ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

URBAN HEAT ISLAND EFFECT ON BUILDING ENERGY CONSUMPTION: A CASE STUDY USING THERMAL LOAD CALCULATION TOOL

M.Sc. THESIS

Mustafa LEBLEBİCİ

Energy Science and Technology Division

Energy Science and Technology Programme

JULY 2020

ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

URBAN HEAT ISLAND EFFECT ON BUILDING ENERGY CONSUMPTION: A CASE STUDY USING THERMAL LOAD CALCULATION TOOL

M.Sc. THESIS

Mustafa LEBLEBİCİ
(301171024)

Energy Science and Technology Division

Energy Science and Technology Programme

Thesis Advisor: Dr. Lecturer Murat ÇAKAN

JULY 2020

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

ŞEHİR ISI ADASI ETKİSİNİN BİNALARDA ENERJİ TÜKETİMİNE ETKİSİ: ISIL YÜK HESAPLAMA PROGRAMI KULLANILARAK YAPILAN ÖRNEK BİR ÇALIŞMA

YÜKSEK LİSANS TEZİ

Mustafa LEBLEBİCİ
(301171024)

Enerji Bilim ve Teknoloji Anabilim Dalı

Enerji Bilim ve Teknoloji Programı

Tez Danışmanı: Dr. Öğr. Üyesi Murat ÇAKAN

TEMMUZ 2020

Mustafa Leblebici, a M.Sc. student of ITU Institute of Energy student ID 301171024 successfully defended the thesis entitled "URBAN HEAT ISLAND EFFECT ON BUILDING ENERGY CONSUMPTION: A CASE STUDY USING THERMAL LOAD CALCULATION TOOL", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Dr. Lecturer Murat ÇAKAN** ....
İstanbul Technical University

Jury Members : **Dr. Lecturer M. Berker YURTSEVEN** ....
İstanbul Technical University

Dr. Lecturer Neşe GANİÇ SAĞLAM ....
Özyeğin University

Date of Submission : 18 June 2020
Date of Defense : 20 July 2020

B.

FOREWORD

When reverse engineering the future to the present moment, most important problem to tackle with seems to be the global warming. One of the aspects of the global warming is overheating (UHI effect) in urban areas which is partially dependent on global warming. Coupled with climate change, Urban Heat Island Effect induces lots of problems. Tackling the temperature increase caused by UHI requires additional cooling which causes additional anthropogenic heat release. In return, it also causes temperature increase as in vicious circle; solution to the problem increases severity of the problem. In order to break this cycle, more research and careful planning are required so that, future cities wouldn’t be locked under heat waves as isolation from heat isn’t quite possible.

I would like to extend my thanks to Prof. Dr. Ali Osman Ayhan, Prof. Dr. Mustafa Özdemir and Prof. Dr. Nedim Sözbir, M.D. Betül Sezgin, Fatma Akım, Süleyman Akım, my teammates Mohammad Abazid and Hashem Mihyar, My Thesis Advisor Dr. Murat Çakan who advised me to study UHI without his encouragement and support I would neither start nor finish my study, for their support and suggestions Prof. Dr. Ahmet Arısoy and Dr. Ece Kalaycıoğlu. Finally, I want to thank my mother, my father and my sisters.

July 2020

Mustafa LEBLEBİCİ
(Mechanical Engineer)

TABLE OF CONTENTS

Page

ABBREVIATIONS

AC	**:** Air Conditioning/Air Conditioner
AH	**:** Anthropogenic Heat (W)
ASHRAE	**:** American Society of Heating Refrigerating and Air Conditioning
BEM	**:** Building Energy Modelling
BIM	**:** Building Information Modelling
CFD	**:** Computational Fluid Dynamics
COP	**:** Coefficient of Performance
DB	**:** Dry-Bulb (Temperature) (˚C)
DOTR	**:** Degree of Temperature Rise (˚C)
ELWT	**:** Evaporator Leaving Water Temperature (˚C)
GDP	: Gross Domestic Product
GR	: Ground Reflectivity
HAP	**:** Hourly Analysis Program
HBM	**:** Heat Balance Method
HVAC	**:** Heating Ventilating and Air Conditioning
NIR	**:** Near-Infrared Band of Solar Spectrum
RH	**:** Relative Humidity (%)
SEB	**:** Surface Energy Balance
SHGC	**:** Solar Heat Gain Coefficient
TFM	**:** Transfer Function Method
T-stat	**:** Thermostat
WB	**:** Wet-Bulb (Temperature) (˚C)
UHI	**:** Urban Heat Island
VIS	**:** Visible Band of Solar Spectrum

SYMBOLS

$\boldsymbol{a}$	:	Albedo
$\boldsymbol{E}$	:	Rate of Evaporation
$\boldsymbol{G}$	:	Ground Heat Flux (W)
$\boldsymbol{H}$	:	Sensible Heat Flux (W)
$\boldsymbol{h_c}$	:	Convective Heat Transfer Coefficient (W/m^2K)
$\boldsymbol{I}$	:	Incoming Total Solar Radiation (W)
$\boldsymbol{k}$	:	Thermal Conductivity of the Ground (W/mK)
$\boldsymbol{L}$	:	Long-Wave Radiative Flux (W)
$\boldsymbol{P_{atm}(T_{oa})}$	:	Absorbed Power due to Atmospheric Thermal Radiation (W)
$\boldsymbol{P_{cond+conv}}$	:	Transferred Heat due to Conduction and Convection (W)
$\boldsymbol{P_{cool}\,(T)}$	:	Cooling Power of the Material (W)
$\boldsymbol{P_{rad}(T)}$	:	Radiated Heat from the Material (W)
$\boldsymbol{P_{sun}(T)}$	:	Absorbed Solar Power (W)
$\boldsymbol{Q}$	:	Direct Short-Wave Radiative Flux (W)
$\boldsymbol{q}$	:	Diffuse Short-Wave Radiative Flux (W)
$\boldsymbol{Q_f}$	:	Anthropogenic Heat Flux (W)
$\boldsymbol{R}$	:	Thermal Resistance of the Material Layer (m^2K/W)
$\boldsymbol{T}$	:	Temperature (˚C)
$\boldsymbol{T_o}$	:	Surface Temperature (subject to convection and radiation) (˚C)
$\boldsymbol{T_{oa}}$	:	Outdoor Ambient Air Temperature (˚C)
$\boldsymbol{T_s}$	:	Surface Temperature (subject to conduction) (˚C)
$\boldsymbol{U}$	:	Heat Transfer Coefficient (W/m^2K)
$\boldsymbol{\alpha}$	:	Total Absorptivity
$\boldsymbol{\alpha_L}$	:	Long-Wave Radiation Absorptivity
$\boldsymbol{\alpha_s}$	:	Short-Wave Radiation Absorptivity
$\boldsymbol{\lambda}$	:	Latent Heat (W)
$\boldsymbol{\sigma}$	:	Stefan-Boltzmann Constant (W/m^2K^4)
$\boldsymbol{\epsilon}$	:	Emissivity of the Surface

LIST OF TABLES

Page

LIST OF FIGURES

Page

URBAN HEAT ISLAND EFFECT ON BUILDING ENERGY CONSUMPTION: A CASE STUDY USING THERMAL LOAD CALCULATION TOOL

SUMMARY

Urbanization increases human comfort and quality of living by altering ground canopy layer. Building façades, roads, pavements, roofs and other urban materials are parts of urban formation. 21st century has seen a rapid urbanization. Conflicts, better life expectancy and lack of resources in rural areas have drawn people into the large cities.

Rapidly increasing population in the cities paved the way to the increased anthropogenic formation on the ground canopy layer and the release of the anthropogenic heat.

Urban formation differs from its surrounding rural areas by having different material, shape and geometry. Altered air flow throughout the city and reduced sky-view factor because of the urban design, increased solar absorption because of the urban material combined with the lack of green areas led to the increased ambient temperatures in the urban areas.

This heat content is called as Urban Heat Island which damages thermal balance of cities. Coupled with Climate Change, UHI Effect induces lots of problems. Tackling the temperature increase caused by anthropogenic formation, solar and infrared heating requires additional cooling which causes additional anthropogenic heat release. In return, it also causes temperature increase as in vicious circle; solution to the problem increases severity of the problem. Factors that form UHI could be listed as sky view factor, urban design and material, urban ventilation (air flow) and urban albedo.

Mitigation strategies of UHI could be listed as, cool urban materials, super-cool materials, urban ventilation, urban greening and reflective/retro-reflective materials. Aim of the thesis is to show dynamics of urban formation and its relation with the surrounding rural areas by explaining factors, variables that form UHI and related mitigation strategies in order to build a ground and related common language for those who wants to study and research UHI which requires extensive multi-disciplinary contribution. Tools used while studying UHI could be listed as; numerical modelling, field measurements and satellite sensors.

Hot Climates that require cooling more than heating are especially vulnerable to UHI effect which increases urban temperature, mortality rates, cooling loads, peak and total electricity demand, causing air pollution and decreasing environmental comfort and public health

Both urban and rural areas receive the same solar radiation from the sun. Albedo meaning fraction of incident radiation reflected by a body or surface determines the amount of short-wave solar radiation absorbed. Due to the low albedo values, short-wave solar radiation is absorbed by the urban materials. Absorbed solar radiation is

then re-radiated to the urban area with a longer wave-length thus causing infrared heating.

Anthropogenic heat is the heat content that is released as waste heat from buildings (HVAC Equipment), transportation systems(vehicles) and power plants. Anthropogenic Heat (AH) and moisture enter urban area simultaneously as it is generated and causes temperature increase.

Using cool materials for urban formation that absorb less (high reflectance) and emit more (high thermal emittance) helps to keep surface temperatures low. Cooler surfaces convect less heat to the air, reducing ambient air temperature, conduct less heat to the buildings, reducing heat gain.

Mitigation of UHI effect by air flow is an important countermeasure thus should be taken into account in the design phase of an urban area. Air flow increases heating load in the winter and reduces cooling load in the summer. By careful selection of the orientation of the urban formation with the help of different prevailing wind directions in the summer and winter which makes air flow an important asset of mitigating UHI.

High rise buildings on both sides in a typical urban canyon configuration, creates reflective surfaces for radiation incident upon it thus, entrapping the radiation within built area and converting it to the heat. If reflected radiation by the window (as it is a mirror like reflection) is directed downwards onto the urban area (pavements, sidewalks etc.) causes discomfort and temperature rise on the ground level. From the ground level, infrared radiation goes upwards but due to the reduced sky view factor, it is possible that it is going to return to the ground level. By changing reflection direction of the windows to the sky by having retro-reflection capability means, reflecting the incident radiation towards its incoming direction. By that, it is possible to send NIR radiation back to the sky without directing it to the ground.

Urban greening is most widely applied mitigation strategy for UHI Effect. Vegetation provides shade and increases evapotranspiration by retaining water especially in hot and arid climates. UHI effect increases total and peak energy consumption of buildings because of higher cooling demands. Buildings in the summer consume electricity to run HVAC equipments. Generally, electricity is generated by coal and gas fired powerplants.

Process of thermal load calculation of buildings consist of all modes of heat transfer as conduction, convection, radiation. All modes play an important role in determining thermal loads. All modes are interrelated, vary with time leading to a transient nature of heat transfer rather than steady-state heat transfer.

A case study is implemented in order to investigate some of the factors forming UHI. Case study building is an imaginary research institute building located in Istanbul Technical University's Ayazağa campus in İstanbul, Turkey. The building is 25 m by 25 m square building, one storey high on the ground soil.

Main aim of the thesis is to show how absorptivity levels (albedo/reflectivity) of the building envelope affect heat gains and cooling loads. Case study building cooling loads have been analysed in the case of UHI effect (+1°C, +2°C, +3°C, +5°C) also by varying the building envelope absorptivity values. (as 0.3, 0.6, 0.9) For the secondary variable, also government mandated thermostat set temperature increase (in the summer) has been analysed. In order to show how ground reflectance should be carefully evaluated, ground reflectance of the case study building surrounding has been increased and cooling loads have been analysed.

It's been concluded that; each degree of ambient air temperature rise caused by the UHI effect increases total and peak cooling loads in the summer. Decreasing absorptivity level of the building envelope (increasing albedo/reflectivity) is an effective counter-measure for UHI effect and could be used to mitigate UHI.

Higher absorptivity levels of the building envelope cause higher building surface temperatures which leads to higher convection/radiation of heat to the surroundings of the building thus creating UHI effect hence built environment is called as micro-climatic formation.

While increasing reflectivity of the building envelope is an effective measure for reducing cooling loads. Reflected heat/radiation might cause discomfort on the urban ground. Increasing reflectivity of the surrounding of a building might increase building's cooling load by reflecting heat/radiation onto the building envelope.

When building energy consumption and urban environmental comfort (pedestrian comfort) are regarded as equally important. There should be criteria/metrics for regulation in order to achieve both as rejecting heat by having reflective building envelope and reflecting this heat/radiation to the urban area might contradict with having urban environmental comfort

Rejecting heat by building envelope and not reflecting heat/radiation onto the urban ground might require to reflect heat/radiation to the sky, meaning retro-reflective building envelope and surroundings might be adopted. Also, solution to UHI effect cannot be more cooling, because cooling itself is one of the main sources of anthropogenic heat release in urban areas.

Future UHI effect and related mitigation studies could be done in 3 stages. In 1st stage, a case study using thermal load calculation tool and CFD analysis should be done. In 2nd stage, small-scale experimental study similar to first stage case should be studied. In 3rd stage, criteria and metrics for regulation of all the parameters effecting UHI should be proposed.

ŞEHİR ISI ADASI ETKİSİNİN BİNALARDA ENERJİ TÜKETİMİNE ETKİSİ: ISIL YÜK HESAPLAMA PROGRAMI KULLANILARAK YAPILAN ÖRNEK BİR ÇALIŞMA

ÖZET

Şehirleşme, insan kaynaklı yapılaşma ile insan yaşamını ve konforunu arttıran bir olgudur. Bina yüzeyleri, yol, kaldırım, çatı vb. şehirleşmeyi oluşturan temel bileşenlerdir. 21. yüzyıl şehirleşme açısından ciddi bir gelişmeye sahne olmuştur. Kırsal kesimlerdeki sorunlar, altyapı eksiklikleri, şehirlerde sunulan hizmetler ve daha iyi yaşam beklentisi, kırsal kesimlerden şehirlere yoğun bir göçe neden olmuştur.

Bu yoğun göç, hızla artan plansız bir yapılaşmaya neden olmuştur. Şehirler temel olarak, çevrelendikleri kırsal kesimlerden, farklı malzemeye sahip olmaları, geometri ve şekillerinin farklı olması dolayısı ile ayrılırlar. Şehirleşme nedeni ile, karakteristiği değişen rüzgâr/hava akımları, gökyüzü görüş oranının azalması, kullanılan malzemelerin özelliği nedeni ile güneş ışınlarının daha fazla soğurulması, şehirlerdeki yeşil alanların az olması ile birleşince, şehirlerin, kırsal alanlara göre daha sıcak olmasına neden olmaktadır.

Bu ısı fazlalığı, Şehir Isı Adası olarak isimlendirilmektedir. Bu etki, şehirlerin ısıl dengesini bozmaktadır. Şehir ısı adası etkisi uzun zamandır bilinen ve araştırılan bir mikro-iklim oluşumudur. Özellikle büyük şehirlerde insanların sağlığını tehdit eder hale gelmiştir. Küresel iklim değişikliği ile birleşince, şehir ısı adası etkisi birçok farklı soruna neden olmaktadır.

Şehirlerdeki yapılaşmadan kaynaklı sıcaklık artışı, insan kaynaklı atık ısı, güneş ışınları ve soğurulan ışınların ışıma ile yayılması kaynaklı ısınma ile birleşince, şehirlerin soğutma ihtiyacını artırmaktadır. Ancak, soğutma ile de çevreye atık ısı verildiği için, şehirlerin sıcaklığı daha da artar. Probleme çözüm olarak sunulan daha fazla soğutma yapmak, aksine durumu daha da olumsuz hale getirerek bir kısır döngü oluşturmaktadır. Şehir ısı adası etkisini oluşturan faktörler, şehir planı ve malzemesi, şehrin havalanması (rüzgâr/hava akımı), şehrin yansıtıcılığı ve şehrin gökyüzünü görme oranı şeklinde sıralanabilir.

Şehir ısı adası etkisini azaltmak için, soğuk/açık renkli malzemeler, süper soğuk malzemeler, şehirlerin içine rüzgâr nüfuzuyetini artırmak, şehirlerde yeşil alanların artırılması, yansıtma ve geri yansıtma katsayısı yüksek malzemeler kullanılması gibi stratejiler bulunmaktadır.

Tezin genel amacı, şehir ısı adası etkisi oluşumunun dinamiklerini ve kırsal kesimler ile olan etkileşimini, faktör ve değişkenler ile göstererek, bu konu ile ilgili yapılacak sonra ki çalışmalara destek olmaktır. Şehir ısı adası etkisi, yapısı gereği birçok farklı daldan araştırmacının beraber çalışmasını gerekli kılan bir konudur. Bu konuyu çalışırken kullanılacak araçlar, nümerik modelleme, saha ölçümleri ve uydu verileri ile analizdir.

Sıcak iklimler, soğutma ihtiyacının ısıtma ihtiyacından daha fazla olmasından dolayı, şehir ısı adası etkisinden, daha olumsuz etkilenirler. Şehir ısı adası etkisi, bu

iklimlerde, şehirlerin ortalama sıcaklığını, ısıl stres kaynaklı ölüm oranlarını, soğutma yüklerini, pik ve toplam elektrik ihtiyacını, şehirlerdeki hava kirliliğini artırarak, şehirlerin konforuna ve halk sağlığına olumsuz etki yapmaktadır.

Şehirler ve çevrelerinde bulunan kırsal kesimler güneşten eşit miktarda ışınım almaktadır. Şehirlerin rengi/yansıtıcılığı, (Beyazlık/Albedo) güneşten gelen kısa-dalga boyundaki ışınların ne kadarının soğurulacağını belirler. Genel olarak şehirlerin düşük yansıtıcılık kabiliyetine sahip olmalarından dolayı, güneşten gelen kısa-dalga boyundaki ışınlar, şehirde bulunan malzemeler tarafından soğurulmaktadır. Soğurulan bu ışınlar, belirli bir zaman aralığından sonra, uzun-dalga boyunda kızıl-ötesi ışın olarak yayılmaktadır. Bu da şehirlerde kızıl-ötesi ışıma ile ısınmaya sebep olmaktadır. HVAC ekipmanları, ulaşım araçları, güç çevrim santralleri vb. gibi insan faaliyetleri kaynaklı atık ısılar da şehirlerde ısınmaya sebep olmaktadır. Atık ısı ve nem, şehrin havasına hemen karışmakta ve sıcaklık artışına sebep olmaktadır.

Şehirlerde, soğurganlığı (yutma) düşük (yansıtıcılığı yüksek) ve ısıl yayıcılığı yüksek, soğuk/açık renkli malzemelerin tercih edilmesi durumunda, yüzey sıcaklıkları daha düşük olacaktır. Daha düşük yüzey sıcaklıkları sayesinde, binalarda iletimle olan ısı geçişi, taşınımla havaya olan ısı geçişi ve kızıl-ötesi ışınım azaltılabilecektir. (Bundan dolayı insan kaynaklı yapılar kendi mikro-iklimlerini oluştururlar.) Bu da binalarda ısı kazanımını azaltacağı için soğutma yüklerini de düşürecektir.

Hava akımlarını kullanarak/faydalanarak da şehir ısı adası etkisini azaltmak mümkündür. Hava akımları, kışın ısıtma ihtiyacını artırır, yazın ise soğutma ihtiyacını düşürür. Şehir/Bölge planlaması yapılırken, hava/rüzgâr akımları hesaba katılarak, şehir/bölge oryantasyonu ve yaz-kış farklı rüzgâr yönlerinin de yardımı ile, şehir ısı adası etkisi azaltılabilir.

Tipik bir şehir tasarımında, şehir-kanyon etkisini oluşturan, bir caddenin her iki tarafındaki yüksek katlı yapılar, gelen güneş ışınları için yansıtıcı yüzey işlevini görerek (cam yüzeyler), şehir yüzeylerinde ışınımın hapsolmasına neden olmaktadır. Bu ışınlar ısı'ya dönüşerek, bina yüzeyi ve şehir yüzeyinde sıcaklık artışına neden olmaktadır. Cam yüzeylere çarpan ışınlar, şehir yüzeyine yönlendirilirse, yaya seviyesinde konforsuzluğa ve sıcaklık artışına sebep olur. Yüzeye gelen ışınların geri yansıması ve soğurulan ışınların, malzemeler tarafından kızıl-ötesi olarak yayılması, düşük gökyüzü görüş oranları nedeniyle çok mümkün olmamaktadır. Cam yüzeylerin yansıtıcılığı ayna yansıtmasından, yansıtma yönünün gökyüzüne çevrilerek, geri yansıtma özelliği kazandırılması durumunda, güneşten gelen kısa-dalga boylu ışınlar, şehir yüzeyine yönlendirilmeden gökyüzüne geri yansıtılabilir.

Şehirlerde yeşil alanların oluşturulması, şehir ısı adası etkisine yönelik olarak en fazla kullanılan hafifletme stratejilerindendir. Yeşil alanlar, gölge oluşturmalarının yanı sıra, özellikle kuru iklimlerde (nem miktarının az olduğu) suyu tutarak buharlaşma gizli ısısı ile soğutma etkisi oluştururlar.

Elektrik enerjisi tüketimini etkileyen parametreler incelendiğinde; nem miktarı, hava sıcaklığı, güneş ışınları, rüzgâr hızı, bulut miktarı ve destekleyici faktör olarak iklimlendirme cihazlarının kullanım oranı görülmektedir.

Şehir ısı adası etkisi, soğutma talebini artırıcı etkisinden dolayı pik ve toplam elektrik talebini artırmaktadır. Binalar, HVAC ekipmanları için yazın elektrik enerjisi kullanırlar. Genel olarak, elektrik enerjisi doğal gaz ve kömür ile çalışan güç çevrim santralleri vasıtasıyla arz edilmektedir. Bundan dolayı şehirlerdeki ısı adası etkisi, direk olarak tüketilen elektrik enerjisini artırmakta dolaylı olarak, kullanılan kömür ve doğal gaz miktarını artırmaktadır. Bunun sonucu olarak, atmosfere daha fazla kirletici gazlar ve daha fazla atık ısı salınmaktadır. Bunlar da tekrar şehir ısı adası etkisinin oluşumuna ve etkisinin artmasına neden olurlar.

Binalarda ısı kazancı ve soğutma yükü hesabı, tüm ısı geçiş türlerini içeren (iletim, taşınım, ışınım) bir mahiyete sahiptir. Tüm ısı geçişleri birbirleri ile ilişkili ve zamana bağlıdır. Isı kazancı, bina kabuğundan geçen ısı miktarı ile, soğutma yükü ise, odadaki sıcaklık değeri ile ilişkilidir. Soğutma yükü, HVAC ekipmanları vasıtasıyla ısı çekilerek karşılanmalıdır. Genellikle, ısı kazancının, soğutma yüküne dönüşmesi arasında bir zaman aralığı vardır. Isıl kapasitesi yüksek bina kabukları daha fazla bir zaman aralığına sebep olurlar.

Şehir ısı etkisini incelemek için, tez kapsamında bir bina üzerinde örnek bir çalışma yapılmıştır. Örnek çalışma, İstanbul Teknik Üniversitesi Ayazağa kampüsünde, 25m x 25 m boyutlarında, 3 metre yüksekliğinde, toprak zemin üzerinde hayali bir araştırma enstitüsü binasıdır. Örnek binada, hava kaynaklı ısı pompası dış ünitesi ile, fan-coil iç üniteleri ve taze hava üfleme kanalına bağlı bulunan kanal tipi sulu batarya sistemi bulunmaktadır.

Tezin temel amacı, bina kabuğunun ısıyı soğurma (yutma) seviyesinin, (yansıtıcılık/albedo) binanın ısı kazancı ve soğutma yüküne etkisini incelemektir. Binanın soğutma yükü, farklı şehir ısı etkisi koşullarında (+1°C, +2°C, +3°C, +5°C) ve bina kabuğunun soğurma katsayısı (0.3, 0.6, 0.9) değiştirilerek incelenmiştir. İkincil değişkenler içinde, yazın oda termostat derecesinin artırılması gibi bir mevzuatın yürürlüğe konulması durumundaki etkisi incelenmiştir. Bununla birlikte, bina çevresinin yansıtıcılığının, bina soğutma yüküne etkisi de incelenmiştir.

Örnek çalışma sonuçlarına göre, her bir derece dış ortam hava sıcaklığının artması, pik ve toplam elektrik talebini artırmaktadır. Bina kabuğunun, ısıyı soğurma katsayısının düşürülmesi (yansıtıcılığın artırılması) şehir ısı adası etkisinin azaltılması için uygun bir strateji olduğu görülmüş, soğurma katsayısının düşürülmesi, soğutma yükünü azaltmıştır.

Bina kabuğunun yansıtıcılığının artırılması, soğutma yükleri açısından avantaj sağlarken, bina kabuğu tarafından soğurulmayıp, şehir yüzeyine yansıtılan ışınlar, yaya seviyesindeki ısıl konforu düşürmektedir. Bununla birlikte, bina çevresinin de yansıtıcı olması, bina çevresinden binaya doğru olan yansımayı artırarak soğutma yüklerinin artmasına sebep olabilmektedir.

Binalarda enerji tüketimi ve şehirlerdeki çevresel konfor aynı derecede önemli olarak görüldüğü taktirde, binaların yansıtıcı yüzeylerinin, soğutma yüklerini azaltmasının yanı sıra, şehir yüzeylerine yansıttıkları ışınımdan kaynaklı ısıl konforun düşmesine neden olabileceği için, iki durumun dengelenmesi ile ilgi mevzuat ve standartların oluşturulması gerektiği görülmektedir.

Yüksek yansıtma katsayısına sahip bina yüzeylerinden yansıtılan ışınların, şehir yüzeylerinde çevresel ve ısıl konforu düşürmemesi için, bu ışınların şehir yüzeyine yansıtılmadan, gökyüzüne doğru geri yansıtılması gerekliliği ortaya çıkabilir. Bundan dolayı geri-yansıtma özelliğine sahip malzemelerin kullanılması tercih edilebilir. Şehir ısı adası etkisinin giderilmesi için, soğutmanın bir çözüm olarak değil, aynı zamanda bir atık ısı kaynağı olduğu için, problemi artıran bir olgu olarak görülmesi gerekmektedir.

Gelecekteki şehir ısı adası çalışmaları 3 aşama halinde yapılabilir. İlk aşamada, örnek bir bina için, CFD analizi ve ısıl yük hesaplama programı ile hesaplamalar yapılabilir.

2. Aşamada, küçük ölçekli saha ölçümleri ile bu veriler doğrultusunda simülasyonların kalibrasyonları yapılmalıdır. Daha sonra daha büyük ölçekli saha ölçümleri yapılabilir.
3. Aşamada ise, şehir ısı adası etkisinin azaltılması ile ilgili kriter ve standartlar ortaya konulabilir.

1. INTRODUCTION

Urbanization increases human comfort and quality of living by altering ground canopy layer. Building façades, roads, pavements, roofs and other urban materials are parts of urban formation. 21st century has seen a rapid urbanization. Conflicts, better life expectancy and lack of resources in rural areas have drawn people into the large cities.

2008 was a threshold year in that globally, urban population exceeded rural population. In 2018, urban population reached 55% of the whole population. Urban population was 30% in 1950 and projected to be 68% by 2050. Urbanization levels vary according to different geographical regions. In Northern America 82% of the population is urbanized, in Europe 74%, Asia is now approaching to 50% and only geographical region that urbanization level below 50% is Africa where 43% of its population lives in urban areas. The global urban population is projected to grow by 2.5 billion urban dwellers between 2018 and 2050, with nearly 90% of the increase concentrated in Asia and Africa. As rapid increase in urbanization continues, sustainable development relies on sustainable urban growth and planning. Today's cities account for between 71% and 76% of CO_2 emissions, between 67% and 76% of global energy use and approximately 80% of global gross domestic product (GDP) [1].

Rapidly increasing population in the cities paved the way to the increased anthropogenic formation on ground canopy layer and the release of the anthropogenic heat. Urban formation differs from its surrounding rural areas by having different material, shape and geometry. Altered air flow throughout the city and reduced sky-view factor because of the urban design, increased solar absorption because of the urban material combined with the lack of green areas led to the increased ambient temperatures in the urban areas. This heat content is called as Urban Heat Island which damages thermal balance of cities.

Coupled with Climate Change, UHI Effect induces lots of problems. Tackling the temperature increase caused by anthropogenic formation, solar and infrared heating requires additional cooling which causes additional anthropogenic heat release. In return, it also causes temperature increase as in vicious circle; solution to the problem increases severity of the problem which has been depicted in Fig. 1.1 given below.

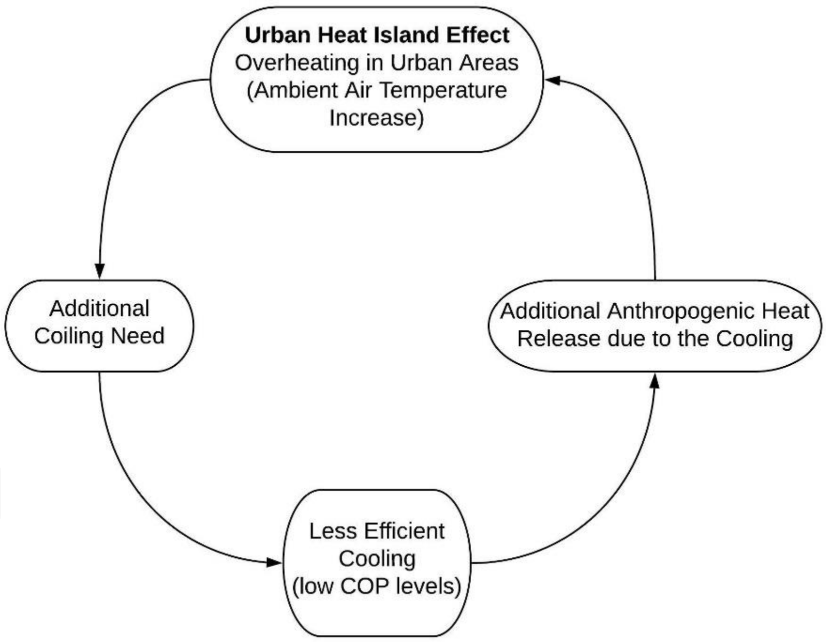

Figure 1.1: Feedback loop of UHI effect.

Hot Climates that require cooling more than heating are especially vulnerable to UHI effect which increases urban temperature, mortality rates, cooling loads, peak and total electricity demand, causing air pollution and decreasing environmental comfort and public health. In hot climates, in the summer due to rapid increase in anthropogenic heat and solar radiation, UHI effect may raise temperatures by up to 10°C [2].

As these adverse effects seem to be enormous, potential UHI Mitigation strategies are also quite promising. Factors that form UHI could be listed as sky view factor, urban design and material, urban ventilation (air flow), urban albedo. Tools used while studying UHI could be listed as; numerical modelling, field measurements and satellite sensors.

2. FORMATION OF URBAN HEAT ISLAND

UHI is caused by Anthropogenic Heat Release and Solar radiation. Anthropogenic Heat enters urban area simultaneously without a time lag (as it is in convection mode of heat transfer) and causes temperature increase. While part of the solar radiation heats the urban area directly, some part of solar radiation is absorbed by urban formation. This absorbed heat is then re-radiated to the urban area with a time lag thus, causing infrared heating [3].

Formation of Urban Heat Island could be described best by Surface Energy Balance (SEB) Equation. The general form of this equation for a unit surface area which is flat, horizontal and homogeneous is given in Watts in Eq. (1.1) [4].

$$\alpha_s Q + \alpha_s q + \alpha_L L + Q_f = \epsilon\sigma T_0^4 + h_c(T_0 - T_{oa}) + k\,\frac{dT_s}{d_z}|_{z=0} + \lambda E \qquad (1.1)$$

Where α_s is absorptivity for short wave radiation,

α_L is absorptivity for long wave radiation,

Q is the direct short-wave radiative flux,

q is the diffuse short-wave radiative flux,

L is the incoming long wave radiative flux,

Q_f is the anthropogenic heat flux, ϵ is the emissivity of the surface,

σ is the Stefan-Boltzmann constant,

T_0 is the surface temperature, (subject to convection and radiation)

T_{oa} is air temperature,

h_c is a convective mode of heat transfer coefficient,

k is the thermal conductivity of the ground,

T_s is the surface temperature (subject to heat conduction through surface)

λ is the latent heat due to evaporation and E is the rate of evaporation

The first two terms represent the absorbed short-wave solar radiation, the third term is the absorbed long wave radiation, and the fourth term is anthropogenic heat flux at the surface. The first and second terms on the right-hand side represent the radiative and sensible heat fluxes, the third term represents heat conduction into or from the sub medium through the surface, and the fourth term is the latent heat flux. Eq. (1.1) can be recast as Eq. (1.2) given below [4].

$$(1 - \mathrm{a})I + L^{*} + Q_f = H + \lambda E + G \tag{1.2}$$

Where a is the albedo, I is the incoming total solar radiation, L^{*} is the net long wave radiation at the surface, Q_f is the anthropogenic heat and H, λE, G are the sensible, latent, and ground heat fluxes, respectively [4].

2.1 Solar Radiation

Both urban and rural areas receive the same solar radiation from the sun. Albedo meaning fraction of incident radiation reflected by a body or surface determines the amount of short-wave solar radiation absorbed. Due to the low albedo values, short-wave solar radiation is absorbed by the urban materials. Absorbed solar radiation is then re-radiated to the urban area with a longer wave-length thus causing infrared heating. Solar radiation reaching the earth's surface consists of 3 bands; Ultra-Violet (~5%), Visible (VIS, ~43%), and Near-Infrared (NIR, ~52%) as depicted in Fig. 2.1 given below.

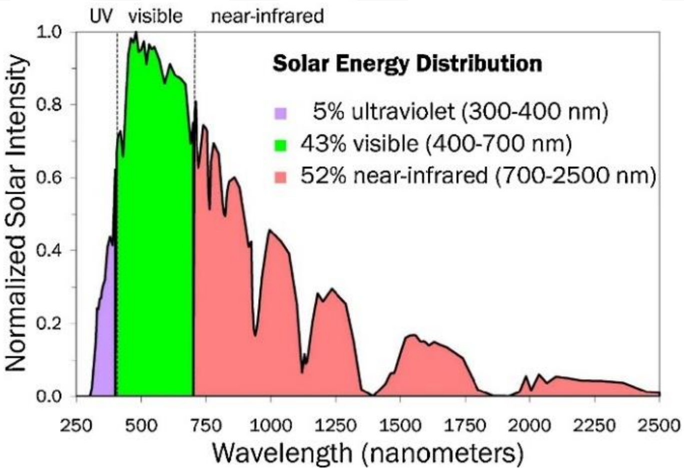

Figure 2.1: Typical spectral solar energy intensity [5].

NIR Radiation (Nearly half of the solar power) is absorbed by the surfaces but not visible to human eyes. Dense and compact urban materials absorb short-wave radiation and emits it with a longer wavelength as infrared heat (see Fig. 2.2). Both solar radiation and infrared heat radiation are the means of heat gain thus subject to contribute cooling loads. Long-wave infrared radiation intensity, depends on albedo, emissivity, temperature, thermal inertia of the material and sky-view factor [6].

Due to reduced sky-view factor in the cities, infrared radiation can't be directed to the sky and would be incident on the urban formation and people.

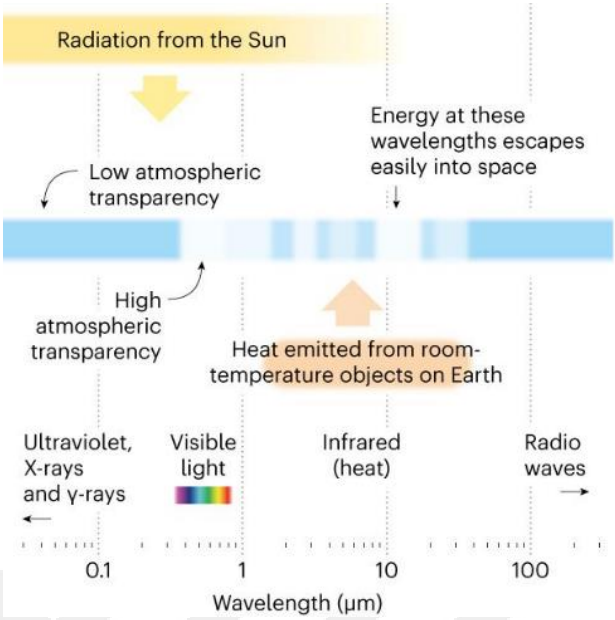

Figure 2.2: All wave radiations to/from earth [6].

2.2 Anthropogenic Heat

Anthropogenic heat is the heat content that is released as waste heat from buildings, HVAC (Heating, ventilation, and air conditioning) equipment, transportation systems and power plants. Anthropogenic Heat (AH) and moisture enter urban area simultaneously (because it is in convection mode of heat transfer) as it is generated and causes temperature increase. Higher Anthropogenic heat release could be seen in cold climates in winter because of the high heating demand. 40% of AH comes from buildings in large cities [2]. AH release might be related to the population density and energy consumption. For major US city centres AH values vary between 20 W/m^2 and 40 W/m^2 in the summer, 70 W/m^2 and 210 W/m^2 in the winter (210 W/m^2 being uncommon extreme) [4].

Rizwan et al. reports from various researches on AH release, values vary as; 5–20 W/m^2 for Basel, Switzerland, 32 and 35 W/m^2 from Lodz, Poland and Reykjavik, Iceland, respectively. 60 W/m^2 in summer and 75 W/m^2 in winter from six large cities of USA while 200 W/m^2 in summer and 400 W/m^2 in winter and the highest value of 1590 W/m^2 in Tokyo [3]. AH needs intense field measurements for proper evaluations. As AH can't be converted into radiation (other than amplifying atmospheric thermal radiation) it should either be converted into sensible or latent heat or stored.

3. MITIGATION STRATEGIES OF URBAN HEAT ISLAND

As seen in Eq. (1.1) solar radiation, corresponding long-wave radiation and anthropogenic heat release (partially dependent on solar radiation) should be converted either sensible or latent heat or stored. Mitigation strategies for a given area should take into consideration of related SEB Eq. of that area. Increase in albedo decreases absorbed solar radiation and emitted/absorbed long-wave radiation. Anthropogenic heat release should also be lowered by proper design and using efficient solutions. Ambient air temperature could be mitigated by evapotranspiration (evaporation +transpiration) with the help of increase in urban greening. UHI Effect, increases cooling load in the summer while it reduces the need for heating in the winter. In cold climates in the winter, absorbed solar radiation by the horizontal surfaces is only a fraction of that absorbed in the summer [7].

3.1 Cool Urban Materials

Urban formation consists of vertical and horizontal surfaces listed as façades, roofs, pavements that absorb and/or reflect solar radiation then emitting the absorbed part as infrared radiation. On a dry surface, 50% of the absorbed solar radiation is convected to the air. Using cool materials for urban formation that absorb less (high reflectance) and emit more (high thermal emittance) helps to keep surface temperatures low. Cooler surfaces convect less heat to the air, reducing ambient air temperature, conduct less heat to the buildings, reducing heat gain. Materials with high solar reflectance and high thermal emittance are referred to as “cool” materials [5].

Effect of building envelope absorptivity value (for different albedo values) and surrounding reflectivity have been evaluated within case study. (please see chapter 6 for more information)

Cooler roofs include, reflective cool-coloured and green roofs. Green roofs, provides favourable conditions because of having more mass, retaining water for evapotranspiration, providing shade and filtering the air around it. Most of the paving materials used in urban areas are asphalt and concrete which are mostly dark-coloured and don’t retain water for evaporation. Porous and permeable paving materials retain water, decrease the amount of run-off water thus helps to increase storm water management capabilities.

3.2 Urban Ventilation

Typical urban formation in large urban areas consist of narrow streets confined by buildings on both sides leads to Urban Canyon Effect [8]. This formation reduces the air flow throughout the city hence reducing the dispersion of pollutants and removal of heat by convection. The reduction of air flow within urban area, may be up to 10% of corresponding air flow in rural surrounding which leads to stagnant, polluted, warm air within urban limits as depicted in Fig. 3.1 given below. Occasionally, wind tunnel effect may be experienced in urban areas [9].

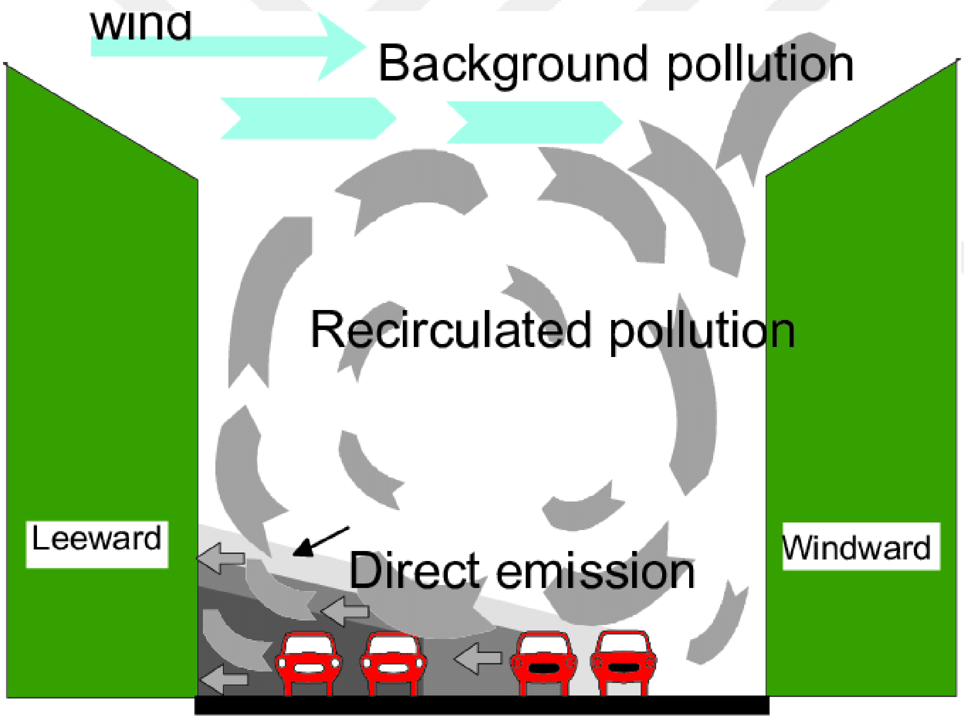

Figure 3.1: Illustration of adverse effect of urban canyon [10].

Mitigation of UHI effect by air flow is an important countermeasure thus should be taken into account in the design phase of an urban area. Air flow increases heating load in the winter and reduces cooling load in the summer. By careful selection of the orientation of the urban formation with the help of different prevailing wind directions in the summer and winter makes air flow an important asset of mitigating UHI. (no evaluation has been done for the effect of urban ventilation/air flow in the case study.)

3.3 Reflective and Retro-reflective Materials

High rise buildings on both sides in a typical urban canyon configuration, creates reflective surfaces for radiation incident upon it thus, entrapping the radiation within the built area and converting it to the heat. As solar radiation passes through the atmosphere some of it gets absorbed, scattered, and reflected. This type of solar radiation is called as diffuse solar radiation. Solar radiation reaching to earth without getting diffused is called direct beam solar radiation [11].

Each type of urban materials reflects solar radiation differently. Windows reflect the solar radiation as specular (mirror like), roofs, pavements and opaque walls reflect solar radiation in the manner of diffuse radiation as depicted in Fig. 3.2 given below. Visible Band of the solar radiation creates illuminance, feeling of openness and reduces lighting demand. By contrast, NIR Band of the solar radiation is not visible to human eyes and heats up the surfaces.

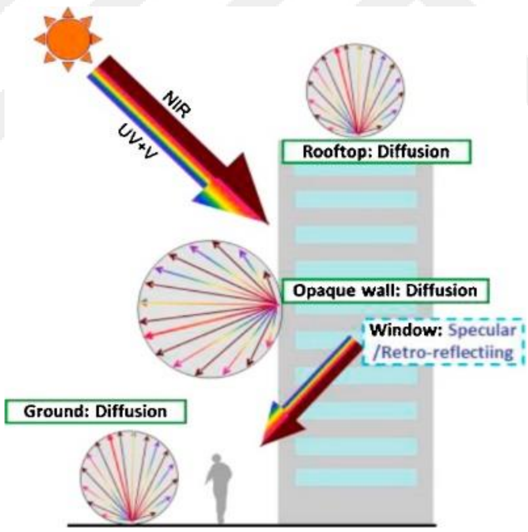

Figure 3.2: Reflection characteristics of solar radiation [12].

Conventional high-reflective windows which are mostly transparent to VIS Band of solar spectrum and translucent to NIR Band provides energy efficiency by reducing the cooling load and lighting demand with selectively reflecting the NIR band as opposed to conventional windows.

If reflected radiation by the window (as it is a mirror like reflection) is directed downwards onto the urban area (pavements, sidewalks etc.) causes discomfort and temperature rise on the ground level as can be seen in Fig. 3.3.

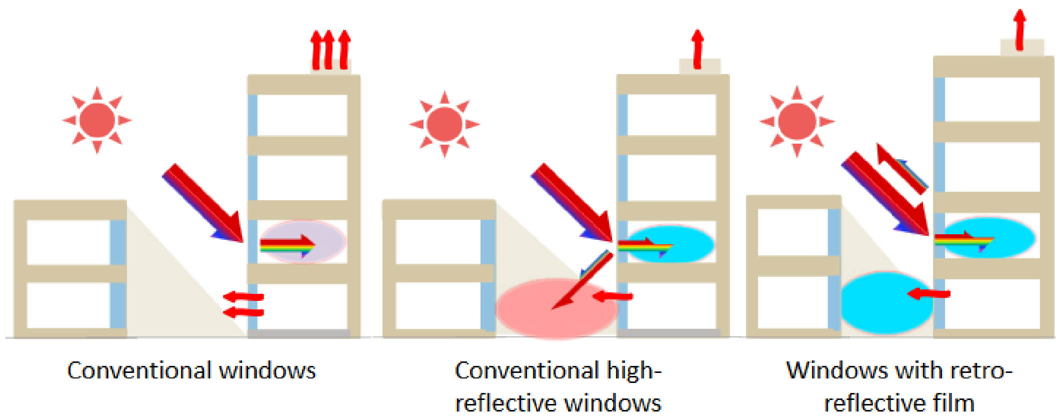

Figure 3.3: Effect of different reflections from window [13].

From the ground level, infrared radiation goes upwards but due to the reduced sky view factor, it is possible that it is going to return to the ground level. By changing reflection direction of the windows to the sky by having retro-reflection capability means, reflecting the incident radiation towards its incoming direction. It is possible to send NIR Radiation back to the sky without directing it to the ground. Selectively Retro-reflecting NIR Band of solar radiation both satisfies building energy savings and urban environmental comfort. Retro reflective materials include coatings, spray paints and thin films [12, 13].

Increase in NIR reflection capability meaning less cooling load for building but higher heat on urban environment will result in need for regulation of reflectivity of building envelopes, anthropogenic heat release and urban environmental comfort [14]. No evaluation has been implemented for the effect of retro-reflective building envelopes in the case study.

3.4 Super-cool Materials

Everything (people, buildings, pavements etc.) that has a temperature more than 0 K radiates heat in the infrared band. Radiated heat escapes to the space through atmosphere. Earth's blanket like atmosphere absorbs most of it and radiates it back to earth's surface. Infrared rays between 8 and 13 micrometres in wavelength, however, are not captured by the atmosphere and leave earth. Night time passive radiative cooling below ambient air temperature has long been utilized [15].

Eq. (3.1) can be applied in order to evaluate a passive radiative cooler material [16].

$$P_{cool}(T) = P_{rad}(T) - P_{atm}(T_{oa}) - P_{sun} - P_{cond+conv} \tag{3.1}$$

$P_{cool}(T)$ is cooling power of the material at ambient air temperature as a function of its temperature $(T < T_{oa})$, $P_{rad}(T)$ radiation from the material, $P_{atm}(T_{oa})$ is the absorbed power due to atmospheric thermal radiation corresponding to the ambient air temperature, P_{sun} is the absorbed solar power, $P_{cond+conv}$ is the transferred heat to the cooler due to conduction and convection.

If there is a positive net outflow from the material, it can be defined as passive radiative cooler at night (when P_{sun} is zero). During daytime, when cooling power is most needed, if a material achieves a positive net outflow meaning, it radiates more heat than it gains from solar radiation and atmospheric thermal radiation. It can be defined as passive radiative cooler under direct sunlight.

Raman et al. devised a material that stays cooler than ambient air temperature (4.9°C cooler) by emitting selectively and strongly only between 8 µm and 13 µm, where the atmosphere is transparent, and reflect all of the other wavelengths [16].

Research teams around the world have made types of materials including films, spray paints and treated wood, that stay cool in the direct sunlight reaching different temperature drops up to 10°C [15].

These materials work best in arid climates as water vapor traps infrared heat. There is still ongoing R&D on these materials in order to prevent cooling in the winter thus causing increase in heating demand. (no evaluation has been implemented for the effect of super-cool materials in the case study)

3.5 Urban Greening

Urban greening is most widely applied mitigation strategy for UHI Effect. Vegetation provides shade and increases evapotranspiration by retaining water especially in hot and arid climates. Parks and gardens create urban cool islands that are 2°C to 8°C cooler than their surroundings [4].

Green cover could be listed as; parks and gardens, green roofs, green façades. Evapotranspiration which is water loss of the plant in the form of vapor in which required energy to evaporate retained water by the plant is taken partially from surrounding air thus resulting cooling of leaves, soil and air surrounding the plant. Urban greening may decrease cooling loads in summer because of the shade provided by the leaves as seen in Fig. 3.4 given below. At the same time, it may increase the cooling load because of the obstruction of the air flow (summer breeze) by the leaves and trees (reverse in winter) [6].

Careful evaluation and field measurements are needed in order to utilize urban greening for mitigation. (no evaluation has been done for the effect of urban greening in the case study)

Figure 3.4: Sidewalk greening as an example for urban greening [17].

4. URBAN HEAT ISLAND EFFECT ON ENERGY CONSUMPTION

UHI effect increases total and peak energy consumption of buildings because of higher cooling demands. Buildings in the summer consume electricity to run HVAC equipments. Generally, electricity is generated by coal and gas fired powerplants. UHI effect directly increases electricity consumption and in-directly increases coal and gas consumption which in return leads to more pollution and heat release to the environment.

4.1 Urban Heat Island Effect on Electricity Consumption

Higher ambient temperature due to urban formation increases total and peak electricity demand for cooling needs. Studies are carried out to determine the impact of various primary climatic parameters on the electricity demand such as; humidity, ambient temperature, solar radiation, wind speed, cloud cover and supporting parameter as penetration of air conditioning (AC) (households that own air conditioning equipment) [18].

Most of the studies conclude that, ambient temperature is most effective parameter on the electricity demand. Eleven studies analysing the impact of ambient temperature increase on peak electricity demand show that, for each degree of temperature rise (DOTR), peak electricity demand increases between 0.45% and 4.6%. Fifteen studies analysing the impact of ambient temperature increase on the total electricity demand show that, total electricity demand increases between 0.5% and 8.5% for each DOTR (see Fig. 4.1).

Utilities use response functions in order to estimate additional electricity demand for each DOTR. Electricity demand increase means an increase in electricity supply in order to meet the demand thus constructing new power plants leading to higher costs of electricity supply [18].

Kolokotroni et al. analysed a typical office building in London heat island and found that, heating load reduced by 22% while cooling load increased by 25% due to the UHI Effect [19]. Santamouris et al. assessed the UHI of Athens where the mean UHI intensity exceeds 10°C and found that, cooling load may be doubled, the peak electricity demand for cooling may be tripled and because of the higher ambient air temperatures, coefficient of performance (COP) values of air conditioners (AC) may be decreased up to 25% thus creating a vicious circle. In parallel, heating load may be reduced up to 30% [9].

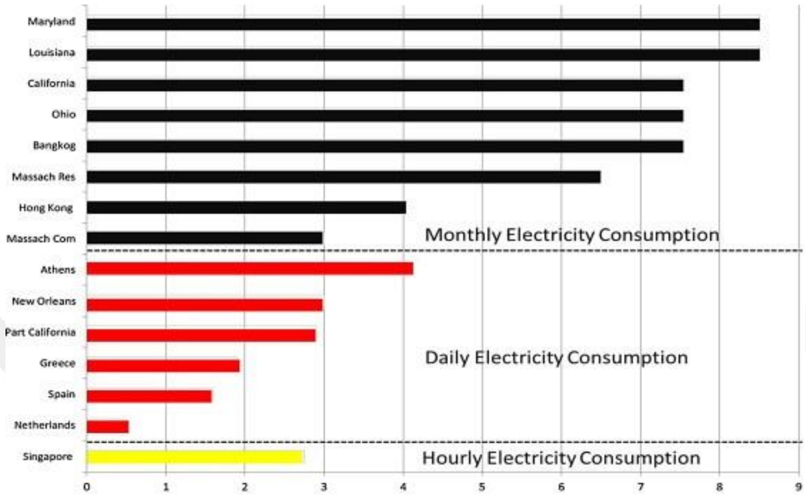

Figure 4.1: Increase in electricity demand per degree of T_{oa} rise [18].

Rising population and increasing income in emerging economies which most of them are in hot climatic zone will require huge electricity supply for cooling needs as air conditioning use and purchase of new equipments in hot climates are increasing as depicted in Fig. 4.2 given below.

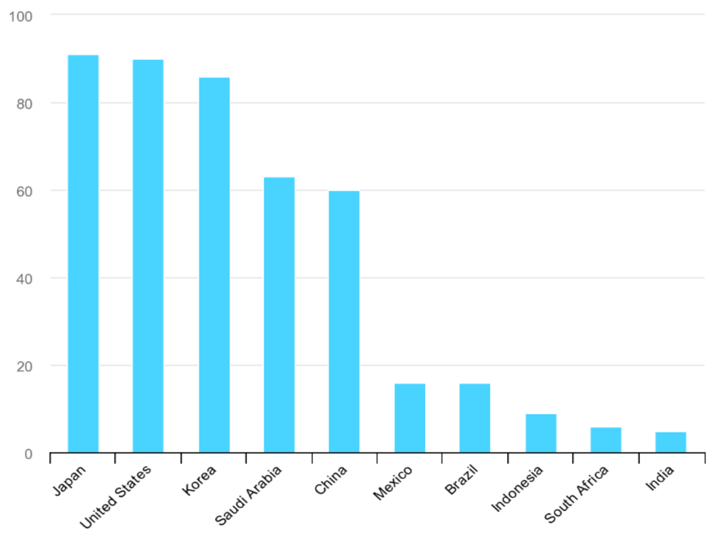

Figure 4.2: Households equipped with AC in selected countries, 2018 [20].

It is projected that air conditioning will be the primary drive for peak and total electricity demand in the upcoming decades (see Fig. 4.3).

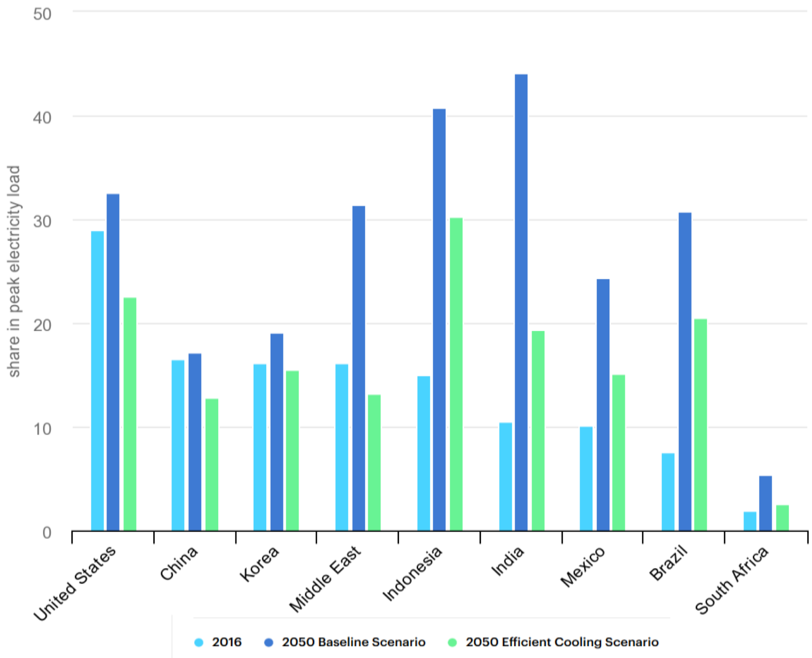

Figure 4.3: Share of cooling in electricity system peak loads in selected countries/region, baseline and cooling scenario [20].

5. THERMAL LOAD CALCULATION OVERVIEW

Process of thermal load calculation of buildings consist of all modes of heat transfer as conduction, convection, radiation. All modes play an important role in determining thermal loads. All modes are interrelated, vary with time leading to a transient nature of heat transfer rather than steady-state heat transfer. In order to analyse heat transfer in buildings, 3 important parameters can be used. Heat gain is the total heat quantity passing through the building envelope. Load is the amount of heat gain quantity transferred to the ambient room air thus increasing ambient room air temperature and if the room is conditioned then shows the excess heat to be removed (cooling load) from the room. This excess heat should be extracted from the room air by the HVAC equipment in order to keep the room temperature within thermostat (T-stat) setpoints. In order to maintain a room temperature at a constant level or within a throttling range, cooling load caused by the heat gain should be extracted by HVAC system.

In order to illustrate the modes of heat transfer in a room and its transient nature following example can be considered. A lighting equipment which is lighting the room affects the room temperature by convecting heat to the air surrounding it thus increasing ambient air temperature and radiating heat to the surrounding environment. Convected heat initiates further convection, radiated heat gets reflected and absorbed by the surfaces causing temperature increase in the surfaces. This temperature increase in the surface initiates heat storage by conduction, heats up the air surrounding the surfaces thus causing convection and re-radiates heat to the surrounding area. This process is inter-related, vary with time and its effects can be seen even after the lights are turned off because of the thermal inertia of the materials. (stored heat will be discharged when suitable conditions occur) As a result of thermal inertia, there is a time lag between a heat gain occurs and its transition to cooling loads in a conditioned room. This excess heat, keeping the room away from its thermostat set points should be extracted by HVAC equipment thus initiating further heat transfer processes.

The example given for a lighting equipment in a room can be used as an analogy for how heat transfer process occurs in urban areas. (outside of building envelope) Sun as in lighting equipment radiates heat to the urban areas and this radiated heat gets reflected/absorbed thus initiating conduction, convection and further re-radiation (summarised from [21]).

5.1 Methods for Thermal Load Calculation

5.1.1 Heat balance method

In order to define heat flow at a node where a node means surface or mass element within the room boundary all conduction, convention and radiation modes of heat transfer at that node should be specified and solved simultaneously. By solving these heat balances simultaneously, the total rate of load (ambient air temperature increase) can be determined. Heat balance equations are typically differential heat transfer equations or linearized forms of these equations.

Heat Balance Method (HBM) is the most reliable method of calculating thermal loads. But it requires detailed input, longer calculation times and powerful computers hence considered as harder to use method. On the other hand, the Transfer Function Method (TFM) which is based on Heat Balance Method proved to be easier to use. By using key assumptions, the Transfer Function Method performs accurate thermal load calculations (summarised from [21]).

5.1.2 Transfer function method

The Transfer Function Method is based on Response Factor Principle. This principle states that the response of the heat gain to cooling load conversion pattern for each specific heat gain for a period of time will always be the same. For example, a 10 W/m^2 lighting equipment heat gain to cooling load conversion response pattern will be same as 20 W/m^2 lighting equipment response pattern. The Response Factor Principle is based on 3 main principles. The Principle of Superposition which allows each load to be considered separately and after calculation to be added in order to get the total load. As opposed to Heat Balance method in which each heat gain should be considered simultaneously. Also, superposition principle allows calculation of the effects of the load for the following hours to be calculated separately.

For example, solar heat gain from a window, and a transmission heat gain through the wall can be computed separately and then added together to determine the total room load. The Principles of Linearity and Invariability enables the patterns to be calculated once by HBM then the response of each type of heat gain to load conversion pattern for each hour will be a linear function thus enabling vast reductions in calculations.

TFM enables to define the load as a function of heat gain and time in a mathematical relationship for each type of heat gain. Then, it can be used to calculate load for each hour. The mathematical relationship for a Room Transfer Function Equation can be expressed as in Eq. (5.1) given below.

$$Q_0 + w_1.Q_1 + w_2.Q_2 = v_0.q_0 + v_1.q_1 + v_2.q_2 \tag{5.1}$$

Q is the cooling load. Subscript 0 is the current hour, subscript 1 is the one-hour previous cooling load and 2 is the two-hour previous, q is heat gain. v and w are coefficients for transfer function.

Coefficients vary according to each type of heat gain, room type and building weight. (American Society of Heating Refrigerating and Air Conditioning, ASHRAE published value tables for these coefficients.) Room Transfer Function Equation states that, load of current hour and the previous two hours loads are the result of heat gains of current hour, and two previous hours. In order to use the room TFE, firstly transfer function coefficients should be specified then conversion of heat gain to load can be easily done (summarised from [21]).

5.1.3 Transfer function example for lighting loads

In Fig. 5.1, an example of lighting heat gain and load calculation using transfer function method for a 12-hour period is shown. Lighting equipment operates between 0-6 hours. When the light is on, heat gain caused by the lighting is larger than the load. This is because part of the heat gain is in radiation mode of heat transfer.

Convected heat caused by the light is turned into load simultaneously but radiant heat gets absorbed by the masses in the room and slowly convects heat to the room air in preceding hours. In the case of radiant heat, there is a time lag between a heat gain occurs and its full effects on cooling load appears. This time lag depends on thermal inertia of the materials within the room and mode of heat transfer. For example, heavier construction materials which stores more thermal energy than lighter ones tend to cause more of a time lag. After light is turned off, its full effects on cooling load continues to develop as stored heat continues to be dissipated to the room air in the form of convection.

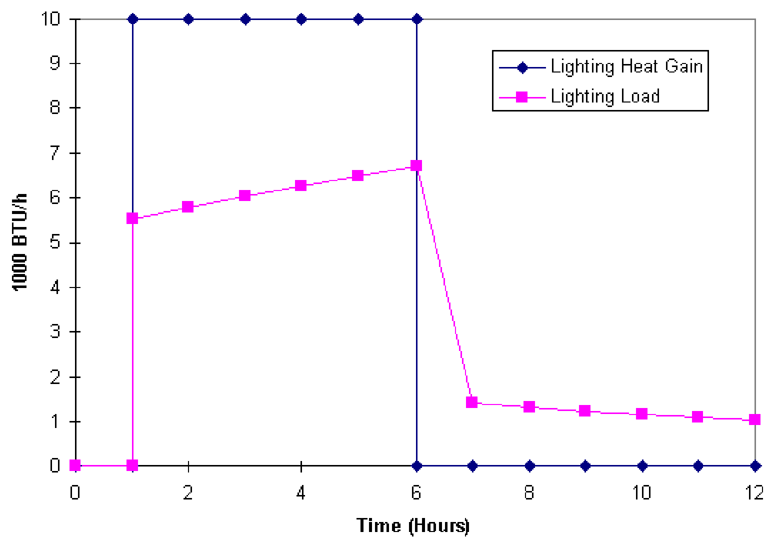

Figure 5.1: Lighting heat gain to cooling load conversion pattern [21].

Lighting heat gain and load calculation show us the transient nature of heat transfer in buildings. Because of the radiated heat as stored, build-up thermal energy slowly dissipates over a period of time. Conduction mode of heat transfer also shows the transient nature of heat transfer in buildings. There is a time lag in which a heat gain occurs at the outer surface of wall and roof and its effects reaches to interior surface of the wall and roof. Building envelope properties effect conduction mode of heat transfer and time lag between a heat gain occurs and its full effect on cooling loads. Taking conduction through a wall into consideration, Conduction transfer function equation is used (summarised from [21]).

5.2 Heat Extraction Principles

Cooling load is calculated in the case that space is conditioned at a fixed thermostat set temperature. The excess heat in the room causes deviation from the thermostat set temperature. If this excess heat is removed by the HVAC equipment, room can maintain its ambient temperature in the event of heat gain to cooling load conversion. Cooling loads is the measure of deviation from thermostat set conditions meaning, heat should be extracted equal to cooling loads in order to have a steady state room temperature which is equal to thermostat set temperature.

Generally, heat extraction causes room temperature to float in a pre-determined thermostat throttling range. If HVAC system is sized insufficiently, the room temperature may not drop to desired conditions meaning, heat extraction amount is less than cooling loads at that given time. HVAC system is sized according to the peak loads meaning when there is less demand than the peak loads heat extraction rate of the HVAC equipment will be less than full.

Fig. 5.2 given below shows an HVAC system which operates from 8 am to 10 pm and is off for the remaining hours of the day. Cooling load is calculated using the room transfer function procedures.

During operation, HVAC system maintains the room temperature within thermostat throttling range. During off hours, hence there is no heat extraction by HVAC system, room air temperature increases.

During off hours, heat accumulates within building mass. When operation starts again, this accumulated heat throughout the night is removed in addition to current hour's cooling load showing a pulldown of heat extraction.

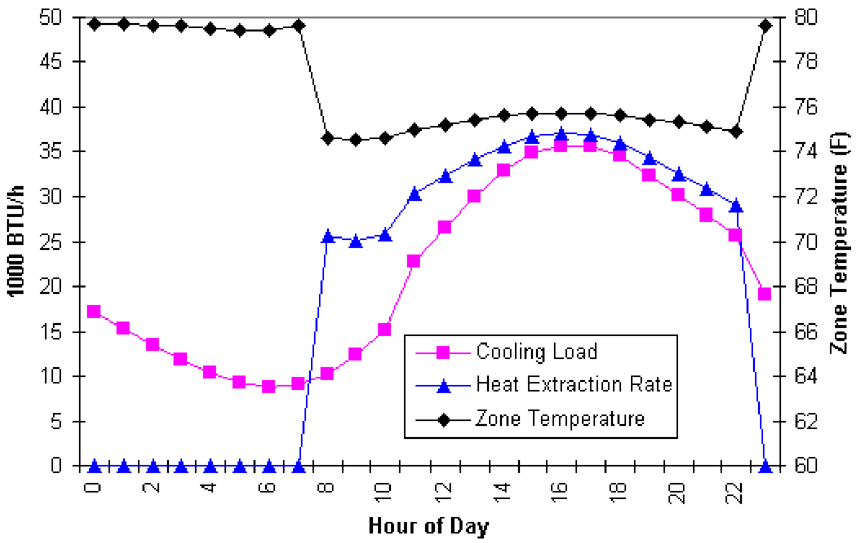

Figure 5.2: An example for cooling load, heat extraction and zone temperature profiles [21].

In the winter, system works in reversed manner. Steady-state heat loss caused by the ambient air temperature leads to instantaneous conversion to heating loads in order to maintain thermostat set temperature. In this case, heat is added to the room air by HVAC system rather than extracted. In heating load calculation neither transient heat transfer nor transfer function method principles are used. All heat gains are excluded from the calculation in order to be on the safe side meaning worst-case scenario is considered (summarised from [21]).

5.3 Thermal Load Calculation Tool

Carrier's Hourly Analysis Program (HAP) is a computer based thermal load calculation and energy analysis/simulation tool. HAP's calculation is based on ASHRAE-endorsed transfer function method. HAP calculates design cooling and heating loads (peak power) for buildings in order to size HVAC system components required to condition building zones, spaces at specified thermostat setpoints. HAP provides information on sizing coils, terminal units, air circulation fans, chillers, boilers etc. HAP simulates each of 8,760 hours of energy consumption of buildings for HVAC and non-HVAC systems which yields to total energy consumption of buildings.

5.3.1 Weather data

HAP uses design parameters as temperature, humidity and solar radiation in order to calculate thermal loads for buildings and constructs 24-hour profiles (design day condition) of temperature and humidity with clear sky conditions for solar radiation for all 12 months of a year. The warmest outdoor air dry-bulb (DB) temperature in a given month is considered to be the design day condition for that month. Each design day condition represents warmer than usual conditions meaning that, conditions targeted for cooling for each month. Cooling is mostly required in the winter for special applications and peak cooling loads may occur at any given time in tropical regions.

For the design day in each month, the dry-bulb temperature profile is created using the design dry-bulb temperature for that month and a model for the hourly variation of temperatures recommended by ASHRAE which produces smooth profiles with maximum temperatures at 3pm and minimum temperatures at 5am. The warmest outdoor air dry-bulb temperature (the warmest month) is set to be the summer design condition which is the worst-case scenario for a building's cooling needs. Summer design properties consist of three items that define characteristics of cooling design temperature profiles. Summer Design Dry-Bulb is the warmest outdoor air dry-bulb temperature, Summer Coincident Wet-Bulb (WB) is the average wet-bulb temperature which is used to generate humidity profiles for design cooling loads. Summer Daily Range represents the difference between maximum and minimum dry-bulb temperatures during the warmest month of the year. For weather data stated in the

ASHRAE Handbook of Fundamentals, 0.4% design values are used. Meaning that, the warmer temperatures occur in only 0.4% or about 35 hours during the year [22].

Heating design properties consists of winter design temperature and humidity values for the calculation of heating loads. For the total thermal loads, HAP uses actual weather data (temperature, humidity, solar radiation) for simulation and analysis of energy use by HVAC equipment.

Approach for calculating total cooling or heating loads and simulating the total energy use are different than each other. For the thermal loads, the worst-case scenario is considered for sizing HVAC equipment and for the total energy use, actual weather data is used.

For the energy management approach, 1-hour cooling/heating load(demand) is the peak power required by the building and for all 8,760 hours, it is culmination of percentages of the peak power which yield to total energy demand. For the peak load calculations, weather properties stated in Table 5.1 given below are used.

Table 5.1: Design weather properties of İstanbul (for peak load calculation).

Parameters	2001 ASHRAE	Design Condition	UHI +1°C	UHI +2°C	UHI +3°C	UHI +5°C
Summer Design DB(°C)	30	33	34	35	36	38
Summer Coincident WB(°C)	21.1	25	25.3	25.5	25.8	26.3
Summer Daily Range (°C)	8.5	10.5	10.5	10.5	10.5	10.5
Elevation (m)	36.9	36.9	36.9	36.9	36.9	36.9
Relative Humidity %	45.33	52.64	50	47.07	44.77	40.19
Humidity Ratio	0.0121	0.0168	0.0168	0.0168	0.0168	0.0168
Dew Point T. (°C)	16.91	22.04	22.12	22.04	22.12	22.14
Winter Design DB(°C)	-3.3	-3	-2	-1	0	2
Winter Coincident WB(°C)	-5.7	-5.7	-5.1	-4.5	-3.9	-2.7
Relative Humidity %	52.03	47.13	42.8	39.07	35.83	31.26
Humidity Ratio	0.0015	0.00138	0.0014	0.0014	0.0014	0.0014
Dew Point T. (°C)	-10.81	-11.63	-11.77	-11.86	-11.9	-11.82

Anthropogenic moisture and/or reduced air flow throughout urban areas may increase humidity levels in urban areas. UHI effect on relative humidity and total moisture amount in the air requires field measurement or climate model. Because of that reason, no consideration on the UHI effect on humidity has been implemented in this study. Humidity amount has been kept constant while increasing the ambient air temperature meaning less than actual effects have been calculated to be on the safe side. (As a result, relative humidity (RH) levels dropped per each degree of air temperature rise.) (summarized from [22]).

5.3.2 Building data

Case study building is an imaginary research institute building located in Istanbul Technical University's Ayazağa campus in İstanbul, Turkey. The building is 25m by 25m square building, one storey high on the ground soil (see Fig. 5.3). Details for the case study building is shown in Table 5.2 given below.

Table 5.2: Case study building parameters.

Parameter	Value
Building Dimension	25m x 25m x 3m
Window coverage	50% of the wall (at all directions)
U_{window}	1.80 W/m^{2}K
Overall Shade Coefficient	0.5 (SHGC=0.435)
Wall Materials	From Inside 2 cm gypsum plaster ($R_{g.p.}$=0.0275) 20 cm HW concrete (R_c=0.11562) 6 cm insulation (R_i=1.38739) 2 cm stucco to outside (R_s=0.02771)
U_{wall}	0.576 W/m^{2}K
Weight of the wall	523.2 kg/m^2
Roof Materials	From Inside 1.2 cm gyps. board ($R_{g.b.}$=0.07455) 20 cm HW concrete (R_c=0.11556) 4.3 cm insulation (R_i=2.07041) 1 cm build-up roof to outside (R_{br}=0.06147)
U_{roof}	0.400 W/m^{2}K
Weight of the roof	470 kg/m^2
Ufloor	0.600 W/m^{2}K
Building Envelope Absorptivity values (α)	0.3 = Light Coloured 0.6 = Medium Coloured 0.9 = Dark Coloured

3D model of the case study building has been generated via using Energy3D software [23].

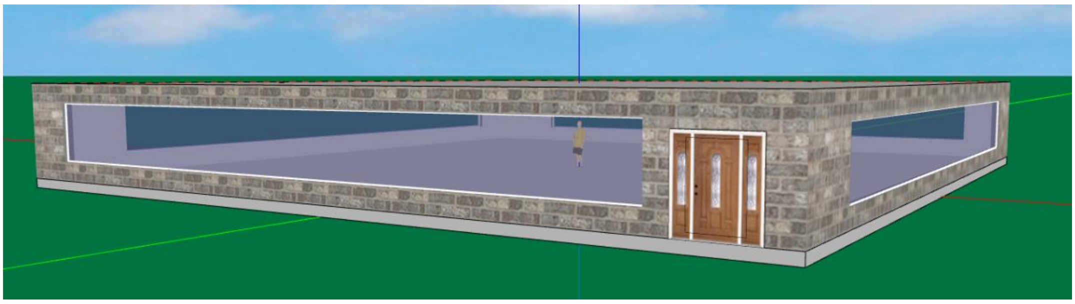

Figure 5.3: 3D Model of the building.

5.3.3 HVAC system data

HVAC system details (heat extraction strategy) is shown in Table 5.3 given below.

Table 5.3: HVAC system details.

Parameter	Value
HVAC operation	from 07:00 to 21:00 (excl. Sunday)
Occupancy	50 people
Fresh air per person	27.2 m^3/h
Lighting Heat Gain	20 W/m^2
Electrical Equip. Heat Gain	5 W/m^2
Sensible Heat Gain per Person	67.5 W
Latent Heat Gain per Person	35 W
Thermostat Set Conditions	Heating Season (7 months)
Temperature	22°C
Relative Humidity	0.5
Thermostat Set Conditions	Cooling Season (May-September)
Temperature	24°C
Relative Humidity	0.5
HVAC Equipment (outside unit)	Air-cooled Heat Pump
Terminal Cooling (inside unit)	Fan-coil Units
Design Supply Temperature (Fan-coil Units)	13°C (in summer) 35°C (in winter)
Cooling Coil (inside unit)	Water Coil in fresh air supply duct
Design Supply Temperature (Water Coil)	16°C (in summer) 30°C (in winter)
Infiltration doesn't occur during HVAC operation (occurs only when fan is off)	

Water has been selected as a primary working fluid (more efficient, denser than air, high thermal capacity) so, fresh air has only been supplied to the building just for ventilation purposes, minimum required air volume is used according to the standards (ASHRAE Std 62.1-2010) and air has been conditioned down to 8°C-10°C below t-stat set temperature of the room. Heat extraction mainly is done by terminal units (terminal cooling) located inside the building. But conditioned fresh air (cooling coil) also removes some part of the heat and reduces cooling load for the terminal units.

6. CASE STUDY

6.1 Aim of the Thesis

Main aim of the thesis is to show how absorptivity levels of the building envelope affect heat gains and cooling loads. Case study building cooling loads have been analysed for different building envelope absorptivity values as 0.3, 0.6, 0.9. Building envelope values set to be the primary variable. As discussed earlier, one of the dynamics of UHI formation is absorption of radiation by urban materials then convection of heat to the ambient air and re-radiation of heat to the urban areas.

Case study building cooling load has been analysed in the case of UHI effect (+1°C, +2°C, +3°C, +5°C) also by varying the building envelope values. (as 0.3, 0.6, 0.9) Within secondary variable, also government mandated thermostat set temperature increase (in the summer) has been analysed. In order to show how ground reflectance should be carefully evaluated, ground reflectance of the case study building surrounding increased and cooling loads have been analysed (please see Table 6.1 for the details).

Table 6.1: Set of variables for the case study (total of 24 sets).

Secondary Variables	Building Envelope Absorptivity Values (α) as Primary Variable		
UHI (+0°C)	0.3	0.6	0.9
UHI (+1°C)	0.3	0.6	0.9
UHI (+2°C)	0.3	0.6	0.9
UHI (+3°C)	0.3	0.6	0.9
UHI (+5°C)	0.3	0.6	0.9
T-stat Set T: 25°C	0.3	0.6	0.9
T-stat Set T: 26°C	0.3	0.6	0.9
Increasing Ground Reflectivity of surroundings of the building from 0.2 to 0.3	0.3	0.6	0.9

Higher building envelope absorptivity values would lead to higher ambient air temperature. Because of that reason, for peak cooling load calculation, summer design values have been increased in order to simulate UHI effect for the case study. Weather and building interact with each other. Weather conditions is the main cause of heat gain. (Others could be listed as heat gain from people, equipment etc.) Also, formation of building creates its own micro-climatic condition due to the distortion of the urban ground. So, ambient air temperature surrounding a building would be warmer than air in rural areas in the case of UHI.

6.2 Analysis and Results

As seen in Eq. (1.1), higher absorptivity level leads to more heat (short-wave solar radiation and long-wave radiation) absorbed by the building envelope meaning more cooling loads, in return more anthropogenic heat release thus creating a heat island effect in that area. While considering UHI, if ambient outside air temperature increases, its effect could be seen as an increase in both terminal cooling and cooling coil loads. Only parameter that affects the cooling coil load is the ambient outside air temperature.

If absorptivity of the building envelope changes, it's effect could be seen only in terminal loads. (As higher absorption would lead to higher heat gain and cooling loads.) In our case study calculations, absorptivity changes affect the terminal cooling loads. In the case of UHI, higher ambient air temperature effect is visible both in terminal and cooling coil loads.

It may be argued that, higher absorption of the building envelope would lead to higher ambient air temperatures because of the convection of heat from surfaces to the surrounding air. Due to limitations of the HAP software, it cannot be taken into consideration. Fresh air supply and HVAC equipments generally located on the roofs. It is safe to assume that, the air is being received by the HVAC equipment would be partially affected by the surface temperature of the rooftop. If anthropogenic heat release is also considered, the air, one is receiving may be the other's waste heat.

For the comparison of the calculations of each set, Absorptivity (α) value of 0.6 has been selected as a base-line case. As absorptivity (α) value of 0.6 corresponds to medium coloured building envelope which is more common than light and dark coloured building envelopes.

As it can be seen in Fig. 6.1 that, increasing absorptivity value of building envelope, increases total cooling loads for each month in cooling season. In July, increasing absorptivity level from 0.6 (medium coloured) to 0.9 (dark coloured) leads to 9.9%

increase in total cooling load, decreasing absorptivity level from 0.6 (medium coloured) to 0.3 (light coloured) leads to 9.47% decrease in total cooling demand. Total cooling load difference for July between 0.3 (light coloured) to 0.9 (dark coloured) building envelope is 21.45% meaning that, dark coloured building requires 21.45% more cooling than its light coloured one.

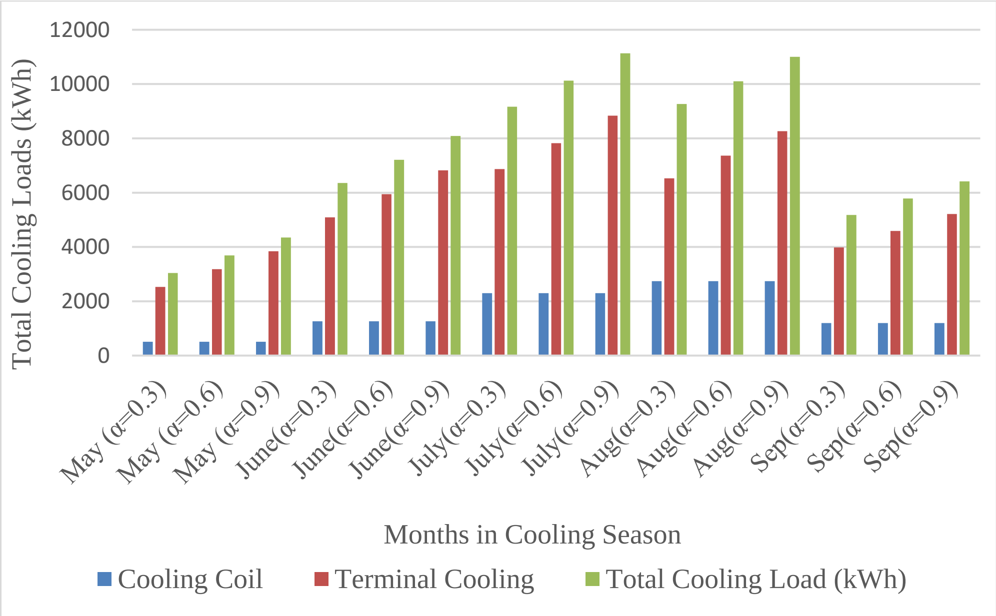

Figure 6.1: Total cooling loads for different absorptivity levels in cooling season [UHI (+0°C)].

While increasing absorptivity value of building envelope increases total cooling loads, at the same time it decreases total heating load in heating season (see Fig. 6.2).

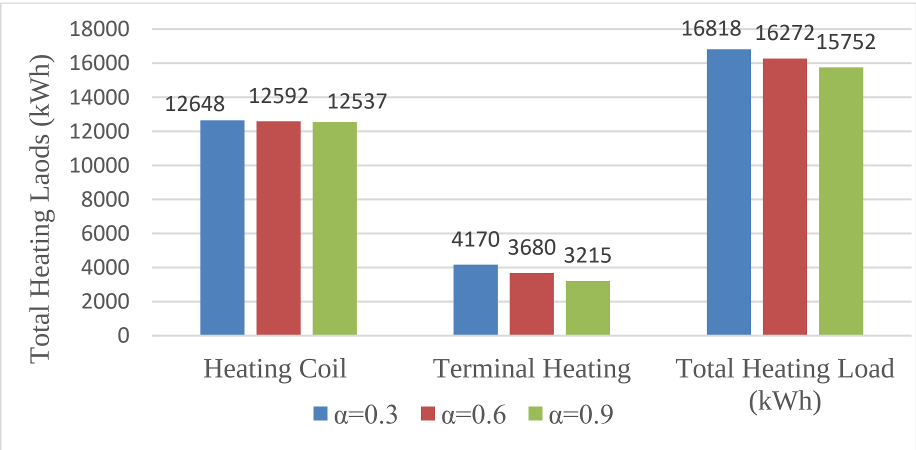

Figure 6.2: Total heating loads in heating season for different absorptivity levels [UHI (+0°C)].

For a medium-coloured building, its total heating demand is 3.25% less than its light-coloured equivalent and 3.2% more than dark-coloured building. It should be noted that, even if less heating demand caused by UHI effect in winter is favourable, UHI's effect in summer is more powerful especially in hot climates.

In Fig. 6.3 given below, comparison for peak cooling loads for different building envelope absorptivity levels (0.3, 0.6, 0.9) can be seen.

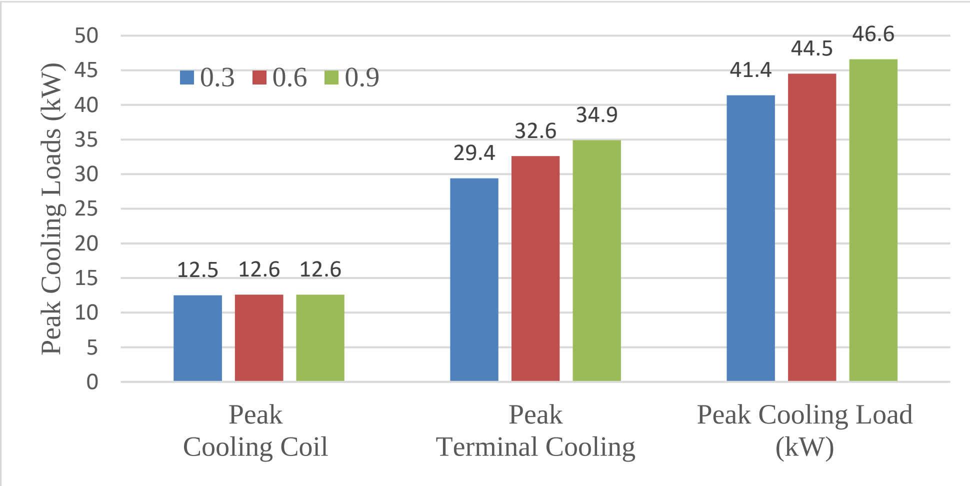

Figure 6.3: Peak cooling loads for different absorptivity levels [UHI (+0°C)].

It is clear that, when the absorptivity level increases, corresponding peak cooling loads for the building increases. Please note that, absorptivity value only affects terminal cooling (hence peak cooling) loads. For medium-coloured building, it requires 7.5% more cooling than light-coloured one and 4.5% less than dark-coloured one. Also, it should be noted that sum of peak cooling coil and peak terminal cooling coil don't need to be equal to peak cooling load as peaks of terminal cooling and cooling coil may occur at different times. Peak cooling load means highest sum of the cooling coil load and terminal coiling load.

In Fig. 6.4, variations of outdoor and indoor DB (Dry-Bulb) temperatures, indoor RH (Relative Humidity) and cooling loads for each hour in design day July can be seen. Peak cooling load has been experienced at 15.00 with a value of 44.5 kW. When considering UHI, its effect on different times may vary. For example, UHI effect may increase ambient outdoor air DB temperature by 2°C at 15.00. But, in order to know UHI Effect on full 8760 hours may require field measurements or UHI climate model to determine given variables' effect on all hours.

In this study, UHI Effect's on the peak cooling load (kW) at 15.00 is investigated. In order to calculate UHI's effect on total cooling load (kWh), realistic climate model and/or field measurement is required.

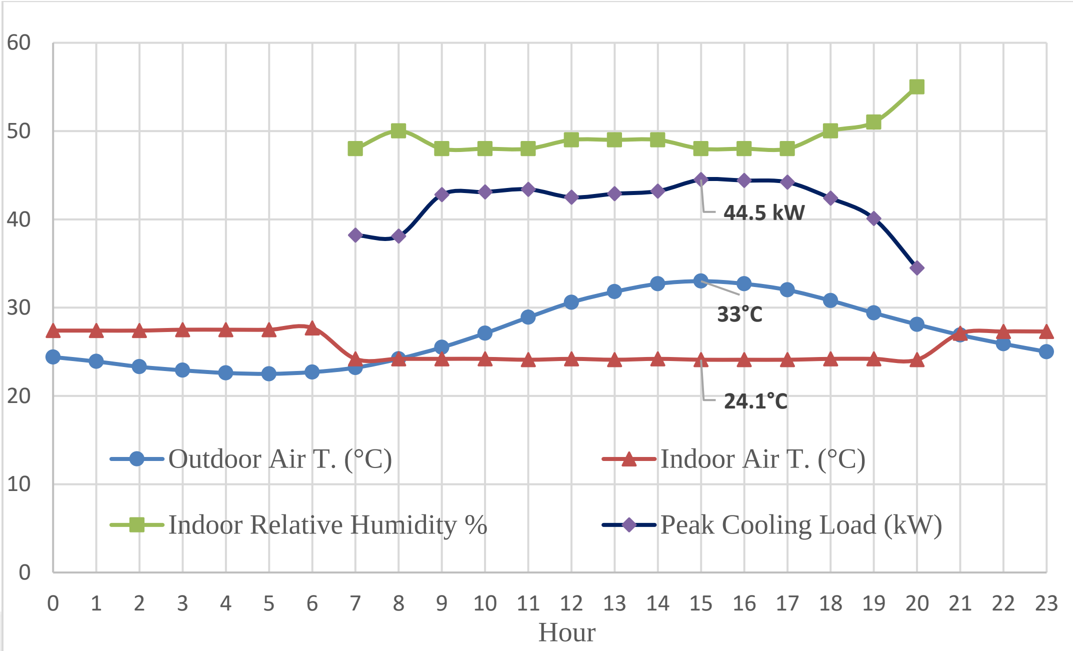

Figure 6.4: Baseline case peak cooling demand for July [UHI (+0°C), α=0.6].

Fig. 6.5 shows UHI effect on peak cooling demand with varying building envelope absorptivity levels. As it can be seen, both increase in UHI intensity (outdoor ambient temperature increase) and absorptivity level result an increase in the peak cooling demand as warmer air and more heat gain contribute to higher cooling loads.

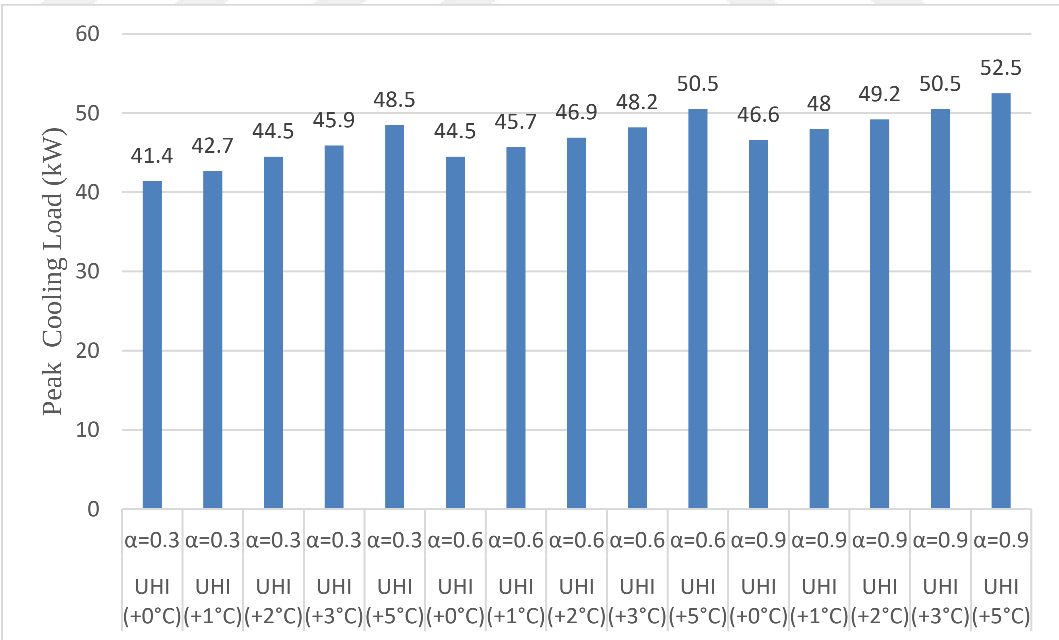

Figure 6.5: UHI effect on peak cooling load with varying building envelope absorptivity levels.

For medium-coloured envelope (α=0.6), from normal weather conditions UHI (+0°C) to UHI (+1°C) one degree of temperature rise increases peak cooling load by 2.7%, from UHI (+1°C) to UHI (+2°C) one degree of temperature rise increases peak cooling load by 2.6%, from UHI (+2°C) to UHI (+3°C) one degree of temperature rise increases peak cooling load by 2.77%, from UHI (+3°C) to UHI (+5°C) two degrees of temperature rise increases peak cooling load by 4.77%. Meaning, each degree of temperature rise increases peak cooling load roughly by 2.6% for medium-coloured envelope. Please note that, effect of increasing ambient air temperature on the humidity levels has not been evaluated in this study and amount of humidity has been kept constant thus, above values would be less than actual values.

For all absorptivity values, one degree of temperature rise increases cooling loads by 3% on average. Also, Fig. 6.5 may give an idea on how absorptivity of building envelope increase would be translated into the ambient temperature increase. While comparing values of; 44.5 kW for α=0.3, UHI (+2°C) and α=0.6, UHI (+0°C) which could be interpreted as increasing albedo value of a building envelope, decreasing absorptivity from 0.6 to 0.3 would be equal to 2°C ambient air temperature decrease. Also, comparing values of; 50.5 kW for α=0.6, UHI (+5°C) and α=0.9, UHI (+3°C) would give us the same interpretation as increasing albedo value of a building envelope, decreasing absorptivity from 0.9 to 0.6 would be equal to 2°C ambient air temperature decrease.

As seen in Fig. 6.6 and Fig. 6.7 given below, peak cooling demand and peak electricity demand occur at 15.00 which may imply that electricity demand for cooling purposes partially drives peak electricity demand (share of cooling in electricity system peak loads, please see Fig. 4.3). Thus, increase in UHI intensity (ambient air temperature increase) would increase peak electricity demand and at the same time, it increases total electricity demand.

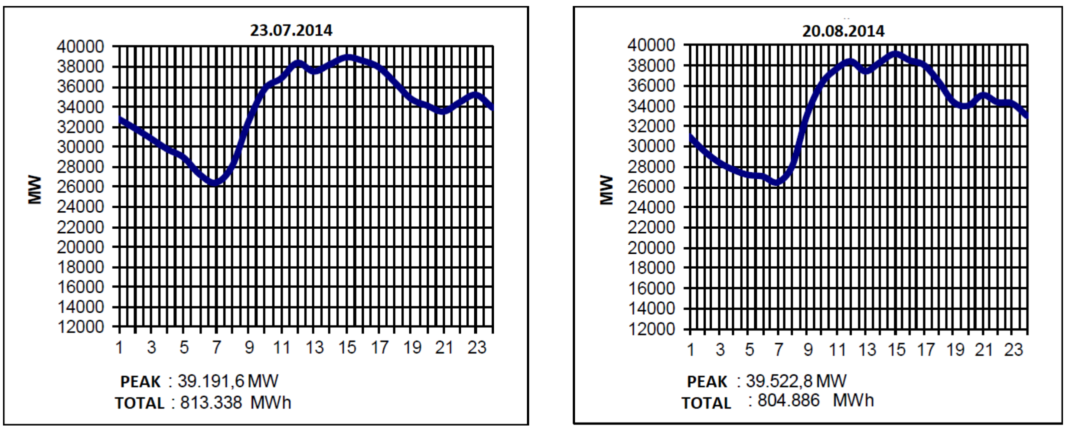

Figure 6.6: Peak electricity demand graph for Turkey in 2014 [24].

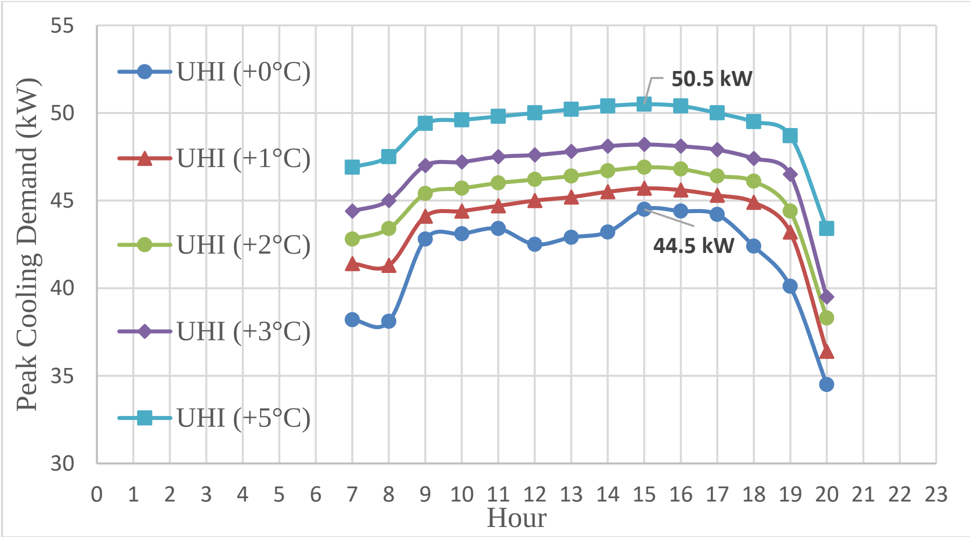

Figure 6.7: Peak cooling demand increase in design day July for different UHI intensities (α=0.6).

When UHI intensity increases, especially in the case of heat waves, only solution seems to increase the use of air conditioners to keep indoor temperatures low. But use of AC also contributes to UHI intensity via increasing anthropogenic heat release. Intense AC use during heat wave periods may accentuate heat wave. It may be also argued that no AC use during this period is a potential health hazard. In some counties, governments are planning to bring AC use restrictions via regulating AC min set-point temperature and also room t-stat set point temperature [25].

Fig. 6.8 given below shows the cooling load reduction in the case of government mandated t-stat set temperature increase during summer season.

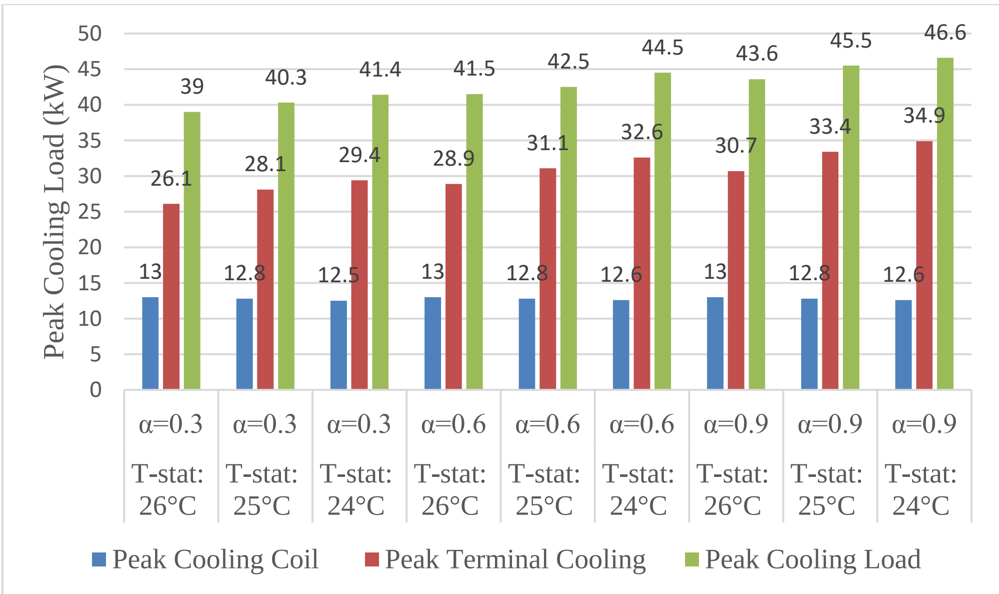

Figure 6.8: Peak cooling loads for different t-stat set temperatures [UHI (+0°C)].

This action reduces total and peak cooling loads, reduces anthropogenic heat release caused by the intense AC use in return it also reduces the UHI intensity and effect of heat waves. For medium-coloured envelope (α=0.6), increasing t-stat set temperature from 24°C to 25°C leads to 4.5% less peak cooling demand and from 24°C to 26°C leads to 6.75% less peak cooling demand, from 25°C to 26°C leads to 2.35% less peak cooling demand.

For the total cooling loads, for medium-coloured envelope (α=0.6), increasing t-stat set temperature from 24°C to 25°C leads to 8.7% less total cooling demand and from 24°C to 26°C leads to 17.2% less total cooling demand, from 25°C to 26°C leads to 9.4 % less total cooling demand (see Fig. 6.9).

Other interpretation of these numbers is that, with the help of passive, active and hybrid design solutions, required cooling loads may be decreased as these solutions would already decrease indoor temperatures so, less cooling would be required to bring down room temperature at t-stat set temperature.

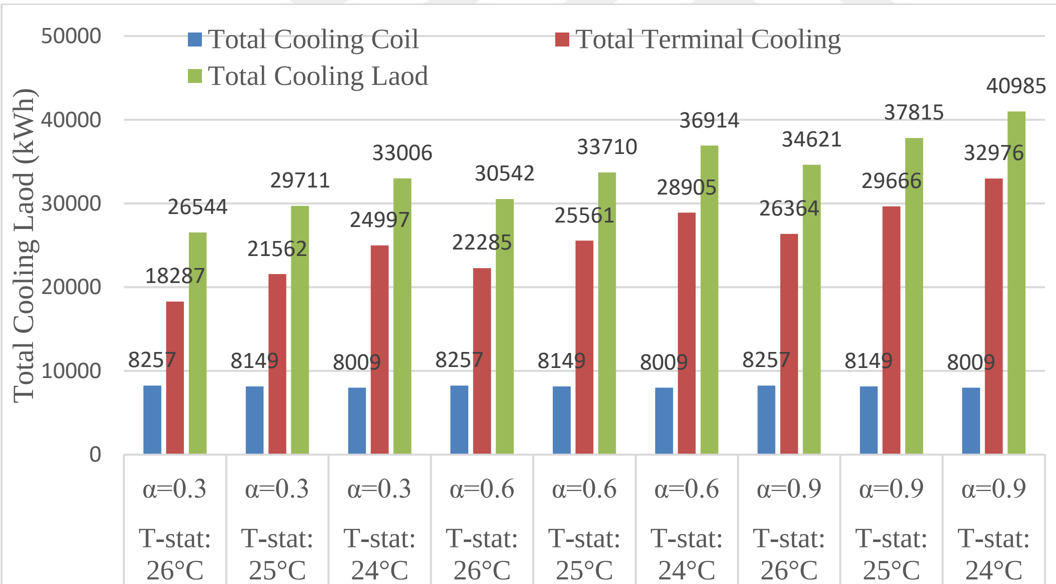

Figure 6.9: Total cooling loads for different t-stat set temperatures [UHI (+0°C)].

There is a balance between reflectivity of the building envelope and reflectivity of the surfaces surrounding the building. As described earlier, when reflected radiation (short wave and long wave radiation) is directed onto the building, it increases cooling loads in the summer and decreases heating loads in the winter. Generally using reflective materials for building envelopes decrease cooling loads of buildings because of the less absorbed heat. But having highly reflective surroundings may increase absorption by sending more radiation via reflecting it onto the buildings from surrounding highly reflective building façades, roads, windows and roofs etc.

As seen in Fig. 6.10, for medium-coloured envelope (α=0.6), increasing ground reflectivity (GR) from 0.2 to 0.3 leads to 3.6% more peak cooling demand caused by the increase in radiation onto the building.

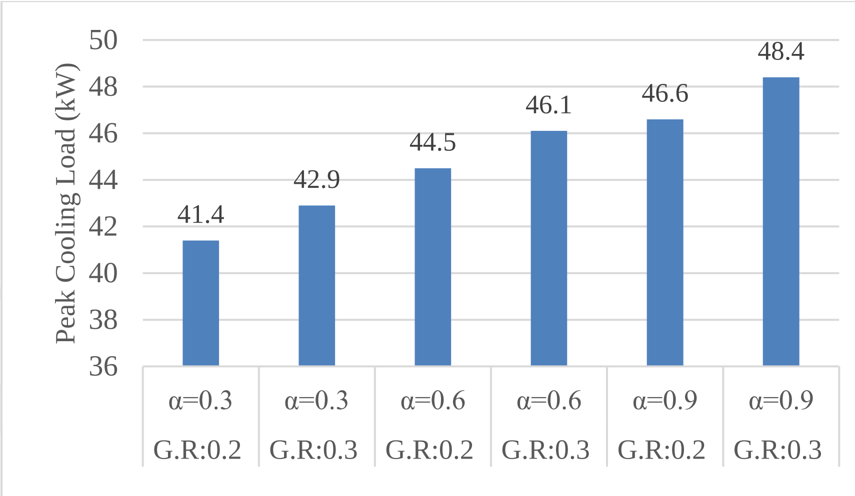

Figure 6.10: Peak cooling loads for different ground reflectivity (GR) levels.

Fig. 6.11 below shows that, increasing ground reflectivity from 0.2 to 0.3 leads to 6.7% increase in total cooling loads for medium-coloured envelope (α=0.6).

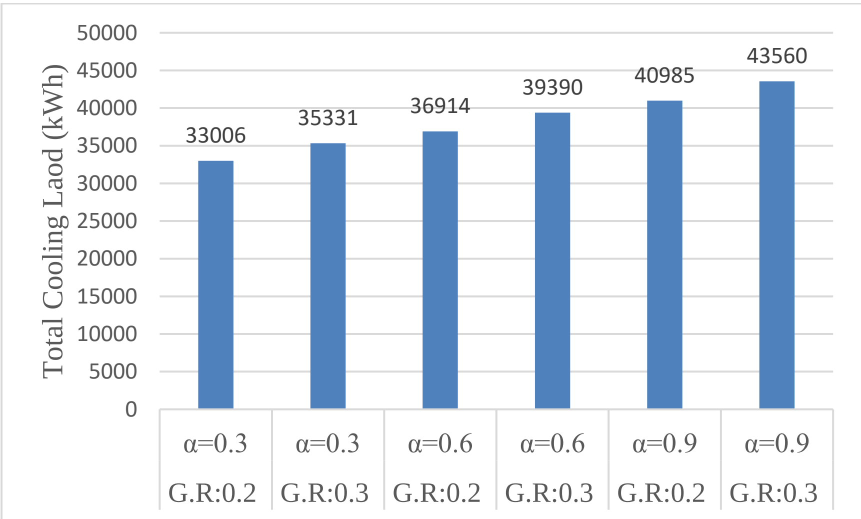

Figure 6.11: Total cooling loads for different ground reflectivity levels.

As seen in Fig. 6.12, as expected, reflected radiation from the surroundings onto the building decreases total heating loads. For reliable evaluation of convecting less heat to the ambient air and reflecting more heat to the building phenomena needs Computational Fluid Dynamics (CFD) analysis and site-specific data.

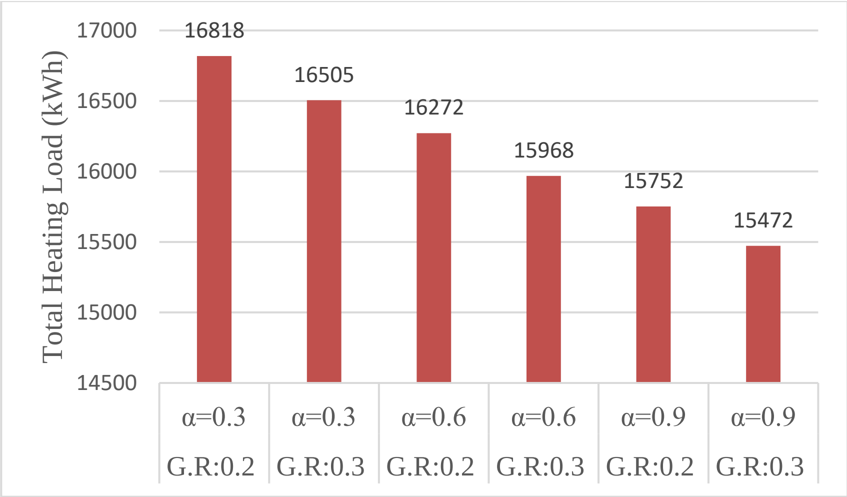

Figure 6.12: Total heating loads for different ground reflectivity levels.

Generally, increased reflectivity, decreases the surface temperatures meaning less heat would be convected to the air so, ambient air temperature effecting the building would decrease. In HAP calculation, only the increased absorption has been taken into consideration. Decrease in air temperature is neglected. Also, it should be noted that, increase in air temperature leads to more transmission loads by conduction at the same time decreased radiation would lead to less radiative heating through windows meaning heat gain percentage for different mode of heat transfers play an important role in determining effect of reflection on building envelopes. Most of the cases, (depending on window/wall ratio) solar radiation have much more effect than heat gain by transmission.

For our case study building, comparison between cooling loads caused by different mode of heat transfers is shown in Table 6.2. As expected, most of the cooling load is caused by solar radiation through windows as window coverage is high. For the ground reflectivity of 0.2 and UHI (+0°C), changing absorptivity value of building envelope affects the transmission loads as no change in radiation because of reflection or retro-reflection is taken into account. Because of the higher outside building surface temperatures, wall and roof transmission loads increased. As there is no increase in outside air temperature (slight increase would occur because of heat transfer from building envelope surface to the surrounding air but it is neglected in this study.) no change occurred in transmission through window. Increasing absorptivity value from 0.3 to 0.6 increases wall transmission loads by 50.5%, from 0.3 to 0.9 by 101%, Increasing absorptivity value from 0.3 to 0.6 increases roof transmission loads by 121%, from 0.3 to 0.9 by 242%.

Table 6.2: Comparison of cooling load types caused by UHI intensity.

Load Types	Details	UHI (+0°C), GR=0.2 Sensible Heat (W)			UHI (+2°C), GR.=0.2 Sensible Heat (W)		
		α = 0.3	α = 0.6	α = 0.9	α = 0.3	α = 0.6	α = 0.9
Window Solar Loads	144 m²	10512	10512	10512	10512	10512	10512
Wall Transmission	156 m²	461	694	927	640	874	1107
Roof Transmission	625 m²	1208	2672	4136	1708	3171	4635
Window Transmission	144 m²	1845	1845	1845	2364	2364	2364
Overhead Lighting	3125 W	2736	2736	2736	2736	2736	2736
Electric Equipment	3125 W	2871	2871	2871	2871	2871	2871
People (Sens.Heat+ Latent Heat)	50	4285	4285	4285	4285	4285	4285

For the effect of UHI to the cooling loads, absorptivity value of 0.6 is compared between UHI (+0°C) and UHI (+2°C) while keeping GR constant. For wall transmission load, from UHI (+0°C) to UHI (+2°C) leads to 26% increase, for roof transmission load, from UHI (+0°C) to UHI (+2°C) leads to 18.6% increase (see Table 6.2).

Ground reflectivity has been increased from 0.2 to 0.3 in order to simulate the effect of reflective surroundings to the building cooling loads. As solar radiation and long-wave radiation could be reflected by the reflective surfaces towards building, both transmission loads and loads caused by radiation have increased.

For our case study building, reflections to the roof have not been taken into account. It should be noted that, reflections from higher building's façades could be incident on roofs. For absorptivity value of 0.6; increasing surrounding ground reflectivity from 0.2 to 0.3 leads to 14% increase in windows solar load and 7.3% increase in wall transmission load (see Table 6.3).

Due to the limitation of HAP software, effect of surrounding surface temperature reduction to the surrounding air temperature because of higher reflection is neglected hence no reduction occurred in window transmission load.

Table 6.3: Comparison of cooling load types caused by surrounding reflection.

Load Types	Details	UHI (+0°C), GR.=0.2 Sensible Heat (W)			UHI (+0°C), GR.=0.3 Sensible Heat (W)		
		α = 0.3	α = 0.6	α = 0.9	α = 0.3	α = 0.6	α = 0.9
Window Solar Loads	144 m²	10512	10512	10512	11989	11989	11989
Wall Transmission	156 m²	461	694	927	486	745	1004
Roof Transmission	625 m²	1208	2672	4136	1208	2672	4136
Window Transmission	144 m²	1845	1845	1845	1845	1845	1845
Overhead Lighting	3125 W	2736	2736	2736	2736	2736	2736
Electric Equipment	3125 W	2871	2871	2871	2871	2871	2871
People (Sens.Heat+ Latent Heat)	50	4285	4285	4285	4285	4285	4285

All cooling loads mentioned in this section can be converted into electrical loads by taking COP into consideration. Cooling load divided by COP value would give electrical load. Peak cooling loads for our case study span a wide interval starting from 41.4 kW up to 52.5 kW which makes it impractical to use the same HVAC equipment for comparison. COP value depends on ambient outdoor air temperature, partial and full loads in which HVAC equipment is operating. So, an air-cooled heat pump as a HVAC equipment is selected which has a nominal cooling capacity of 49.7 kW and max. cooling capacity of 59.3 kW. HVAC equipment works in the range of 7°C to 12°C. So, Evaporator leaving water temperature (ELWT) is 7°C [26].

Fig. 6.13 shows that, COP value decreases when ambient air temperature increases. For the comparison of electrical loads, UHI (+0°C) equivalent of ambient air temperature of 33°C and UHI (+2°C) equivalent of T_{oa} 35°C with building envelope value of 0.6 are selected. Corresponding nominal COP values are 2.61 and 2.52 respectively (COP value decreased by 3.45%), cooling loads are 44.5 kW and 46.9 kW respectively (in both situations, HVAC unit is considered to be working in nominal conditions) which yields to 17.05 kW and 18.61 kW electrical loads respectively, meaning 9.15% more electricity is required where cooling demand increase is 5.4%.

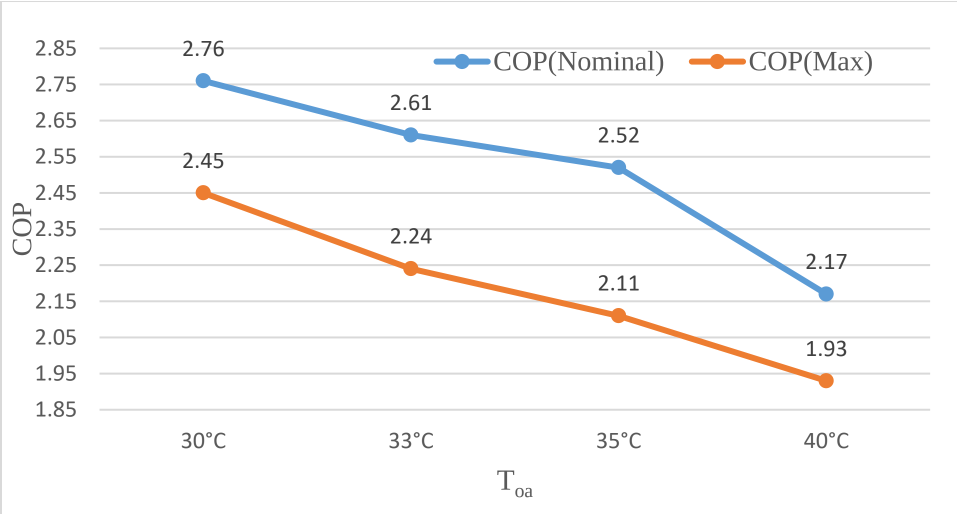

Figure 6.13: Effect of ambient air temperature on COP value.

Also, it should be noted that, UHI increases ambient air temperature, in return it leads to more cooling load thus more electricity is required. Important parameter to consider here is that, UHI effect also reduces the efficiency of cooling by decreasing COP value meaning when heating caused by UHI effect starts, more cooling will lead to overheating in urban areas thus creating a vicious cycle.

7. CONCLUSIONS

Heat waves in Europe, bush fires in Australia showed how much overheating matters not only in urban areas but also in rural areas. UHI is the by-product of urban formation. Solar radiation and anthropogenic heat release are the main causes of UHI while, increasing solar reflectance and evapotranspiration are the main mitigation strategies. For a given urban area; from SEB equation to deciding required method to mitigate UHI by selecting proper material then policies to govern and implement these strategies in order to lead sustainable urban area is a must.

It's been concluded that; each degree of ambient air temperature rise caused by the UHI effect increases total and peak cooling loads in the summer.

(1) Decreasing absorptivity level of the building envelope (increasing albedo/reflectivity) is an effective counter-measure for UHI effect and could be used to mitigate UHI. Results showed considerable decrease in peak and total cooling loads leading to decrease in peak and total electricity demand and anthropogenic heat release.

(2) While increasing reflectivity of the building envelope decreases total and peak cooling loads, at the same time it increases total and peak heating load in heating season. It should be noted that, even if less heating demand caused by UHI effect in winter is favourable, UHI's effect in summer is more powerful especially in hot climates.

(3) Higher absorptivity levels of the building envelope cause higher building surface temperatures which leads to higher convection/radiation of heat to the surrounding of the building thus creating UHI effect hence built environment is called as micro-climatic formation.

(4) As cooling itself is one of the heat sources in the urban area, government mandated air conditioning restrictions/regulations and room thermostat set temperature increase might be put into effect in the near future as it is an effective mitigation strategy of UHI by decreasing anthropogenic heat release to the urban environment.

(5) While increasing reflectivity of the building envelope is an effective measure for reducing cooling loads. Reflected heat/radiation might cause discomfort on the urban ground. Increasing reflectivity of the surrounding of a building might increase building’s cooling load by reflecting heat/radiation onto the building envelope.

(6) When building energy consumption and urban environmental comfort (pedestrian comfort) are regarded as equally important. There should be criteria/metrics for regulation in order to achieve both as rejecting heat by having reflective building envelope and reflecting this heat/radiation to the urban area might contradict with having urban environmental comfort.

(7) Rejecting heat by building envelope and not reflecting heat/radiation onto the urban ground might require to reflect heat/radiation to the sky, meaning retro-reflective building envelope and surroundings might be adopted.

(8) Solution to UHI effect cannot be more cooling, because cooling itself is one of the main sources of anthropogenic heat release in urban areas which in return increases ambient air temperature, decreases COP values of HVAC equipment, accentuating UHI effect thus decreasing urban environmental comfort.

(9) Even 1°C overheating or decreasing urban area’s ambient air temperature by 1°C has a significant impact on electricity consumption. So, for energy efficient system design and operation, all available tools as passive, active and hybrid design solutions, retrofit ready solutions to existing building stock should be used and should be supported by government incentives in order to drive the change for the sustainable urban areas.

(10) UHI studies require extensive multi-disciplinary contribution and deep analysis. Future cities would require building information modelling (BIM) and building energy modelling (BEM) in order to be designed as climate-proper in which extend of modelling should be the whole urban area.

(11) Future Urban Heat Island effect and related mitigation studies could be done in 3 stages.

(1st stage) A case study using thermal load calculation tool and CFD analysis should be done. Effect of rooftop HVAC outside unit’s waste heat release, air flow throughout a building should be studied. Simulating UHI effect on a single building might require modelling of a small-scale urban area in which minimum area should be carefully evaluated in order to include all of the important parameters effecting UHI intensity for the building in the CFD analysis.

(2nd stage) Small-scale experimental study similar to first stage case should be studied. According to the measurements, CFD analysis should be calibrated. After that, a large-scale experimental study could be implemented using satellite sensing technology, remote sensing technology and geographic information system model. For the large-scale experimental study, İTÜ's Ayazağa campus could be proposed as being very close to densely populated business district with high-rise buildings and containing buildings, pavements, tree canopy and a lake inside the campus. Also, required data and tools in order to study UHI effect might be already there and/or can be acquired with less effort as it is a university campus.

(3rd stage) Criteria and metrics for regulation of all the parameters effecting UHI should be proposed.

8. REFERENCES

[1] **United Nations** (2019). Department of Economic and Social Affairs, Population Division, World Urbanization Prospects: The 2018 Revision, New York.

[2] **Yuan, J., Yamanaka, T., Kobayashi, T., Kitakaze, H. and Emura, K.** (2019). Effect of highly reflective building envelopes on outdoor environment temperature and indoor thermal loads using CFD and numerical analysis, in *E3S Web Conf. 111 06031*

[3] **Rizwan, A. M., Dennis, Y. C. L., Liu, C.** (2008). A review on the generation, determination and mitigation of Urban Heat Island, *Journal of Environmental Sciences*, vol. 20, no. 1, pp. 120-128.

[4] **Taha, H.** (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat, *Energy and Buildings,* vol. 25, no. 2, pp. 99-103.

[5] **Akbari, H. and Kolokotsa, D.** (2016). Three decades of urban heat islands and mitigation technologies research, *Energy and Buildings,* vol. 133, no. 0378-7788, pp. 834-842.

[6] **Gago, E. J., Roldan, J., Pacheco-Torres, R. and Ordonez, J.** (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects, *Ren. and Sus. Energy Reviews,* vol. 25, no. 1364-0321, pp. 749-758.

[7] **Akbari, H. and Hosseini, M.** (2016). Effect of cool roofs on commercial buildings energy use in cold climates, *Energy and Buildings,* vol. 114, no. 0378-7788, pp. 143-155.

[8] **Gagliano, A., Nocera, F. and Aneli, S.** (2017). Computational Fluid Dynamics Analysis for Evaluating the Urban Heat Island Effects, *Energy Procedia,* vol. 134, no. 1876-6102, pp. 508-517.

[9] **Santamouris, M., Papanikolaou, N., Livada, I., Koronakis, I., Georgakis, C., Argiriou, A. and Assimakopoulos, D.N.** (2001). On the impact of urban climate on the energy consumption of buildings *Solar Energy,* vol. 70, no. 3, pp. 201-216.

[10] **Hertel, O.** (2009). Integrated Monitoring and Assessment of Air Pollution, *Doctor's dissertation, National Environmental Research Institute,Aarhus University,* p. 80.

[11] **Url-1.** energy.gov, U.S. Department of Energy website, [Online]. Available: https://www.energy.gov/eere/solar/articles/solar-radiation-basics. [Accessed 24 02 2020].

[12] **Ichinose, M., Inoue, T. and Nagahama, T.** (2017). Effect of retro-reflecting transparent window on anthropogenic urban heat balance, *Energy and Buildings*, vol. 157, no. 0378-7788, pp. 157-165.

[13] **Inoue, T., Shimo, T., Ichinose, M., Takase, K. and Nagahama, T.** (2017). Improvement of urban thermal environment by wavelength-selective retro-reflective film, *Energy Procedia*, vol. 122, no. 1876-6102, pp. 967-972.

[14] **Danks, R., Good, J. and Sinclair, R.** (2016). Assessing reflected sunlight from building facades: A literature review and proposed criteria,, *Building and Environment*, vol. 103, no. 0360-1323, pp. 193-202.

[15] **Lim, X. (2020).** The super-cool materials that send heat to space, *Nature*, vol. 577, pp. 18-20.

[16] **Raman, A., Anoma, M., Zhu, L. et al.** (2014). Passive radiative cooling below ambient air temperature under direct sunlight, *Nature*, vol. 515, no. 7528, p. 540–544.

[17] **Url-2.**https://www.123rf.com/, [Online]. Available: [Accessed 14 06 2020].

[18] **Santamouris, M., Cartalis, C., Synnefa, A. and Kolokotsa, D.** (2014). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings: A review, *Energy and Buildings*, vol. 98, no. 0378-7788, pp. 119-124.

[19] **Kolokotroni, M., Zhang, Y. and Watkins, R.** (2007). The London Heat Island and building cooling design, *Solar Energy*, vol. 81, no. 1, pp. 102-110.

[20] **International Energy Agency.** (2018)**.** The Future of Cooling, IEA, Paris.

[21] **HAP**. Horly Analysis Program v5.0 Help Menu , *28: Load Calculations.*

[22] **HAP.** Horly Analysis Program v5.0 Help Menu , *27: Weather Calculations.*

[23] **Xie, C., Schimpf, C., Chao, J., Nourian, S. and Massicotte, J. (2018).** Learning and Teaching Engineering Design through Modeling and Simulation on a CAD Platfor*m, Computer Applications in Engineering Education,* 2018.

[24] **TEİAŞ.** (2015). Türkiye Elektrik Enerjisi 5 Yıllık Üretim Kapasite Projeksiyonu (2015 – 2019), Planlama ve Stratejik Yönetim Dairesi Başkanlığı, Ankara.

[25] **Url-3.** https://tech.hindustantimes.com/, [Online]. Available: https://tech.hindustantimes.com/tech/news/govt-has-mandated-24-degrees-as-the-default-temperature-for-acs-what-does-this-mean-and-how-will-it-affect-you-story-Zdt1BZOlkBMgmnlEmIoc2J.html. [Accessed 13 06 2020].

[26] **DAIKIN.** 2016**.** General Catalogue, Model EWYQ050BAWP, 2016. [Online].

CURRICULUM VITAE

Name Surname: Mustafa Leblebici

E-Mail: me.leblebici@gmail.com

EDUCATION:

- **B.Sc.:** Mechanical Engineering, 2010-2016, University of Sakarya, Turkey
  Mechanical Engineering, 2011-2012, IT Tralee, Ireland

PROFESSIONAL EXPERIENCE:

- JAZARI Powertrain Technologies, R&D Project Manager, 2020- Present
- JAZARI Powertrain Technologies, Mechanical Engineer, 2018- 2020
- AKIM Engineering, Mechanical Engineer, 2016-2018