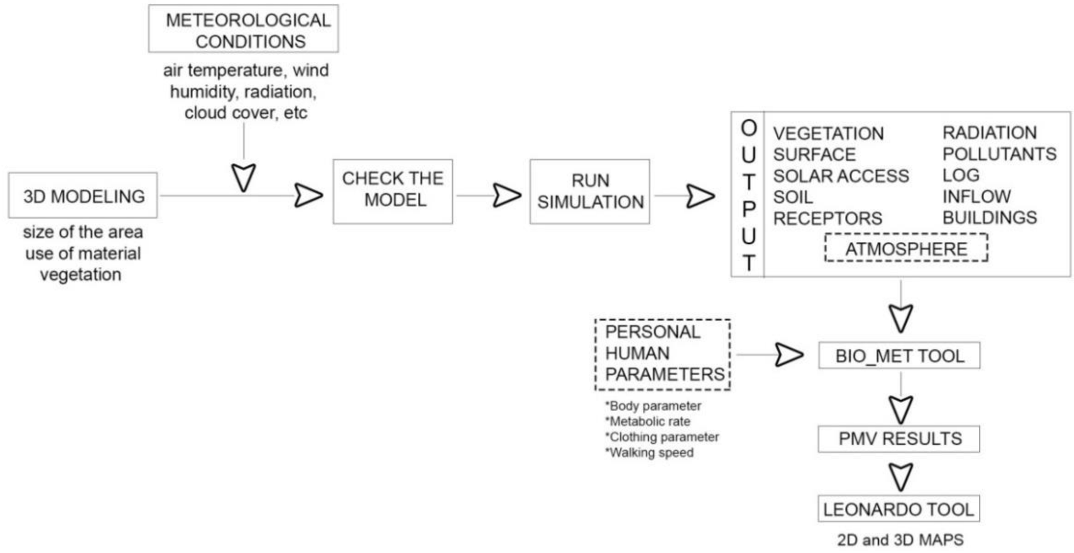


Figure 3.10: Workflow of ENVI_met simulation tool.

Drawbacks and limitations

However, there are some drawbacks of the software. Firstly, working on a grid base is decreasing the geometric accurateness in the creation of a 3D model of the study area. As so, an environment having an irregular shape (round etc.) cannot be represented well. Secondly, the wind distribution is constant during all simulation times, what affects the final result of thermal comfort perception.

3.6.2 Generation of the 3D model for the case study

The ENVI-met model requires the user-specified space input file to create the 3D geometry of the built-in space. The following steps have been taken in creating the 3D model of the settlement:

1. A 300x300-grid area has been created horizontally at a resolution of 2 meters, and the area around the site has been included in the analysis to reduce the potential error margin.
2. In the vertical direction, an area of 25 grids (each grid square considered as 2 meters) has been created.
3. ENVI-met model has been created with nested grid cells to minimize border effects.
4. The entire campus has been selected as the study area. Thermal comfort has been studied in open spaces of the campus consisting of faculty buildings and the main walking path (Figure 3.11).

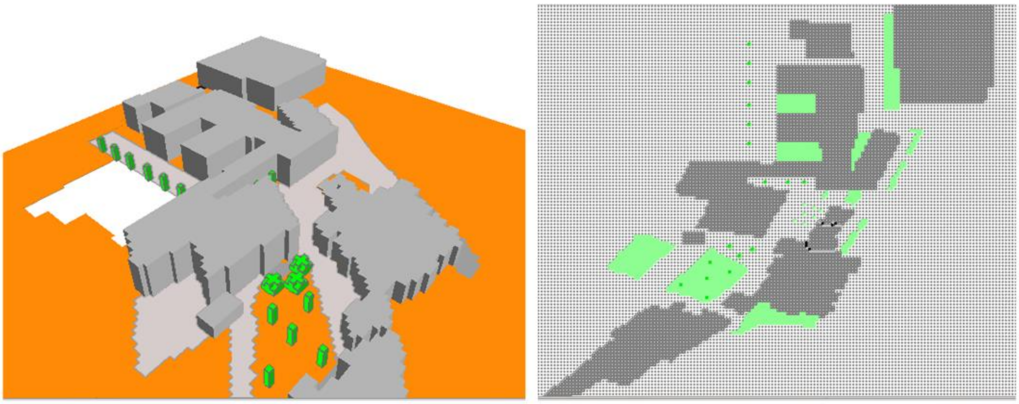


Figure 3.11: Creation of simulation model.

Simulating settings

The existing environment has been modeled where the size of the area, the height of the buildings, materials and vegetation has been modeled in 3D. Weather conditions for selected scenarios have been processed as input i.e.,, weather conditions for July simulations have been entered as: maximum wind velocity (4.2 m / sec), wind direction (358^0), highest temperature (25.8^0C), highest relative humidity (54%), the lowest and highest degree of both parameters (air temperature and humidity) have been entered as hourly data additionally. After creating the simulation file, simulation has been run.

Simulation process and outcomes

In order to prevent errors that may occur during the simulation, the prepared file has been checked. If there are no any errors observed, simulation can be run. Otherwise, the errors should be revised and model should be checked again. The outcomes of simulation have been organized hourly into files according to the sections as following: atmosphere, soil, vegetation, surface, solar access, receptors, radiation, pollutants, log, inflow and buildings. As the purpose of the study is to assess the outdoor thermal comfort in open spaces, atmospheric data has been used for further calculating PMV Index. BIO_met tool has been used for obtaining PMV outcomes of the case study. In here, user-related parameters have been modified. Age of the users has been determined as 20-year-old, as the majority of the campus population is students. Similarly, the activity level has been determined to sitting since open spaces are where students spend their free time during the class breaks. Clo level has been modified according to the season assessed. Yet, in order to assess the effect of the user-related parameter on outdoor thermal comfort, these parameters have been modified and examined afterward.

3.6.3 Validation of simulation software

3.6.3.1 Pilot study

Before starting simulation for the entire study area, the pilot work has been conducted in the northern part of campus where two courtyards and white coating roof are present (Figure 3.12 and 3.13). In August, measurements have been made with the portative meteorological station at certain points in the area, and then these measurements have been used to validate the results of the simulations. Information on the modeling and analysis process for the pilot study is given below. Additionally, the survey has been conducted for obtaining subjective results.

Figure 3.12: Location and site plan for the pilot study.

Figure 3.13: View of the pilot study area.

Meteorological measurements

Measurements have been done via three different devices. One of them is portable mini-weather station used to measure air temperature, humidity, wind speed and solar radiation (Figure 3.14) at 1.1 m. The accuracy of the device is as follows: i)absolute error of radiation probe less than 10% ii) humidity sensor accuracy ± 1.8% iii)accuracy of temperature sensor ±0.3K iv) accuracy of wind anemometer 0.5m/s and wind direction can be measured within ±5°.

Additionally, two portable devices (Thermo-Anemometer and humidity meter as seen in Figure 3.15) have been used for measuring wind speed, air temperature and humidity for exact places where interviewee has been located. At the same time, the measurement values have been written down to the survey sheet in order to correlate data with survey answers. Heights of devices have been set at 0.6 and 1.1m for sitting and standing users correspondingly.

Figure 3.14: Portable mini-weather station during the field measurements.

Figure 3.15: Thermo-Anemometer and Humidity meter.

Survey questionnaire

The survey has been done in order to validate the outputs of ENVI_met extension, BIO_met tool where outdoor thermal comfort assessment has been done for obtaining the PMV Index values. According to the survey results, it can be validated if the simulation software has been proper for predicting the outdoor thermal comfort. The survey has been prepared in three parts collecting the demographic data about the user (nationality, the period of living in Istanbul, age, gender, and height-to-weight ratio), the clothing and activity level, the reason for visiting area and the time of exposure. Last part aimed to collect the data about thermal perception, satisfaction as well as preferences of the area. The questions in this part have been prepared according to ISO 10551, 1995 and ASHRAE 55, 2010 standards (Appendix 1).

Creating the model

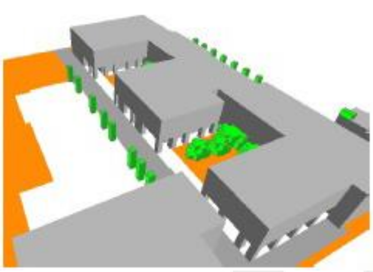
The following steps have been taken in creating the 3D model and simulation file of the pilot study (Table 3.6):

- Horizontal 120x100-grid area (each grid square considered 2 meters) has been modeled so that the area around the study area has been included in the analysis to reduce the margin of error. Vertical area of 20 grids has been created.
- The measurements have been conducted at a height of 1.1 m and at 22 points (Figure 3.16). The output of ENVI_met simulation is given in Figure 3.17 and comparison of measurement and simulation values is in Figure 3.18.

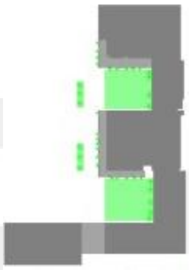
Figure 3.16: Measurement points of the pilot study.

Table 3.6: Details of the created 3D model and simulation file.

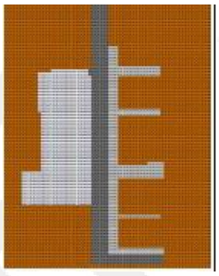
3D model		**Initial meteorological conditions**	
Size of the area	140x170x20	Initial temperature in atmosphere	28
Size of the grid cell in meter	1.00x1.00x1.00	Wind speed measurement in 10 m height	3.00
Position		Wind direction	90
Location	Istanbul/Turkey	Roughness length at measurement site	0.01
Longitude	29.00	Specific humidity at model top	70
Latitude	41.06	Relative humidity at 2m height(%)	50
Start and duration		**Solar radiation and clouds**	
Date of simulation	24.08.2017	Adjustment factor for solar radiation	1.0
Start time	8:00:00	Cover of low clouds	0
Total simulation time	12	Soil data	Default



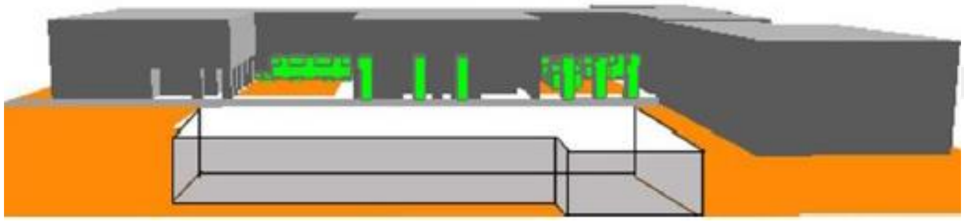
3D model



Top view



Soil and flooring material



Sectional Perspective

Findings from the pilot study

The values shown in Figure 3.18 are indicated according to the measured points seen in Figure 3.16. Observed air temperatures cluster around 25 °C and 26 °C with the maximum temperature being 26.87 °C. According to the simulation results, lower temperatures have been recorded in the shaded areas of the buildings, but the highest value has been 26.69 °C. This can be considered as a very close to the measured values. The simulated wind speed results (0.20 m/s) have been similar to the field measurements (0.18 m/s) at the points where lowest wind speeds occur. Measured direct radiation overlaps significantly with the simulated values; (940 W/m^2 and 25 W/m^2) and (995 W/m^2 and 35 W/m^2) with peaks and bottoms taking place at the same points in both cases.

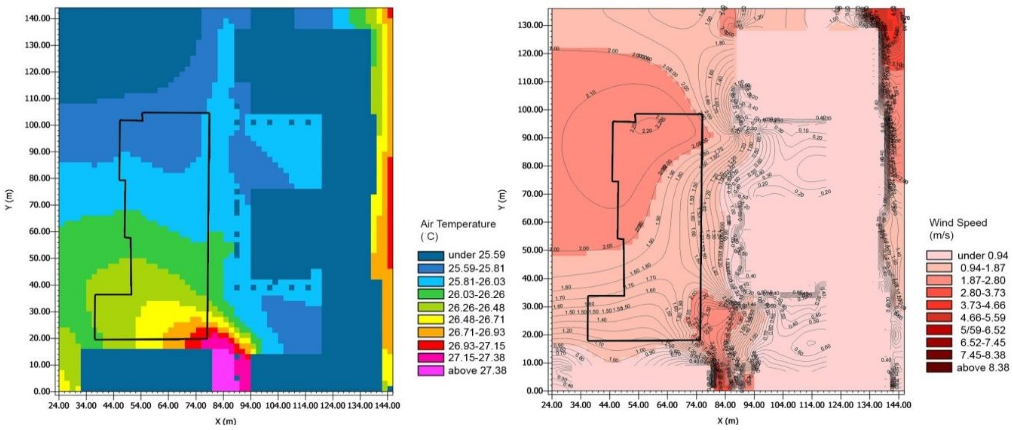


Figure 3.17: Sımulated air temperature and wind speed of the pilot study.

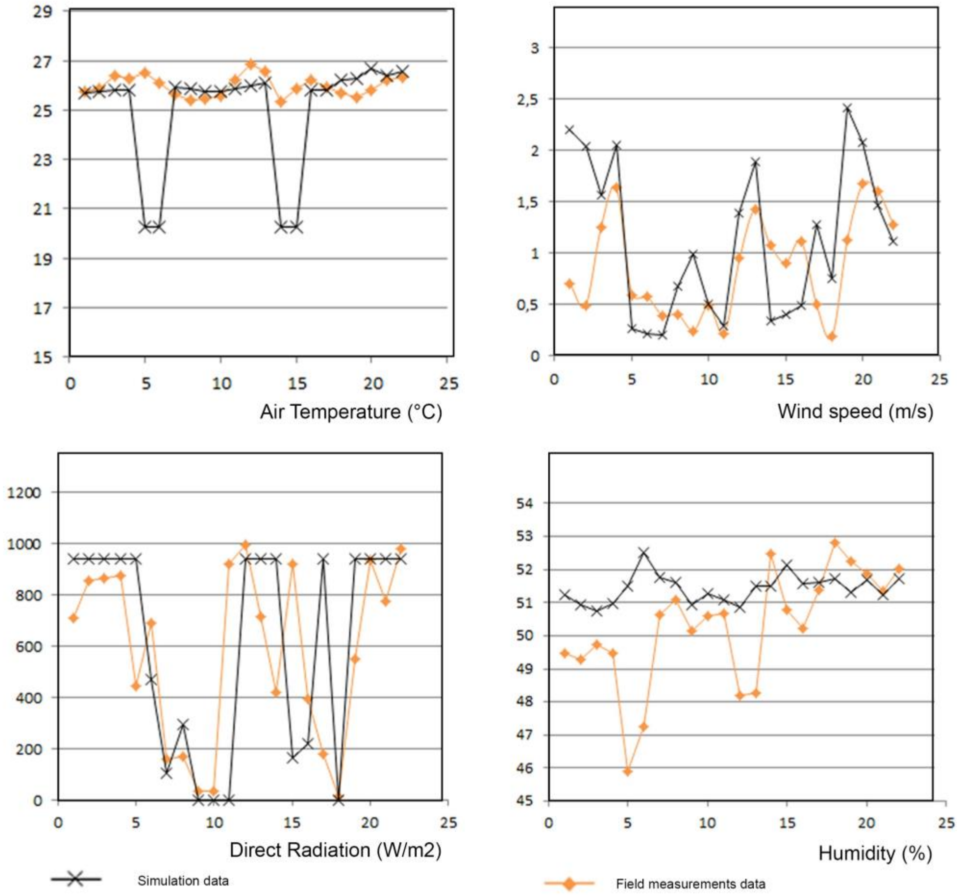


Figure 3.18: Comparison between field measurement and ENVI_met modeling.

Considering that outdoor thermal comfort is user-related, the subjective perception is examined as well. Survey study has been conducted on the same day in order to validate the BIO_met outputs obtained later. In Figure 3.19 the outputs from both studies have been juxtaposed. The map demonstrates how thermal comfort has been perceived by users according to PMV index, obtained from BIO_met Tool. Points overlapped are survey results obtained from the same question, thermal perception according to PMV index. As visible from the map, the areas being perceived as optimal are within green courtyards bellow and around dense vegetation. Colder areas, in this case, blue, are building corners and eastern side of the building due to the sun position in this time period. As in the summer session, the thermal perception has been obtained as uncomfortable (hot) on the light-colored roof and part of the green courtyards where solar radiation reaches pedestrian level directly. This is considered as reasonable since there is lack of vegetation and shading objects in these areas. In addition, the wind speed has been low.

Comparing survey results with ENVI_met output have validated the simulation program, although there are some concerns needing attention. Firstly, survey respondents feeling hot overlap with the points where the simulation obtained the highest scale of PMV index. The user who is feeling slightly cool (-1) on the southern courtyard corresponds to the -1 PMV index. On the contrary, the respondents perceiving the thermal environment as neutral on the light colored roof are contradicting to the simulation results of the same area. This can be explained as a result of a user-related parameter (clothing, level of activity, time of exposure etc.) affecting the subjective perception. The users found in the northern courtyard perceive the environment as neutral (0) while the software outputs tend to be slightly cool (-1). And at the point where one of the users felt slightly warm (+1), the PMV software output shows neutral (0). This can be the result of the contiguous warmer (+2) and hotter (+3) environment affecting the subjective perception.

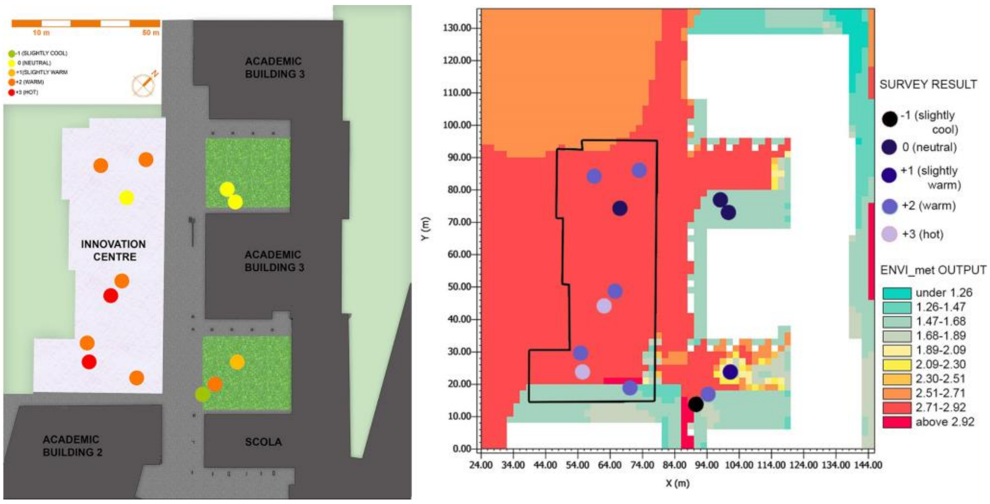


Figure 3.19: Survey results and superposing of survey study and ENVI_met results on PMV map.

3.6.4 Scenarios

Outdoor thermal comfort parameters that can be assessed with simulation tools are meteorological parameters, microclimatic and user related parameters (Figure 3.20).

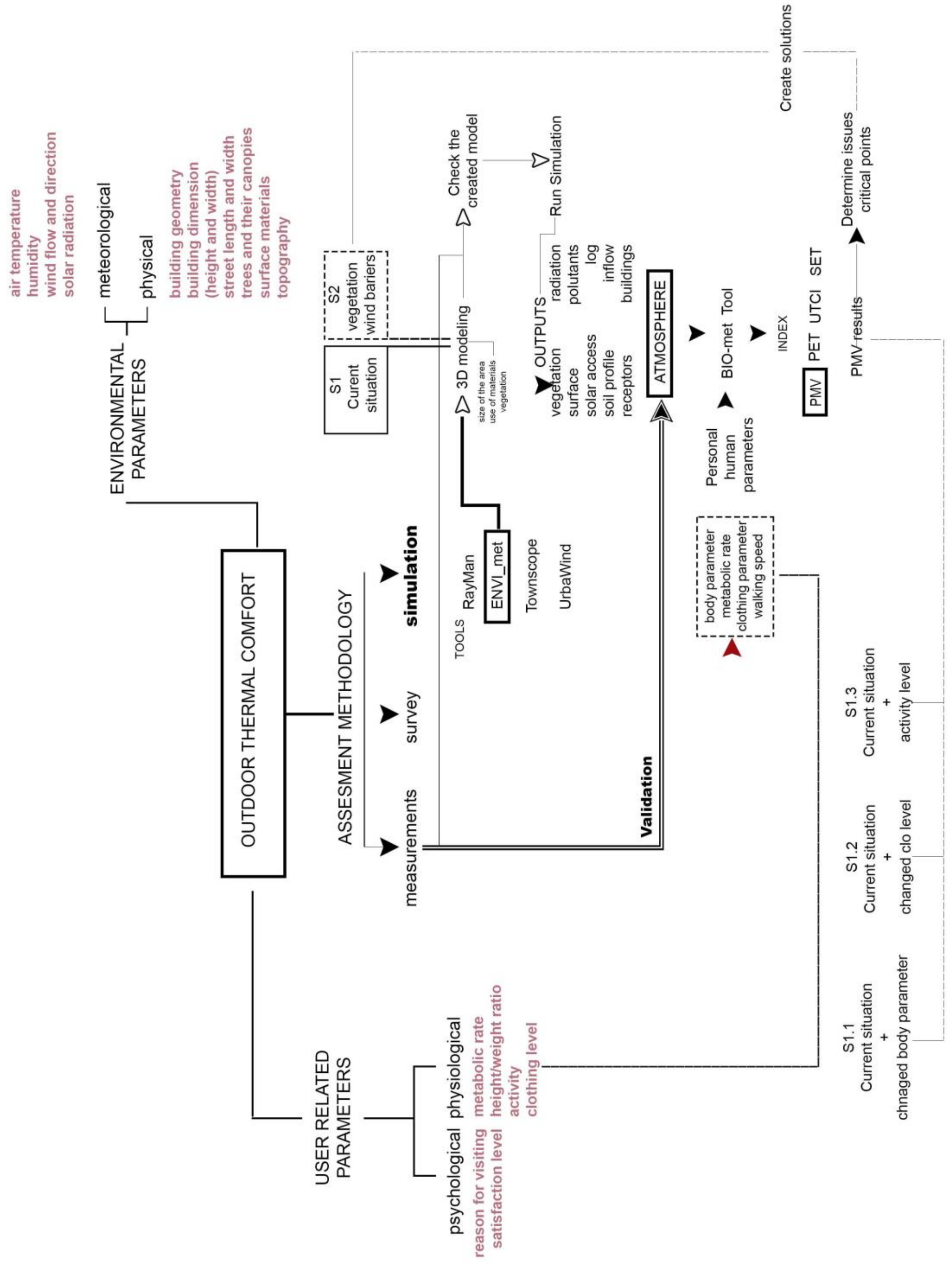


Figure 3.20: Application model for assessment of outdoor thermal comfort at a university campus open spaces.

In this thesis, firstly the assessment has been done for summer and winter seasons, in order to determine the seasonal differences in air temperature, humidity and wind speed within temperate climate region. Simulations have been carried for summer and winter season, July and February correspondingly, so that outdoor thermal comfort can be assessed seasonally and do emphasize the significance of natural and physical environment in both seasons. In order to analyze the difference in the daytime, 9.00 am, 12.00 pm and 15.00 pm have been selected. Moreover, for both (summer and winter) variations in terms of user-related parameters have been determined and PMV index has been calculated in accordance with them. With obtained PMV results, evaluation of outdoor thermal conditions has been done.

The effect of vegetation on outdoor thermal comfort is emphasized. In this case, the vegetation, specifically trees are only changing parameters that can be modified after implemented design. Also, they are changeable throughout the time (grow in height, size of canopy etc.). For this reason, the assessment of vegetation effect has been conducted in order to determine its impact on outdoor thermal comfort in summer and winter seasons separately. Additionally, the user related parameters are assessed in order to determine their impact as well. Similarly, the parameters that are changing in an urban environment are user related parameters: age, clothing and activity level as well as metabolic rate. As population hosted at university campuses in the majority are students around 20 years old, the age parameter is set to be 20. Clothing parameter is detailed according to the season simulation is conducted for. For the summer season, the clothing parameter is set to be 0.5 and winter 1.5. The activity level is set to be sitting. The weight-height ratio has been determined to normal. Further, these parameters are being modified in further scenarios in order to investigate the relation between user parameters with urban environment (table 3.7 and 3.8). However, due to the diverse population in every community, these parameters cannot be modified and so their influence over thermal conditions cannot be defined. Yet, the influence over thermal comfort perception can be determined.

Table 3.7. Assessed parameters and variations for the summer season.

Summer	Meteorological parameters	Physical Parameters	User related parameters		
	Air temperature	Vegetation	Body parameter	Clothing	Activity
	Humidity	Surface	Normal weight	0.5	sit
	Wind speed		Overweighted	1.0	walk

Table 3.8. Assessed parameters and variations for the winter season.

Winter	Meteorological parameters	Physical Parameters	User related parameters		
	Air temperature	Vegetation	Body parameter	Clothing	Activity
	Humidity	Surface	Normal weight	0.5	sit
	Wind speed		Overweighted	3.0	run

4. FINDINGS

In this section, results obtained from the simulations have been explained. Firstly, the seasonal microclimatic results, afterward the evaluation of outdoor thermal comfort according to PMV index has been given. For user-related parameters, PMV evaluation has been done for midday session as the major differences have been observed at this time period. As for last part of findings, the assessment of vegetation effect on outdoor thermal comfort has been explained. All the maps have been obtained at the 1.1 m height, as corresponding to the previous works.

4.1 Seasonal Assessment

July and February have been chosen as representative months for summer and winter period, respectively. Results for summer (July) and winter (February) season obtained primarily are microclimate results, in this case, air temperature, humidity, wind flow and direction. The vegetation and surface material effect on PMV values also have been discussed. Further, PMV index has been obtained with BIO_met tool. The summer and winter results have been discussed correspondingly in three time periods: morning (9.00), midday (12.00) and afternoon (15.00).

4.1.1 Assessment of microclimate data in the summer season

Data used as input for the simulation has been obtained from Alemdag Meteorological Station. Summer simulation has been done for 5th July, where maximum wind speed has been 4.2 m/s and direction 358^{o}, maximum air temperature 25.8^{o}C and maximum humidity 54%. Additionally, hourly data of air temperature and humidity has been inputted as well.

4.1.1.1 Morning session

According to the ENVI_met results, in the morning session (9.00) due to the warm and hot weather conditions, air temperature has been varying between 22^{o}C-24.77^{o}C, as seen in Figure 4.1. Areas where hard surface covering (concrete etc.) take place, air temperature has been reaching 23.19^{o}C. On the contrary, the temperature above the green areas such as main quad and two small courtyards has been around 22.60^{o}C. Here, the positive impact of green areas on air temperature has been observed similarly to the studies reviewed (Lin et al., 2010; Lin et al., 2007; Robitu et al., 2006). Moisture level or humidity varies between 65%-83%. Disregarding the surface materials within campus open areas observed humidity has been 69.23%, while the nearby forest and other open areas tend to be 76% (Figure 4.2). Wind speed has been observed as uniform throughout the campus open spaces (below 0.60 m/s), main alley and quads (Figure 4.3). Areas surrounding the campus have been observed to have higher wind speed (3.50 m/s). During the summer season in hot and arid climates and temperate climate types wind has a positive effect on outdoor thermal comfort perception; still, it should not be high above 2.6 m/s for sitting and 5.4 m/s for walking person that lead discomfort (ASCE, 2003). The value observed at this time period (0.60 m/s) can be described as an advantage. The mornings of the summer season are likely to be more comfortable when comparing to other day periods. The sun radiation does not reach its maximum and air temperature is still at its optimal values.

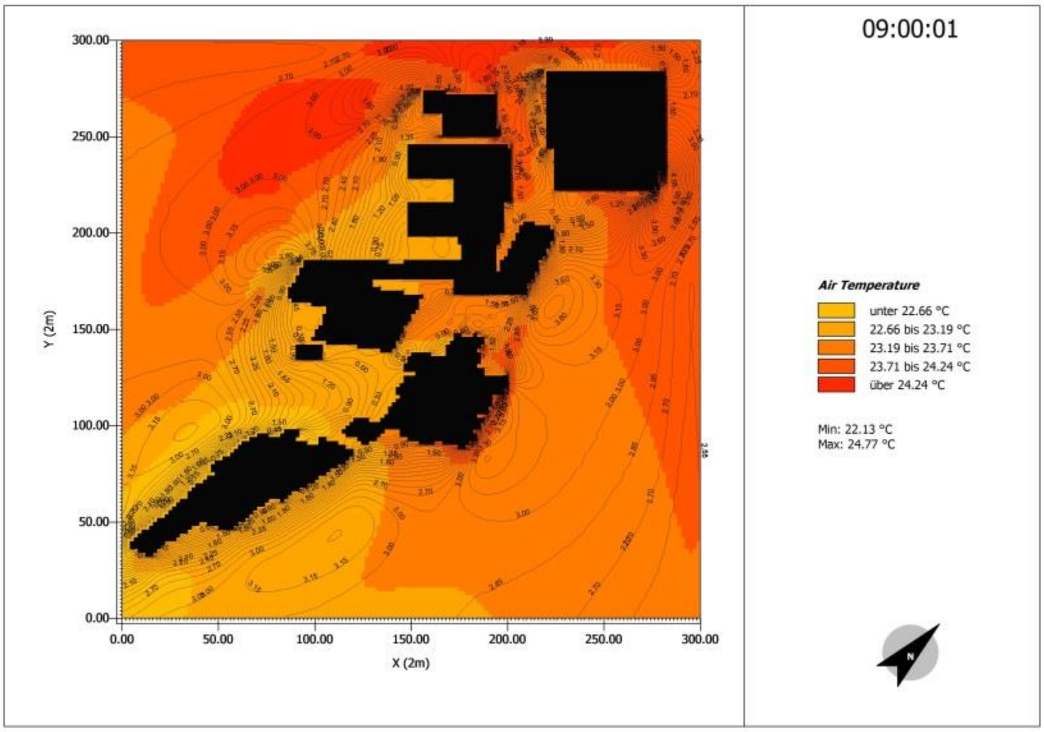


Figure 4.1: Simulated air temperature for summer season-morning session.

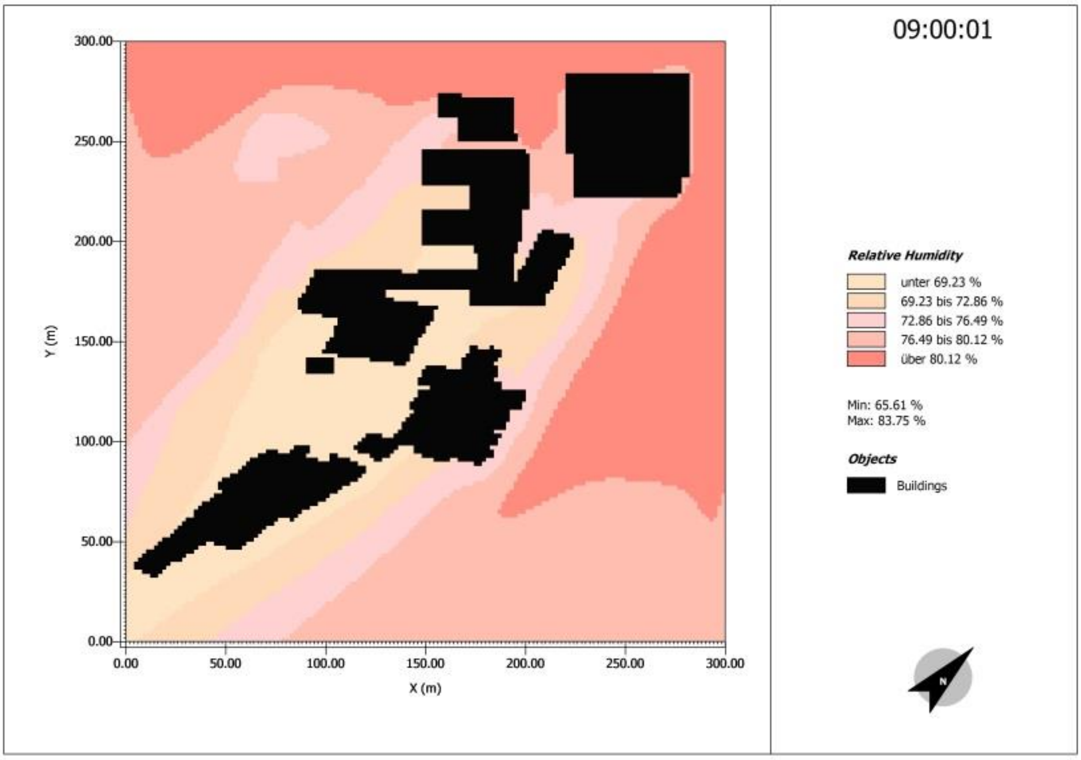


Figure 4.2: Simulated humidity for summer season-morning session.

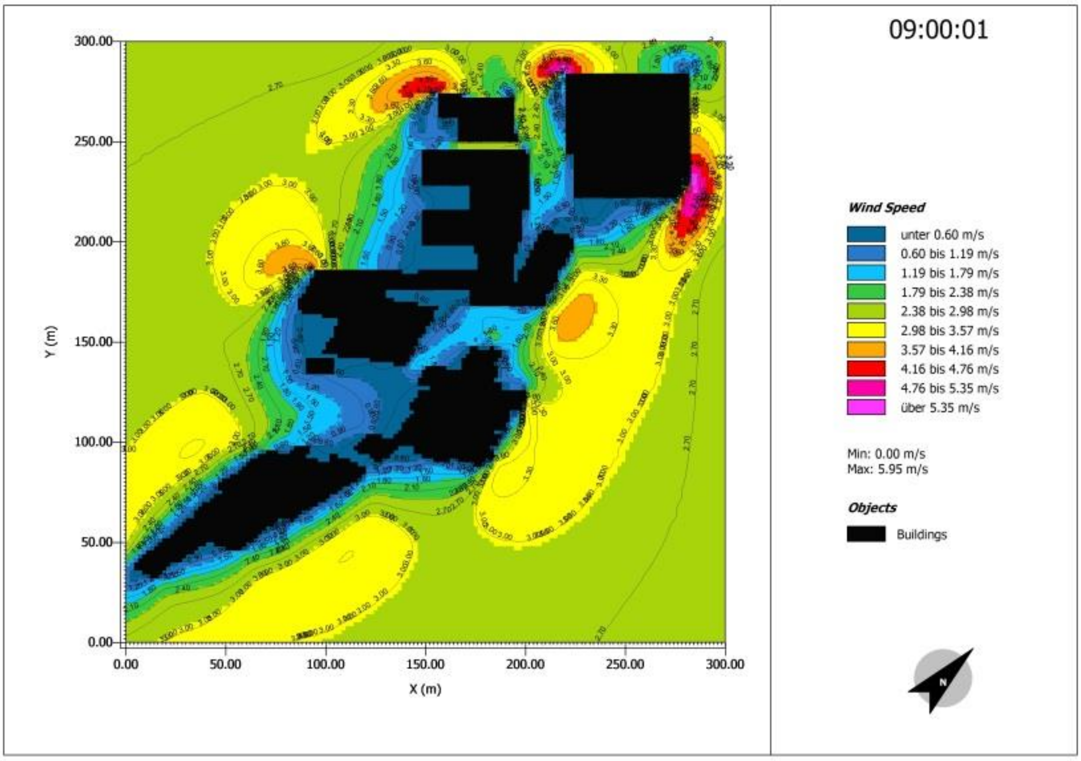


Figure 4.3: Simulated wind speed for the summer season- morning session.

4.1.1.2 Midday session

Figures 4.4, 4.5 and 4.6 show simulation results for 12.00 o'clock. Due to the increase in the air temperature above 24^{o}C, humidity level decline to 54.89%-64.90%. Similar to the previous results, the air temperature has been higher at hard surface materials when compared to green areas (26.68^{o}C hard surface materials; 25^{o}C green areas). Wind speed again being lower within campus open spaces, shows higher results at areas outside the campus. Within campus areas, there are wind corridors occurring at points where wind speed increases.

4.1.1.3 Afternoon session

In the afternoon period (15.00), as a consequence of increase in air temperature (27^{o}C -32^{o}C) the humidity level decrease (31%-41%). In this time period, the air temperature and humidity perform spatially even throughout campus open spaces (the difference in between the green and hard surfaced area has not been observed, as seen in Figure 4.7 and 4.8). The areas surrounding the campus are reaching air temperature above 30^{o}C. Due to the uniform values of wind throughout the day, this time period does not face any changes (Figure 4.9).

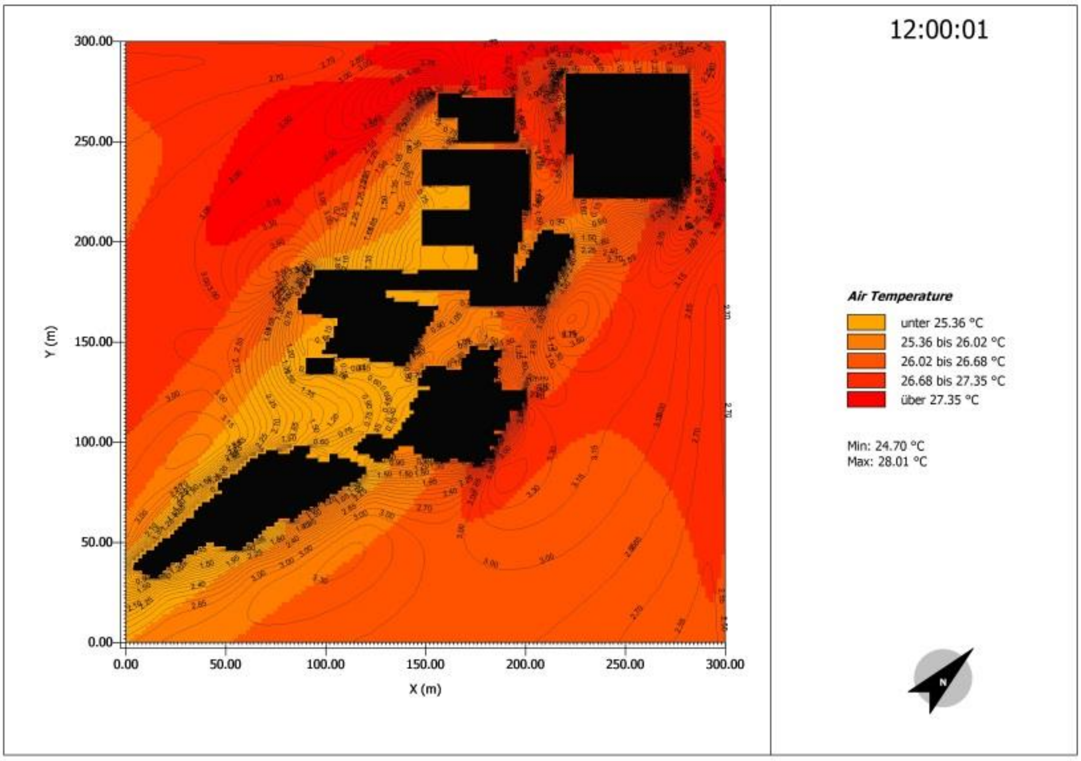


Figure 4.4: Air temperature for the summer season- midday session**.**

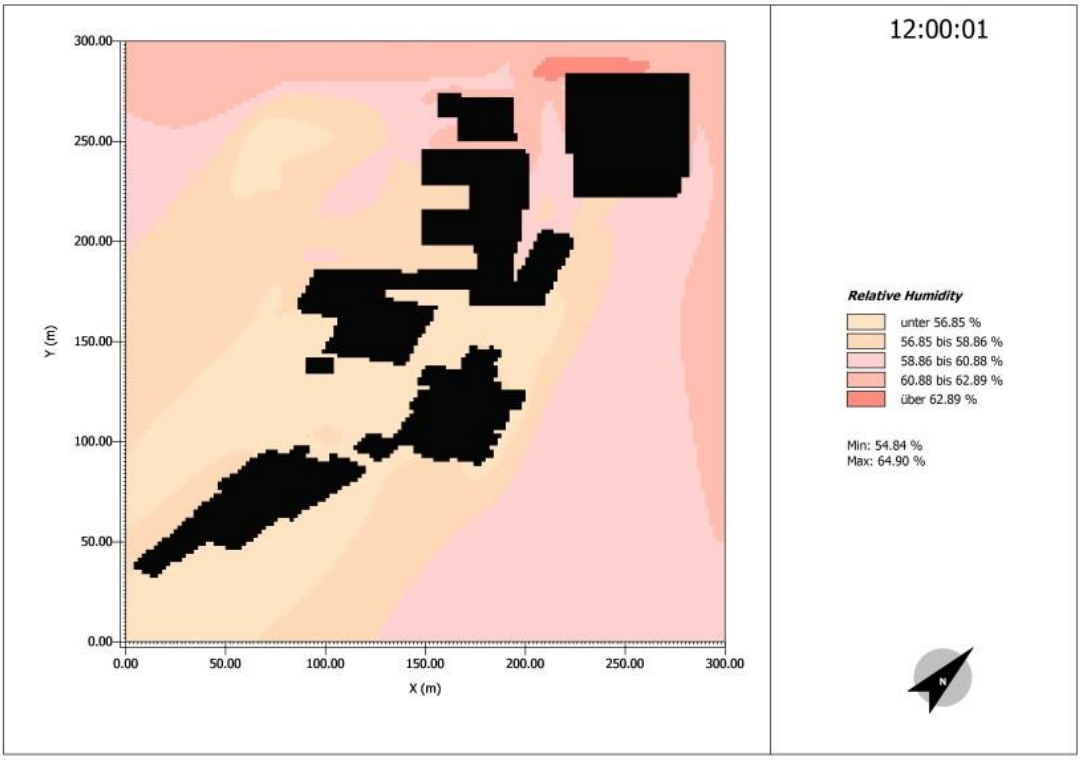


Figure 4.5: Humidity for summer season-midday session.

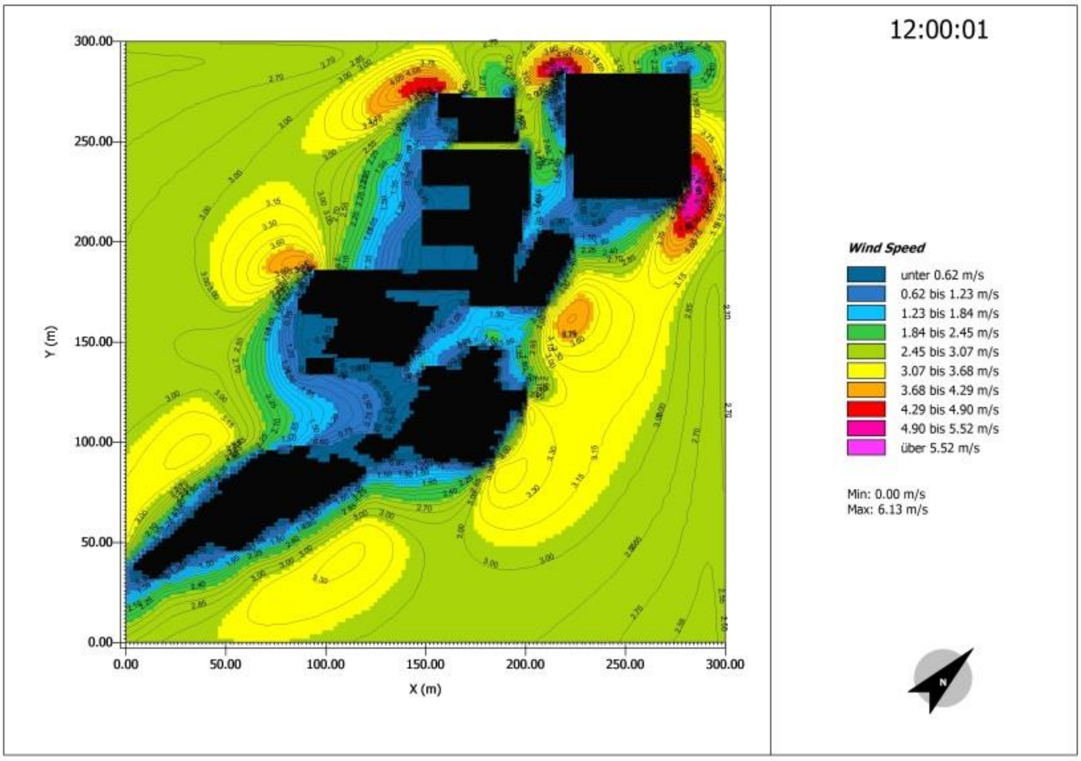


Figure 4.6: Wind speed for the summer season- midday session.

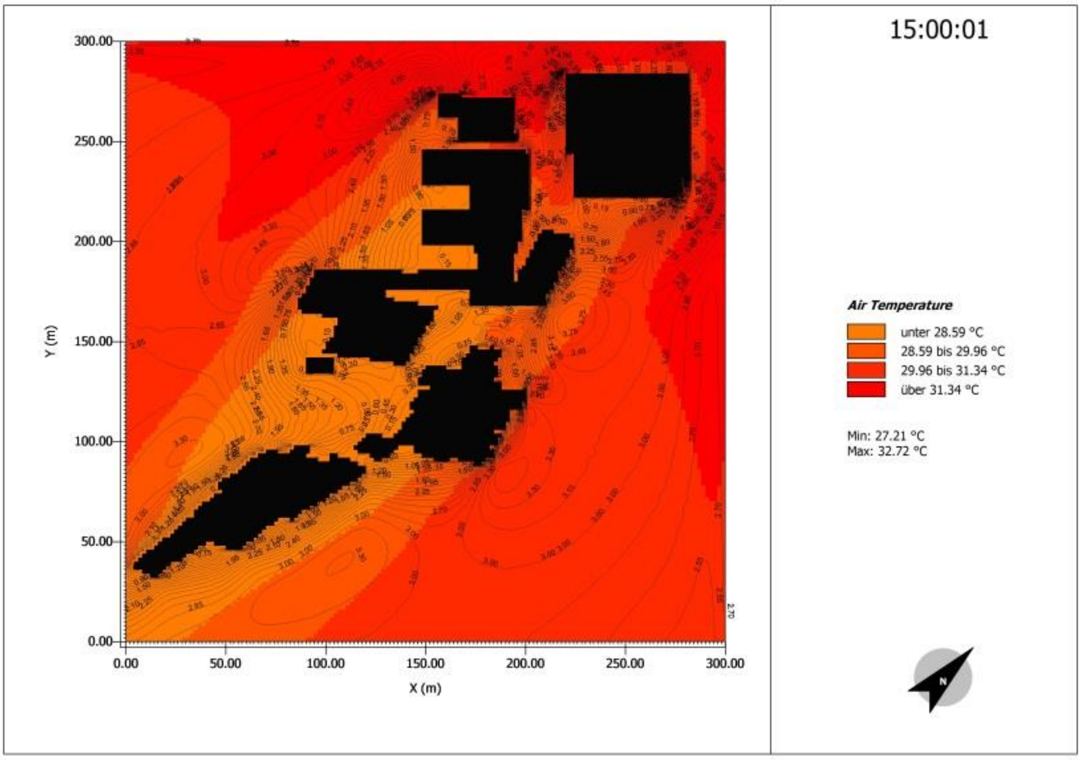


Figure 4.7: Air temperature for the summer season- afternoon session.

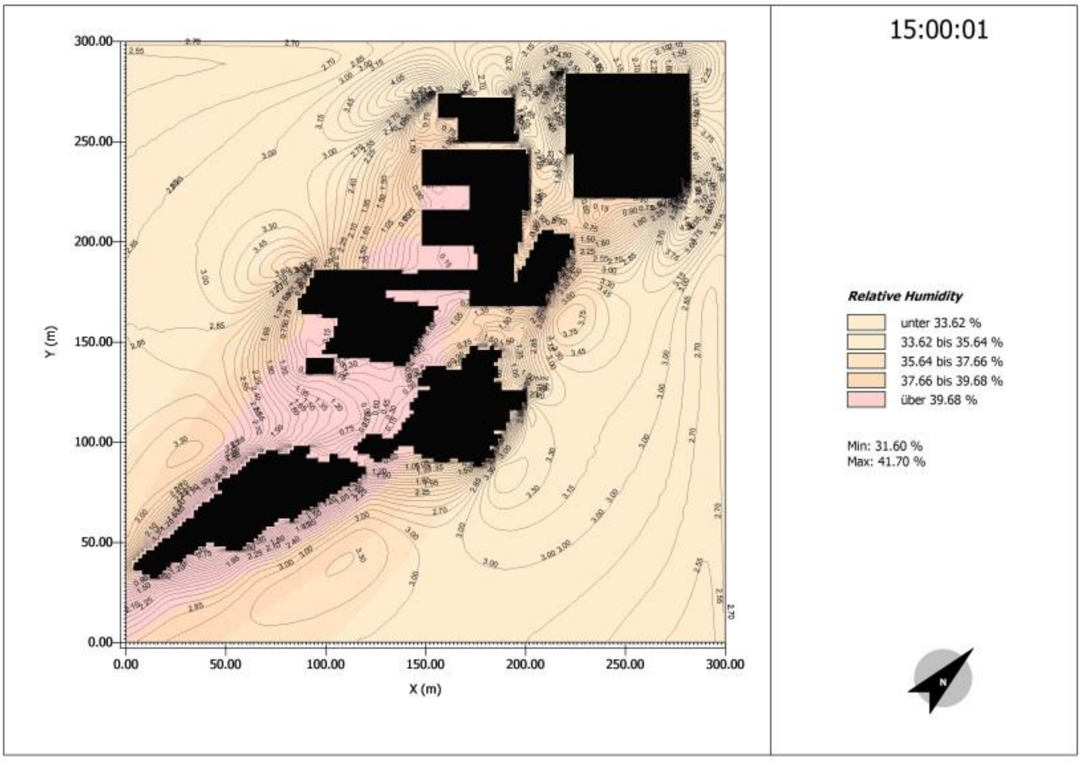


Figure 4.8: Humidity for summer season-afternoon session.

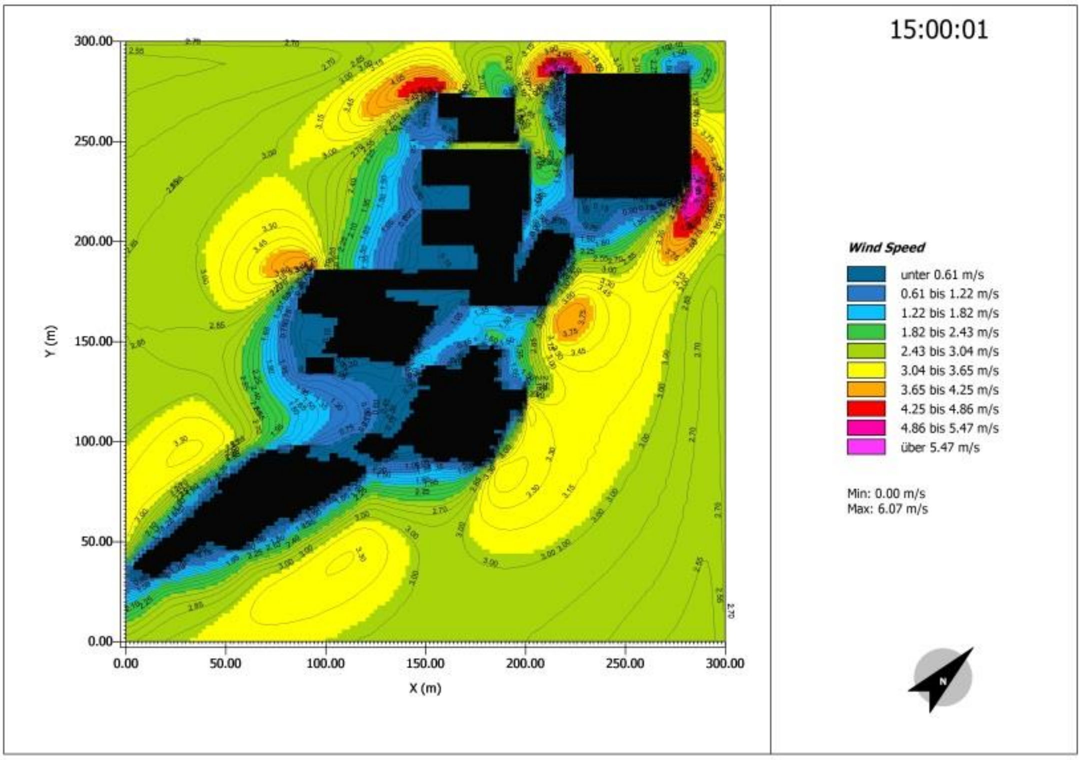


Figure 4.9: Wind speed for summer season-afternoon session.

4.1.2 Assessment of microclimate data in the winter season

Winter simulation has been conducted for February where weather conditions have been as following; maximum wind 4.2 m/s and wind direction 208^{o}, maximum air temperature 18.9^{o}C and maximum humidity 83%; separately hourly data of air temperature and humidity has been added as simulation input. Although being a winter season, the day chosen for the simulation to be conducted had minimum cloud cover and direct solar radiation in order to treat winter season similarly to the summer conditions.

4.1.2.1 Morning session

Conditions of the simulation day are the reason for air temperature to be higher than Istanbul's average winter air temperature (13.27^{o}C-14.37^{o}C). Observing the spatial distribution, recreational areas show similarities in between while the front of the SCOLA building tends to be a bit higher due to the hard surfacing material. Direct solar radiation affects the air temperature at eastern fronts of buildings in a similar way (Figure 4.10). Humidity percentage diverges from 74.75% to 86.35%, being highly related to solar radiation; the higher direct radiation (in this time session eastern part of the buildings) the lower humidity level and vice versa (Figure 4.11). Wind speed varies between 0.00 m/s- 5.23 m/s. It is remarkable how wind speed at the openings of small courtyards is being higher than it is in the inner part (2.50 m/s and 0.5 m/s) emphasizing the role of building geometry (Figure 4.12). Likewise, the main quad that can be considered as a courtyard as well (due to the surrounding buildings) has been facing the same conditions in terms of wind speed. Winds coming from western side tend to decrease when reaching the inner part of the quad and Student Centre.

4.1.2.2 Midday session

With the increase in air temperature at 12.00 o'clock (15. 53°C -17.53°C) the spatial distribution of air temperature, as seen in Figure 4.13, is being equal in the inner part of the campus (16.33°C- 16.73°C). Related to air temperature increase, the humidity level felt for 3% (Figure 4.14). On the contrary, wind speed (Figure 4.15) increases on the main alley and courtyards (3.15 m/s and 1.00 m/s).

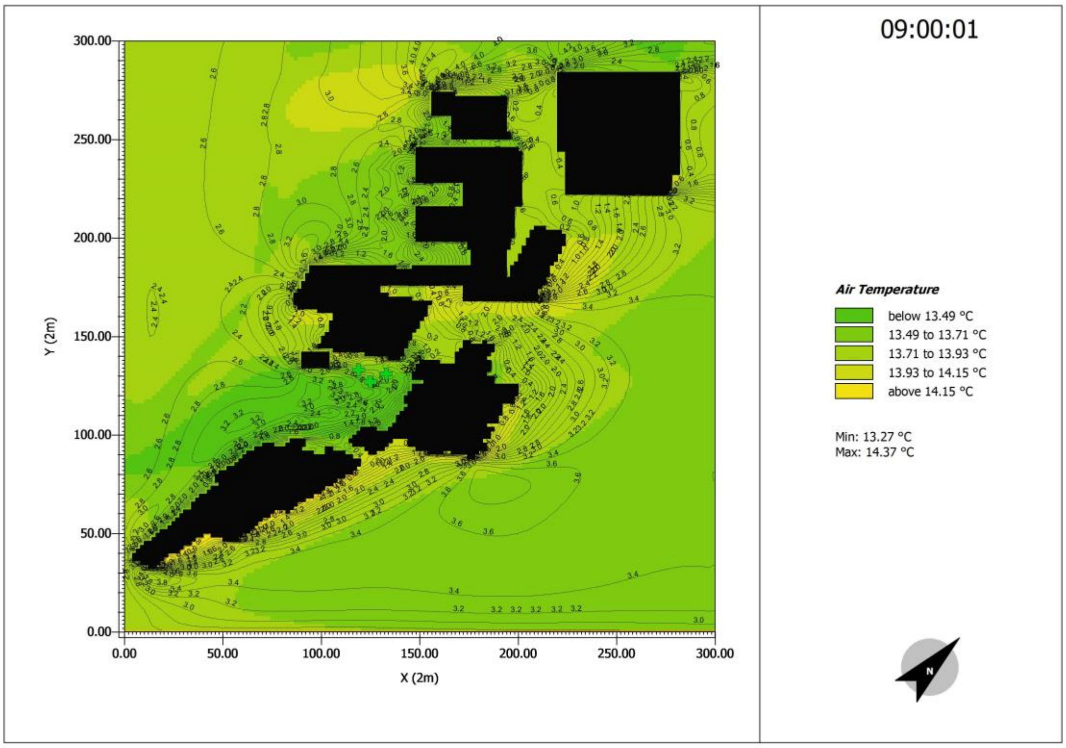


Figure 4.10: Simulated air temperature for winter season-morning session.

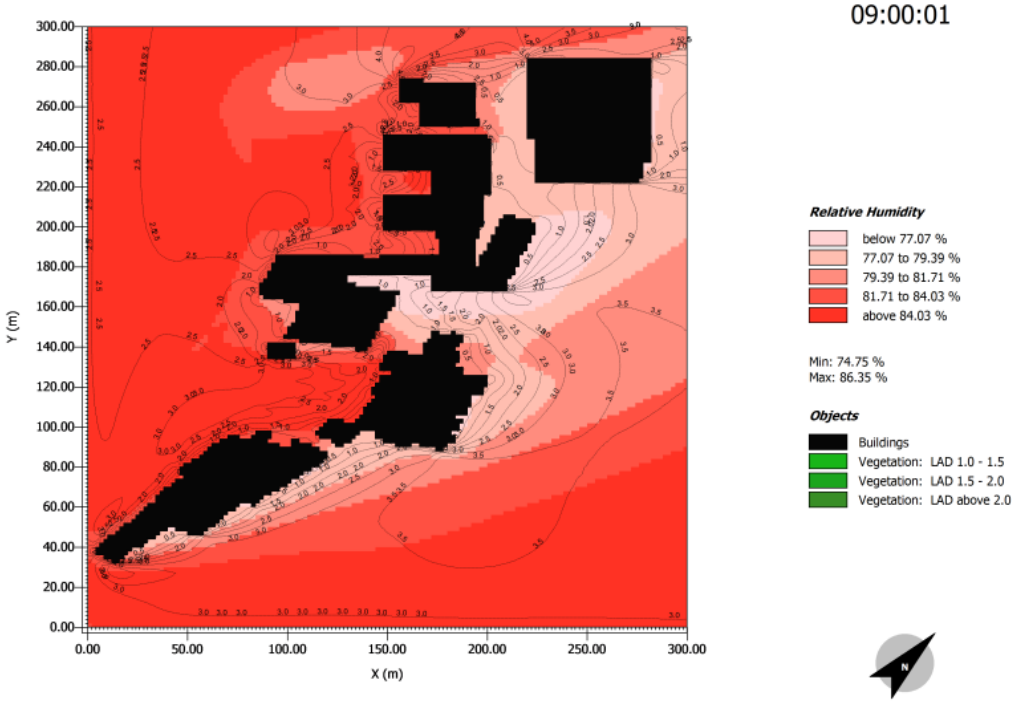


Figure 4.11: Humidity for winter season-morning session.

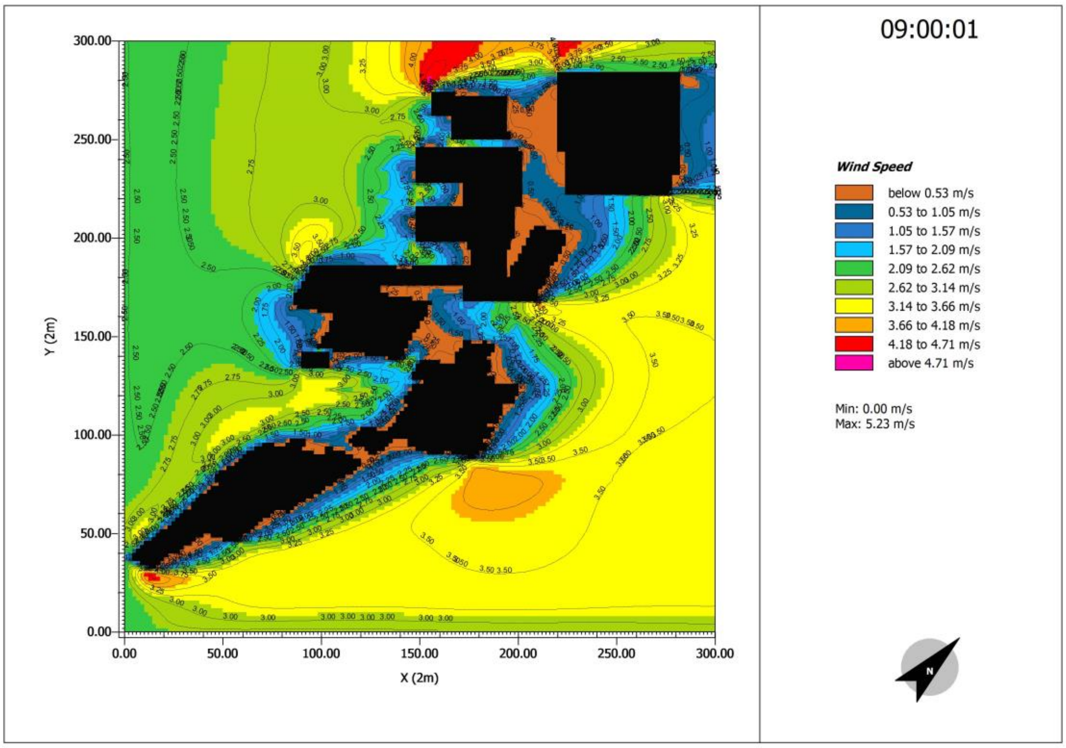


Figure 4.12: Wind speed for winter season-morning session.

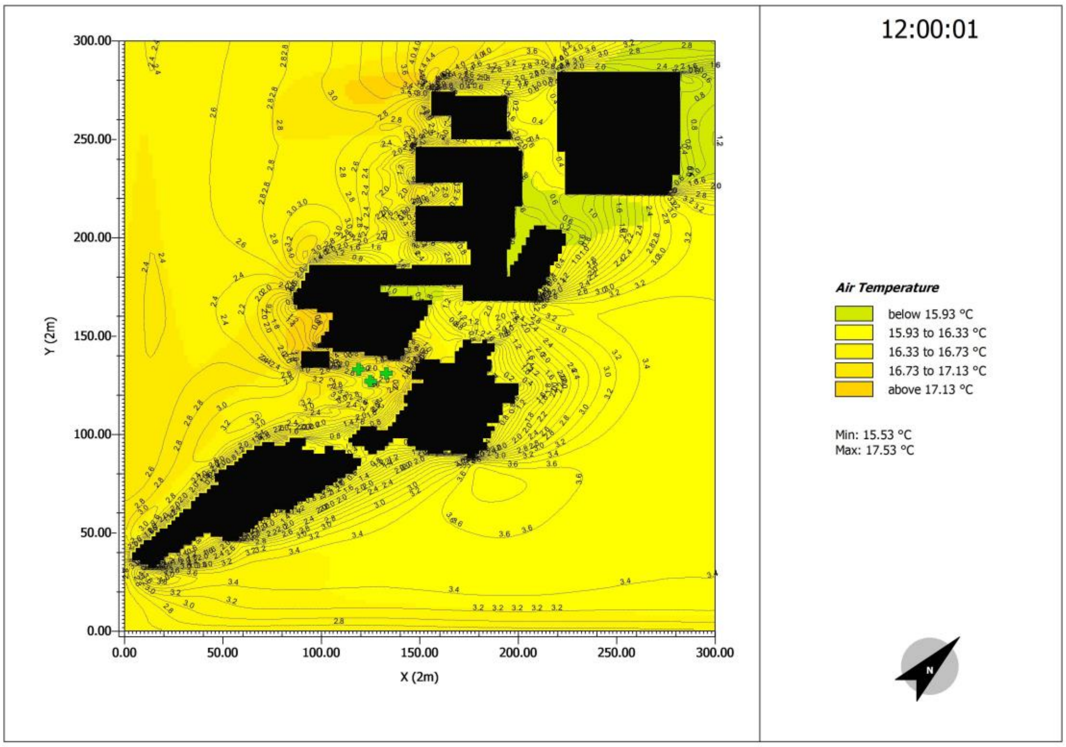


Figure 4.13: Air temperature for winter season-midday session.

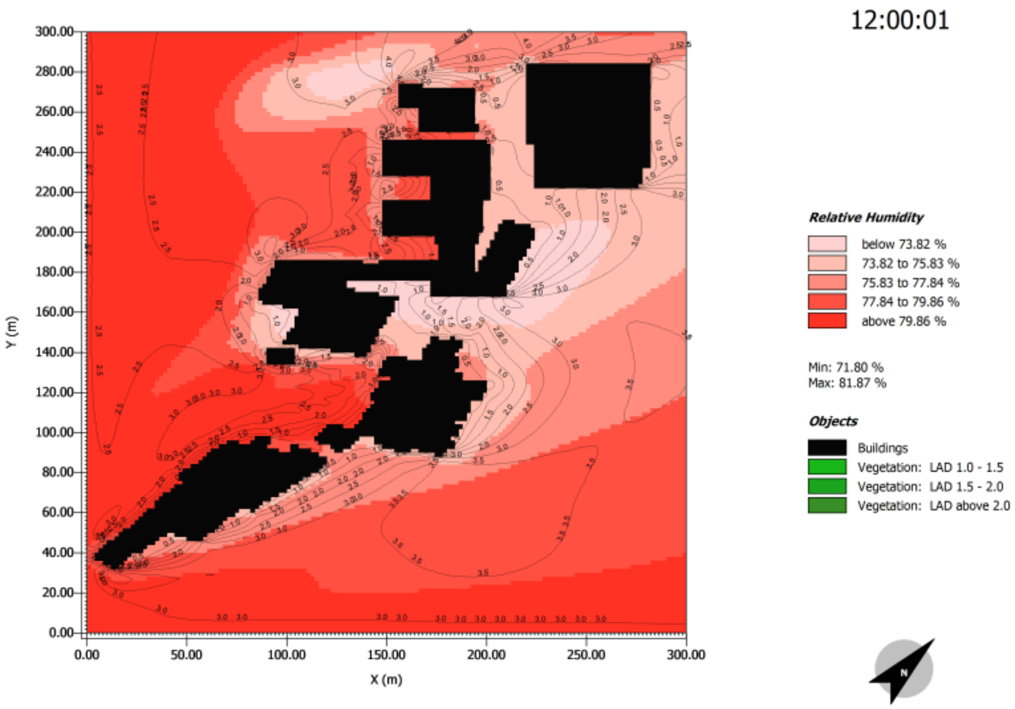


Figure 4.14: Humidity for winter season-midday session.

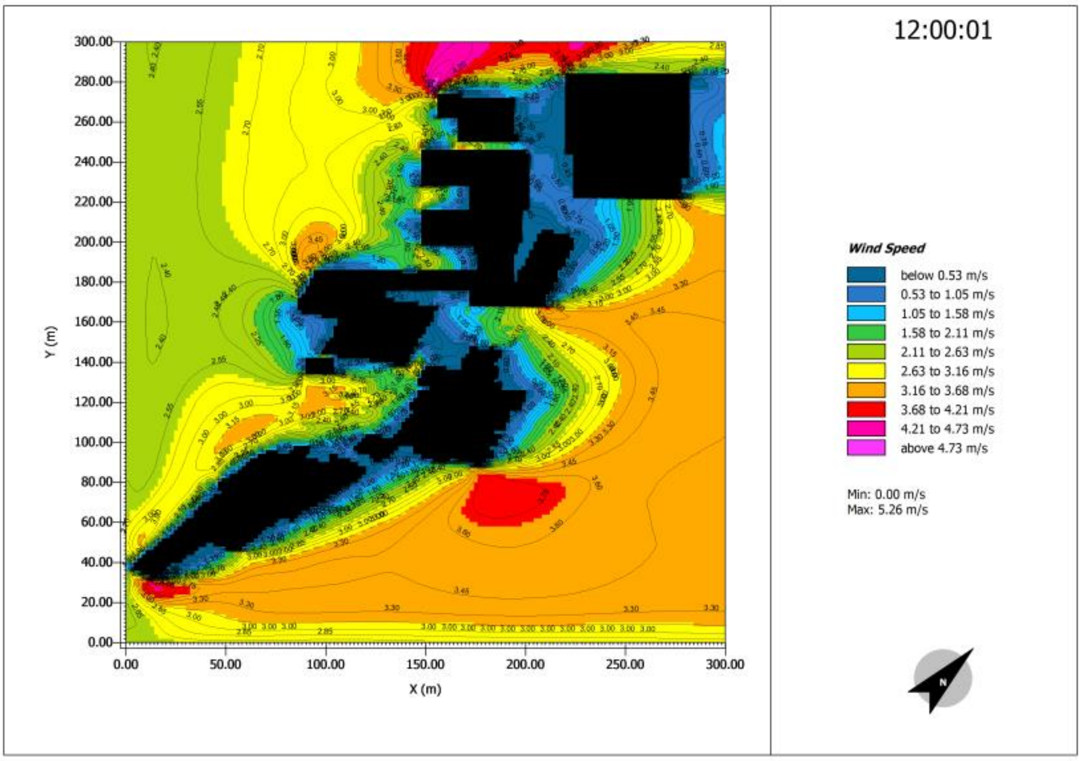


Figure 4.15: Wind speed for winter season-midday session.

4.1.2.3 Afternoon session

In the afternoon session, the results of microclimate data have been similar to the previous session. Still, there are differences in spatial distribution and values to some extent. For instance, the air temperature tends to be higher at two small courtyards and in the areas on the western side of the buildings as a consequence of direct sun radiation (Figure 4.16). Here, it can be misunderstood that green areas are being warmer than hard-surfaced areas; in fact, this situation proves that geometry has the higher impact on the urban microclimate comparing to surface materials. Because it is the geometry of the buildings that creates shadows and blocks sun rays reaching the pedestrian level. Humidity as a parameter related to air temperature and solar radiation in opposing terms has been decreased generally. Hence, the relation of surface material with humidity has been observed. Although air temperature has been higher in courtyards and lower in the areas with hard surface materials (concrete) the humidity level has been higher in green areas (main quad above 76% and two small courtyards 74%) than it is in shadowed area in front of the SCOLA and AB2 (70%-72%) (Figure 4.17). Wind, being uniform throughout the day, has not been changed in values and the spatial distribution has been changed to an insignificant extent (Figure 4.18).

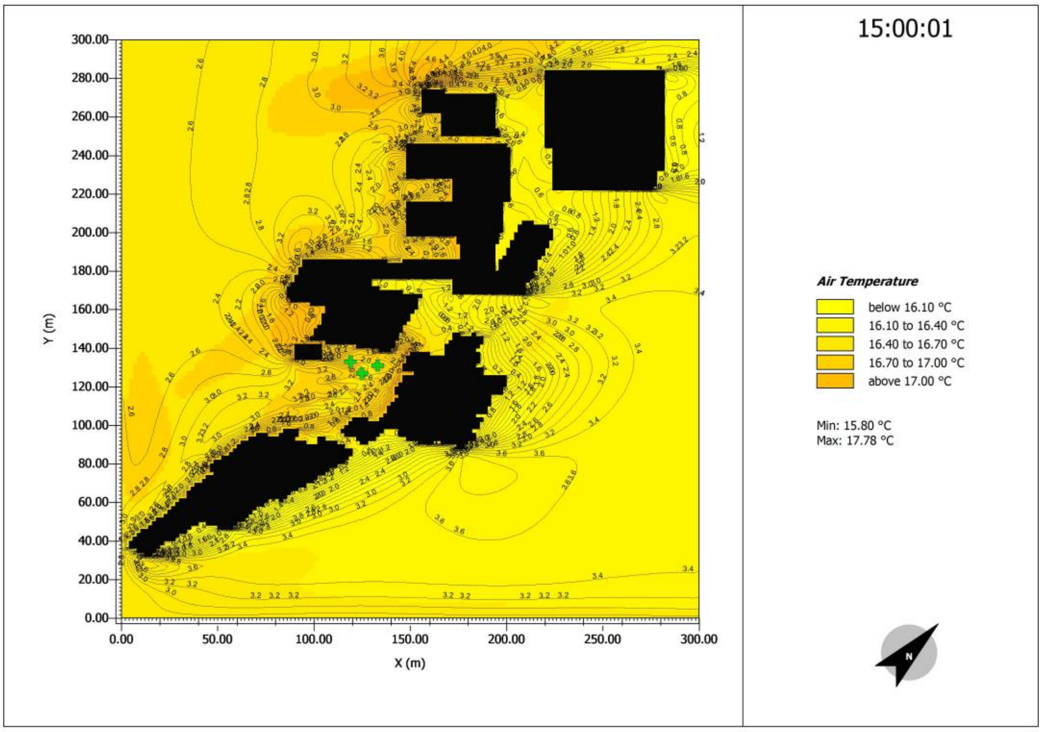


Figure 4.16: Air temperature for winter season-afternoon session.

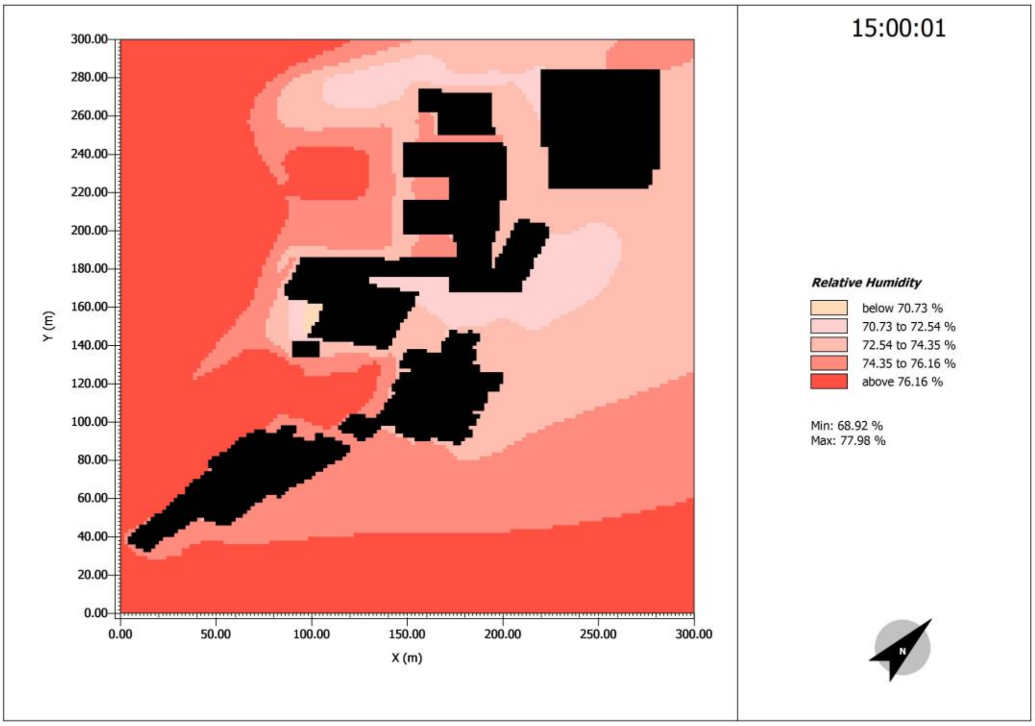


Figure 4.17: Humidity for winter season-afternoon session.

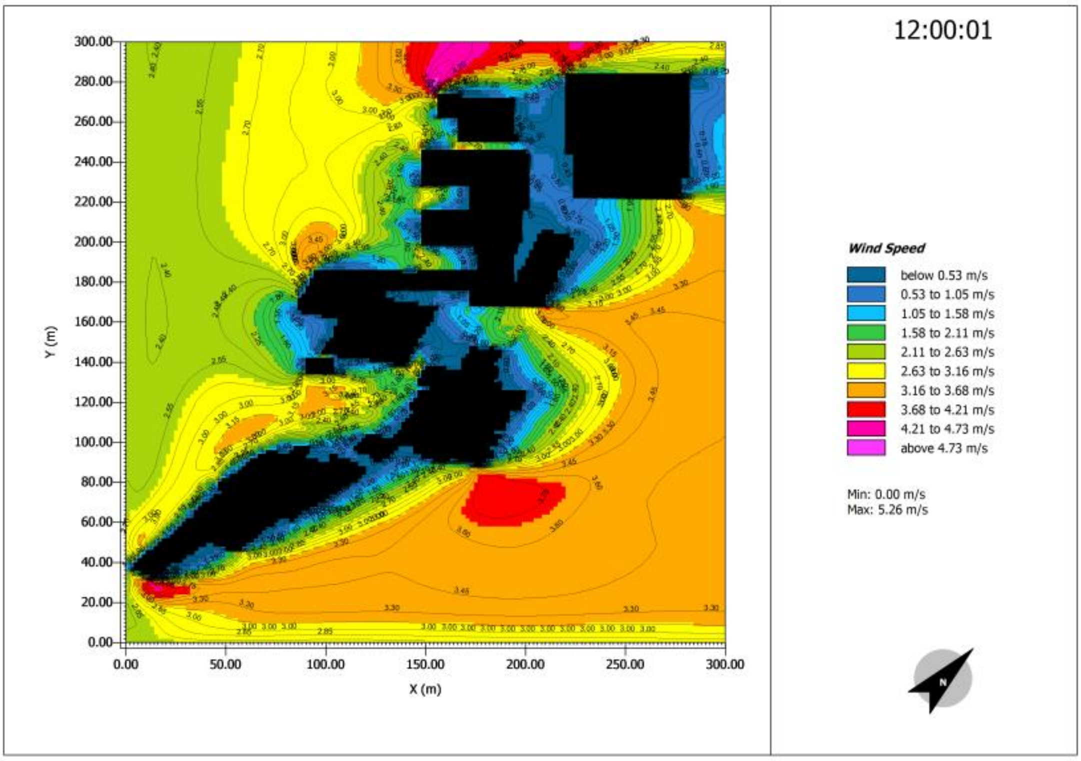


Figure 4.18: Wind speed for winter season-afternoon session.

4.2 Outdoor Thermal Comfort Assessment via PMV Index

4.2.1 Assessment of microclimate parameters

4.2.1.1 Summer season

When evaluating the PMV results, due to the warm weather conditions index value has been observed above 0 ("neutral"- nor hot nor cold). Though, in the morning hours, in areas where direct solar radiation does not reach pedestrian level (such as the western side of the buildings), PMV has been observed as "cool" (-1). Two small courtyards and the front of Student Centre have been evaluated as "neutral" (0). Similar results have been obtained for the areas where trees canopy provide shadings. This shows the importance of vegetation in thermal comfort perception during the summer; hence its importance has been better explained in further hours when solar radiation increases. Areas, where solar radiation has been reaching directly to the pedestrian level, has been evaluated as 1.50 ("warm"), such as main quad and fronts of eastern sides of buildings (Figure 4.19).

As expected, with the increase in the air temperature the perception of outdoor thermal comfort changes, affecting the PMV index negatively. The values of PMV are varying between 0.45- 3.32 (Figure 4.20). "Neutral" areas have been only those where direct sun radiation does not reach. Even the evaluation of the areas under the tree canopy increased to 1.17 ("warm"). Corresponding to the increase in air temperature, the evaluation of PMV value of the hard surface areas increased to 3 ("too hot") and green areas 2 ("hot").

The increase in air temperature affects the PMV values. Respectively, increase in the PMV values being 1.70-5.00 shows that in some circumstances simulated PMV values can be higher than the PMV index itself is. As for, the areas where PMV value has been 4 and above is not evaluated as to "hot", but "extremely hot". Areas evaluated as "too hot" are main quad and front of the Faculty of Engineering due to the direct solar radiation in this time period. Eastern front sides of the buildings although being covered by building shadows have been evaluated as "hot". Similarly, although the cooling effect of vegetation is evident the areas under the tree canopies were calculated as "hot". However, in hot summer conditions, this is more acceptable than "too hot" and "extremely hot" conditions, as it has been observed in other areas (Figure 4.21).

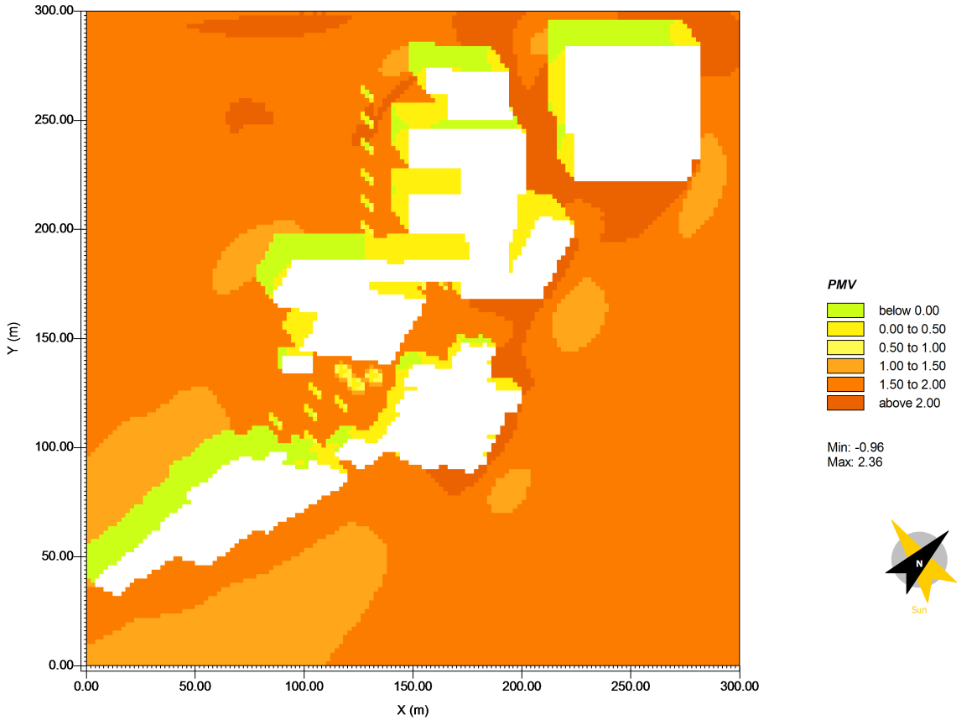


Figure 4.19: Outdoor thermal comfort evaluation according to PMV index (summer season, morning session).

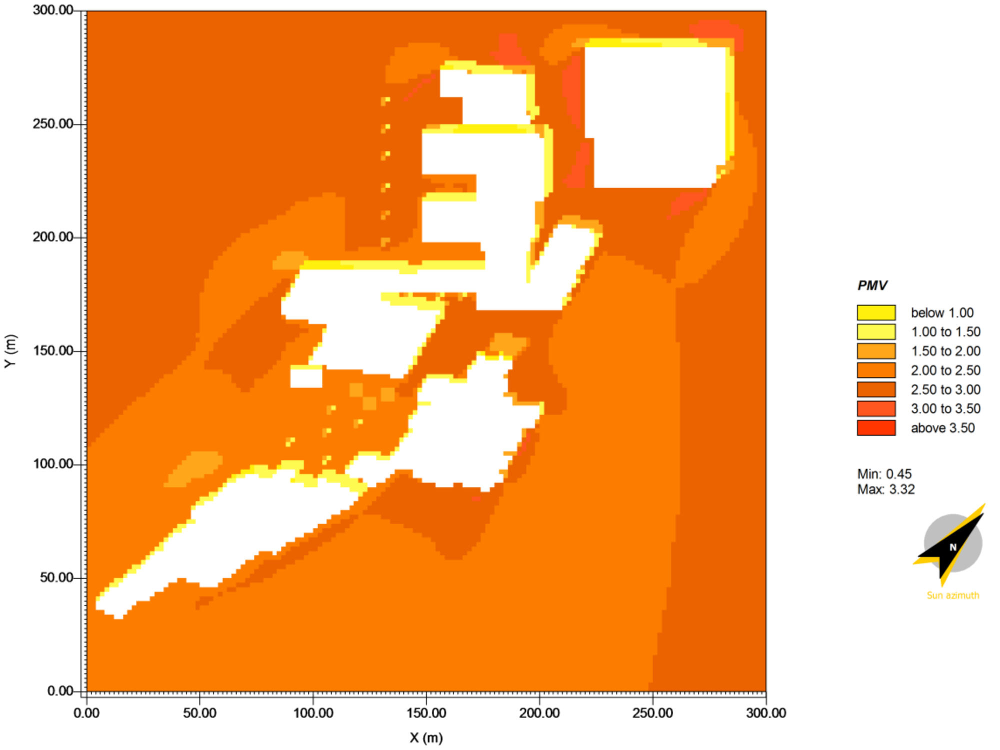


Figure 4.20: Outdoor thermal comfort evaluation according to PMV index (summer season, midday session).

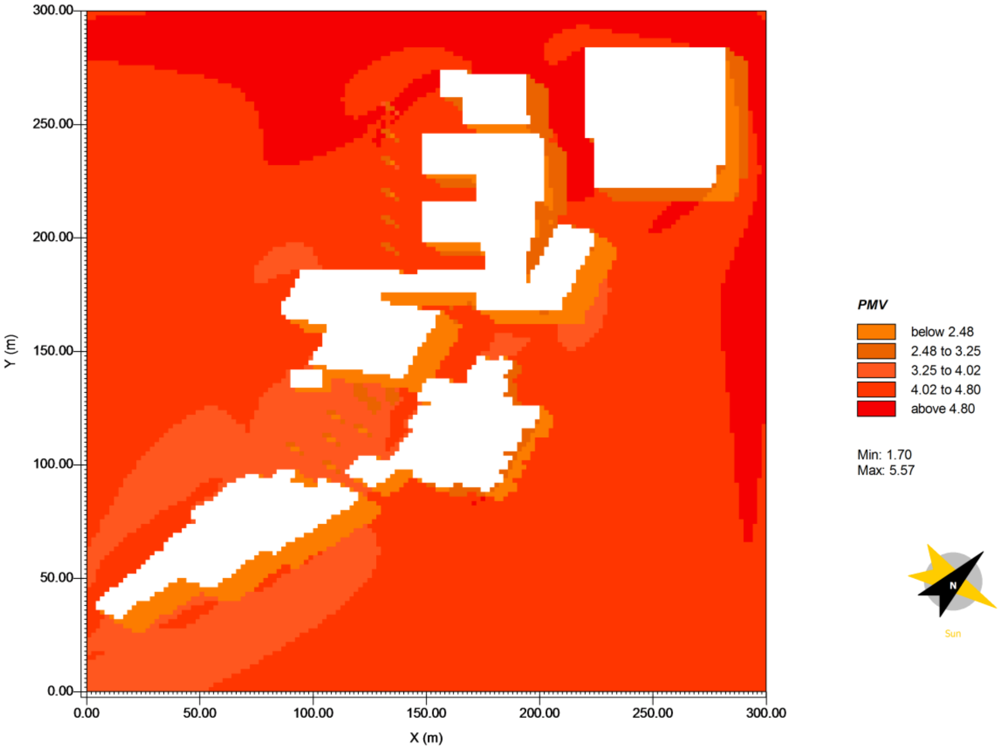
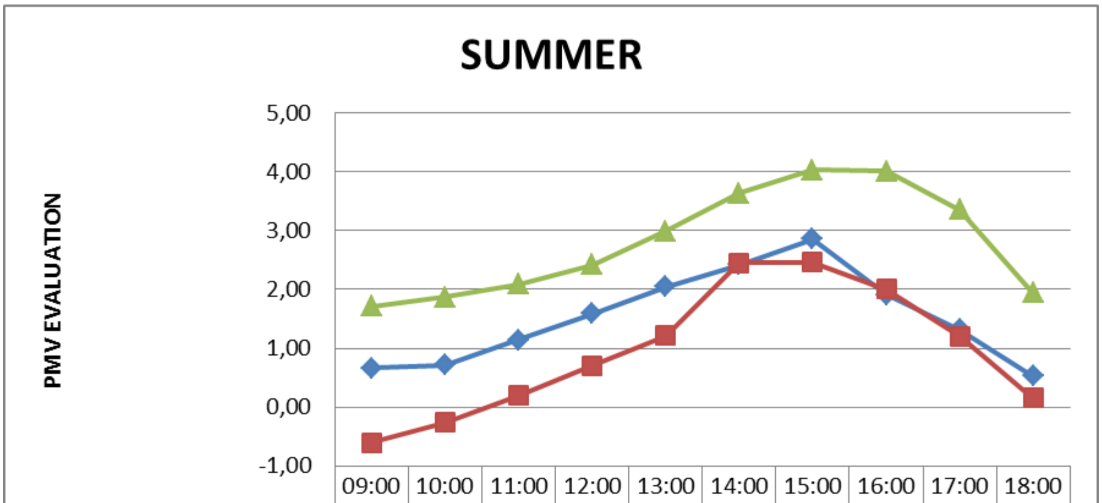


Figure 4.21: Outdoor thermal comfort evaluation according to PMV index (summer season, afternoon session).

Diurnal profile of simulated PMV index for the summer season at certain points has been shown in Figure 4.22. The results show that there are differences how thermal comfort has been perceived during the day in different places. It has been observed that PMV index for areas being exposed to direct solar radiation (where trees or buildings have not shadow effect) has been the highest during the day. However, after the 16.00 the change in sun's position has been affecting the area to be shaded by the nearby building, further resulting in PMV index decrease (from "hot" to "neutral"). On the contrary, areas being shaded by buildings in the morning periods have lower PMV value ("cool" or "warm"). With the change in the sun azimuth, shaded areas are getting exposed to direct solar radiation causing PMV index to escalate from "cool" to "too hot". Again, with the sunset PMV value tend to accelerate back to "neutral". The role of trees has been emphasized once again. Although the existing trees are sample trees with small canopies lacking in the provision of significant shade, their impact on outdoor thermal comfort has been positive. As seen in Figure 4.22, the areas under tree canopy have been the most comfortable areas during the hot summer conditions. In the morning, the simulated PMV value has been "neutral" with slightly increasing towards midday. Afternoon, as sun azimuth change, exposure to direct solar radiation from the west affects even the areas under the tree canopy to get "too hot". Afterward, the PMV value tends to decrease towards "neutral".

Therefore, it would be significant to state that although the vegetation has a positive effect over outdoor thermal comfort perception, its characteristics and position should be considered in order to benefit from canopy shadow and achieve comfortable environment.



	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
PMV tree canopy()	0,66	0,72	1,14	1,58	2,04	2,42	2,86	1,92	1,32	0,53
PMV shading areas()	-0,60	-0,26	0,19	0,70	1,21	2,45	2,46	2,01	1,2	0,15
PMV direct solar rad	1,71	1,87	2,09	2,42	2,99	3,64	4,04	4,01	3,35	1,94

Figure 4.22: Diurnal profile of simulated PMV index at determined points during the summer.

4.2.1.2 Winter season

PMV index in the winter season, as expected, is being below 0 due to the cold conditions (Figure 4.23). Main alley and quads have been evaluated as uncomfortable or in other words "too cold" (-2.65), as in this time period sun is not reaching pedestrian level. It is predictable that eastern parts of the buildings have been evaluated a bit positive (as "cool") due to the sun radiation occurring at these points. It is noteworthy how the effect of vegetation is not observed as being negative for the winter season, due to the fact that trees and vegetation are cooling urban environment. The areas under tree canopies were evaluated as other areas where PMV value has been -2.65. In the winter season, the evaluation of outdoor thermal comfort has reached its minimum of PMV index (below -4.00).

The PMV index at 12.00 is higher comparing to morning session with minimum value -2.10 and maximum -0.24 (Figure 4.24). The position of the sun at this hour affects the main alley and main courtyard positively, improving the PMV value from below -2.65 ("too cold") to 1.00 ("cool"). The front of the AB2 has been evaluated as closest to "neutral" (-0.10), due to the direct sun exposure. Slightly negative effect of trees has been observed in this time period, as they create shadow areas and block sun rays. The area between SCOLA building and AB2 and its parallel area to the north have been evaluated as the coldest areas (-2.10). Two small courtyards, being isolated from sun radiation are similarly valued between -2.10 and -1.70.

PMV assessment shows similarity to 12.00 o'clock having its minimum at -2.84 and maximum at -0.29. The eastern sides of the buildings, on the contrary to the morning, have been evaluated as "cold" (-2.50 and -2.11). Similarly, the front of the SCOLA and AB2 has been represented as "cold" area (-2.11). Front of the Student Centre, main quad and northern quads have PMV value of -0.66 and above, attributable to direct sun radiation from western side (4.25).

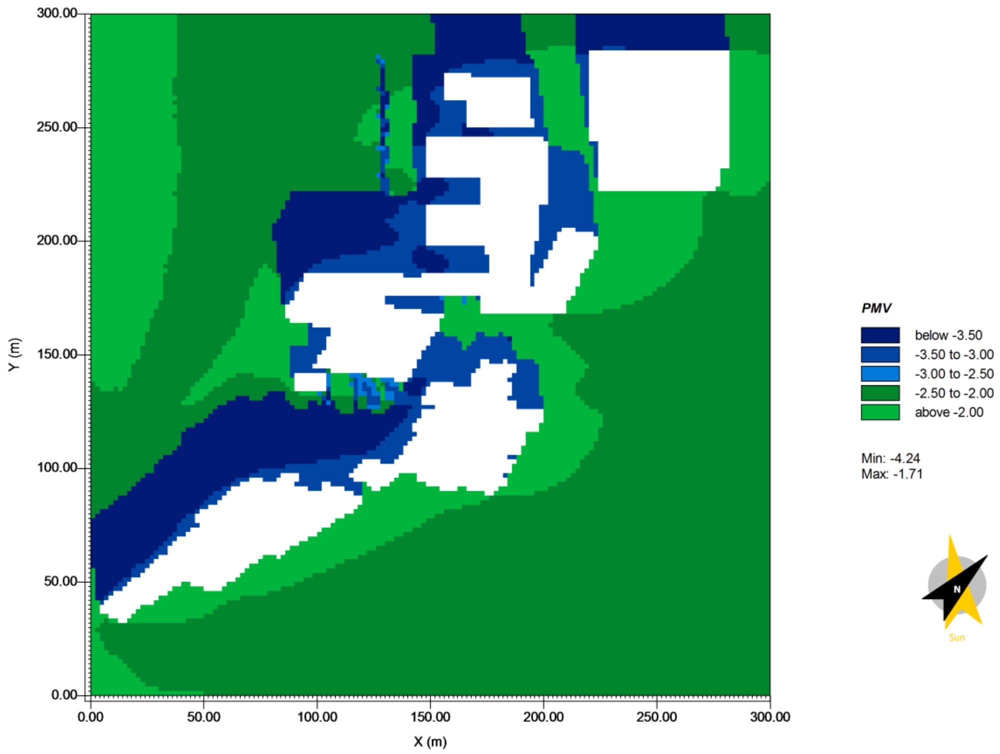


Figure 4.23: Outdoor thermal comfort evaluation according to PMV index (winter season, morning session).

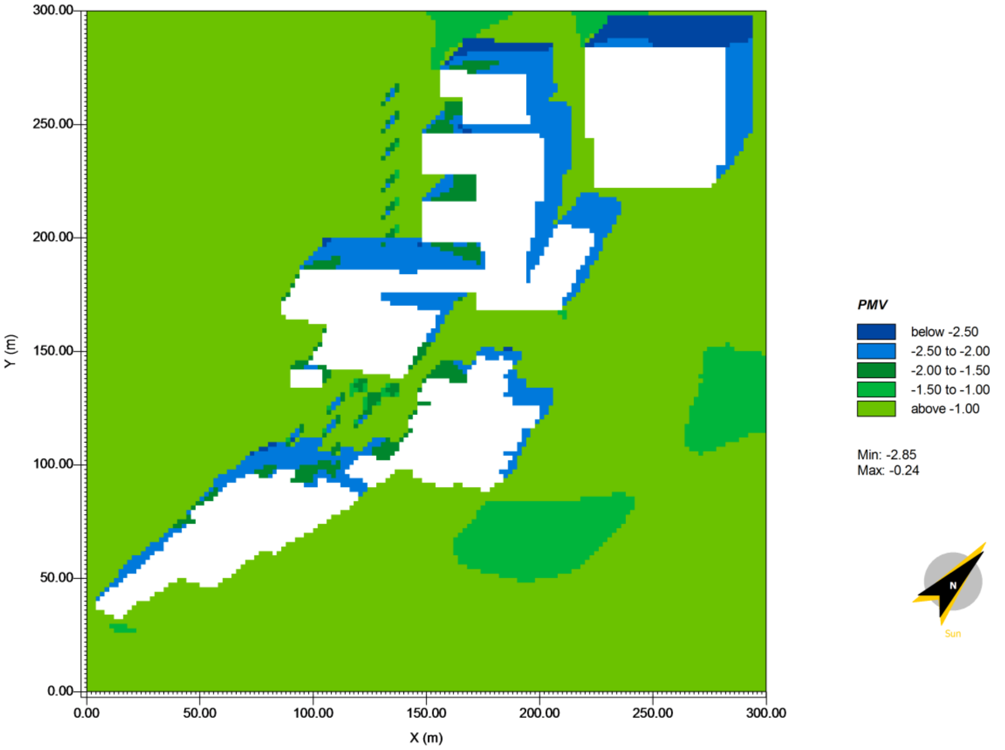


Figure 4.24: Outdoor thermal comfort evaluation according to PMV index (winter season, midday session).

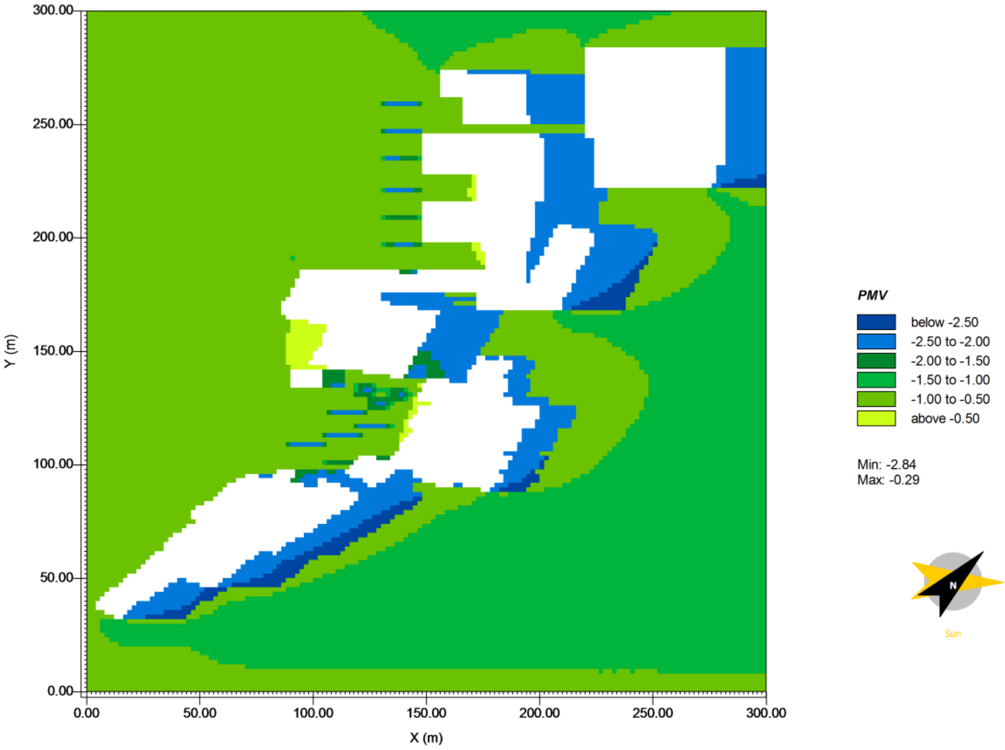
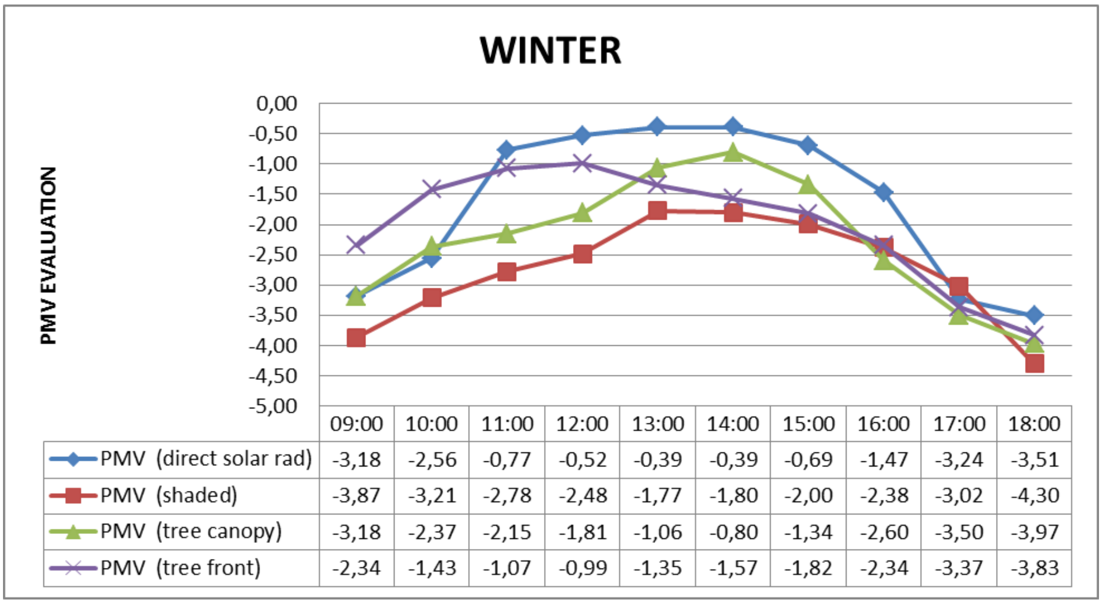


Figure 4.25: Outdoor thermal comfort evaluation according to PMV index (winter season, afternoon session).

Evaluating the diurnal profile of simulated PMV index for a winter season at certain areas has been conducted (Figure 4.26). Similar to the summer season, in the morning PMV index has been the lowest in the shaded areas (-3.87-"extremely cold"). In the areas where solar radiation reaches pedestrian level directly, PMV has been 3.18, the same as in the areas under canopy. This can be related to the fact that trees are not leafy in the winter season and do not block the solar access. Yet, the areas in front of the trees have been evaluated as “cold” (-2.34), what might be the result of tree abilities to block the cold winds.



	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
PMV (direct solar rad)	-3,18	-2,56	-0,77	-0,52	-0,39	-0,39	-0,69	-1,47	-3,24	-3,51
PMV (shaded)	-3,87	-3,21	-2,78	-2,48	-1,77	-1,80	-2,00	-2,38	-3,02	-4,30
PMV (tree canopy)	-3,18	-2,37	-2,15	-1,81	-1,06	-0,80	-1,34	-2,60	-3,50	-3,97
PMV (tree front)	-2,34	-1,43	-1,07	-0,99	-1,35	-1,57	-1,82	-2,34	-3,37	-3,83

Figure 4.26: Diurnal profile of simulated PMV index at determined points during the winter.

4.2.2 Assessment of vegetation parameter

As the user related parameters do not affect the design process directly, because in every community there is diversity in population in terms of body parameter, clothing level along with activity or metabolic rate; the proposals should be done to improve the general terms of environment. For this purpose, the physical environmental parameters should be modified and improved. Vegetation has been demonstrated as significant parameter that can be used for outdoor thermal comfort, as in other studies (Chudnovsky et al., 2004; Robitu et al., 2006; Chatzidimitriou et al., 2004; Lin et al., 2010; Lin et al., 2007) so in the implemented study where it is observed that during the summer season trees provide shading areas and decrease the temperature. While in the winter season they can be used as wind barriers. For this purpose, the proposal for outdoor thermal comfort improvement in university campus' outdoor thermal comfort is emphasized to be vegetation, more specifically trees. However, the type of trees should be selected sensibly. Trees should be effective in providing shaded area during the summer season, still should not block the solar radiation during the cold winter days. For this purpose, type of trees used should be adaptive to different conditions. The best examples are deciduous trees that would provide enough shaded areas during the summer; and in the winter season they would lose leaves and allow solar radiation to reach under the tree canopy. As a study result (Figure 4.27), it has been found that areas under the tree canopy during the summer season are more comfortable (0-“neutral”) than surrounding area exposed to direct solar radiation (+2-“hot”). The planting of the trees in open spaces should be emphasized in order to improve the outdoor thermal comfort.

Additionally, the location of the trees should be determined carefully taking into account the sun azimuth; due to the fact that tree canopy can provide large shaded areas and improve outdoor thermal comfort during the morning or midday periods, the change in sun azimuth will affect the same areas stay shaded in the afternoon.

In the winter season, the negative effect of trees can be observed. Tree canopies can block the solar radiation and cool the environment in the summer; but, they should not have the same effect for the winter season as already the thermal conditions in open spaces have been cold and uncomfortable (Figure 4.28). For this reason, it is important to plant the deciduous trees that would create shaded areas in the summer but would not block the solar radiation due to the leaves fall in the winter.

On the other side, the impact of vegetation on outdoor thermal comfort in winter season has been observed in terms that it blocks the wind and reasons for the environment to be more comfortable. As an example, conifers can be used in spaces where wind speed has been high and disturbing.

Figure 4.27: Effect of vegetation on outdoor thermal comfort (summer season).

Figure 4.28 Effect of vegetation on outdoor thermal comfort (winter season).

4.2.3 Assessment of surface material

Simulated air temperature has shown alterations in different surface materials. For this reason, assessment of surface material impact over PMV index has been conducted. In Figure 4.29, a diurnal profile of simulated PMV index in the summer season for different surface materials has been generated. Although the conditions of the solar radiation are equal for both surface materials, the PMV for hard surface has been higher during all the day but not to the significant extent. The noteworthy difference has been observed for the period in the afternoon where PMV for areas with the hard surface has been “extremely hot” (around 4.5) and with green surface “too hot” (around 3.00). However, this can be related to "heat absorption" and "heat loss" processes; hard surface material absorbs more heat during the day and in the afternoon period it releases the heat causing outdoor thermal conditions and PMV to be uncomfortable.

The effect of the surface material has not been observed in the areas where a mixture of the surface has been implemented so that the green and hard surface areas cover small areas alternately.

On the contrary, in the winter season, the impact of surface material has not been observed.

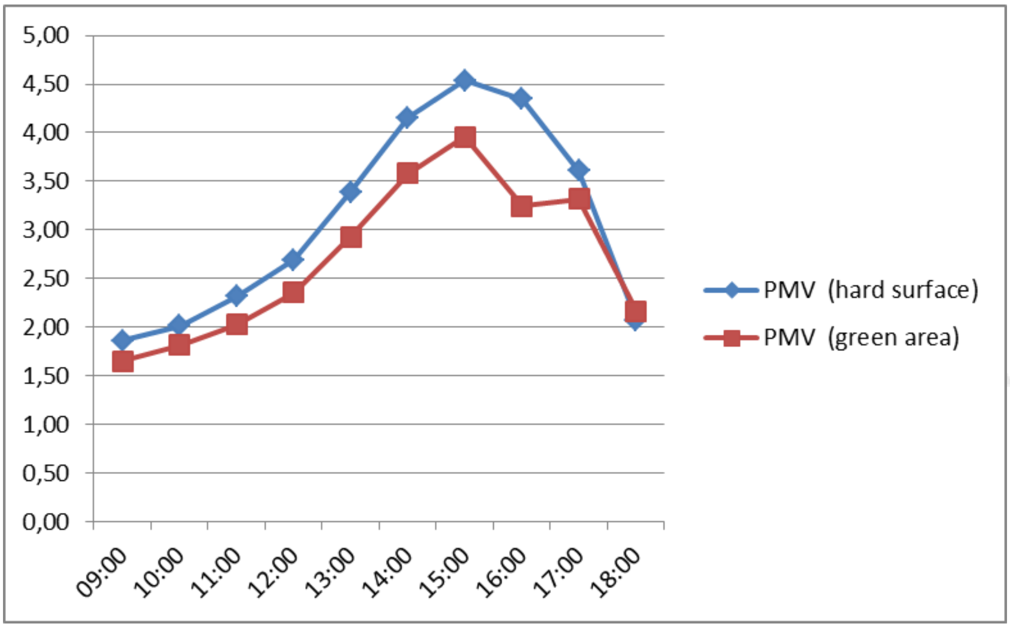


Figure 4.29: Diurnal profile of PMV index for the summer season at hard-surfaced and green surfaced areas.

4.2.4 Assessment of user-related parameters

In this section, user-related parameters have been examined in order to determine their effects on outdoor thermal comfort perception. Simulation tool allows modifying of body parameter, clothing and activity level where varieties can be created. Although simulation results have been obtained for three periods during the day (morning, midday and afternoon), only results of midday session have been given, as there are minor significant differences observed in the other two sessions.

4.2.4.1 Assessment of user-related parameters for the summer season

Assessment of body parameter (Height to weight ratio)

Body parameter or in other words height-to-weight ratio increases metabolic rate affecting the perception of thermal conditions. Here, the difference between the perception of normal weighted and an overweighed person has been simulated. Activity parameter has been set to sitting, age 20 and clothing level to 0.5. Obtained PMV index value for a normal weighted person varies from 0.42 to 3.33, while for an overweight person -0.03 to 3.48 (Table 4.1). An overweight person tends to perceive thermal conditions “neutral” in shaded areas where normal weighted person perceive them as “warm”. Similarly, the vegetation has more positive effect for an overweighed person, as the value below trees is lower (1.35) than for normal weight person (1.70). Although the values show the differences, the spatial distribution shows similarities.

Table 4.1: Simulated conditions for assessing body parameter and obtained PMV value for the summer season.

Height-to-weight ratio	**activity**	**age**	**clothing**	**PMV value**	
				min	max
Normal	sitting	20	0.5	0.42	3.33
Overweight	sitting	20	0.5	-0.03	3.48

Assessment of clothing level

It is familiar that person can use clothing for adapting to certain climatic conditions. In the hot summer season, shorter and thinner cloth is chosen in order to prevent sweating and provide person feel comfortable. In order to determine whether the clothing level affects the perception of the outdoor thermal comfort, clothing parameter is modified and simulated as seen in Table 4.2. According to simulation result, the person wearing thinner cloths perceives outdoor thermal comfort more “neutral” than the person with thicker clothing level. For instance, in shaded areas, PMV level for the first one is 0.70 while for the second it is 1.38. Likewise, the values for the areas under tree canopy are 1.56 and 1.89. On the contrary, in the areas where the solar radiation is direct the value of short and thin clothed person varying from 2.40 to 2.70 is being 2.39-2.58 for thick clothed (Table 4.2). This might be related to the direct exposition of skin to the sun, what might cause the increase of the metabolic rate. It is observable that thicker clothed person perceive the thermal conditions homogeneous when compared to the thin clothed person.

Table 4.2: Simulated conditions for assessing clothing level and obtained PMV value for the summer season.

HW ratio	activity	age	clo	PMV value				
				min	max	Shaded areas	Tree canopy	Direct solar rad.
Normal	sitting	20	0.5	0.42	3.33	0.70	1.56	2.40-2.70
Normal	sitting	20	1.5	1.16	2.96	1.38	1.89	2.39-2.58

Assessment of activity level

Activity level, increasing the metabolic rate, tends to affect the perception of outdoor thermal comfort. In order to examine this relation, the level of activity has been simulated in two variations: sitting and walking (Table 4.3). Although the obtained values have been approximate to each other (0.42-3.33 and 1.06-3.01), the vegetation effect tends to be lower for walking person due to the fact they do not spend enough time under the tree canopy to perceive the cooling effect. Additionally, walking person tend to perceive most of the areas as “hot”, while sitting person tends to perceive the same areas "hot" or "too hot" due to the long sun exposition.

Table 4.3: Simulated conditions for assessing activity level and obtained PMV value for the summer season.

Height-to-weight ratio	activity	age	clothing	PMV value	
				min	max
Normal	sitting	20	0.5	0.42	3.33
Overweight	walking	20	0.5	1.06	3.01

4.2.4.2 Assessment of user-related parameters for the winter season

Assessment of body parameter (Height to weight ratio)

Winter season simulation results for height-to-weight ratio have not shown any significant differences neither in value nor in the spatial distribution (Table 4.4). For this reason, it can be stated that body parameter does not affect the perception of cold conditions to a significant extent.

Table 4.4: Simulated conditions for assessing body parameter and obtained PMV value for the winter season.

Height-to-weight ratio	activity	age	clothing	PMV value	
				min	max
Normal	sitting	20	1.5	-0.93	0.85
Overweight	sitting	20	1.5	-0.94	0.85

Assessment of clothing level

The clothing effect on thermal perception in winter is opposing from summer; the higher clothing level tends to protect a person from cold conditions and make it perceive thermal conditions as more comfortable. In order to analyze the effect of cloths on thermal comfort perception, clothing level has been modified as seen in Table 4.5. As a consequence, the person who wears winter clothes tends to perceive thermal conditions as "cold" and "cool". In the areas of direct solar radiation, it reaches above 0 or "neutral". On the other side, the person wearing more clothes tends to perceive thermal conditions more positively. In shaded and vegetated areas the PMV value has been obtained as below 0 with a minimum of -0.19. Other areas are varying from 0.50 (“neutral”) to 1.22 (“warm”).

Table 4.5: Simulated conditions for assessing clothing parameter and obtained PMV value for the winter season.

Height-to-weight ratio	activity	age	clothing	PMV value	
				min	max
Normal	sitting	20	1.5	-2.25	-0.19
Normal	sitting	20	3.0	0.17	1.22

Assessment of activity level

Impact of the activity level of the user at the open spaces in winter season differs from the summer season. The higher metabolic rate can lead to the perception of the thermal environment as more comfortable. Users performing passive activities, such as sitting and standing, are exposed to weather conditions longer what further affects them perceive thermal environment more objectively. On the other side, transit users performing walking or running activities have increased metabolic rate and perceive the thermal environment as more comfortable (Table 4.6). Spatial distribution of perception differs according to user activity level. For example, in the shadowed area at the north of the buildings sitting person tend to perceive thermal conditions as "cool" while running person perceives as a "neutral". While some areas in front of the Student Centre are perceived as "warm" according to running person, sitting person tend to perceive them as "neutral".

Table 4.6: Simulated conditions for assessing activity level parameter and obtained PMV value for the winter season.

Height-to-weight ratio	activity	age	clothing	PMV value	
				min	max
Normal	sitting	20	1.5	-0.93	0.85
Normal	running	20	1.5	-0.30	1.10

4.3 Summary of the findings

The outcomes of the simulations results have been discussed briefly above. In order to summarize the effect of environmental and user related parameters on outdoor thermal comfort, the following items can be concluded.

1. Meteorological conditions have a substantial impact on the outdoor thermal comfort.
2. Air temperature has been related to the surface material (as seen in Table 4.7) the difference between hard surface and green surface area affect the difference in the air temperature during the summer season (Figure 4.1 and Figure 4.4).

Table 4.7: Difference in the air temperature (C) during the summer season.

Summer	Morning	Midday
Hard Surface	23.19	26.68
Green Surface	22.60	25

3. Air temperature has been highly related to PMV index; increase in the air temperature has led to the acceleration in the simulated PMV result.
4. In the winter season, the effect of building geometry has been observed; wind tends to be lower at the inner parts of the courtyards; wind tends to decrease while reaching the inner parts of the courtyards (Figure 4.30).

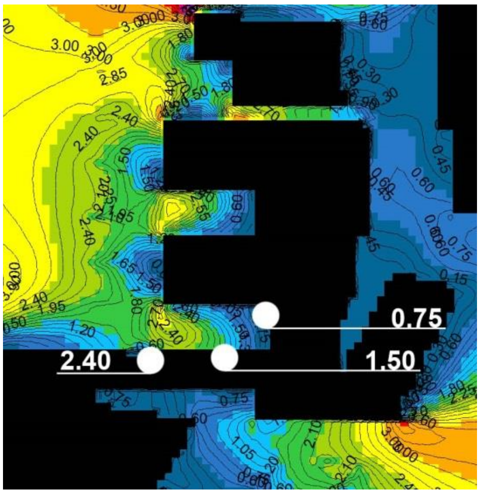


Figure 4.30: Wind pattern at the courtyards.

5. Building geometry has a higher effect on PMV than surface material (in both seasons); it can provide shadow (summer season, Figure 4.19, 4.20 and 4.21) or allow direct exposure to the sun (winter season, Figure 4.23, 4.24 and 4.25) improving the thermal environment.
6. Diurnal profile of the microclimate conditions in both seasons has been noteworthy; rise in PMV index have a positive effect in the winter season (from "too cold" to "neutral", Figure 4.26); in the summer season it causes uncomfortable conditions (from "neutral" to "too hot", Figure 4.22).
7. Sun azimuth has the significant impact on the outdoor thermal comfort.
8. Sun azimuth has the significant impact on the microclimatic design; although the trees and shading elements provide shaded areas during the morning and midday session (Figure 4.19 and 4.20), in the afternoon session (Figure 4.21) they can be exposed to direct solar radiation what increase the PMV index (negatively in the summer, positively in the winter season).
9. Surface material has been determined as a parameter affecting the solar radiation reflection and the perception of outdoor thermal comfort.
10. Surface materials have not been observed as influencing factor where a mixture of materials has been used alternately but only in large areas, such as courtyards and main quad (Figure 4.20 and 4.21).
11. Trees have been observed as a significant tool for improving the outdoor thermal comfort; providing shading areas has been decreasing the PMV index in the summer (Figure 4.22).

12. Trees cause the decrease in PMV index during the summer season for at least 1℃(i.e. “extremely hot” to “too hot”, “hot” to “warm” etc.)
13. Trees can be used as a wind barrier in order to decrease high wind speed; yet, the type and tree canopy should not block the solar radiation during the winter season.
14. Although trees have been emphasized as a strong tool for outdoor thermal comfort improvement, their location, size and type are determining their efficiency.
15. User-related parameters affect the perception of outdoor thermal comfort; height-to-weight ratio, activity and clothing level affect the metabolic rate further affecting the perception of the thermal environment. However, in some cases, the increase in metabolic rate does not cause an increase in PMV value. In the summer season, exposure to the sun has been a more affecting parameter.
16. User-related parameters cannot be "modified" in a real environment, for this reason, the physical parameters should be considered in order to create a comfortable and livable environment

5. CONCLUSION

Implementing an outdoor thermal comfort assessment methodology to the case study of a university campus in a temperate climate zone for determining the outdoor thermal comfort parameters indicate the importance of microclimate as well as physical environment. Due to the different weather conditions and needs during the summer and winter, the effect of each parameter has been observed differently. The most influencing factor has been direct solar radiation and sun azimuth; while improving the thermal conditions in the winter it causes thermal discomfort in the summer season. Additionally, the building layout and geometry have been influencing factor; according to the building geometry and layout the open spaces have been exposed to the direct solar radiation or have been shaded by the buildings. The wind pattern has been affected by building geometry. It has been observed that wind pattern tend to change within a courtyard, being higher at the corners and lower as reaching inside. The vegetation (surface material and tree) has been influencing the outdoor thermal comfort to a great extent. Due to the heat absorption, hard surface materials cause higher air temperature in the afternoon periods (heat release) during the summer. On the contrary, the effect of surface material during the winter has not been observed. The existence of trees has been affecting the outdoor thermal conditions; providing the shaded areas during the summer season has affected the PMV to drop from < +3”extremely hot” and “too hot” to “hot” or “warm”, while reducing “warm” conditions to “neutral”. User-related parameters affect the perception of outdoor thermal comfort. The activity and clothing level has been increasing the metabolic rate, affecting the rise in PMV value. However, the exposure to the solar radiation has been more influencing (Figure 5.1).

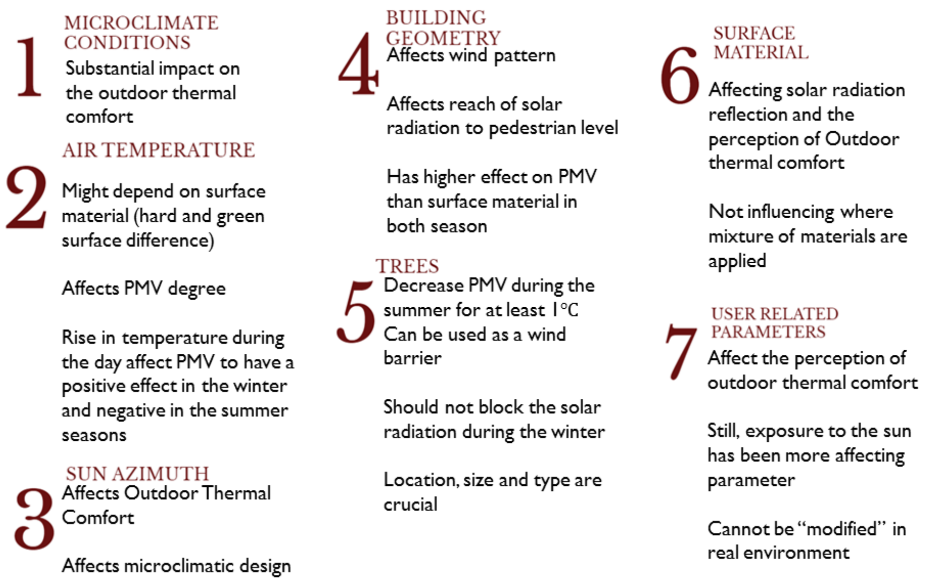


Figure 5.1: Parameters affecting the outdoor thermal comfort of the case study.

Findings strongly emphasize the significance of appropriate design strategies and requirements for the simulation tools in the pre-design process. Attention should be paid to the building layout and geometry as the main physical parameters affecting the outdoor thermal comfort. Wind pattern and air temperature tend to change according to the building geometry and exposure to the microclimatic conditions. Similarly, the influence of the trees as enhancers of outdoor thermal comfort has been highlighted. Still, the locations and type of trees should be selected carefully. The implementation of green surface materials has been observed as improving parameter for air temperature and outdoor thermal comfort during the summer season; however, the influence has not been observed for the areas where the combination of surface materials has been implemented.

In order to improve the outdoor environment and sustainability of campus, attention should be paid to the microclimatic design and green infrastructure. As found out, the impact of vegetation, especially trees on the outdoor thermal comfort has been positive especially in the summer seasons. Similarly, the geometry and layout of the buildings should be determined according to the microclimatic conditions for all circumstances. Suburban campus should preserve their settings and configurations according to the surrounding settlements. They should not destroy the surrounding natural environment nor consist of high-rise buildings and affect the creation of microclimate in surrounding living areas. Campus should be planned and design integrated with the surrounding environment. Outdoor thermal comfort as comprehensive approach for evaluation of the open spaces lacks in the determination of global assessment index according to which the general state of an urban environment could be determined. The parameters could be listed as achievement goals and scored according to the success.

As a recommendation, assessment of outdoor thermal comfort within urban city centers should be conducted. The use of urban squares, parks and other open areas within city center should be investigated in order to determine the issues and improve the conditions. Similarly, studies can be done for determining outdoor thermal comfort conditions during the year and taking into consideration user-related data, obtained via surveys or questionnaires. Obtained data can be used for comparison with the standards and determine the local adaptation level, preferences and satisfaction.

Simulation tool can be used for investigating the historical settlements within Istanbul where passive cooling design techniques may have been implemented originally and enrich the design possibilities required for a temperate climate. In addition, the effect of climate change on outdoor thermal comfort can be assessed by examining the changes, as well as creating scenarios for future. Visions for further effort should provide accurate passive design strategies and improve outdoor environment not only seasonally, but for longer periods. As one of the most important passive design tool, trees should be investigated and simulation studies should be conducted in order to determine the location and type of trees within an urban environment.

Providing comfortable thermal condition within an environment is extremely important for people to enjoy urban spaces. In crowded cities like Istanbul where the urban population has been increasing and so the needs and use of open spaces, the investigation of outdoor thermal comfort should be emphasized and intrigued in order to achieve livable and sustainable environment. Because understanding the microclimate implications and outdoor thermal comfort conditions within urban environment open up new possibilities for the developments and improvements.

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APPENDICES

APPENDIX A.1: Sample of a survey conducted for the pilot study

Outdoor Thermal Comfort

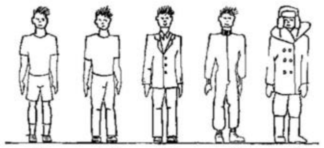
Mimarlık Fakültesi, Mimarlık Bölümü, Özyeğin Üniversitesi

The aim of this research is to carry out a post occupation assessment study based on the time-spatial mapping method in the outdoors of university campuses.

Completing the survey will only take 2 minutes. Thank you very much for your participation. Please answer your questions and consider your experiences on campus outdoors. contact the Department of Architecture for your inquiries. Contact Özgür Göçer (ozgur.gocer@ozyegin.edu.tr).

temperature:............
humidity:.................
wind:............
wind speed:............
radiation:..................

1. Nationality :......................................
2. How long have you been living in Istanbul ....
3. How old are you ☐ <20 ☐ 21-25 ☐ 41-45 ☐ 26-30 ☐ 46-50 ☐ 30-35 ☐ 51-55 ☐ 36-40 ☐ 56-60 ☐ >60
4. Gender ☐ male ☐ female
5. height:
6. weight :
7. weight height ratio ☐ Normal ☐ fat ☐ overweight
8. current clothing



☐ ☐ ☐ ☐ ☐

9. What activity were you performing before survey?
☐sitting ☐ lie down ☐ walking ☐ running
10. Where did you spend last 15-20 minutes?
☐Indoor ☐ Outdoor
11. time of exposure in this area
☐<10 min ☐10-15 min ☐15-20 min ☐ 20-40 min
☐ 40-60 min ☐ >60 min
12. the reasons for visiting
☐ environment (landscape, fresh air, etc)
☐ weather conditions (sun, wind, shadow etc)
☐ resting
☐ studying
☐ eating/drinking
☐ transit
13. (questions are prepared according to ISO 10551, 1995 and ASHRAE 55, 2010 standards)

A. How do you feel now?

☐very cold ☐cold ☐cool ☐ Neither hot nor cold ☐ warmish ☐ hot ☐very hot

B. how do you find this area in terms of weather conditions?

☐comfortable ☐ Little uncomfortable ☐ comfortless ☐ Very uncomfortable

C. personaly this area is:

☐ Absolutely acceptable ☐acceptable ☐ unacceptable ☐ Absolutely unacceptable

D. how would you like this environment to be

☐ Colder ☐ A little colder ☐ Neither hot nor cold ☐ Slightly hotter ☐ warmer

E. Your satisfaction with this environment?

☐ Not satisfied at all ☐ not satisfied ☐not satisfied nor unsatisfied ☐ satisfied ☐ very satisfied

14. If you are not satisfied with the weather, what did you do:
☐ Go to the shaded / sunny area ☐To open an umbrella / to wear a hat
☐ Take hot / cold drink ☐ Remove / wear clothes
☐ Nothing ☐leave the area

Thank you!

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