

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**AN APPROACH TO THE EVALUATION OF DAYLIGHT IMPACT AND
CONTRIBUTION TO THE ENERGY DEMAND OF OFFICE BUILDINGS
IN THE URBAN CONTEXT**

Ph.D. THESIS

Dilay KESTEN ERHART

Department of Architecture

Construction Sciences Programme

SEPTEMBER 2012

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

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KULLANILABİLECEK BİR YAKLAŞIM**

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To the memory of my father,

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ABBREVIATIONS

ADI	Average Daylight Illuminance
BGI	British Glare Index
BMZ	Cubic Density
BRE	Building Research Establishment
BREDEM	Building Research Establishment Domestic Energy Model
BREEAM	Building Research Establishment's Environmental Assessment Method
BSI	British Standard
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CBD	Central Business District
CEN	European Committee for Standardization
CFD	Computational Fluid Dynamics
CFL	Compact Fluorescent Lamps
CGI	The CIE Glare Index
CHP	Co-generation Heating Plants
CHPS	Collaborative for High Performance Schools
CIE	International Commission on Illumination
DA	Daylight Autonomy
DA_{con}	Continuous Daylight Autonomy
DAYSIM	Daylight Simulation Program
DEMs	Digital Elevation Models
DF	Daylight Factor
DGI	Daylight Glare Index
DGIN	New Daylight Glare Index
DIMFAC	Dimming Factor
DIN	Deutsches Institut für Normung
DRELAT	Daylight Responsive Electric Lighting Analysis Tool
DSE	Display Screen Equipment
DSP	Daylight Saturation Percentage
EnEV	German Energy Saving Ordinance
EPBD	Directive on "Energy Performance of Buildings"
EU	European Union
GHG	Greenhouse Gas
GFZ	Plot Ratio
GNP	Gross National Product
GRZ	Site Occupancy Index
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IRC	Internal Reflected Component
ISO	International Organization for Standardization
LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench

LBOBW	Federal State Building Ordinance of Baden-Württemberg
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
LENI	Lighting Energy Numeric Indicator
LT	Lighting and Thermal
MaxDA	Maximum Daylight Autonomy
OECD	Economic Co-operation and Development
PGSV	Predicted Glare Sensation Vote
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
PV	photovoltaic
PVB	Polyvinylbutyral
SAP	Standard Assessment Procedure
SHGC	Solar Heat Gain Coefficient
SRA	Strategic Research Agenda
SVR	Stationary Virtual Reality
TMY	Typical Meteorological Year
TRY	Test Reference Year
T_{vis}	Visible Transmittance
UCL	Urban Canopy Layer
UDI	Useful Daylight Illuminance
UGR	Unified Glare Rating
US	United States
USA	United States of America
VCE	Visual Comfort Evaluation Method
VCP	Visual Comfort Probability
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WYEC	Weather Year for Energy Calculations
CO₂	Carbon dioxide
d	Room depth
D	Building depth
E_α(x)	Illuminance at x due to S _α
GW_p	Gigawatts of electric peak power
GW_{th}	Gigawatts of thermal power
h	Room height
H	Building height
H/W	Aspect Ratio
H_w	Window height
I	Radiant intensity
I_b	Beam solar radiation
I_d	Diffuse solar radiation
I_l↑	Long wave radiation
L₁	Spacing distance
L₂	Frontal length
Lux/lx	luminous flux [lm/m ²]
L_z	Zenith luminance [cd/m ²]
L_{γ_α}	Luminance in any arbitrary sky element S _α .
L_θ	Absolute luminance of the sky element with altitude of θ

MW_{th}	Megawatts of thermal power
$^{\circ}C$	Degree Celsius
p_h	Height of the wall part between floor and window
P_{lamp}	Electric Lamp power
R	Radiance
R_z	Zenith radiance [lux]
R_{θ}	Absolute radiance of the sky element with altitude of θ
S_{α}	Sky segment P
Z_s	Zenith distance of the sun
ΔS_{α}	Angular size of S_{α}
λ	Wavelength [nm]
ω	Solid angle [$^{\circ}$]
x	The angular distance of the sky element from the sun

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AN APPROACH TO THE EVALUATION OF DAYLIGHT IMPACT AND CONTRIBUTION TO THE ENERGY DEMAND OF OFFICE BUILDINGS IN THE URBAN CONTEXT

SUMMARY

In response to environmental concerns, demands for improved energy efficiency and a desire to create a more pleasant working environment, building designers and urban planners are looking for ways to make better use of daylight in the urban context. Although daylight is free and non-polluting, it can cause visual comfort problems and under some conditions, thermal comfort problems such as unwanted heat related to the effect of direct sun beam.

There are various tools and techniques that estimate natural illumination. Unfortunately, some of those models are just based on overcast sky conditions and some only consider direct sunlight and shading effects.

The most important challenges in this field of study include:

- A lack of an existing homogenous, all-in-one simulation environment.
- Significant computational power and time is still required by simulations. Many environments are not optimised for multiple core CPUs. Thus, not everyone can fully participate in development of this field.
- A present lack of a fully integrated daylight-glare-thermal simulation process.
- A lack of a clear understanding of relevant parameters and simulation outcomes and misinterpretation.

The last decade has seen many advances in dynamic daylight computation, climate-based daylighting calculation methodologies, glare studies, visual comfort and energy use analysis. These innovations have been put into practice through synergistic interaction of technical and computational expertise.

Most researchers in this field are concerned with daylighting performance of individual buildings, often under isolated circumstances. If the urban surrounding is also considered, such as neighbourhoods buildings of various height and distance, then the problem becomes more realistic and of course, more complicated. To evaluate the energy performance of the urban quarters it is important to know the influence of surrounding urban structures. This work derives a method for urban quarters regarding daylight availability in a space. The interactions with heating, cooling and electrical energy demand are investigated and a regression model for this purpose is produced. The lighting, heating and cooling performance of a space in an urban structure with different distances between buildings is simulated in detail using software tools such as EnergyPlus, Radiance, Daysim and Insel8. Additionally, the interaction between energy performances has been considered. Further daylight responsive electric lighting consumption has been calculated for the cases. These results have been taken as input variables for the heating and cooling. In line with

this objective, the first chapter describes the energy demand expectations and the energy efficiency measures in buildings, city quarters and urban areas. Pointing out the disadvantages of the current energy performance evaluation methods and daylight utilization schemes, the requirement of a method to quantify the energy performance concerning daylight in urban environment is underlined. The second chapter examines comfort conditions and energy performance in office buildings. Both thermal and visual comfort subjects are explained, divided into natural and built environmental parameters. Sky luminance distribution models, daylight simulation algorithms, performance metrics criteria, shading, artificial devices and control systems are explained in terms of visual comfort conditions and energy performance subtopic. Energy performance standards including thermal – visual comfort and lighting systems are mentioned here as well.

The third chapter mainly describes the urban environment and energy use through examples of urban structure and the legal framework for land use zoning and interactions between urban climate and energy. Solar energy and daylight availability in cities is examined in two groups: urban form characterisation for solar evaluation and shading effects from nearby buildings. The last part of the chapter gives an evaluation of the existing methods and points out the necessity for a new approach.

In the fourth chapter, a principle for a new approach to assess the office building energy demand in urban context is described. Using the proposed methodology, the daylight performance is investigated and energy consumption of artificial lighting is calculated, taking daylight availability into account. Internal gains, caused by artificial lighting are also considered. Details of the each step and determination of the each parameter is explained within this chapter.

Chapter five presents an example of the implementation of the proposed approach. The interactions between all parameters of daylight and energy performance of a building depend on the urban geometry are examined in a simplified scenario. The office building is assumed to be located in Stuttgart, Germany. Analyses were done with Stuttgart TMY2 (test meteorological year 2) weather data and the distance between buildings in urban context was chosen according to “the permissible space distance” as defined by the federal state building ordinance of Baden-Württemberg. The daylight illuminance distributions in the simple side lit office room including supplementary lighting energy demand and heating and cooling within the defined urban configuration are presented here.

Chapter six focuses on the comparative testing and experimental validation of the proposed approach. The accuracy of the predictions such as illumination level, lighting demand, heating and cooling demand are evaluated by comparing predicted values with monitored data of the test room. The accuracy of artificial lighting illuminance and energy use is evaluated by comparing simulation results using data provided by manufacturers.

In the seventh chapter simulation results are examined. Furthermore a regression analysis based on the simulation results is performed. The analysis includes statistical analysis and a stepwise description from data to an applicable correlation. Afterwards, the lighting energy demand for each office building types were calculated and compared with simulation results.

Lastly, section eight presents the conclusion and possible directions for further work which can be based on findings from this research.

ŞEHİRSSEL DOKUYA BAĞLI GÜN IŞIĞI KATKISININ OFİS BİNALARINDAKİ ENERJİ İHTİYACINA ETKİSİNİN DEĞERLENDİRİLMESİ AMACIYLA KULLANILABİLECEK BİR YAKLAŞIM

ÖZET

Günümüz mimarları ve şehir plancıları enerji verimliliği politikaları kapsamında çalışma ortamlarında konfor koşullarının sağlanması amacıyla mevcut çevresel kaygıları da göz önünde bulundurarak, günışığının şehrsel dokuda daha etkin kullanımı konusunda yeni çözüm önerileri aramaktadırlar.

Güneş her ne kadar tükenmeyen bir doğal aydınlatma kaynağı ve çevre dostu olsa da, bazı durumlarda görsel konfor sorunlarına yol açabilmekte, direkt güneş ışınımının etkisi ile de termal konforsuzluk yaratabilmektedir. Binaların yıllık toplam aydınlatma, ısıtma ve soğutma enerjisi ihtiyacının belirlenebilmesi amacıyla şehrsel dokuya bağlı gerçekçi hesaplamaların yapılabilmesinin gerekliliği açıktır.

Bu çalışma kapsamında eksikliğine dikkat çekilen, incelenen ve çözülmeye çalışılan konular şunlardır:

- Isıtma, soğutma ve aydınlatma hesaplamalarını bir arada aynı doğruluk ve detayda yapabilen bir tekniğin ve bilgisayar tabanlı bir yöntemin olmaması
- Bina enerji ihtiyacını belirlemeye yönelik kullanılan programların bir kısmının hesaplama sürelerinin uzun olması, farklı bir bilgisayar alt yapısı ve kurulumu gerektirmeleri bununla birlikte program kullanıcılarından beklenen özel bilgi ve donanım ihtiyacı
- Bütünleşmiş enerji ihtiyacı hesaplaması yapan programların; ısıtma, soğutma ve aydınlatma enerjilerinin birbirleriyle olan etkileşimlerini hesaplamalara dahil eden, gerektiğinde fiziksel çevreye ait yapılan değişiklikleri de dikkate alan bir aydınlatma ve termal enerji simülasyon kombinasyonunun bulunmayışı
- Hesaplamalarda kullanılan parametrelerin dokümanlarda kullanıcıya yeterince açık olarak ifade edilememiş olması ve bu durumun hesaplama sonuçlarının değerlendirilmesinde yarattığı yanlış yorumlama olasılığı.

Son on yılda geliştirilen dinamik - iklim tabanlı günışığı hesaplama modelleri, kamaşma analizleri, görsel konfor ve aydınlatma enerjisinin etkin kullanımına ait yeni yöntemler sayesinde aydınlatma alanında büyük bir ilerleme kaydedilmiştir. Bu yenilikler, teorik bilgi ve bilgisayar tabanlı programlamanın bir araya gelmesiyle araştırmacıların ve bu alanda çalışanların kullanımına sunulmuştur.

Aydınlatma alanında yapılan çalışmaların çoğunluğu çevre binaların etkisi değerlendirilmeden yahut sadece belli etkileri değerlendirilerek ele alınmıştır. Şehrsel dokuda bina enerji performansını değerlendirmek için, çevre binaların yükseklikleri ve incelenen binaya uzaklıkları, ısıtma, soğutma ve özellikle aydınlatma enerjisi analizleri açısından büyük önem taşımaktadır. Bu çalışma

kapsamında şehir dokusunda yer alan ofis binalarının enerji performanslarının değerlendirilmesi için bütüncül bir yaklaşım önerilmiştir. Önerilen yaklaşımda, günışığının aydınlatma enerjine katkısı detaylı olarak incelenmiş olup, yapma ve doğal aydınlatma hesaplarının ısıtma ve soğutma enerjisi ihtiyacı hesaplamalarına dahil edilebilmesi yolunda bir öneride bulunulmuştur. Önerilen yöntem önce bilgisayar ortamında bir ofis hacminde incelenmiş, ardından analiz sonuçları Almanya Stuttgart şehir merkezinde yer alan örnek ofis hacminde yapılan ölçümlerle karşılaştırılmıştır. Simülasyon sonuçları ve ölçümler arasındaki fark kabul edilebilir düzeyde saptanmış olup, önerilen yaklaşımın uygulanabilirliği ortaya konulmuştur. Ortaya konulan yöntem ile binalar arası uzaklıkların değiştiği çeşitli şehrsel doku örneklerinde enerji performansı değerlendirilmiş ve sonuçlar farklı parametreler açısından (yükseklik farkının binaların y aksı yönündeki uzaklığa oranı, bina boyunun binaların x aksı yönündeki uzaklığa oranı ve bina eninin binaların x aksı yönündeki uzaklığa oranı) değerlendirilmiştir. Bununla birlikte her parametrede şehrsel dokudaki bina yoğunluğu yüzdesi de göz önünde bulundurulmuştur.

Tez kapsamında yapılan simülasyonların istatistik analizi sonucunda belirlenen modelde, şehir dokusunda yer alan ofis binalarının günışığına bağlı aydınlatma enerjisi ihtiyacını belirlemek için şehir plancıları ve mimarların proje geliştirme aşamalarında kullanabilecekleri uzaklık değişkenlerine bağlı bir denklem önerilmiştir.

Tezin amacı doğrultusunda ilk bölümde dünya ve Avrupa ölçeğinde güncel enerji ihtiyacına dair tahminlere yer verilmiş, kentsel dokuda yer alan binalarda enerji ihtiyacının azaltılabilmesine yönelik enerji verimliliği doğrultusunda alınan önlemler açıklanmıştır. Mevcut enerji performans değerlendirme yöntemleri ve günışığının binalarda etkin kullanımına yönelik yöntemlerdeki eksiklikler işaret edilerek, yeni bir yaklaşımın gerekliliğinin altı çizilmiştir.

Çalışmanın ikinci bölümünde ofis binalarında konfor koşulları ve enerji performansı kriterleri incelenmektedir.

Binalarda çeşitli amaçlarla tüketilen enerji miktarları da göz önüne alınarak, aydınlatma amacıyla tüketilen enerjinin en aza indirilmesi için aydınlatma sistemlerinin doğru olarak tasarlanmaları gerekmektedir. Bu amaçla bina tasarım ve yenileme sürecinde alınacak kararlarla günışığının etkin kullanılması sağlanarak yapma aydınlatma sisteminin devrede olması gereken süre olabildiğince kısaltılabilmektedir. Özellikle gün boyu kullanılan binalarda görsel ve termal konfor koşullarından ödün vermeksizin, gün saatleri içindeki yapma aydınlatma kullanımının düşürülmesiyle aydınlatma enerjisi tüketiminin önemli ölçüde azaltılabilmesi olanaklıdır. Günışığının etkin kullanımını sağlayan bir tasarım, yerleşme ölçeğinden başlamak üzere tüm aşamalarda alınacak kararlara bağlıdır. Bu bölümde, enerji etkin bina tasarımı ve yenileme sürecinde ele alınması gereken parametreler ve bu parametreler için belirlenecek uygun değerler açıklanmıştır. Görsel ve termal gereksinimlerin karşılanması ve enerji verimliliği açısından etkili olan parametreler; doğal ve yapma çevreye ilişkin parametreler başlıkları altında tartışılmıştır. Dış aydınlık düzeyi, iklim, coğrafi durum, atmosferin bulanıklığı doğal parametreler arasında yer alıp, gün içinde ve yıl içinde farklı değerlerde gerçekleşmektedirler. Yapma çevreye ilişkin parametreler ise; yerleşme, bina, hacim, yapı elemanları ve malzemeye ilişkin değişkenler olarak sınıflandırılmıştır.

Dış aydınlık düzeyinin belirlenmesindeki temel bilgi olan gök modelleri de ikinci bölüm kapsamında incelenmiştir. Günışığı simülasyon algoritmaları, performans

ölçütleri, gölgeleme ve yapma aydınlatma cihazlarıyla kontrol sistemleri, görsel konfor koşulları ve enerji performansı başlığı altında açıklanmıştır. Enerji performans standartları termal, görsel konfor ve yapma aydınlatma sistemlerine ait standartlar da bu bölümde ele alınmıştır.

Doktora çalışmasının üçüncü bölümünde, şehrsel yapı ve enerji kullanımı başlığı altında; öncelikli olarak dünyadaki şehirleşme oranları verilmiş ve buna bağlı olarak şehirlerin enerji ihtiyacındaki artışın altı çizilmiştir. Bir yandan dünya nüfusu hızla artarken diğer yandan da tüm dünyada küçük şehirlerden büyük şehirlere / metropollere doğru büyük bir göç yaşanmaktadır. Tahminlere göre 2030'a gelindiğinde dünya nüfusunun %70'i şehirlerde yaşar hale gelecektir. Artan nüfusa ve yoğunlaşan şehirlere paralel olarak enerji ihtiyacı da artmaktadır. Şehrsel strüktür ve imar kanunlarının bölgesel planlamadaki yeri kent tasarımı için önemi Almanya örneğinden yola çıkılarak bölüm kapsamında tartışılmıştır. Şehrin oluşturduğu mikro iklimin enerji üzerindeki etkisi ve bu konu ile ilgi yapılmış çalışmaların bir kısmı da yine bu kapsamda incelenmiştir. Şehir ve imar planlarında binaların güneş mimarisine uygun şekilde tasarımı ve yapımı ile güneş enerjisinin bina enerji tüketiminin azaltılmasındaki katkısı göz ardı edilemez bir faktördür. Kentsel bağlamda güneş enerjisinin ve güneş ışığının kullanılabilirliği; şehir formu tanımı ve komşu binaların gölgeleme etkisi alt başlıkları altında iki grupta incelenmiştir. Yerleşme ölçeğinde yapılan çeşitli bilimsel çalışmalarda şehir geometrisinde sadeleştirilmelere gidilmiş ve binaların oluşturduğu gruplar formlarına göre sınıflandırılmıştır. Bu genel kentsel yapılar; pavyon, plaka, teras, bahçeli teras, orta bahçeli pavyon ve bahçeli formlar olarak literatürde yerini almıştır. Çalışma kapsamında burada yer alan sadeleştirilmiş kent formlarından yararlanılmıştır. Bölümün sonunda, güneş enerjisi ve güneş ışığının binaya olan erişiminin ve katkısının hesaplandığı mevcut yöntemler karşılaştırmalı olarak incelenmiş ve yerleşim ölçeğinde ısıtma, soğutma ve aydınlatma enerjilerinin bütüncül olarak hesaplanabildiği yeni bir yaklaşımın ihtiyacı ortaya koyulmuştur.

Tezin dördüncü bölümünde şehrsel dokuda yer alan ofis binalarının enerji ihtiyacının belirlenebilmesi için önerilen yeni yaklaşım tanıtılmıştır. Ortaya konulan yöntem ile binanın güneş ışığı performansı belirlenebilmekte ve güneş ışığı katkısına bağlı yapma aydınlatma enerjisi ihtiyacı hesaplanabilmektedir. Yapma aydınlatmadan kaynaklanan ısısal iç kazançlar da göz önünde bulundurularak binanın yıllık toplam enerji ihtiyacı farklı şehrsel doku alternatifleri için hesaplanabilmektedir. Metodun her basamağı ve basamaklarda yer alan parametreler bu bölümde ayrıntılı olarak açıklanmıştır.

Doğal parametrelerin belirlenmesinde; iklim, coğrafi durum ve dış aydınlık düzeyleri göz önünde bulundurulmuştur. Yapma çevreye ilişkin parametrelerin belirlenmesi aşamasında ise; öncelikle, hacimim genişlik, derinlik ve yüksekliği ile ayrıca hacmin duvar, döşeme ve tavan gibi yüzeylerinin ışık yansıtma katsayıları ve termal özellikleri, yapma aydınlatma ve kontrol sistemleri belirlenmiştir. Hacimde yer alan pencerelerin boyutları, üzerinde bulunduğu alandaki konumu, camın ışık ve ısı enerji geçirime katsayıları da hacme ilişkin parametreler kapsamında incelenmiştir. Binanın biçimi, yönlendirilişi, cepesinde yer alan girinti, çıkıntıların boyutları ve biçimleri, bina kullanım saatleri ve işlevine bağlı olarak direkt güneş ışığının engellenmesi amacıyla yer alan güneş kontrolü sistemlerinin konumları ve boyutu binaya ilişkin parametrelerin belirlenmesine yönelik aşamada yer almaktadır. Son olarak, çevre binaların yükseklikleri, birbirine göre uzaklıkları ve yerleşme dokusu özellikleri: "Yerleşme birimine ilişkin parametreler" başlığı altında tariflenmiştir.

Günişliğine duyarlı aydınlatma enerjisinin hesabı için kullanılabilecek hesaplama alternatifleri ile termal enerji hesaplamalarına yönelik alternatifler ve önerilen yöntemde kullanılan EnergyPlus bina enerji simülasyon programının hesaplama adımlarına ve kullandığı modellere ilişkin bilgilere bu bölümde detaylı olarak yer verilmiştir. Gün ışığına duyarlı aydınlatma enerjisi hesabının, termal enerji hesabı yapan EnergyPlus programına aktarılabilmesi için tüm bir yıla ait yapma aydınlatmanın ve gölgeleme sisteminin devreye girdiği saatlere göre oluşturulmuş girdi ve çıktı dosyalarının oluşturulması gerekmektedir. Doktora tezi kapsamında geliştirilmiş olan DRELAT (Günişliğine duyarlı yapma aydınlatma analiz aracı) termal hesaplamalar için aydınlatma hesaplarından gerekli dosyaları oluşturan, hacim içindeki günişliği dağılımını yılın her saatinde mevcut çalışma düzlemi üzerindeki sanal ızgara sistem üzerinde eş aydınlık düzeyi (isolux) çizgileri ve renkleriyle görselleştirebilmektedir. DRELAT'ın amacına ve kullanımına ait detaylar bu bölümde açıklamıştır. Bölüm sonunda şehir dokusunda yer alan bir hacme ait aydınlatma enerjisi ve termal enerji hesaplamalarının entegrasyonun nasıl yapılacağı belirtilmiştir.

Beşinci bölümde, önerilen yaklaşımın şehirselle dokuda yer alan örnek bir ofis binası için uygulaması sunulmaktadır. Günişliği ve bina enerji performans parametreleri arasındaki etkileşimler kentsel geometri bağlamında basitleştirilmiş bir senaryo dahilinde incelenmiştir. Örnek ofis binasının Stuttgart, Almanya'da bulunduğu varsayılmıştır. Hesaplamalar için kullanılan çeşitli veriler bu kabule göre alınmıştır. Örneğin; termal analizler için Stuttgart TMY 2 (meteorolojik test yılı) dosyası kullanılmış, kentsel konumlandırmalar için de Baden Württemberg eyaletinin belirlediği bina aralıkları ile ilgili kısıtlamalar ve kurallar kullanılmıştır. Kabul edilen bina aralıkları ve yükseklikleri ile belirlenen şehir geometrisinin içinde yer alan örnek ofis binasına ait günişliği aydınlık dağılımları, günişliğine duyarlı yapma aydınlatma sisteminin enerji ihtiyacı ile ısıtma ve soğutmaya ilişkin enerji ihtiyacının belirlenmesi beşinci bölüm kapsamında Radiance, Daysim, DRELAT ve EnergyPlus Programlarının yardımıyla hesaplanıp sunulmuştur.

Altıncı bölüm önerilen yaklaşımın deneysel doğrulanmasına odaklanmıştır. Bu bölümde önerilen yaklaşım doğrultusunda tahmin edilen günişliği aydınlık değerleri, yapma aydınlatmaya bağlı elektrik enerjisi, ısıtma ve soğutma enerji harcamaları gibi değerler, Stuttgart şehir merkezinde bulunan ofis binasına ait çalışma odasında yapılan ölçümler ile karşılaştırılarak değerlendirilmiştir. Yapılan deneysel çalışma kapsamında ölçülen aydınlık düzeyi ve enerji tüketimi değerleri simülasyon sonuçları ile karşılaştırılmıştır.

Doktora çalışmasının yedinci bölümü; şehirselle dokuda yer alan ofis hacmi için farklı senaryolarla üretilen simülasyon sonuçlarını inceleyerek günişliğine duyarlı yapma aydınlatma sisteminin elektrik enerjisi ihtiyacının tahminine yönelik yüksek doğruluk derecesine sahip istatistiksel bir model ve bu modelin sonucu olarak şehir dokusunda yer alan ofis hacminin günişliğine bağlı aydınlatma enerjisi ihtiyacı tahmini için uzaklık parametrelerine bağlı bir denklem önermektedir. Bu bölümde, yapılan istatistiksel çalışma incelenerek, geliştirilen regresyon modelinin tüm adımları açıklanmıştır. Ofis hacmi için yapılmış olan simülasyonlar ve hesaplamalar belirli ofis bina tipleri için yapılmış, bina ölçeğinde aydınlatmaya bağlı enerji ihtiyacı belirlenmiştir. Bina ölçeğinde belirlenen enerji ihtiyacı yine farklı bina aralıklarına sahip şehir geometrisi içinde analiz edilerek sonuçları karşılaştırılmıştır.

Son olarak sekizinci bölümde elde edilen sonuçlar yorumlanarak, çıkarımlar yapılmıştır.

Önerilen yaklaşım ile şehirseldokuda yer alan ofis binasının termal ve aydınlatma enerjisi ihtiyacı, çevresindeki binaların gölgeleme etkileri değerlendirilerek bütüncül olarak hesaplanabilmektedir.

Bu yaklaşım, şehir ve imar planlarındaki bina aralıkları ile ilgili kısıtlama ve kurallar, kullanıcı konforu ve uluslararası standartların temelleri üzerine kurulmuştur.

Tez kapsamında geliştirilen DRELAT sayesinde, günışığına duyarlı aydınlatma hesaplamalarının sonuçları görselleştirilebilmekte ve termal hesaplamaların yapılabilmesi için uygun bir formata dönüştürülebilmektedir.

Bu çalışma kentsel bağlamda gölgeleme etkilerinin önemini ve günışığı duyarlı elektrik enerjisi tüketimi hesaplamasındaki rolünü vurgulamaktadır.

Örnek ofis ile ilgili yapılan çalışmalar, şehir dokusunda günışığına bağlı elektrik enerjisi ihtiyacında en önemli performans belirleyici faktörün ofis hacmin bulunduğu yükseklikle engel binanın yüksekliği arasındaki farkın binalar arasındaki uzaklığa olan oranının (H_{dif}/W) olduğunu ortaya koymuştur.

Önerilen regresyon modeli sonucu, şehir dokusunda yer alan ofis hacmine ait günışığına bağlı elektrik enerjisi ihtiyacını başarılı bir şekilde tahmin edebilmektedir. Bu durum regresyon analizi sonuçları ile simülasyon sonuçları arasındaki korelasyonda kolayca görülebilmektedir.

Tanımlanan sonuç denklem, mimarlar ve şehir plancılarının şehir dokusu içinde gerçekleştirecekleri tasarımlarda günışığına bağlı aydınlatma enerjisi ihtiyacına yönelik bir öngöründe bulunabilmeleri için yardımcı olacaktır.

Bu doktora çalışması kapsamında yer almayan fakat gelecekte yapılabilecek olası araştırmalar için yol haritası çizilmiş ve önerilerde bulunulmuştur.

1. INTRODUCTION

Recent increases in energy prices and a steady escalation in global energy demand — expected to rise by nearly 60% over the next 20 years — have led the European Union (EU) to engage in a wide ranging debate over how best to address the future energy requirements. Similarly, energy availability has become a political priority. The EU imports about 50% of its energy needs. Bearing significant changes, the European Commission expects this figure to rise to 65% by 2030. In the face of increasing concern regarding Europe's reliance on imported energy resources, and growing public pressure to address global climate change, EU member states agreed on a series of policy measures intended to form the foundation of an “Energy Policy for Europe”.

The EU energy policy signed in January 2007 set demanding goals for 2020 that can be summarised as: 20% less energy consumption, 20% less carbon emission and 20% of energy produced to come from renewable energy sources, compared to 1990 levels. Renewable energies are expected to be economically competitive with conventional energy sources in the medium to long term. Nevertheless, at 8.5%, the penetration of renewable energy sources into Europe's energy market is still comparably low.

Local and regional authorities play an important role in building sustainable communities in urban and rural areas. The Strategic Research Agenda (SRA) anticipates that the European construction sector must have a sustainable and competitive structure by 2030. In the Vision 2030 document of SRA, it is recommended that the construction industry should both meet the client-user requirements and also be sustainable and knowledge-based. These two key goals are supported by strategic research themes dealing with materials and technology, industry transformation and service (European Construction Technology Platform, 2005, p. 3).

Urban areas are responsible for nearly 80% of global CO₂-emissions. The impacts of climate change are amplified in the urban areas, which urge cities to respond quickly.

The first requirement is to develop a new generation of “highly efficient buildings”, which demand less energy and are net producers of CO₂-free energy. However, the existing building stock has a long lifetime and affordable solutions to retrofit existing buildings are lacking. Furthermore, it is even more pressing to upgrade the existing built environment to a high level of energy efficiency in order to comply with Kyoto Protocol.

On the basis of a strong reduction of energy demand through energy efficiency measures, solar thermal energy can be the most important energy source for heating and cooling in new buildings and in the existing building stock (European Solar Thermal Technology Platform, 2006, p. 2). The typical share of solar thermal energy in meeting the domestic hot water, heating and cooling demands of a single building can be from 50% up to 100%.

Lighting is one of the major usages of energy in buildings. The excess heat created due to the usage of inefficient lighting systems increases cooling loads of a building, which in turn necessitates the usage of air-conditioning. Lighting technologies developed in the past 10 years can help cut lighting costs in a range of 30% to 60% while enhancing lighting quality and reducing environmental impacts. Consumer and industry focus has shifted to energy efficient forms of lighting. The main areas of concern regarding the decrease of energy consumption are the utilisation of daylight more efficiently and the increase daylight autonomy. In today's context it is understood, 80% of energy consumed during the entire lifecycle of a building is consumed during its service life (only 20% is consumed for materials, construction and demolition). The priority is to reduce the energy consumption of buildings during their lifetime. This must be done for both existing and new buildings. Many technical solutions already exist to build new energy-efficient structures. . The difficulties are focused more on affordability of such buildings. For existing buildings, technical options to create a more energy-efficient structure are rare and most remain to be invented. Also, minimally-intrusive retrofit techniques mostly lack affordability.

Energy demand reduction options should be examined not just on a building scale but also on urban scale. Building solar gain potential is determined by the shading of the facade, the solar reflectance of the surrounding building and irradiation of the envelope. In winter conditions, more solar heat gain is desired to reduce the heating

energy consumption; on the other hand, for summer conditions, the shade from the surrounding buildings is helpful to reduce the cooling load. For this reason lighting, cooling and heating should be investigated together and the overall energy consumption optimization for the building must also be considered. In this context, site design according to daylighting opportunity is recognised as a useful strategy in energy-efficient building and site operation.

Daylight performance is especially significant for office buildings. Buildings are usually characterised high lighting energy consumption and the productivity of the employees within buildings is highly affected by lighting conditions. This work presents the effect of external factors related to the quality and quantity of natural light entering a building. The energy consumption of the building is calculated and the effects of the surroundings are discussed.

The impact of the urban form on the energy demand of buildings is challenging to quantify. Only very few software tools are available that calculate the influence of mutual shading of buildings and topography on the energy demand. Some dynamic building simulation tools consider shading situations, but are limited to calculations of a specified window surface area with a given horizon line. They cannot be used to simulate an urban area. If electrical energy for lighting is also considered, the simulations become more complex, as the sky models need to be realistically represented. As a result there is not much information available about just how the total energy demand is affected by the specific urban form.

The PhD work highlights the importance of perspective in studying the shading effects in the urban context and its role in the daylight responsive electric energy consumption calculation. In general, office buildings require high energy demands. Even when located in mild climates as the buildings that are studied here, cooling demands of the office buildings can be very high. To minimize the artificial lighting heating effect and electricity energy load, it is important to evaluate daylight availability in office spaces and take into consideration its surroundings. After a thorough evaluation, systems and methods can be developed to enhance daylight and light distribution in the space.

In summary, the thesis aims to develop an integrated dynamic daylighting and thermal analysis approach that considers surrounding building effects. The

daylighting evaluation steps are determined using relevant information regarding daylight availability, occupant comfort and energy. Computer-based daylighting analysis simulation results are then visualised and prepared in a transferable format for thermal analysis.

Effect of urban configurations on building energy performance especially lighting energy performance is examined with different dimension ratios between buildings. The suggested methodology offers combination of several new known and new simulation tools to calculate daylight responsive lighting energy and thermal energy demand. To reduce the complexity and time consumption of the process, simulation results are analysed through linear regression model and a linear equation is suggested to predict daylight responsive electric lighting consumption in urban district.

The objectives of the thesis work can be summarised as follows:

- To gather and summarise the existing literature of daylight and daylight responsive artificial lighting, including solar and daylight availability studies in urban quarters.
- To develop an approach for integrated dynamic daylighting and thermal analysis considering surrounding building effects.
- To prepare the daylight analysis results for thermal analysis in a transferable format.
- To implement the daylight responsive shading and artificial lighting control in to dynamic daylighting analysis.
- To find the most relevant indicator in terms of daylight responsive energy demand in urban area.
- To suggest a simple equation to predict daylight responsive energy demand of a sample office.
- To evaluate the lighting energy demand at the earliest stage of urban design using suggested equation.

In order to evaluate energy related consequences of a chosen daylight concept, the simulation of daylight should be coordinated with thermal analysis. In this study, the lighting, the heating and cooling performance of office spaces in an urban form having varying distances between buildings is calculated by using specialized software tools such as EnergyPlus, Radiance, Daysim and Insul. An integrated

scheme is established for simulation programs to interact with each other. Daylight responsive electric lighting consumption is calculated first and thermal gains caused by artificial lighting are used as input for heating – cooling energy calculations. Testing of the proposed methodology in the urban context is conducted using nine buildings within the city quarter, assumed to be located in Stuttgart, Germany. Sets of simulations are done using the suggested approach. Simulation results are used for the regression analysis. In order to predict daylight responsive electric energy demand of sample office spaces in an urban context, a simple linear equation is proposed.

The proposed equation can be used at the earliest design of urban settlement to acquire a range of distance ratio options and alternative building forms and to evaluate the success of several lighting energy conservation and lighting energy use reduction measures.

Urban planners, architects, energy planners can use the suggested approach to estimate energy demand, especially lighting energy demand, in urban district. With this approach, users can decide to appropriate space distance between buildings and determine which option has advantage for better energy performance. Moreover, the strategies for reducing the energy demand can be determined with the approach.

Specifically, the approach provide users to specify all natural and build environmental design inputs for urban quarter, than analyse daylight responsive electric lighting energy with self-defined luminary , lamp and shading device system and finally to transfer the thermal gains due to the artificial lighting and shading device control schedule as input for heating and cooling energy demand calculations.

2. COMFORT CONDITIONS AND ENERGY PERFORMANCE IN OFFICE BUILDINGS

Energy performance cannot be considered separately from physical and physiological comfort conditions. Comfort is defined as a condition or feeling of pleasurable ease, well-being, and contentment. Concerning the satisfaction of occupants in their working environment, thermal and visual comfort plays a very important role. The satisfaction of comfort needs of occupants also strongly influence the working productivity and thereby, has an economic impact on total output (United Nations, 2010).

Office buildings consume a large amount of energy for heating, cooling and lighting. Therefore, energy efficiency of office buildings is extremely important for overall energy cost reduction and minimisation of greenhouse gas production. Recently, the total primary energy consumption has become limited by standards and national codes. Within the EU, there are several research projects that are promoting energy efficient commercial buildings.

The main aim of the energy efficient design is to form a built environment that ensures maximum comfort with minimum energy contribution. The design of commercial buildings and their systems so that quality of comfort is guaranteed has become more important in 2002 with the European “Energy Performance of Building Directive” (EPBD).

The reduction of energy consumption and energy expenses requires passive systems with optimal performance.

2.1 Thermal Comfort Conditions and Energy Performance

Today, people spend most of the time in buildings or urban spaces. Both indoor and outdoor climates should be taken into consideration. It is important to define the relationship between thermal comfort and climatic design by asking the question: “What are the comfort conditions and thresholds and how can buildings adjust themselves?”

Thermal comfort has been defined by Hensen as “a state in which there are no driving impulses to correct the environment by the behaviour” (United Nations, 2010).

Thermal comfort is defined as that condition of mind which expresses satisfaction with the thermal environment (Koclar Oral and Yilmaz, 2002, p. 1173-1180) (American Society of Heating Air-Conditioning Engineers (ASHRAE), 2004).

The most important design parameters affecting indoor thermal comfort and energy conservation on the building scale are:

- orientation
- building form
- optical and thermo-physical properties of the building envelope

All these parameters are interrelated and the optimum value of each parameter should be determined in correlation with the other values (Koçlar Oral and Yilmaz, 2003, p. 383-388).

The diverse technical approaches to achieve a good indoor climate are often accompanied by complaints from office workers about many types of discomfort and dissatisfaction, which can also be summarised as the “Sick Building Syndrome”.

In order to predict the thermal behaviour of the building envelope, the values of climatic variables should be known. These data are easily obtained from meteorological measurements. In order to ensure heating energy conservation through building design, the optimum values of thermo-physical properties of the building envelope and the operation period of heating system should be determined in terms of the climatic conditions of the under-heated period for the region. Instead of repeating the calculations for all days of the under-heated period, it is convenient to select the representative day of the under-heated period by means of the statistical analysis of meteorological data obtained for this period. The comfort values of indoor air temperature, relative humidity and air velocity can be determined from thermal comfort charts. The comfort value of the inner surface temperatures can be estimated by using the relationship between mean radiant temperatures representing the surface temperatures in a room and the comfort value

of indoor air temperature (Koclar Oral and Yilmaz, 2002, p. 1173-1180) (American Society of Heating, 2004).

For the climatic design, the comfort models should be easy to process with no long calculations, providing direct design guidelines for different design steps instead of numbers and knowledge instead of just data. The most known comfort models are examined herein, while taking into consideration these points and simplifying the design process. Up to now many scientists have worked on different comfort models. Some of them mostly aim at defining the comfort zone, while others have tried to cover parts of the design subject such as climate-activities-clothing. Still other scientists have tried to provide climatic design advice such as shading-thermal mass- evaporative cooling-thermal insulation-suitable orientation.

The well-known comfort models, used in a wide range of applications, include: the Fanger thermal equation (Fanger, 1972) and the Adaptive Models (Dear and Brager, 2001). The design strategy models include: the Olgyay Model (Olgyay, 1969), the Givoni Model (Givoni, 1976), the Mahoney Model (Koenigsberger, Ingersoll, Mayhew and Szokolay, 1973) and the Zeren Model (Arens, Gonzalez, Berglund, McNall and Zeren, 1980).

It is appropriate to use the Fanger and Adaptive Models for defining comfort zone, while the Mahoney model is the best for design advices due to its rather complete comfort zone definition. Givoni, Olgyay and Zeren models work with pictures rather than charts so they could be more easily used by architects, although they have very rough comfort zone.

The climatic design models should be descriptive about zone definitions, mention about different clothing and activity levels together with improved design advices. Furthermore, the models should also consider outdoor comfort, to allow designers to consider open and semi-open spaces in their design as well. The building cannot be considered without natural outdoor condition and its outdoor built environment.

Standards have been developed to analyse comparative building comfort performances. Comfort criteria are described in ISO7730 and EN 15251, whether an acceptable thermal comfort is achieved in the buildings or not. According to EN15251, three comfort classes are described using an adaptive approach (Fig.

2.1). In this case, the comfort temperature is related to the monthly mean ambient temperature with a more or less wide comfort range (EN 15251:2008-07, 2007).

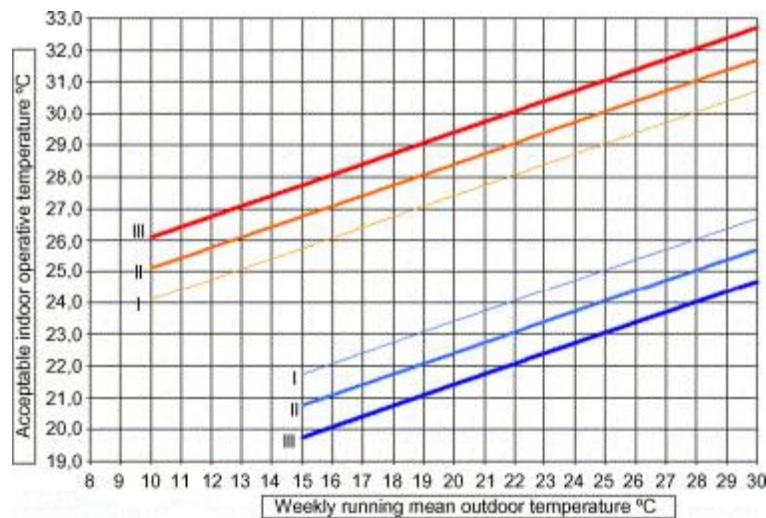


Figure 2.1 : Thermal comfort classes according to the EN15251 for free running indoor environments during summer operation (EN 15251, 2007-08).

In Figure 2.1 acceptable ‘summer’ indoor temperatures (cooling season) are presented for buildings without mechanical cooling systems. The operative temperatures (room temperatures) presented in figure are valid for office buildings and other buildings of similar type used mainly for human occupancy with mainly sedentary activities and dwelling, where there is easy access to operable windows and occupants may freely adapt their clothing to the indoor and/or outdoor thermal conditions.

The adaptive thermal comfort model of EN 15251 classifies three different comfort categories. Category I for a high level of expectation targeted at very sensitive and fragile persons, like sick people, elderly or young children. Category II is recommended for a normal level of expectation, for new buildings and renovations, and category III is targeted at existing buildings for a moderate level of expectation. Values outside these categories (=category IV) should only be accepted for a limited part of the year (EN15251, 2007-08).

2.1.1 Natural parameters related to thermal comfort

The designer must consider natural parameters when analysing the need for thermal comfort. These parameters include:

- Outdoor air temperature

- Solar radiation
- Outdoor humidity
- Outdoor wind velocity

Outdoor physical environment conditions should be examined and the properties and values of the outdoor design parameters should be determined according to the relevant data such as regional, geographic, meteorological, topographic, etc. The soil cover and nature of the ground (plant cover and groups of trees) should also be defined properly.

2.1.2 Built environmental parameters related to thermal comfort

One of the primary requirements of a built environment is to provide for users' bioclimatic comfort. The architect should pay attention to the determination of the optimum combination of design parameters affecting the indoor climate in order to create an indoor climate which satisfies users' comfort while using supplementary heating and acclimatisation in the most economical manner (Yilmaz, 1983).

The main design parameters related to the built environment with an influence on the control of heat and energy conservation can be considered on 3 different scales. The parameters on the building scale are:

- orientation of the building
- position of the building according to other buildings
- building form (Koclar Oral, Koknel Yener and Tamer Bayazit, 2004).

The parameters on the room scale are:

- position of the room within the building
- dimensions of the room and its shape factor
- orientation of the room
- absorption coefficient of the room for solar radiation entering through the transparent component

In order to get the benefit from the cooling effect of wind, the size of the ventilation inlet and outlet openings should be determined in accordance with the design values of outdoor wind speed. The design values of outdoor wind speed affecting building facades vary with orientation of the facade and the texture of the settlement.

The following criteria must be considered to determine the required values for distance between buildings: the facades of the buildings should receive maximum direct solar radiation during the winter period and minimum radiation during the summer period. Therefore, the required values of this design parameter should be determined by considering profile angles between buildings and sun exposure in accordance with orientation and height of the buildings.

The design parameters related to be structural elements can be differentiated in two groups: as opaque components and transparent components, each considered separately:

(a) Properties of the opaque components of the building envelope:

- thickness of the materials
- density of the materials
- specific heat of the materials
- heat conduction coefficients of the materials
- porosity of the surface
- construction of the surface (flat, with interstices, ribbed)
- single or multilayer structure
- depth of the cavity between the layers
- kind of connection between layers of different materials and their number

(b) Properties of the transparent components of the building envelope:

- dimensions of the transparent component
- number of layers of the glazing
- heat transmission coefficient of the glazing
- absorption, reflection and transmission coefficient of the glazing for solar radiation
- type of frame used for the transparent component
- maintenance factor of the glazing (Koclar Oral, Koknel Yener and Tamer Bayazit, 2004, p. 281-287).

Optimum combinations of orientation and building form must be determined in accordance with the required values of overall heat loss or gain through the envelope. The required values of thermo-physical properties of the building

envelope should be determined to ensure a temperature difference of +3°C between indoor air and inner surface of the envelope. The necessary values of overall heat transfer coefficient for opaque components of the envelope must be determined on the basis of these criteria.

The properties should be determined by means of the relevant literature and national–international standards, regulations, guidelines, etc. For instance, while determining the heat conduction coefficients, recommended values for the room function should be taken into account.

2.2 Visual Comfort Conditions and Energy Performance

Lighting affects almost every aspect of our lives. It is used to produce conditions that enable us to see what we are doing and also to create an ambiance appropriate to the setting. With inadequate or poorly directed lighting, seeing may be inefficient, uncomfortable or hazardous. A lighting designer has to provide adequate visibility so that tasks can be performed with required speed and accuracy. Lighting levels should be designed to permit work to be done with minimum effort under lighting conditions that provide maximum safety and freedom from visual discomfort.

Generally, good visibility is defined by an adequate quantity of light for the expected visual task, uniform distribution of illuminance and luminance, directional sufficiency to model three-dimensional objects and surfaces (direction of incident light from the side or from above), the absence of glare and having sufficient spectral content to render colours accurately when required.

The visual comfort conditions, which should be reached in order to create a comfortable environment and to maximise the visual ability of the occupants, are the required levels of illumination, glare avoidance and a uniform distribution of light. These values are given in international standards, recommendations or requirements in relation with the function of the room. Obviously, the recommended values cannot always be obtained by daylight; supplementary artificial lighting is needed (Yener, 2005).

Since May 2003, European CEN- countries have a mutual standard for the planning of the light of indoor work places (EN 12464-1, 2002). The new European Standard

EN12464-1 that provides recommended values for illumination levels will be discussed in Chapter 2.3.2. Again in the same standard, luminance distribution and luminance limitation, glare index calculation according to UGR (Unified Glare Ratio). EN 12464 is an application standard. The standard explains how to gather the necessary project data and laying down the preconditions considers different alternatives (determining the most suitable lighting concept) and clarifies the calculating and documenting steps.

Excessive luminance contrasts in the visual field cause glare. Glare occurs whenever one part of an interior is much brighter than the general brightness in the interior (Hopkinson, 1957). Luminance and the size of the source and the luminance of the background influence glare (Hopkinson and Bradley, 1960). Glare can be evaluated by calculating the Glare Index values and comparing them with the maximum allowable Glare Indices given in standards.

Discomfort glare produces visual discomfort and eye fatigue, over a period of time, but it does not necessarily interfere with visual performance. An example is the sensation created by the bright headlights of an oncoming car at night. Disability glare is glare that interferes with visual performance. The glare from a glossy magazine page that makes the print unreadable would be an example of disability glare (Hopkinson, 1972).

Glare is typically classified into two major categories: direct and reflected. Direct Glare is caused by light that enters the eye directly from a bright light source, even though the person is not looking directly at the source. Reflected Glare is the result of the reflection of light from a glossy or polished surface. It can cause visual discomfort and impair visual performance. Reflected glare, however, is not always a problem and can sometimes be desirable. Reflected glare can be used to an advantage for quality control inspections and to make some merchandise stand out in retail displays.

Several discomfort glare indices have been developed to assess glare from artificial light sources, including:

- The British Glare Index (BGI) developed by Hopkinson
- The CIE Glare Index (CGI) proposed by Einhorn

- The Unified Glare Rating (UGR), wherein Sorenson has combined the “best” aspects of the British Glare Index and the CIE Glare Index
- The J-Index developed by Meyer
- The Stationary Virtual Reality (SVR) Method created by Sick and Wienold (Bellia, Cesarano, Iuliano, and Spada, 2008).

Because these glare indices were developed for artificial lighting, they are less reliable for day-lit environments. Several glare ratings have been developed to consider the glare caused by daylight, which include:

- The Daylight Glare Index (DGI) developed by Hopkinson and modified slightly by Chauvel
- The New Daylight Glare Index (DGIN), a reworking of the above by Nazzari and Chutarat
- The Visual Comfort Evaluation Method (VCE) and User Acceptance Studies designed by Velds
- The Predicted Glare Sensation Vote (PGSV) proposed by Iwata and
- Vertical Illuminance at the Eye suggested by Osterhaus (Inkarojrit, 2005).

Standards and recommendations about glare will be given in the Chapter 2.3.2.

Visual Comfort Probability (VCP) is a method used to predict a lighting system’s potential for direct glare problems. VCP is an estimate of the percentage of people that would consider a given lighting arrangement visually comfortable. A VCP of 70 % is considered acceptable by IES (The Illuminating Engineering Society) Standards. Tables are used to determine Visual Comfort Probability and estimate the level of discomfort glare produced by a regular array of their luminaires for a range of standard interiors. These tables provide all the precision necessary for estimating the level of discomfort glare likely to occur in interiors.

It is important to note that VCP values are presented for very specific conditions. Room reflectances are 80% for ceilings, 50% for walls, and 20% for floors. The table lists VCP values calculated for a fixed program of room lengths, widths and ceiling heights. Unfortunately, these parameters do not always relate to actual project conditions which may include rooms smaller than 6 m x 6 m and illuminances less than 1000 lux.

Lighting systems (both artificial and daylighting systems) of interiors should provide visual comfort conditions by minimising the energy consumption. In order to design an energy conscious lighting system in indoors, the daylight availability should be maximised and the artificial lighting energy consumption should be minimised. To achieve this goal, all of the parameters should be investigated solidly.

2.2.1 Natural parameters related to visual comfort

Archiving visual comfort, the most common lighting assessment is an illuminance check on the working level. It is not only important to achieve a particular level of illuminance; however, it is also important to have a certain degree of uniformity of both illuminance and luminance across the space and to avoid glare to ensure visual comfort.

To evaluate the visual comfort conditions of indoors, outdoor illuminance level should be known. External horizontal illumination is affected by the following factors: day of the year, time of the day (solar position), cloud cover (sun shine duration, sky type), geographical location of the region (latitude, solar position) and turbidity* of the atmosphere.

In daylighting, sky models are characterised by their luminance distributions. Reliable prediction of illuminance and luminance distribution in day-lit interiors necessitates an accurate model of the daylighting source, i.e., the sky.

2.2.1.1 Sky luminance distribution models

It is necessary to know daylight conditions during the whole year. There are several methods for defining daylight conditions in different climates and locations, for example, the illuminance availability approach. In order to simplify calculations concerning daylight, some models for standard skies have been developed.

Until recently, most lighting simulation programs used only simplified sky luminance models, such as standardized clear, overcast or even uniform skies.

*Before the solar radiation reaches the ground, it is weakened by different influences in the atmosphere (air molecules, aerosols, gases and water vapour). This effect is known as the turbidity of the atmosphere.

There have been concerns that the results obtained from such programs may not reflect intermediate conditions between the two extremes of completely clear or completely overcast. In the case of the uniform sky model, the location and time are not even considered. In recent years, a number of more elaborate sky luminance models have been developed (Muneer, Solar radiation and daylight models).

The position of the sun and of the arbitrary sky element as well as angles which are used in sky models describing atmospheric conditions have to be taken as input calculation quantities. The position of the arbitrary sky element is defined by the zenith angle Z and the azimuth difference A_z between the element and the solar meridian can be seen in Figure 2.2.

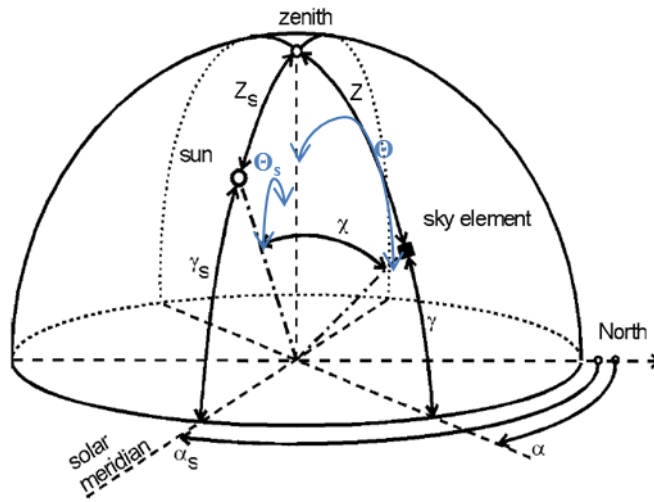


Figure 2.2 : Angles and directions on the sky dome (Darula and Kittler, 2002).

Overcast sky distributions

Several authors have described the radiance distribution of overcast skies by (2.1):

$$R_{\theta} = R_z \frac{1 + b \cdot \cos \theta}{1 + b} \quad (2.1)$$

R_{θ} and R_z are respective radiance counter part of L_{θ} and L_z . According to previous works, value of coefficient 'b' is between 0 and 2 (Lam, Mahdavi, Ullah, Ng and Pal1, 1997).

- Uniform sky

The simplest model assumes a constant luminance for the whole sky dome.

$$\frac{L_{o(\alpha,\theta)}}{L_{o,z}} = \frac{1 + b \cdot \cos \theta}{1 + b} \quad (2.2)$$

This formula is only a simple description of a real overcast sky (2.2).

- Moon and Spencer overcast sky

The first non-uniform CIE standard for the luminance distribution on the overcast sky was suggested by Moon and Spencer (1942). The changes of luminance from horizon to zenith in ratio 1:3 were described by a trigonometric relation in formula (2.3).

$$\frac{L_\gamma}{L_z} = \frac{1 + 2 \sin \gamma}{3} = \frac{1 + 2 \cos Z}{3} \quad (2.3)$$

- CIE overcast sky

The CIE Standard Overcast Sky, based on the Moon and Spencer Sky, was devised to better approximate the luminance distribution observed for overcast skies, adopted as a standard by the CIE in 1955. This sky, as defined by the CIE has a non-uniform, isotropic luminance distribution, increasing from the horizon to the zenith (Hopkinson, Petherbridge and Longmore, 1966).

The luminance distribution of the CIE Overcast Sky was published as ISO/CIE standard in 1996 (ISO 1996) (ISO 15469/CIE S003, 1996) using the formula (2.4):

$$\frac{L_\gamma \cdot \alpha}{L_z} = \frac{\left(1 - \exp\left(\frac{-0.32}{\sin(\gamma)}\right)\right) \cdot (0.91 + 10 \cdot \exp(-3\chi) + 0.45 \cdot \cos^2 \chi)}{0.274 \cdot (0.91 + 10 \cdot \exp(-3Z_s) + 0.45 \cdot \cos^2 Z_s)} \quad (2.4)$$

Where $L_\gamma \alpha$ is luminance in any arbitrary sky element, χ is the angular distance of the sky element from the sun; Z_s is the zenith distance of the sun.

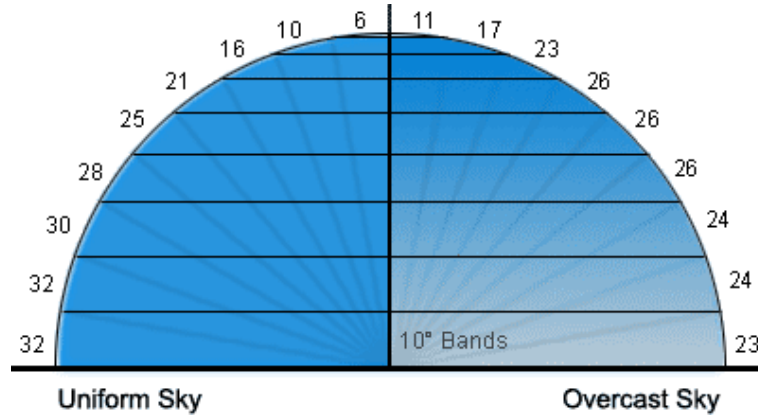


Figure 2.3 : Comparing the vertical illuminance of the CIE uniform and overcast sky formulations (Archived Ecotect Resources - Community, 2008).

In overcast sky model the luminance at the zenith is three times brighter than at the horizon. In Uniform sky model represents a sky with a constant value of luminance. The difference between these two models is illustrated in Figure 2.3.

- Perez overcast sky

Perez presented an exponential model for an overcast sky with two modelling coefficients (2.5). In a publication from Kittler and Valko, the use of values $\alpha=3.5$ and $b=-0.56$ as standard values is proposed (Kittler and Valko, 1993).

$$\frac{L_{o(\alpha,\theta)}}{L_{o,z}} = \frac{1 + \alpha \cdot \exp\left(\frac{b}{\cos(\theta)}\right)}{1 + \alpha \cdot \exp(b)} \quad (2.5)$$

Clear sky distributions

In clear sky models it is assumed that the Sun is visible and has very non-uniform distribution where the area around the sun is much brighter than any other area. Clear sky models relate the luminance at any point in the sky vault with the zenith luminance and adjust the luminance with coefficients and defined angles.

- a- Kittler Clear sky

Kittler proposed the equation that became CIE standard clear sky (CIE Technical Committee 4.2, 1973). All angles are given in radians (2.6a).

$$\frac{L_{c(\alpha,\theta)}}{L_{c,z}} = \frac{1 - \exp\left(\frac{-0.32}{\cos(\theta)}\right) (0.91 + 10 \exp(-3\zeta) + 0.45 \cos^2(\zeta))}{1 - \exp(-0.32) (0.91 + 10 \exp(-3\theta_s) + 0.45 \cos^2(\theta_s))} \quad (2.6a)$$

With (2.6b):

$$L_{c,z} = 300 + 3000 \cot(\theta_s), \left[\frac{cd}{m^2}\right] \quad (2.6b)$$

b- Gustev clear sky

For a more polluted sky, a slightly different equation was proposed by Gustev. The German DIN 5034 decided to use this model for German conditions (German Industrial Standard, DIN 5034, 1996). As above, the clear sky zenith luminance depends only on the sun position.

Intermediate Sky distributions

It is also possible to simulate sky luminance distribution by using intermediate sky models. Several models that attempt to define intermediate sky models can be found in the literature. The basic models are Brunger and Matsuura Models, which will be described below.

a- Brunger intermediate sky

This model describes the sky luminance distribution by parameterizing insolation conditions as functions of the ratio of global to extra-terrestrial irradiance (Brunger, 1987). Brunger found that real sky radiance distributions depend strongly on the position of the sun, the diffuse fraction and the clearness index.

b- Matsuura intermediate sky

The intermediate sky model of Matsuura (1987) was proposed by the CIE working committee. In contrast to the other intermediate sky models, this model does not require an empirical parameter. Thus, it is much easier to handle and might be less site sensitive.

All-sky distributions

Daylighting calculations depend on the luminance distribution of the sky. The new concept of sky luminance distributions is to model skies under a wide range of conditions, from the overcast sky to cloudless situations, with or without sunlight. This concept was proposed for the standardisation of exterior daylight conditions.

The overcast and clear sky models described above are well suited to evaluating daylight under static conditions. However, if energy savings from daylighting are to

be calculated, a time varying simulation is necessary. It must consider the fluctuating sky conditions, which never remain purely clear or overcast.

a- Perez all weather sky luminance model

The Perez all weather sky luminance model was developed in the early nineties by Richard Perez et. al. The model consists of two independent models. The Perez luminous efficacy model calculates the mean luminous efficacy of the diffuse and direct sunlight for a given sky condition.

Input parameter are the solar zenith angle, solar altitude, direct and diffuse illuminances, as well as the atmospheric perceptible water content (Perez, Ineichen, Seals, Michalsky and Stewart, 1990). The Perez sky luminous distribution model produces the sky luminous distribution based on date, time, direct and diffuse illuminances (Perez, Seals and Michalsky, 1993). This model uses a clearness index and a sky brightness factor to compute the sky luminance distribution and all skies are classified into eight categories (2.7).

$$l_{(\theta,\xi)} = \left(1 + a \cdot \exp\left(\frac{b}{\cos(\theta)}\right)\right) \cdot (1 + c \cdot \exp(d\xi) + e \cdot \cos^2(\xi)) \quad (2.7)$$

The five coefficients a-e depend on the sky brightness parameter Δ and the sky clearness parameter ϵl , which were already introduced by Perez as well. It should be mentioned that for a particular choice of parameter (a=1, b=-0.32, c=10.989, d=-3, e=0.4945), this model is similar to the CIE standard clear sky (2.8a).

$$\epsilon l = \frac{\frac{I_{d,h} + I_{b,n}}{I_{d,h}} + 1.041 \cdot \theta^3}{1 \cdot 1.041 \cdot \theta^3} \quad (2.8a)$$

With (2.8b):

$$\Delta = \frac{I_{d,h} \cdot m}{I_0} \quad (2.8b)$$

b- CIE Standard General Sky

Kittler et al. have proposed a new range of standard skies using a set of mathematical equations that describes 15 alternate sky luminance distributions. Kittler team used data sets from Berkley, California, Tokyo and Sydney to derive a new generation of CIE sky standards. The influences of solar altitude, turbidity, and

luminance parameter, as well as typical daylight conditions were specified and their functional relations modelled.

The CIE Standard General Sky is a generalization of the CIE Clear Sky formula (2.9). It has been shown to be a good model of skies with smoothly varying luminous distributions occurring in various climatic conditions (Kitler, Perez and Darula, 2002). Formula of this type has also been shown to provide a good approximation to skies of broken cloud in maritime climates (2.10). It has also been shown that approximations of types of General Sky can give a good characterisation of the exterior daylight conditions, although the particular sky types may differ between climates (Tregenza, 1999).

The position of the sun, the arbitrary sky element, and the parameters a , b , c , d , e describing atmospheric conditions, are used as input for the calculation quantities. The luminance gradation function φ , relates the luminance of a sky element to its zenith angle:

$$\varphi(Z) = 1 + a \cdot \exp\left(\frac{b}{\cos(Z)}\right) \quad (2.9)$$

$$\varphi(0) = 1 + a \cdot \exp(b) \quad (2.10)$$

While:

$$0 \leq Z \leq \frac{\pi}{2}$$

The function f is expressing the scattering indicatrix which relates the relative luminance of a sky element to its angular distance from the sun (2.11):

$$f(\chi) = 1 + c \left(\exp(d\chi) - \exp\left(\frac{d\pi}{2}\right) \right) + e \cdot \cos^2 \chi \quad (2.11)$$

Its value at the zenith is expressed as (2.12):

$$f(Z_s) = 1 + c \left(\exp(dZ_s) - \exp\left(\frac{d\pi}{2}\right) \right) + e \cdot \cos^2 Z_s \quad (2.12)$$

The parameters a to e in the equations (2.8) - (2.11) can be selected from Table 2.1. It lists fifteen standard relative luminance distributions, which are based on six groups of a and b values for the gradation function and six groups of c , d and e

values for the indicatrix function. The resulting curves are illustrated in Figure 2.4 and Figure 2.5.

Table 2.1 : Standard parameters.

Type	Gradation	Indikatrix	a	b	c	d	e	Description of luminance distribution
1	I	1	4	-0.7	0	-1.0	0.00	CIE Standard Overcast Sky, alternative form Steep luminance gradation towards zenith, azimuthal uniformity
2	I	2	4	-0.7	2	-1.5	0.15	Overcast, with steep luminance gradation and slight brightening towards the sun
3	II	1	1.1	-0.8	0	-1.0	0.00	Overcast, moderately graded with azimuthal uniformity
4	II	2	1.1	-0.8	2	-1.5	0.15	Overcast, moderately graded and slight brightening towards the sun
5	III	1	0	-1	0	-1.0	0.00	Sky of uniform luminance
6	III	2	0	-1	2	-1.5	0.15	Partly cloudy sky, no gradation towards zenith, slight brightening towards the sun
7	III	3	0	-1	5	-2.5	0.30	Partly cloudy sky, no gradation towards zenith, brighter circumsolar region
8	III	4	0	-1	10	-3.0	0.45	Partly cloudy sky, no gradation towards zenith, distinct solar corona
9	IV	2	-1	-0.55	2	-1.5	0.15	Partly cloudy, with the obscured sun
10	IV	3	-1	-0.55	5	-2.5	0.30	Partly cloudy, with brighter circumsolar region
11	IV	4	-1	-0.55	10	-3.0	0.45	White-blue sky with distinct solar corona
12	V	4	-1	-0.32	10	-3.0	0.45	CIE Standard Clear Sky, low illuminance turbidity
13	V	5	-1	-0.32	16	-3.0	0.30	CIE Standard Clear Sky, polluted atmosphere
14	VI	5	-1	-0.15	16	-3.0	0.30	Cloudless turbid sky with broad solar corona
15	VI	6	-1	-0.15	24	-2.8	0.15	White-blue turbid sky with broad solar corona

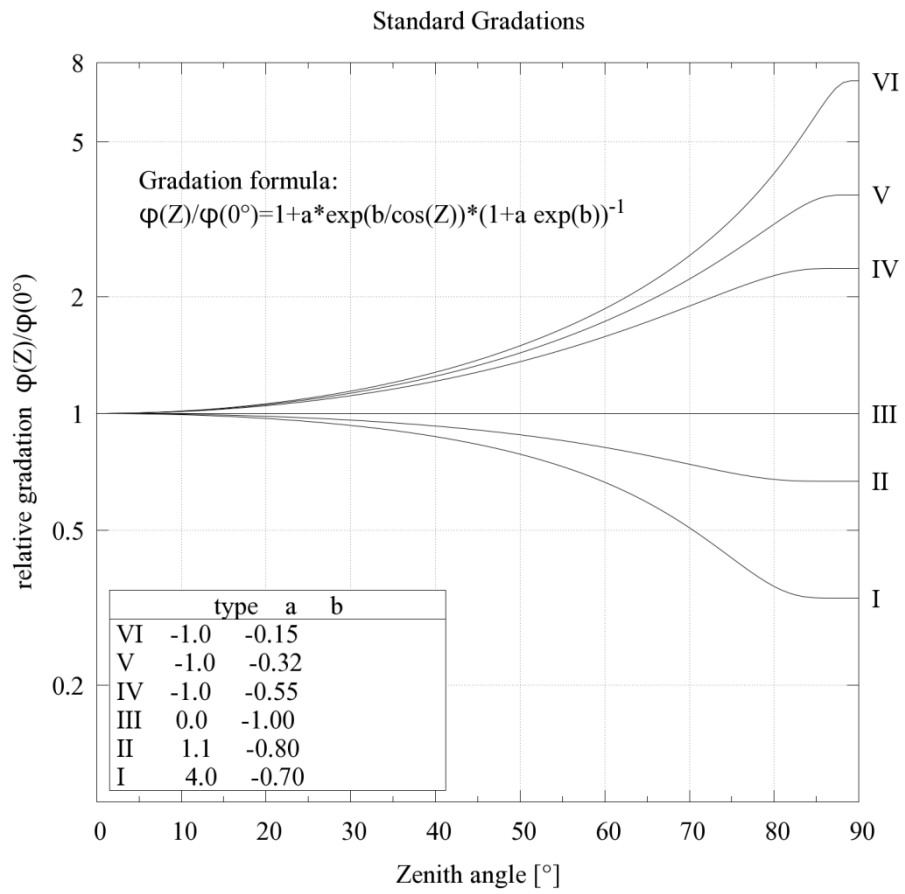


Figure 2.4 : Standard gradations.

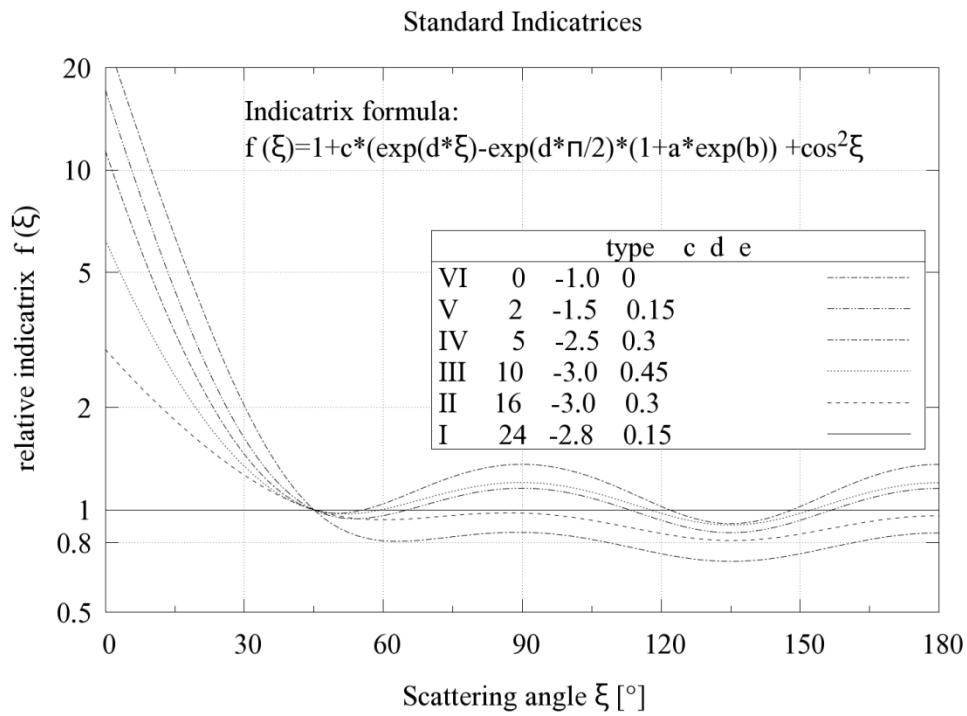


Figure 2.5 : Standard indicatrices.

Studies at De Montfort University in 1995 evaluated the performance of the four sky luminance distribution models by comparing estimates with vertical illuminance measurements (Asimakopoulos, Chrisomallidou, Klitsikas, Mangold, Santamouris and Tsangrassoulis, 2001). The models evaluated were: CIE overcast sky, CIE clear sky, Intermediate sky and Perez all-sky distribution. The reported results are as follows:

- The CIE overcast model shows an overall negative bias in the predictions of illuminance due to north and east facing windows.
- The CIE clear sky model is the worst of all four models, having mean bias errors four times higher those associated with the intermediate sky model and almost ten times higher than those from Perez et al. sky model.
- For all but one aspect, the Perez et al. model generates single-digit mean bias errors.

In 2000, Vartiainen (Vartiainen, 2000) from the Helsinki University of Technology in Finland used measured data from Otaniemi, Finland to estimate the quality of six luminous efficacy models. The models in this comparison are: Littlefair (Littlefair, 1988), Perez (Perez, Ineichen, Seals, Michalsky and Stewart, 1990) et al., Olseth and Skartveit (Olseth and Skartveit, 1989), Chung (Chung, 1992) and Muneer and Kinghorn (Muneer and Kinghorn, 1998). Vartiainen found that the Perez sky luminous efficacy model has the lowest root mean square errors and mean bias errors with respect to the measured data.

Because the first step in planning for daylight utilisation is to ensure that daylight can be provided for both in the interior and exterior of the building and adjacent buildings, sky modelling is critical to creating a successful design. The comparative studies underline that the choice of model matters significantly and show how important it is to use a valid and reliable sky model for daylight simulations to provide the best possible data for incorporation into the design.

2.2.1.2 Daylight simulation algorithms, performance metrics and criteria

Lighting calculations are based on the laws governing the transport of radiation, and hence, the transport of energy. Lighting calculation tools should employ physically-correct calculation methods. There are different kinds of calculation

methods including: Lumen Method (Zonal-Cavity Method), Split-Flux, Ray-tracing and Radiosity methods.

Lumen method was developed to calculate the Daylight Factor using an empirical formula. In the method, the first reflected flux from the interior surface is obtained by weighting the window area with the incident illumination falling normal to the window plane (Walsh, 1951). With this first methodology daylighting was treated the same lines as the design of artificial lighting. The formula uses a coefficient of utilization based on factor tables. Then, Internal Reflected Component (IRC) was implemented by Dresler (Dresler, 1954). Initially, the formula did not take into account the light coming from the ground and the external reflected component or inter-reflection of light in the room.

Split-flux method, which is an empirical formula for calculating the IRC, proposes the flux entering the room in two parts. In this method, the window is divided into two parts by a horizontal imaginary plane passing through the centre of the room. The first part is the flux coming from the sky and any external obstruction above the imaginary plane. The second part is the flux coming from the ground and any external obstruction falling below the imaginary plane. The first flux summations are then multiplied by the average reflectance of the lower surfaces of the room and the second by the reflectance of the upper surfaces of the room. Then the unit sphere method is applied for the inter-reflection of light (Hopkinson, Petherbridge and Longmore, 1954). One of the drawbacks of the split-flux method is that it works well with certain kinds of geometry that closely resemble a sphere (such as a square or rectangle type shape), but not with all kinds of geometry (Hopkinson, Petherbridge and Longmore, 1966). Split-flux also cannot predict illumination levels accurately at a point very close or farther away from window in spaces whose depths is twice that of the height of the window. Also, the split-flux method cannot handle complex daylighting strategies using light shelves or reflective overhangs that are highly directional and force more light onto the ceiling (Kota and Haberl, 2007).

The difference between Ray-tracing and Radiosity is the starting point. Ray tracing follows all rays from the eye of the viewer back to the light sources (Tobler, 1997) Radiosity simulates the diffuse propagation of light starting at the light sources. The idea behind raytracing is to simulate individual light rays in space in order to

calculate the luminous distribution in a room from a given viewpoint. Therefore, rays are emitted from the point of interest and traced backward until they either hit a light source or another object. Radiosity works on the basis of the energy conservation law (energy balance). In other words, radiation is partially reflected on the surfaces until such time as all the energy has been absorbed by the different surfaces. This method will only work with fully diffuse areas.

An advantage of radiosity compared to raytracing is that it requires less calculation times for straightforward geometries that do not contain too many surface elements. However, if physically correct results are needed, only raytracing based methods can succeed, as most real surfaces exhibit specular components (IEA SHC Task 21, 1999).

Depending if a single or a series of consecutive sky conditions is considered, daylight calculation methodologies can be classified as static or dynamic. Photo realistic images and the illuminance values at certain points of interest in a building under a reference sky express the results of static daylight simulations.

Static daylight calculation methodologies usually concentrate on the indoor illuminance distribution under overcast sky conditions. The daylight factor is the most common parameter to characterize the daylight situation in buildings. It is defined as the ratio of the indoor illuminance at the point x to the outdoor horizontal illuminance under the overcast CIE sky. The major weakness of the daylight factor is that the orientation of the investigated building does not influence the daylight factor since the reference sky is rotationally invariant and independent of the geographical latitude of the investigated building (Littlefair, 1990).

As daylight is extremely dynamic and cannot be stored, static daylight calculation methodologies are only of limited usage. Usually, it is necessary to calculate the daily and seasonal availability of indoor illuminances and/or luminances in order to evaluate the effectiveness of a given daylight concept. Dynamic daylight calculation methodologies produce the time development of indoor illuminances under multiple sky conditions, resulting in Annual Daylighting Profiles, which was introduced by Reinhart in 2002 (Reinhart, 2002). Besides this methodology, various dynamic calculation methods exist to calculate annual indoor luminance distributions. The most basic dynamic daylight calculation methodology relies on

the daylight factor method. The most advanced methodologies use refined methods like statistical sky and daylight coefficients, which produce annual hourly mean indoor illuminance.

To judge the suitability of a method, a dynamic calculation methodology should satisfy some requirements such as: producing results for complex building geometries, convenient calculation time to allow interactive design process, and having short time step variances of the available daylight. RADIANCE ray tracing algorithms are reliable for implementation of dynamic daylight calculation methodologies. RADIANCE is a validated, physically based backward ray tracer that can simulate indoor illuminance and luminance distributions due to daylight for complex building geometries and a wide range of material surface properties for one sky condition at a time (Ward and Shakespeare, *Rendering with RADIANCE*).

RADIANCE based dynamic daylight calculation methodologies can be compared in terms of their specific formation. Using the first methodology, a single raytracing run is carried out for every hourly mean sky condition of the year. The Perez model was used to model the sky conditions with Test Reference Year (TRY) weather data.

Annual daylight calculations with overcast sky model based on the daylight factor method serve as a worst case scenario of the annual daylight availability because of direct sunlight absence. Daylight factor analyses are traditionally performed scaling the cumulative distribution of horizontal external diffuse illuminance with daylight factor at the point of interest inside the building (Littlefair, 1990). The weakness of this definition is that weather data generally only provides direct and diffuse irradiance, not illuminance. For conversion of irradiance values into illuminance values, luminous efficacy models must be used. It has been proven in Reinhart's PhD thesis that luminous efficacy models decisively influence the quality of an indoor illuminance calculation (Reinhart, 2002).

Another approach has been developed within the Task 21 of the Solar Heating and Cooling Program of the International Energy Agency. This approach has been integrated into the lighting calculation methodologies and the concept is based on statistical sky according to Szerman (Szerman and Stoffel, 1996). The availability of indoor illuminance levels under CIE overcast and clear skies with and without

sun is calculated for the 15th day of each month of the year with one hour time steps. Hourly mean illuminance levels are approximated by mixing the corresponding clear and overcast skies, depending on the effective sunshine probability of the hour. The effective sunshine probability is a ratio of the actual length of sunshine to the length of the time interval (Szerman and Stoffel, 1996). To obtain this ratio, the direct and normal radiation data from meteorological input is used, and divided by calculated maximum direct normal radiation for the geographical location and ambient atmosphere. This approach does not consider diffuse horizontal irradiance for input data.

Before Szerman and Stoffel, Aydinli Average Sky Model also used relative sunshine duration (Aydinli, 1981). According to the model, average exterior illuminance can be evaluated as two parts: sunlight and skylight. Skylight can also be considered to be sourced from two effects: clear sky and overcast sky. The average exterior daylight illumination can be obtained by using sun and sky correction factors and relative sunshine duration. Although measured bright sunshine duration values are considerably high, monthly average hourly exterior illuminance values are significantly low due to the empirical coefficients used for Aydinli Average Sky Model.

Herkel (Herkel, 1997) et al. has proposed a methodology to reduce the over 4700 hourly annual mean daylight situations classifying ensembles into a set of some 450 classes. In this method, similar sets of daytime, sun position, direct and diffuse illuminances are grouped into classes that represent all appearing sky distributions during the course of a year.

The method to calculate indoor illuminance levels associated with daylight under arbitrary sky conditions based on daylight coefficients was originally proposed by Tregenza. The celestial hemisphere is theoretically divided into a disjointed sky in this idea. Afterwards, the contribution to the total illuminance at a point in a building is calculated for each sky patch individually. The Figure 2.6 shows the sky division according to Tregenza (145 sky patches with a cone opening angle of 11,15 degrees) and depicts the concepts of a daylight coefficient. Daylight coefficient $DC_{\alpha}(x)$ describes the illuminance $E_{\alpha}(x)$ at point x in the building that is caused by sky segment S_{α} , which is glowing with normalized luminance L_{α} .

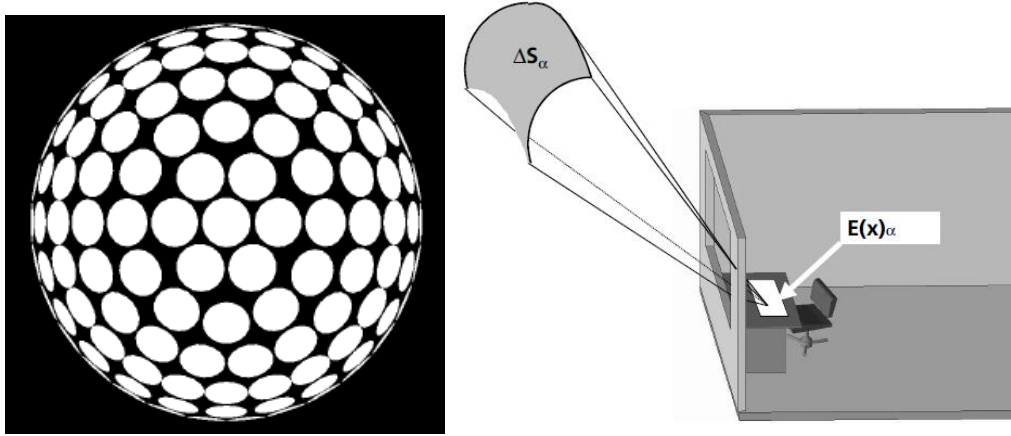


Figure 2.6 : Tregenza sky division and daylight coefficient definition.

Definition of a daylight coefficient (2.13):

$$DC_{\alpha}(x) := \frac{E_{\alpha}(x)}{L_{\alpha} \cdot \Delta S_{\alpha}} \quad (2.13)$$

with:

- x: point in a building
- S_{α} : sky segment P
- ΔS_{α} : angular size of S_{α}
- $E_{\alpha}(x)$: illuminance at x due to S_{α}
- L_{α} : luminance of S_{α} .

The sky division is interpreted differently for the implementation of daylighting calculation for individual tools. One of the daylighting tools defines the cone opening angle as 13.39 degree, in order to compensate for the uncovered regions of sky. Under another tool, the celestial hemisphere is completely covered and there is no overlap between sky segments.

DAYSIM calculation methodology distinguished between contributions from the diffuse daylight, ground reflection and direct sun light in order to reduce the number of raytracing runs calculating a complete set of daylighting coefficients (Reinhart, 1998).

$$E(x) = \sum_{\alpha=1}^{145} D_{\alpha}^{dif}(x) L_{\alpha}^{dif} \Delta S_{\alpha}^{dif} + \text{diffuse daylight}$$

$$\begin{aligned}
& \sum_{\alpha=1}^3 D \subset_{\alpha}^{gnd} (x) L_{\alpha}^{gnd} \Delta S_{\alpha}^{gnd} + \text{ground reflection} \\
& \sum_{\alpha=1}^3 D \subset_{\alpha}^{dir} (x) L_{\alpha}^{dir} \Delta S_{\alpha}^{dir} \quad \text{direct sunlight} \quad (2.14)
\end{aligned}$$

Contributions from direct sunlight are modelled by some 65 representative sun positions, which are a subset of all possible sun positions throughout the year. These positions were generically chosen, as they generate an evenly spaced grid across all possible sun positions throughout the year for median latitudes. Once daylight coefficients are available, they need to be coupled with the mean luminances of their associated sky segments for a given sky condition according to Equation 2.14 (2.14). The luminances of the 145 diffuse sky segments for particular sky condition are calculated using the Perez all weather sky models based on date and time, as well as on the direct normal and diffuse horizontal irradiances.

Mardaljevic (Mardaljevic, 2000) interpreted the daylight coefficient approach in a different way. This approach distinguishes between direct and indirect contributions to indoor illuminances from direct sunlight, as well as diffuse daylight. Contribution from diffuse daylight and indirect contributions from the sun are all treated via a division of the celestial hemisphere into 145 sky segments.

It is a big challenge to define the quantity and quality of daylighting because of the dynamic nature of light. Static and dynamic daylighting performance metrics have been developed to assess the daylight indoor environment. Those metrics are also used in sustainable building rating systems such as: BREEAM (BREEAM, 2006) (Building Research Establishment's Environmental Assessment Method), CASBEE (CASBEE, 2008) (Comprehensive Assessment System for Building Environmental Efficiency) and LEED[®] (Leadership in Energy and Environmental Design, 1998).

Daylight performance metrics have been developed with the purpose of setting a scale for designers to use when comparing aspects of daylighting design. Each metric differs and has a variety of strengths. The daylighting metrics that will be described in the section are: Daylight Factor (DF), Daylight Autonomy (DA), Useful Daylight Illuminances (UDI), Continuous Daylight Autonomy (DA_{con}),

Maximum Daylight Autonomy (DA_{Max}), Annual Light Exposure and Daylight Saturation Percentage (DSP).

The DF metric is named for the calculation method, which is a common parameter to characterise the daylight situation at a point in a building. It is defined as the ratio of the indoor illuminance at a point of interest to the outdoor horizontal illuminance under the overcast CIE sky (see sky models in section 2.2.1.1). British Standards Institution, BS 8206 part 2 (British Standards Institution) recommends that if electric lighting is not normally to be used during daytime, then the average daylight factor should be not less than 5%. If electric lighting is to be used throughout daytime, then the average daylight factor should be not less than 2% if a predominantly day-lit appearance is desired.

The definition of daylight autonomy at a point in a building is ‘the percentage of the year when a minimum illuminance threshold is met by daylight alone’ and goes at least as far back as 1989 when it was mentioned as a Swiss norm (Association Suisse des Electriciens, 1989). In 2001, Reinhart and Walkenhorst redefined daylight autonomy at a sensor as the percentage of the occupied times of the year when the minimum illuminance requirement at the sensor is met by daylight alone (Reinhart and Walkenhorst, 2001). In later publications, the concept of daylight autonomy was further refined by combining it with a manual blind control model that predicts the status of movable shading devices at all-time steps in the year. The resulting concept of ‘effective’ daylight autonomy was applied to open plan and private offices (Reinhart, 2002; Reinhart and Andersen, 2006).

As the name indicates, Useful Daylight Illuminance (UDI) calculates the total number of occupied hours that “useful” daylight enters a space at a select point. Useful daylight is defined as providing ambient light at the workplane at illuminance levels between 100 lux to 2,000 lux in occupied times of the year (Nabil and Mardaljevic 2005; Nabil and Mardaljevic, 2006). Based on the upper and lower thresholds of 2000 lx and 100 lx, UDI results in three metrics, that is, the percentages of the occupied times of the year when the UDI is achieved (100–2000 lx), falls-short (<100 lx), or is exceeded (> 2000 lx). Continuous Daylight Autonomy (DA_{con}), recently proposed by Rogers, is another set of metrics that resulted from research on classrooms (Rogers, 2006). In contrast to earlier definitions of daylight autonomy, partial credit is attributed to time steps when the

daylight illuminance lies below the minimum illuminance level. For example, in the case where 500 lx are required and 400 lx are provided by daylight at a given time step, a partial credit of $400 \text{ lx} / 500 \text{ lx} = 0.8$ is given for that time step. Continuous Daylight Autonomy also addresses only occupied times of the year.

Maximum Daylight Autonomy (DA_{Max}) (Rogers, 2006) is a method that uses a maximum illuminance bound instead of a minimum. Times of the occupied schedule are counted if the given point has an exceedingly high illuminance, which is used as an indicator of glare or unwanted heat gains. The threshold typically is ten times the illuminance criterion, though this value is not grounded in a specific glare or heat gain study.

The annual light exposure is defined as the cumulative amount of visible light incident on a point of interest over the course of a year. It can be expressed in lux hours per year. Some recommended annual light exposures are given in the standard according to CIE Division 3 TC3-22, for example, ‘Museum lighting and protection against radiation damage’.

Daylight saturation percentage is a modification of useful daylight illuminance that modifies the lower limit to 40 foot-candles (approx. 430lux) and increases the upper limit to 400 foot-candles (approx. 4300 lux). It goes further to penalise grid point annual hour values above 400 foot-candles by using shading devices to bring annual hour values above 40 foot-candles and below 400 foot-candles. The Lighting and Daylighting Committee for the Collaborative for High Performance Schools program (CHPS) developed it in 2006 (CHPS, 2006).

2.2.2 Built environmental parameters related to visual comfort

Occupants in buildings are exposed to all built environmental parameters simultaneously. Mostly they have to deal with a combination different environmental parameters. Many studies examined the issue of occupant comfort on the effect of those environmental conditions. Visual comfort is affected by the quality of the indoor space the occupant perceives from the physical configuration of the building. In this section, parameters that have effect on visual comfort conditions are evaluated.

2.2.2.1 Design parameters on urban, building and room scales

At a construction site, the sky is usually obstructed by surrounding buildings and vegetation. External obstructions cause a reduction in the daylight availability to the rooms. However, obstructions also reflect light according to their light reflectance, which depends on the material and colour of the facades. The reflected light can cause discomfort, like light reflected from the glazed facades of the high-rise buildings. The amount of the reflected light from the external surfaces of obstructions is one of the components of the interior illuminance.

Local zoning regulations limit a building's design and also define the impact that a new building may have on surrounding buildings. Zoning regulation, which is described in more detailed in Chapter 3, and floor area indices that regulate the extent of urban density, also affect daylight availability. The aim of maximising floor area in order to get the best economic return from new building may conflict with the design goal of providing interior daylight.

Ground reflection is a design parameter related to the built environment. External horizontal illuminance is reflected by the ground and reaches the interior surfaces, especially the ceiling, where it is re-reflected to the work plane. During an urban design one can decide occasionally on this parameter.

To maintain visual comfort conditions, the main design parameters related to the built environment on the building scale are:

- Orientation of the building
- Position of the building in relation to the other buildings

The parameters on the room scale are:

- Position of the room within the building.
- Dimensions of the room
- Orientation of the room
- Light reflection coefficients of the surfaces inside the room

The dimensions (width, depth and height) of the rooms effect the available daylight and its distribution. Daylight is usually not sufficient in the deeper parts of the rooms in relation to the transparency ratio (window area/window wall area) and the width/depth ratio of the rooms (Yener, 2003).

On the element scale, the parameters are as follows:

- dimensions of the transparent component
- number of layers of the glazing
- transmission coefficient of the glazing for diffuse light
- transmission coefficient of the glazing for direct light
- maintenance factor of the glazing (Koçlar Oral et al., 2004).

Window dimensions are generally given as transparency ratio, which equals to the ratio between the window area and the window wall area. The lower limit of the transparency ratio is to be accepted as 20% in order to satisfy the psychological human needs and visual communication with the surrounding environment (Lynes and Crisp, 1979).

Glazing with high light transmittance can cause both advantages and disadvantages in the context of energy conservation. Glazing types differ from each other according to their physical properties, such as heat transmission, light transmission, light reflection and sound absorption coefficients. Low transmission glazing reduces the effectiveness of daylight, but cannot reduce intensities enough to provide comfort in direct sun. Clear glazing is the best way to admit the amount of light desired, it must be used with shading in order to reduce the heat gain. Low transmission glazing is useful when the amount of light is not as important as the view (Yener, 2003).

Glazing types can be classified as: insulated glazing, tinted glazing, reflective glazing, low-e glazing and laminated glazing (Carmody et al., 2004).

Insulated glazing construction, the inner and outer panes of glass are both clear and they are separated by an air gap. Double glazing reduces heat loss (as reflected by U-factor) by more than 50% in comparison to single glazing. Although U-factor is reduced significantly, the VT and SHGC for a double-glazed unit with clear glass remain relatively high. Tinted glazing retains its transparency from inside, although the brightness of the outward view is reduced and the colour is changed. The reflective coatings come in various metallic colours _ silver, gold, bronze - and they can be applied to clear or tinted glazing. The solar heat gain coefficient can be reduced by varying degrees, depending on the thickness and reflectivity of the coating and its location in the glazing system.

When heat or light energy is absorbed by glass, it is either convected away by moving air or re-radiated by the glass surface. The ability of a material to radiate energy is called its emissivity. Low-E glass coatings can have an emittance as low as 0.04. Laminated glass consists of a plastic interlayer made of polyvinyl butyral (PVB) bonded between two panes of glass under heat and pressure. Laminated glass provides durability, high performance, and multifunctional benefits, while preserving aesthetic appearance.

After many years of development, various switchable windows that can readily adapt in response to changing climatic conditions or occupant preferences are commercially available. There are two basic types of smart windows: passive devices that respond directly to environmental conditions such as light level (Photochromics) or temperature (Thermochromics); and active devices that can be directly controlled in response to occupant preference or heating and cooling system requirements (Chromogenic Materials, 2010). Electrochromic windows change tint with a small applied voltage, providing building owners and occupants with the option to have clear or tinted windows at any time, irrespective of whether it is sunny or cloudy (Platzer, 2003).

Orientation of windows effect the daylight availability of room, as the sun movement throughout the year and during the day is an important influence on the indoor illuminance. Direct sunlight reaches the window surface through the window. The amount of the illuminance level has different values according to window orientation.

2.2.2.2 Electric lighting and control system properties and solar shading

35% to 45% of all the electricity used in office buildings is used for lighting, making it one of the most attractive ways to save energy (The American Institute of Architects, 2008). To improve the occupants' productivity, minimize the operating and maintenance costs and meet the energy codes, appropriate electric lighting and control systems should be chosen for offices.

The EU has set a target to reduce total energy consumption by 20% before 2020. In order to reach this target, the Energy Using Product Directive has been developed. One directive is to reduce the environmental impact of energy-using products. To ensure at least the minimal energy efficiency requirements of lighting are met,

some products will be phased out. For example, energy efficient lamps are taking the place of incandescent lamps.

Lamp selection in office should be based on a balance between the requirements and maintenance inventories. The efficiency (lumens per watt), colour temperature, colour rendering index, life and lumen maintenance, availability, switching, dimming capability, and cost must be known.

Fluorescent lamps are commonly used lamps for office buildings. Linear fluorescent lamps such as T8, T5 and T12 work well in luminaires that provide the general ambient lighting for a space.

Fluorescent lights need a ballast. A ballast is an electrical component that supplies the initial electricity at start-up and in operation regulates the amount of electricity flowing through the bulb so that it emits the right amount of light.

There are 4 different types of fluorescent ballasts available in market: rapid start ballasts, instant start ballasts, program rapid start ballasts and dimming electronic ballasts. Electronic ballasts are most efficient and commonly used for fluorescent office lighting (Guidelines for High Performance Buildings, 2004).

Compact fluorescent lamps (CFL) are also encouraged used due to their significantly longer life and better energy efficiency in general office lighting. Self-ballasted, screw socket retrofit CFL lamps are sometimes used for energy savings.

Light Emitting Diode (LED) lamps are the newest addition to the list of energy efficient light sources. While LED lamps emit visible light in a very narrow spectral band, they can produce "white light". LED office lighting is widely being used to reduce expenses. According to producers, the LED commercial office fixture line is 30% more energy efficient than the average two tube T-8 fluorescent office fixture and operates 21% cooler, without compromising the quality of illumination or light output (Dikel, 2012).

A luminaire, or light fixture, is a unit consisting of one or more of the following components: lamp(s) and lamp socket(s), ballast(s), reflective material, lenses, refractors, louvers, blades, or other shielding (Nelson, 2010). Types of the fluorescent luminaire that can be used in office lighting are indirect or direct linear luminaire. For task lighting there are task luminaries that can work with either fluorescent lamps or compact fluorescent lamps.

Controls are an excellent way to reduce lighting energy while enhancing lighting quality. Occupancy sensors can eliminate wasted lighting in unoccupied spaces, especially in open offices. Daylighting controls or advanced load management can reduce lighting demand when energy is most expensive. Manual dimmers, which allow occupants to adjust light levels to their preference, are becoming more affordable. Lighting controls have been shown to reduce lighting energy consumption by 50% in existing buildings and by at least 35% in new construction (Advanced Lighting Guidelines, 2001).

General strategies for using lighting controls can be summarised as:

- occupancy sensing
- scheduling
- tuning
- daylighting control
- demand limiting
- adaptive compensation
- lumen maintenance

The control device is the physical equipment that is installed to implement the desired control strategies for a particular application. Different lighting control systems can be found in the market including technology such as: motion sensors, presence detector, remote controls, timer switches, illumination sensors, occupancy sensors.

Solar control systems function obstructing the entry of direct sunlight into the space to prevent glare and control the direct solar radiation to decrease overheating. Meanwhile, shading elements should minimize the reduction in daylight entrance.

Sun control and shading devices can be divided into interior and exterior types. Shading devices can be fixed or adjustable and they can vary in type (horizontal or vertical), in number of elements (single or multi), in inclination and in surface reflectance.

Fixed shading devices mounted on windows reduce the amount of daylight entering the rooms and also increase the load on the illumination system during the year. The important problem during the design of a fixed shading device is the

determination of the proper depth that ensures proper sun control and allows adequate daylight into the room.

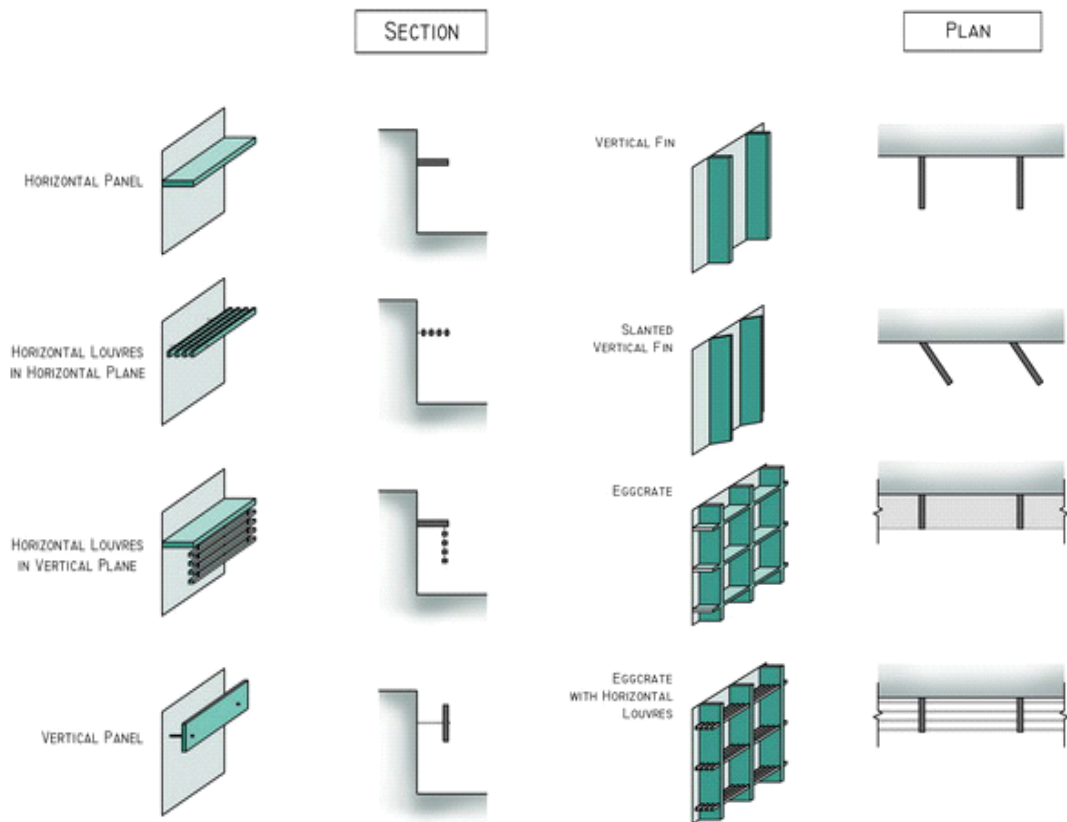


Figure 2.7 : Basic typology of horizontal, vertical or eggcrate shading devices (Reduce Loads / Demand – Shading 2010).

General types of shading devices can be seen in Figure 2.7. Exterior shading devices can be identified as Horizontal, Vertical and/or Eggcrate. Horizontal shading devices are suitable for southern facades. To block the sun effectively on south easterly and south westerly directions, vertical shading devices can be used. Eggcrate are generally chosen on non-south facing facades.

The types of movable (adjustable) solar shading systems which are commonly used in office buildings include: venetian blinds, roller blinds and glass lamellas (Dionísio, 2007).

A venetian blind is a blind composed of parallel spaced slats that can be tilted in order to control the amount of solar gains and light entering the room. The slats are available in different widths and can be made of different materials (usually wood

or aluminium). They are also available in different finishes and colours according to the desired esthetical effect.

The venetian blinds have the great advantage of being retractable and they can be internal or external.

A roller blind is a retractable blind made of a flexible material which is flat when drawn. They are available in different fabrics that can be more or less transparent according to their openness factors. The fabrics can have a metallic or non-metallic finish and are available in different colours. The roller blinds can also be external or internal, but they have different requirements depending on where they are mounted.

The glass lamellas are another type of external solar shading systems. They are composed of adjustable glass lamellas supported by a metallic structure. Besides controlling the solar gains contributing to reduce overheating and the energy demand for cooling, they also control the daylight. They may improve the daylight conditions by redirecting the light further into the room where it is needed most. The glass lamellas can be set at different angles according to the desired function. Thus, on sunny days they can be tilted as a solar shading system in order to block the direct sun rays, while on overcast days they can be tilted in such a way to reflect the daylight into the room, increasing the indoor daylight levels, especially far from the window.

To make office environments as responsive, productive and attractive as possible, it is important to fulfil the occupants' comfort conditions. Choosing the right office lighting solutions can help to achieve the desired mix of ambiance, well-being and sustainability.

2.3 Energy Performance Standards

Buildings are one of the largest end users of energy; in OECD countries, the building sector accounts for 25-40% of the final energy demand. Globally, carbon emissions could be reduced by 715 million tons by 2010 by simply improving the energy efficiency in buildings and appliances. This would be equivalent to 27% of the projected increase of GHG (greenhouse gas) emissions expected by this date (The World Business Council for Sustainable Development, 2009).

According to the World Business Council for Sustainable Development (WBCSD), the “Energy efficiency in Buildings” project aims at producing a roadmap for reaching energy self-sufficiency in buildings by 2050, while being economical and socially acceptable.

In order to promote energy-efficient buildings, the European Parliament has adopted the directive on “Energy Performance of Buildings” (EPBD, 2002). The definition of the general framework for a methodology of calculation of the integrated energy performance of buildings includes; the thermal characteristic of the building, its associated boundary conditions, the heating installation, hot water supply and ventilation as well as air conditioning installations and built-in lighting installations. The European Union (EU) member states are requested by the EPBD to set up minimum requirements on the energy performance of buildings, based on the mentioned methodology.

The EPBD’s objectives are; promoting the improvement of energy performance of buildings within the EU through cost-effective measures and convergence of building standards towards those of Member States that already have ambitious levels. The measures to put the strategy into effect are as follows:

- methodology for integrating building energy performance standards
- application of these standards on new and existing buildings
- certification schemes for all buildings
- inspection & assessment of boilers/heating and cooling installations.

In 2004, EU directed The European Committee for Standardization (CEN) to develop standards to support the Member States in order to achieve the required transparency and support the implementation of the EPBD through the Member States’ regulations, get access to reliable tools and procedures for all EU Member states, promote a free market in energy saving services and products throughout the EU. This mandate asked CEN to elaborate and adopt standards on a methodology, calculating the integrated energy performance of buildings and estimating the environmental impact, in accordance with the directive (EPBD, 2002). The calculation methodology of EPBD can be seen in Figure 2.8.

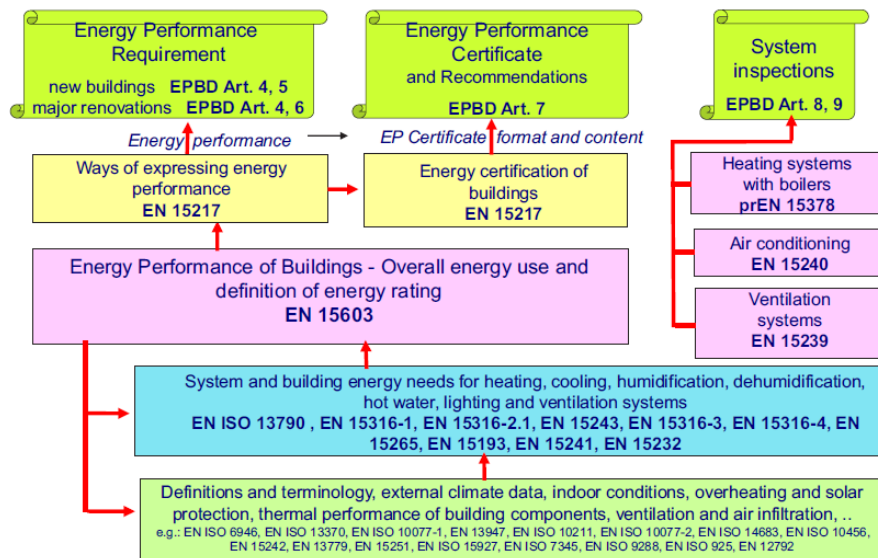


Figure 2.8 : Methodology for calculating energy performance (EPBD, 2002).

The following are the applicable subdivisions when calculating energy performance: energy uses and losses for heating and cooling, ventilation, domestic hot water, lighting, natural lighting, passive solar systems, passive cooling, position and orientation, automation and controls, and auxiliary installations necessary for maintaining a comfortable indoor environment. The methodology integrates, where relevant, the positive influences of active solar systems and heat and electricity from renewable energy sources, as well as quality co-generation heating plants (CHP, including micro-CHP) and district heating and cooling systems. It also facilitates an estimation of the environmental impact from this energy use and provides data requirements for carrying out standard economic evaluations for the use of different systems. Finally, the standards are set for inspection procedures for boilers, heating systems, ventilation systems and cooling/ac systems.

In the case of Germany, there was already a methodology for the calculation of the energy performance of buildings in place that satisfied the requirements for residential buildings. According to the Energieeinsparverordnung (Energy Saving Ordinance, German Government 2002/2004), the primary energy demand of buildings and installation systems for heating, ventilation and domestic hot water must be determined with two German standards: DIN V 4108-6 and DIN V 4701-10 (DIN standard committee, 2000/2001). Also, minimum requirements for the energy performance of new buildings and for major renovations at existing buildings have been applied for a sometime now (DIN V 18599, 2007).

However, the energy performance assessment for non-residential buildings including the primary energy demand for heating, ventilation, domestic hot water plus for cooling and lighting was not possible with the existing calculation standards. Therefore, the German government mandated that the Standard Committee develop a new calculation code, which covers all the necessary energy parts, the new DIN V 18599 (DIN V 18599, 2007). It was a major step forward to require the Standard Committee to include members from the building, the building systems and the lighting section.

The EPBD has already been revised on 19 May 2010; the EU adopted the Energy Performance of Buildings Directive which is the main legislative instrument to reduce the energy consumption of buildings (EPBD, 2010). The current directive of EPBD 2010 as a supplementary source, on 16th of January 2012 European Commission established a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements (European Commission Energy Efficiency in Buildings, 2012).

In Germany, the Energy Saving Ordinance regulates energy performance in buildings. German Energy Saving Ordinance (EnEV 2009) stipulates energy performance certificates for buildings. Within the scope of the ordinance, minimum energy requirements for new buildings, for modernisation, reconstructions and extensions of existing buildings are indicated. The ordinance specifies minimum requirements for heating, cooling and air conditioning systems, as well as water systems and energy inspections of air condition systems. The German Energy Saving Ordinance applies to all heated and cooled buildings and/or part of buildings.

The requirements for new residential buildings and commercial buildings are defined by the annual primary energy demand. However, in addition to the energy demands for heating, hot water and air conditioning, the balance sheet also includes the proportion of energy for cooling and lighting installations. The new comprehensive calculation method is defined in the new German standard DIN V 18599. The requirements are defined by means of a reference building that corresponds to the real building in terms of geometry, net floor area, orientation and utilisation, but whose technical structure is defined according to the German Energy

Saving Ordinance (EnEV, 2009). The energy quality of the building cladding and the limitation of the insulation parameter are prescribed as ancillary requirements.

The maximum value of the annual primary energy demand of a commercial building to be constructed is the annual primary energy demand, related to the net floor area, calculated according to the procedure stated in EnEV 2009.

2.3.1 Thermal comfort and energy demand calculation standards

The definition of acceptable indoor climates in buildings is important to the success of a building not only in making it comfortable, but also in determining its energy consumption and ensuring its sustainability. On the basis of the research and experience, local and international standards have been developed concerning the thermal comfort and energy demand calculations.

The standards that directly address thermal comfort and related thermal environment are examined first.

ISO 7730 (EN ISO 77) provides the PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) indices and specifies the conditions for thermal comfort. The purpose of this standard is to present a method for predicting the thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments as well as to specify acceptable thermal environmental conditions for comfort (ISO 7730, 1994).

ISO 7993 is the international standard that specifies a method of analytical evaluation and interpretation of the thermal stress experienced by a subject in a hot environment. It describes a method of calculating the heat balance as well as the sweat rate that the human body should produce to maintain this balance in equilibrium (ISO 7993, 1989).

ISO 7726 is the Ergonomics of the Thermal Environment, which specifies the minimum characteristics of instruments for measuring physical quantities characterizing an environment, as well as the methods for measuring these physical quantities (ISO 7726, 1998).

The heating and cooling sector accounts for approximately 50% of overall final energy consumed in the EU. Many standards have been developed to calculate the energy use for space heating and cooling.

The standards ISO 8996 and ISO 9920 are used for determining the personal factors in thermal comfort (ISO 8996, 1990 and ISO 9929 1995).

EN ISO 13790 gives the calculation methods for the assessment of the annual energy use for space heating and cooling of a residential or a non-residential building. The International Organization for Standardisation provides calculation methods for the assessment of the annual energy use for space heating and cooling of a residential or a non-residential building, which is referred to just as “the building”, in ISO 13790:2008 (ISO 13790, 2008).

This method includes the calculation of the following:

- the heat transfer by transmission and ventilation of the building zone when heated or cooled to constant internal temperature
- the contribution of internal and solar heat gains to the building heat balance
- the annual energy needs for heating and cooling to maintain the specified set-point temperatures in the building – latent heat not included
- the annual energy use for heating and cooling of the building, using input from the relevant system standards referred to in ISO 13790:2008 and specified in its Annex

ISO 13790 also provides an alternative simple hourly method using hourly user schedules (such as temperature set-points, ventilation modes or operation schedules of movable solar shading). Procedures are given for the use of more detailed simulation methods to ensure compatibility and consistency between the application and results of the different types of methods. It also provides, for instance, common rules for the boundary conditions and physical input data irrespective of the calculation approach chosen. ISO 13790 has been developed for buildings that are, or assumed to be, heated and/or cooled for the thermal comfort of people, but can be used for other types of building or other types of uses (e.g. industrial, agricultural, swimming pool), as long as appropriate input data are chosen and the impact of special physical conditions on the accuracy is taken into consideration.

The calculation procedures in ISO 13790 are restricted to sensible heating and cooling. The energy use due to humidification is calculated with the relevant standard on the energy performance of ventilation systems, as specified in Annex.

Similarly, the energy use due to dehumidification is calculated with the relevant standard on the energy performance of space cooling systems.

Each item that is in the standard requires input from other standards. The required standards can be examined in three categories. These categories are as following:

- a. Building element and building components' thermal performance calculation methods
- b. Building construction thermal performance calculation methods
- c. Thermal performance calculation methods for buildings

a. Building element and building components' thermal performance calculation methods

The thermal performance of the building component elements is assessed via U-Values of plane walls, roofs, floors, etc. Calculations may be undertaken in accordance with the ISO 6947 combined method to assess the U-Values and interstitial condensation risk for a wide range of construction types. Where the building construction elements comprise complex non-uniform geometry or non-repeating thermal bridges, then assessment by way of a numerical modelling tool may be required.

ISO 6946 provides the method of calculation of the thermal resistance and thermal transmittance of building components and building elements; excluding doors, windows and other glazed units, curtain walling, components that involve heat transfer to the ground, and components through which air is designed to permeate. The calculation method is based on the appropriate design thermal conductivities or design thermal resistances of the materials and products for the application concerned. The method applies to components and elements consisting of thermally homogeneous layers (which can include air layers). The standard also provides an approximate method that can be used for elements containing non-homogeneous layers (ISO 6946, 2007).

ISO 10077-2 specifies a method and gives reference input data for the calculation of the thermal transmittance of frame profiles and of the linear thermal transmittance of their junction with glazing or opaque panels. The method can also be used to evaluate the thermal resistance of shutter profiles and the thermal

characteristics of roller shutter boxes. The standard also gives criteria for the validation of numerical methods used for the calculation. This standard does not include effects of solar radiation, heat transfer caused by air leakage or three-dimensional heat transfer, such as pin-point metallic connections. Thermal bridge effects between the frame and the building structure are not included (ISO 10077-2, 2003).

ISO 13786 specifies the characteristics related to the dynamic thermal behaviour of a complete building component and provides methods for their calculation. It also specifies the information on building materials required for the use of the building component. The characteristics depend on the way materials are combined to form building components, which is not applicable to building materials or to unfinished building components. The definitions given in the standard are applicable to any building component. A simplified calculation method is provided for plane components consisting of plane layers of substantially homogeneous building materials (ISO 13786, 2007).

ISO 13788 Hydrothermal performance of building components and building elements, internal surface temperature to avoid critical surface humidity and interstitial condensation, gives calculation methods for the internal surface temperature of a building component or building element below which mould growth is likely, given the internal temperature and relative humidity (ISO 13788, 2001).

ISO/FDIS 12631, Thermal Performance of Curtain Walling, sets standards for calculating the thermal transmittance of curtain walls consisting of glazed and/or opaque panels fitted in, or connected to, frames. The calculation includes different types of glazing such as: glass or plastic; single or multiple glazing; with or without low emissivity coating; with cavities filled with air or other gases; frames (of any material); with or without thermal breaks; and different types of opaque panels clad with metal, glass, ceramics or any other material. Thermal bridge effects at the connection between the glazed area, the frame area and the panel area are included in the calculation. The calculation does not include: effects of solar radiation; heat transfer caused by air leakage; calculation of condensation; effect of shutters; additional heat transfer at the corners and edges of the curtain walling; connections

to the main building structure nor through fixing lugs; or curtain wall systems with integrated heating (ISO/FDIS, 2012).

b. Building construction thermal performance calculation methods

The International Organization for Standardisation defined building construction calculation process for thermal bridges. ISO 10211 sets out the specifications for a three-dimensional and a two-dimensional geometrical model of a thermal bridge for the numerical calculation of heat flows, in order to assess the overall heat loss from a building or part of it; and minimum surface temperatures, in order to assess the risk of surface condensation. These specifications include the geometrical boundaries and subdivisions of the model, the thermal boundary conditions, and the thermal values and relationships to be used. ISO 10211 is based upon assumptions such as: all physical properties are independent of temperature and there are no heat sources within the building element. This standard can also be used for the derivation of linear and point thermal transmittances and of surface temperature factors (ISO 10211, 2007).

ISO 14683 deals with simplified methods for determining heat flows through linear thermal bridges which occur at junctions of building elements. The standard specifies requirements relating to thermal bridge catalogues and manual calculation methods (ISO 14683, 2007).

c. Thermal performance calculation methods for buildings

“ISO 13792, Thermal performance of buildings, provides for the calculation of internal temperatures of a room in summer without mechanical cooling” specifies the required input data for simplified calculation methods for maximum, average and minimum daily values of the operative temperature of a room in the warm period in order to define the characteristics of a room to avoid overheating in summer at the design stage and to define whether the installation of a cooling system is necessary or not. The criteria to be met by a calculation method to satisfy this standard are also given (ISO 13792, 2005).

“ISO 13789, Thermal performance of buildings, Transmission and ventilation heat transfer coefficients calculation method” specifies a method and provides conventions for the calculation of the steady-state transmission and ventilation heat transfer coefficients of whole buildings and parts of buildings. It is applicable to

both heat loss (internal temperature higher than external temperature) and to heat gain (internal temperature lower than external temperature). For the purpose of ISO 13789, the heated or cooled space is assumed to be at uniform temperature (ISO 13789, 2007).

“ISO 13370, Heat transfer via the ground” provides methods of calculation of heat transfer coefficients and heat flow rates for building elements in thermal contact with the ground, including slab-on-ground floors, suspended floors and basements. It applies to building elements, or parts of them: for slab-on-ground floors, below a horizontal plane in the bounding walls of the building situated, for suspended floors and unheated basements, at the level of the inside floor surface; for heated basements, at the level of the external ground surface (ISO 13370, 2007).

In EnEV 2009, the primary energy demand for the heating and cooling system of commercial buildings is determined in accordance with DIN V 18599.

The primary energy demand for the heating and the heating function of the ventilation and air-conditioning system is to be balanced when, in the case of heating, the target room temperature of the building or a building zone is at least 12°C and it is intended that the building heating will be used to heat to the target room temperature for an average period of at least four months per year.

The primary energy demand for the cooling system and the cooling function of the ventilation and air conditioning is to be balanced when the use of cooling technology is provided to cool the building or a building zone and it is intended that the building cooling will be used to cool to the target room temperature for more than two months per year and more than two hours per day.

Maximum values of heat transfer coefficients of the heat transmitting surface area of commercial buildings, which stated in EnEv 2009, is given in Table 2.2.

Table 2.2 : Design of the reference building.

Line	Component/System	Parameter (for line: 1.1 to 1.13)	Reference design/value (measuring unit)	
			Target room temperatures in case of heating to $\geq 19^{\circ}\text{C}$	Target room temperatures in case of heating to between 12°C and $\leq 19^{\circ}\text{C}$
1.1	Outside wall, storey ceiling against external air	Heat transfer coefficient	$U = 0.28 \text{ W}/(\text{m}^2\text{K})$	$U = 0.35 \text{ W}/(\text{m}^2\text{K})$
1.2	Curtain wall (see also line 1.14)	Heat transfer coefficient	$U = 140 \text{ W}/(\text{m}^2\text{K})$	$U = 1.90 \text{ W}/(\text{m}^2\text{K})$
		Overall energy permeability of the glazing	$g^{\perp} = 0.48$	$g^{\perp} = 0.60$
		Level of light transmission of the glazing	$\tau_{D65} = 0.72$	$\tau_{D65} = 0.78$
1.3	Wall against ground, foundation slabs, walls and ceilings unheated spaces (except components in accordance with line 1.4)	Heat transfer coefficient	$U = 0.35 \text{ W}/(\text{m}^2\text{K})$	$U = 0.35 \text{ W}/(\text{m}^2\text{K})$
1.4	Roof (if not under Line 1.5), top-floor ceiling, walls to long pane of roof	Heat transfer coefficient	$U = 0.20 \text{ W}/(\text{m}^2\text{K})$	$U = 0.35 \text{ W}/(\text{m}^2\text{K})$
1.5	Glass roofs	Heat transfer coefficient	$U_w = 2.7 \text{ W}/(\text{m}^2\text{K})$	$U_w = 2.7 \text{ W}/(\text{m}^2\text{K})$
		Overall energy permeability of the glazing	$g^{\perp} = 0.63$	$g^{\perp} = 0.63$
		Level of light transmission of the glazing	$\tau_{D65} = 0.76$	$\tau_{D65} = 0.76$
1.6	Light bands	Heat transfer coefficient	$U_w = 2.4 \text{ W}/(\text{m}^2\text{K})$	$U_w = 2.4 \text{ W}/(\text{m}^2\text{K})$
		Overall energy permeability of the glazing	$g^{\perp} = 0.55$	$g^{\perp} = 0.55$
		Level of light transmission of the glazing	$\tau_{D65} = 0.48$	$\tau_{D65} = 0.48$
1.7	Dome lights	Heat transfer coefficient	$U_w = 2.7 \text{ W}/(\text{m}^2\text{K})$	$U_w = 2.7 \text{ W}/(\text{m}^2\text{K})$
		Overall energy permeability of the glazing	$g^{\perp} = 0.64$	$g^{\perp} = 0.64$
		Level of light transmission of the glazing	$\tau_{D65} = 0.59$	$\tau_{D65} = 0.59$
1.8	Windows. French windows (see also line 1.14)	Heat transfer coefficient	$U_w = 1.3 \text{ W}/(\text{m}^2\text{K})$	$U_w = 1.9 \text{ W}/(\text{m}^2\text{K})$
		Overall energy permeability of the glazing	$g^{\perp} = 0.60$	$g^{\perp} = 0.60$
		Level of light transmission of the glazing	$\tau_{D65} = 0.78$	$\tau_{D65} = 0.78$
1.9	Skylights (see also line 1.14)	Heat transfer coefficient	$U_w = 1.4 \text{ W}/(\text{m}^2\text{K})$	$U_w = 1.9 \text{ W}/(\text{m}^2\text{K})$
		Overall energy permeability of the glazing	$g^{\perp} = 0.60$	$g^{\perp} = 0.60$
		Level of light transmission of the glazing	$\tau_{D65} = 0.78$	$\tau_{D65} = 0.78$
1.1	Outside doors	Heat transfer coefficient	$U = 1.80 \text{ W}/(\text{m}^2\text{K})$	$U = 2.90 \text{ W}/(\text{m}^2\text{K})$

2.3.2 Visual comfort, lighting system performance and energy calculation standards

The major international organization in charge of coordinating the management of standards, recommendations, and technical reports in the field of lighting is the Commission Internationale de l'Eclairage (CIE). The CIE has published several recommendations for indoor lighting and has contributed to a joint ISO-CIE standard ISO 8995-1 (CIE, 2001/ISO 2002) concerning indoor working places.

There are a number of regulations, codes and standards that stipulate the provisions, requirements and criteria for good natural light in buildings, which identify daylight as able to counteract premature fatigue and to promote attentiveness (BS-8206, 1992) (Rea, 2000).

A variety of documents exist to ensure visual comfort conditions in indoor spaces. Some of the relevant standards and directives that are related to lighting are listed in Table 2.3.

Table 2.3 : European and international standards.

Subject	European Standard	International Standard
Lighting of workplaces – indoor workplaces	EN 12464-1:2003	-
Lighting of workplaces – outdoor workplaces	EN 12464-2:2007	CIE S 015/E:2005
Light and lighting – Sports lighting	EN 12193:1999	-
Emergency lighting	EN 1838	CIE S 020/E:2007
Emergency lighting – testing and inspection	EN 50172:2004	-
Road lighting practice	EN 13201-1/4:2004	-
Energy performance of buildings, lighting	EN 15193:2007	-
Radiation exposure limits	EN 14255	-
Maintenance of indoor electric lighting	-	CIE 97.2
Lighting education	-	CIE 99
Discomfort glare in interior lighting UGR	-	CIE 117
Obtrusive light	-	CIE 150
Maintenance of outdoor electric lighting	-	CIE 154

The European Commission has ruled on health and safety regulations in Europe and published the European standard on lighting EN 12464-1 (Light and lighting - Lighting of work places - Part 1: Indoor work places) which specifies lighting requirements for indoor work places that meet the needs for visual comfort and performance. All usual visual tasks are considered under this standard, including Display Screen Equipment (DSE), lighting design criteria, schedule of lighting requirements, and verification procedures.

EN 12464-1 highlights the minimum illuminance requirements of an actual working area rather than the entire room. The guidelines recommended that the lighting outside the working area should be adapted to the conditions that apply inside the working area. As it is seen in Figure 2.9, the working area is defined according to EN12464-1 as the area of the workspace in which task are performed. The areas where the size and/or placement of the working area is unknown or the

area where the task may be performed is to be considered as the working area and can be taken 0,6 m by 0,6 m for an office workplace. In this case the working area is thought to be located directly in front of the person's normal position and at the front edge of the desk. The lighting of the immediate surrounding area should relate to the lighting level within the working area and in addition, create the conditions for a well-balanced luminance distribution with the normal field of vision. Extensive changes to the light level around the working area can cause visual stress and discomfort. The immediate surrounding area is defined as an area around the working area with a width of at least 0,5 metres. The size of the immediate surroundings should be determined by the planner and may need to be increased to a width greater than 0,5 metres for specific types of workplaces. There are no defined demands in the illuminance for the peripheral surrounding areas in the EN 12464-1, which is the area outside of the immediate surrounding area. This area is defined as the area outside the surrounding areas, to a distance of 0,5 metres from the room's wall.

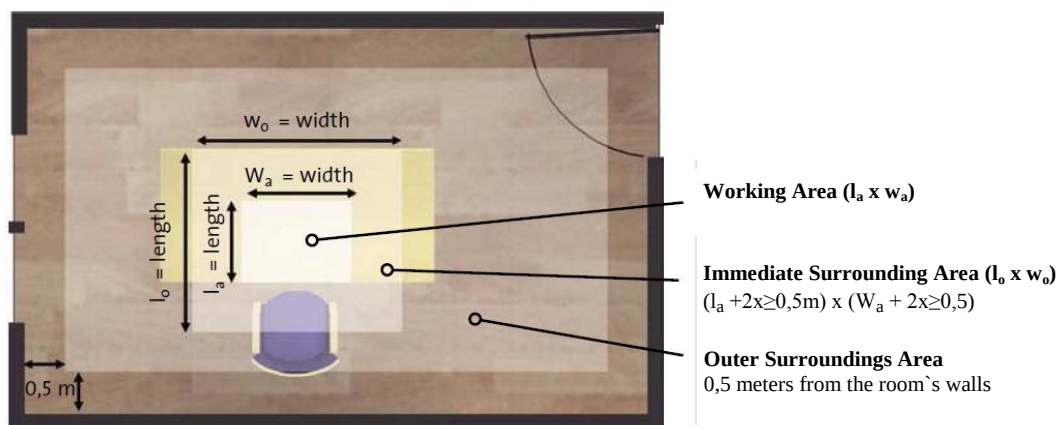


Figure 2.9 : Office desk working area (EN 12464-1, 2002).

Uniformity within the space is important and relations between different illuminances and uniformity demands can be seen in the Table 2.4.

Table 2.4 : Table of uniformity demands and the relation between illuminances within the immediate surroundings of the working area.

Illuminance within the working area	Illuminance within the immediate surroundings
$\geq 750 \text{ lx}$	500 lx
500 lx	300 lx
300 lx	200 lx
$\leq 200 \text{ lx}$	200 lx
Uniformity ($E_{\min}/E_{\text{ave}}$) $\geq 0,7$	Uniformity ($E_{\min}/E_{\text{ave}}$) $\geq 0,5$

Some of the norms have been implemented to ensure work place safety and adequate ergonomic working conditions such as: German Industrial Standard DIN 5035 “Artificial lighting of interiors”. DIN 5035 defines work safety as one of the goals of lighting, along with quality, effect on human visual performance, activation and well-being. In Part 2 of DIN 5035, the basic requirements for work environments are defined. Such documents rely on measurable physical parameters. Notable requirements that are indicated in DIN 5035 are minimum illuminance levels at work plane height and maximum luminance levels and contrast with direct view of a PC work place to avoid glare.

Like all electrical work, lighting installations must be compliant to regulations and be properly and safely installed. Lighting products also have to be compliant with standards. Lighting standards cover two areas, performance and safety. Performance standards address lighting design, covering illumination levels in specific applications, luminance conditions of luminaires, etc. For instance, in order to conform to EN 12464-1 demands, luminance conditions are recommended for the work place as follows: the working area (inner field of vision) - immediate surroundings (the near field) 3:1; the working area (inner field of vision) - surroundings (adjacent walls within the field of vision) 5:1; the working area (inner field of vision) – periphery wall surfaces (background) 10:1.

Safety issues are also a topic of the standards, which defines the absolute minimum requirements to which the products should conform. All installations should be appropriate to ensure the standards are met.

Components in luminaires, such as fluorescent ballasts, starters, transformers and lamp holders, must be approved and the product must be fully traceable to tests and standards.

Directive 2005/32/EC of the European Parliament promotes environmentally conscious product design (eco-design) and contributes to sustainable development by increasing energy efficiency and the level of environmental protection. According to the EU directive, lighting products have been selected as one of the priority product groups. Preparatory studies have been prepared for street, office and residential lighting products. These regulations give generic and specific requirements for lamps, luminaires and ballasts.

Some of the relevant standards and directives which are related with lighting are listed in Table 2.5.

Table 2.5 : European and international standards.

Subject	European Standard	International Standard
Luminaires – General requirements and tests	EN 60598-1	-
Luminaires – General types	EN 60598 2-1	IEC 60598-2-1
Luminaires – Recessed	EN 60598 2-2	IEC 60598-2-2
Luminaires – Street lighting	EN 60598 2-3	IEC 60598-2-3
Luminaires – Floodlights	EN 60598 2-5	IEC 60598-2-5
Luminaires – with transformers	EN 60598-2-6	IEC 60598-2-6
Luminaires – Air handling	EN 60598 2-19	IEC 60598-2-19
Luminaires – Emergency	EN 60598 2-22	IEC 60598-2-22
Luminaires Track systems	EN 60570	IEC 60570
Photometric Measurements	-	CIE 24/CIE 27
Photometry and data transfer	EN 10302-1: 2004	-
Photometry for workplace luminaires	EN 10302-2: 2004	-
Photometry for emergency luminaires	EN 13032-3: 2007	-
EMC Emissions-Lighting	EN 55015	CISPR 15
EMC Immunity-Lighting	EN 61547	IEC 61547
Quality Systems	EN ISO 9000	ISO 9000
Emergency Lighting	EN 1838	-
Electronic transformers for lamps	EN 61347-2-2	IEC 61347-2-2

German Industrial Standard DIN 5034 "Daylight in Interiors" and Illuminating Engineering Society of North America (IESNA) (Rea, 2000) recommends simple calculation methods and spread sheets to estimate the daylight availability for buildings.

It is essential to specify the minimum standards for the energy performance of buildings when providing energy efficiency improvements. Some of national building energy codes (US and Canada) (ASHREA/IESNA, 1999) (The Canadian Commission on Building and Fire Codes, 1995) have listed the maximum installed

artificial lighting power densities in work places in order to limit the electricity demand in commercial buildings and encourage the usage of daylight to substitute artificial lighting.

In Europe, The Lighting Energy Numeric Indicator (LENI) has been established to show the annual lighting energy per m² required to fulfil lighting requirements in the building specifications (EN 15193, 2007).

The LENI can be used to make direct comparisons of the lighting energy used in buildings which have similar categories with different sizes and configurations. The standard considers different aspects of energy consumption, namely: installed load, usage during the day, usage at night, use of constant illuminance, standby and algorithmic lighting and scene setting.

In summary, within any given community, ordinances, such as the German Energy Saving Ordinance (EnEV 2009), may regulate the energy performance in buildings. Minimum requirements for heating, cooling and air conditioning systems, as well as water systems and energy inspections of air condition systems are often set forth by local, state or national law. In regards to thermal comfort and energy demand, several standards set forth by the International Organization for Standardisation provide calculation methods of energy use for space heating and cooling of a residential or a non-residential building. Governing bodies such as the European Union also issue directives regarding the energy efficiency of lighting, an area which is targeted because of the great potential for energy savings. For example, German Industrial Standards define work safety goals for work place safety, human visual performance, activation and well-being related to lighting. European and International standards further stipulate performance and safety for all electrical product work. Various models for determining thermal comfort and lighting energy usage have been developed in order for architects and engineers to design within the given parameters of a community. Thus, building designers and especially HVAC and lighting designers, must consider all of these standards, guidelines and directives when designing a new building or a major renovation to ensure the results are relevant, efficient, and comfortable for the end user.

3. URBAN ENVIRONMENT AND ENERGY USE

Cities are progressively expanding their boundaries and populations. The increased urbanization and industrialization of the recent years have dramatically affected the number of the urban buildings and population.

Globally, the number of the urban inhabitants rose from 2,5 billion in 1950 to nearly 7 billion in 2012. If this growth continues, more than 9,5 billion people will live in cities by 2050 (United Nations, 2012). Current and projected urban and rural populations by major area, as reported by the United Nations, are given in Figure 3.1.

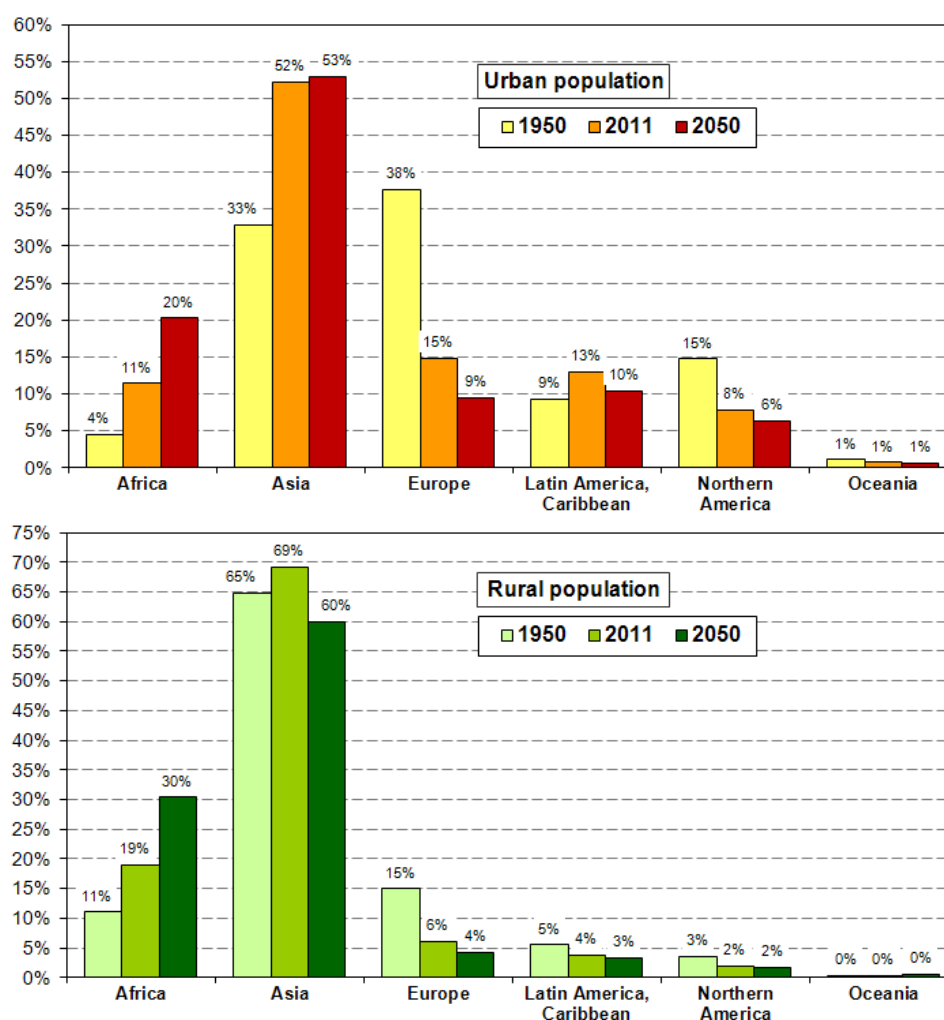


Figure 3.1 : Distribution of the world urban and rural population by major area (United Nations, 2010).

The urban environment is not just the collection of buildings; it is also the physical result of various economic, social and environmental processes that are strongly related to the standards and needs of society (Asimakopoulos et al., 2001).

Development of the urban environment has major effects on energy consumption and serious effects on global environmental quality. The main concerns are the quality of the air, increase in temperature, increased use of raw material and loss of biodiversity.

Buildings, the main component of urban structure, are the most important energy consuming economic sector. Energy consumption in buildings represents close to 40 % of the world's total energy use, including climate control and energy used for appliances, lighting and other installed equipment (Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings, 2008). Studies by the International Energy Agency (IEA) show that a long-term 70 % reduction in energy consumption is possible in new buildings in most Organisation for Economic Co-operation and Development (OECD) countries, with little or no additional total costs for the owners. The IEA estimates that the total feasible potential for energy savings by renovation and refurbishment in most OECD countries would be around 50 % of actual consumption.

Urban planning has a considerable impact on the future energy efficiency of buildings. In terms of their energy and environmental efficiency, the design of the morphology should mainly consider both solar accessibility and pollution dispersion aspects.

When the urban density increases, buildings closely packed together decrease the availability of natural elements such as sun and wind. Designing in the real world should be discussed within the context of both science and politics. It is necessary to understand and examine both dimensions in order to resolve problems and develop implementable solutions.

3.1 Urban Structure and the Legal Framework for Land Use Zoning

Zoning, which may regulate building height, lot coverage, and similar characteristics, is used in urban planning as a system of land-use regulation in various parts of the world. Municipalities are generally permitted by provincial acts to enact municipal

zoning bylaws. They regulate building size, land use (including type of occupancy), front and side yard clearances, orientation, population density and sometimes even landscaping and the exterior appearance of buildings. Urban zoning is illustrated in Figure 3.2.

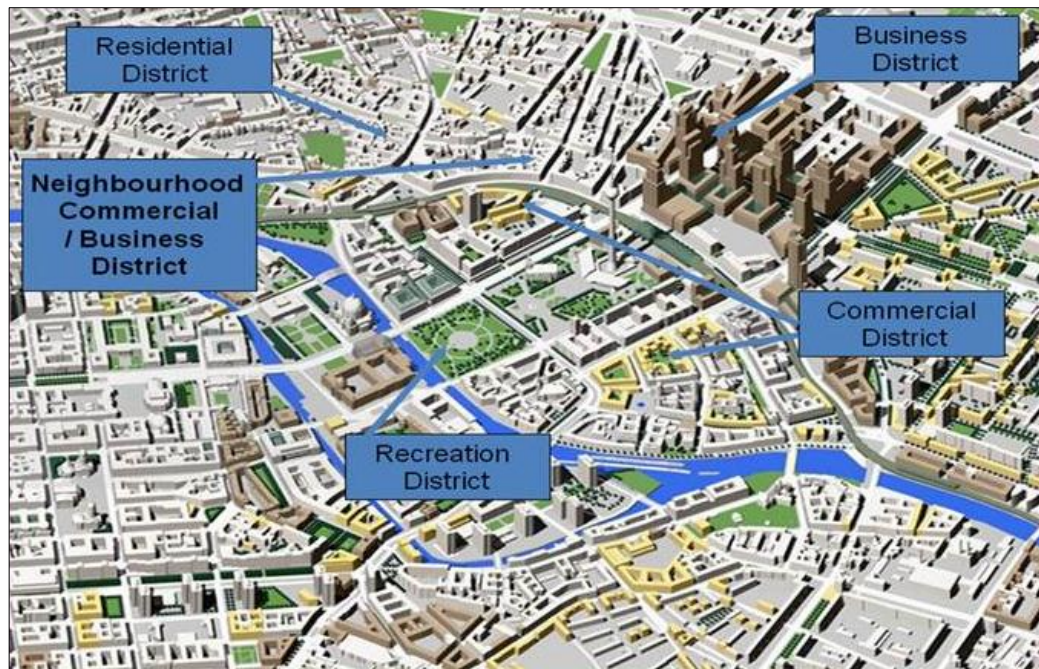


Figure 3.2 : Urban zoning.

The Concentric Zone model was the first to explain the distribution of social groups within urban areas. Based on one single city, Chicago, it was created by the sociologist Ernest Burgess in 1924. According to this model, a city grows outward from a central point in a series of rings. The innermost ring represents the central business district. It is surrounded by a second ring, the zone of transition, which contains industry and poorer-quality housing. The third ring contains housing for the working-class and is called the zone of independent workers' homes. The fourth ring has newer and larger houses usually occupied by the middle-class. This ring is called the zone of better residences. The outermost ring is called the commuter's zone. This zone represents people who choose to live in residential suburbs and take a daily commute into the central business district to work.

A central business district is the commercial and often geographic heart of a city. The phrase is often abbreviated to "CBD" (Central Business District). The CBD is characterised by a higher-than-usual urban density, as well as often having the tallest buildings in a city. The shape and type of a CBD almost always closely reflect the

city's history. Cities with maximum building height restrictions often have a separate historic section quite apart from the financial and administrative district.

The land use in the central business district may follow the core frame model of urban structure and is likely to have many of the following characteristics:

- Geographical centre of the settlement
- Land use
 - Distinct land use patterns different from the surrounding areas
 - High concentration of public buildings and offices
 - Very tall buildings to maximise land use of expensive real estate
 - Activities concentrated in areas of functional zoning
 - Major retail outlets (less the case for United States and Canada)
- Transport
 - High concentration of traffic
 - Great concentration of pedestrians
 - High use of public transport

Zoning is a device of land use planning used by local governments in most developed countries (Lefcoe, 2005). Zoning may be use-based (regulating the uses to which land may be put), or it may regulate building height, lot coverage, and similar characteristics, or some combination of these. Zoning is commonly controlled by local governments such as counties or municipalities, though the nature of the zoning regime may be determined or limited by state or national planning authorities or through enabling legislation.

In Australia, land under the control of the Commonwealth (Federal) government is not subject to state planning controls. The United States and other federal countries are similar. Zoning and urban planning in France and Germany are regulated by national or federal codes. In the case of Germany, this code includes contents of zoning plans as well as the legal procedure. Zoning may include regulation of the kinds of activities which will be acceptable on particular lots, the densities at which those activities can be performed, the height of buildings, the amount of space structures may occupy, the location of a building on the lot, and the proportions of the types of space on a lot, such as how much landscaped space, impervious surface, traffic lanes, and parking.

Germany is the birthplace of zoning. From the 19th century to the present, German zoning practices have evolved over 100 years. As the urban detailed plan, the Bebauungsplan (B-plan: The German terminology “der Bebauungsplan” means “the legally binding land-use plan” or “the local development plan” (Yin, 2008). The stages of spatial planning system of Germany can be seen in Figure 3.3.

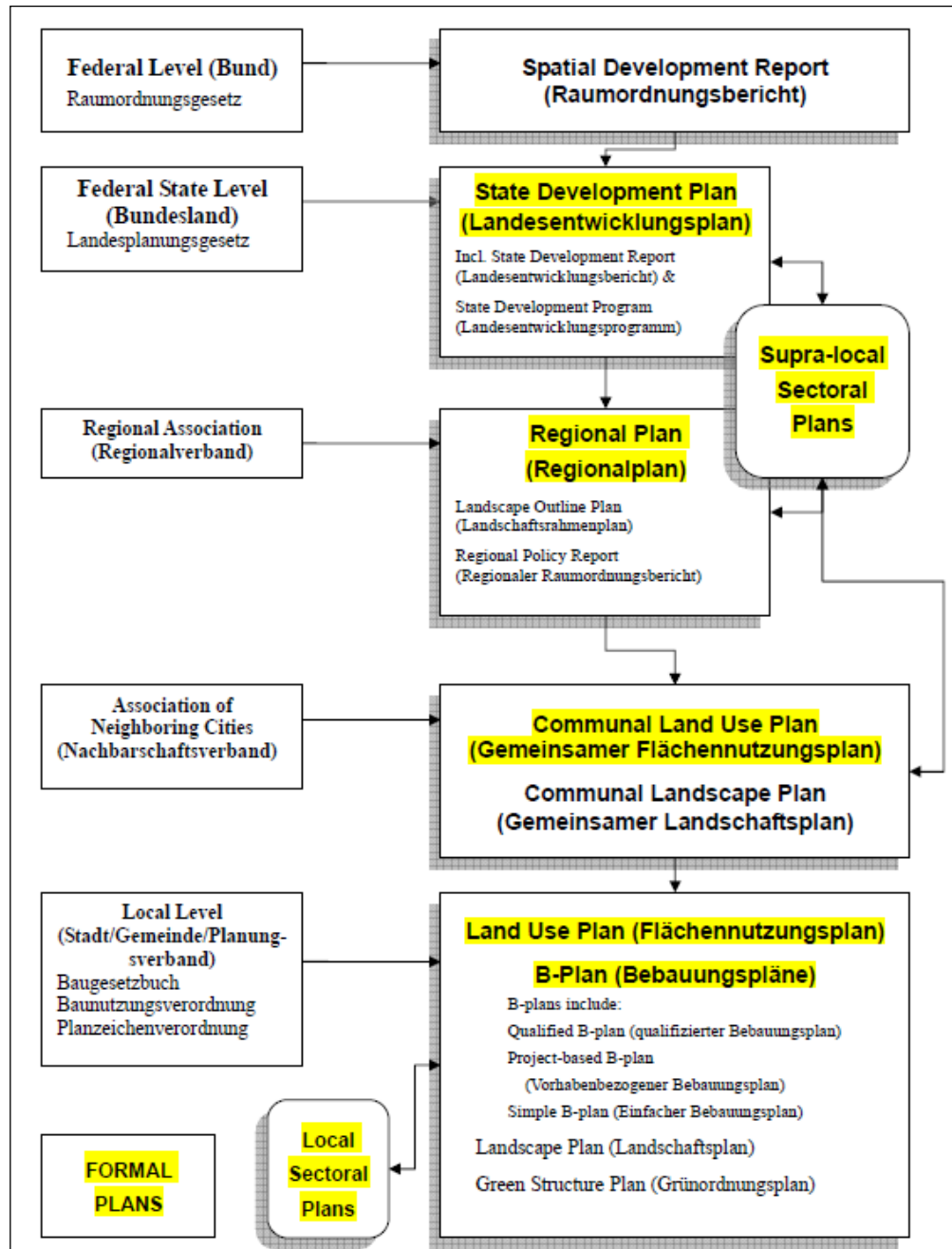


Figure 3.3 : Spatial planning system of Germany (Hangarter, 2006).

As the local statute, the German B-plan is an integral part of the German legal system. The primary German acts and ordinances related to the B-plan are: The Federal Building Code (Baugesetzbuch), The Land Utilization Ordinance

(Baunutzungsverordnung), The Planning Symbols Ordinance (Planzeichenverordnung), as well as The Federal State Building Ordinance (Landesbauordnung). Moreover, other relevant acts, for instance, The Federal Nature Protection Act (Bundesnaturschutzgesetz), must also be carefully considered and implemented.

The Federal Building Code (Baugesetzbuch), which forms the main body of the German urban planning acts, constructs the German urban planning system, a regulates the planning principals and procedures and guides the preparation and implementation of urban planning (Bundesministerium für Verkehr, 2006).

The Land Utilization Ordinance (Baunutzungsverordnung) provides the technical requirements for B-planning. First of all, it defines the types of building and land uses that are classified as the construction sites (Bauflächen) and the building sites (Baugebiete). Content and classification standards for each land use type are explained. Secondly, it clarifies the control requirements for the degree of building and land use, such as the site occupancy index (GRZ), plot ratio (GFZ), cubic density (BMZ), and coverage type (Bauweise). The control requirements for secondary structures are also available in this ordinance. For instance, the control requirements for garage and parking space are also explained and defined (BauNVO, 1993).

The Planning Symbols Ordinance (Planzeichenverordnung) provides the legally binding terminologies and legends for urban planning, which include the type and degree of building and land use, coverage type, building line (Baulinie), building restriction line (Baugrenze), public facilities, spaces for transportation, municipal utilities, green spaces, water bodies, topographic engineering, agricultural land and woodland, spaces for environmental protection and historic preservation. Matching the legal provisions in the Land Utilization Ordinance, mapping standards are the key to understanding B-plans (Planzeichenverordnung (PlanzV 90), 1990).

In Germany, federal states have a high degree of autonomy. Based on the local historic tradition and environment, The Federal State Building Ordinance (Landesbauordnung) provides detailed requirements for urban planning and architecture, which should be integrated in the B-plans. For example, The Federal State Building Ordinance of Baden-Württemberg (LBOBW) (revised edition 2004) includes nine parts: general provisions; building activities on the plot; general

requirements for building; building types; building parts; dwellings, as well as other structures; affected parties and building administrative authorities, administrative procedures and building responsibilities; and acts and ordinances. The LBOBW regulates many details of building behaviour which cover the classification of building types, interrelations among buildings, internal structures, related facilities, building administration (Landesbauordnung für Baden-Württemberg LBO- BW, 2005).

3.2 Urban Climate and Energy

Inadequacies in development control have great impact on urban climate and the environmental efficiency of buildings. The increasing densities of cities are associated with decreasing numbers of vegetation and trees. This situation has resulted in changes in the heat balance. Air temperature in densely built urban areas is higher than the temperatures of surrounding areas.

According to Oke (Oke et al., 1991), the urban heat island is defined as the maximum temperature difference between the city and surrounding area. Various sources show that heat island intensity can be as high as 15 °C (Santamouris et al., 1999). Because of scattering and absorption, global solar radiation can be seriously reduced. In addition, the specific roughness of a city influences wind speed through urban canyons.

Increased urban temperatures affect the concentration and distribution of urban pollution because heat accelerates the chemical reactions in the atmosphere that lead to high ozone concentrations. It is estimated that in Europe, the level of air pollution exceeds the World Health Organization (WHO) standards at least once in a year (Stanners and Bourdeau, 1995). The impact of outdoor conditions on the indoor climate, as well as the relation between outdoor and indoor pollution, are obvious concerns of buildings physics.

Buildings are the largest energy consumers in cities. International Energy Agency (IEA) splits final energy consumption into three main sectors: industry, transport and 'other', included in the latter are agriculture, service sector and residential uses (Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings, 2008). Building energy consumption has risen with population growth to the levels of transport and industry, together with the rise in time spent

inside buildings. Table 3.1 shows the significant reduction of the ratio of industry and the expansion of ‘other’ due to buildings.

Table 3.1 : World final energy consumption by sector (Key World Energy Statistics, 2006).

Final energy consumption by sector (%)	1973	2004	Ratio
Industry	39	30	0.76
Transport	25	28	1.14
Other sectors	36	42	1.16

Many international, national and regional sources divide building energy consumption into two categories: commercial and residential buildings, which can be seen in Table 3.2 (Key World Energy Statistics, 2006).

Building consumption of EU was 37% of final energy in 2004. The proportion of energy use in buildings in the UK is slightly above the European number, mainly due to the increase in service sector activities compared to heavy industry.

Table 3.2 : Weight of buildings energy consumption.

Final energy consumption (%)	Commercial	Residential	Total
USA	18	22	40
UK	11	28	39
EU	11	26	37
Spain	8	15	23
World	7	16	24

Year 2004 / Sources: EIA, Eurostat, and BRE.

Today it is well accepted that urbanization leads to a very high increase in energy use. As stated in World Bank analysis, 1% of increase in the Gross National Product (GNP) per capita relates to an almost equal (1,03%) increase in energy consumption. On the other hand, the rate of increase in energy consumption is twice the increase of the urban population (Jones, 1992).

Higher urban temperatures have a serious impact on the electricity demand for air conditioning of buildings. Watanabe et al. (Watanabe, Yoda and Ojima, 1990/91), analysed the land temperature distribution and thermal environment of Tokyo metropolitan area. Their analysis showed that there is much higher energy consumption in the central Tokyo area. Santamouris et al. reported that the cooling

load of a reference building at the centre of Athens is about the double that in the surrounding city area (Santamouris et al., 1999).

Increase in energy consumption in urban areas puts a high stress on utilities that must supply the necessary additional load. Construction of new generating plants may solve the problem, but this is not a sustainable solution. Benefiting from passive design strategies that provide a more efficient use of energy seems to be a much more reasonable option.

3.3 Solar Energy and Daylight Availability in Urban Context

The sun is practically the only source of energy that influences our climate. The rate of total solar energy at all wavelengths incident on a unit area exposed normally to rays of the sun at one astronomical unit is called the solar constant. Table 3.3 shows the distribution of the extra-terrestrial energy within different wavelength bands.

Table 3.3 : Distribution of extra-terrestrial energy within different wavelength bands.

	Wavelength (μm)	Irradiance (W/m^2)	% of the solar constant
Ultraviolet	< 0,4	109,81	8,03
Visible	0,39-0,77	634,4	46,41
Infrared	> 0,77	634,4	46,41

The radiation balance R in the urban environment is the sum of the incoming absorbed short and long wave radiation minus the long wave radiation emitted by components of the Earth surface **(3.1)**:

$$R = (I_b + I_d)(1 - \alpha) - I_1 \quad (3.1)$$

where the I_b and I_d are the beam and diffuse solar radiations incident on the surface of the city, α is the mean albedo of the city to the solar radiation, and the term I_1 refers to the long wave radiation balance **(3.2)**:

$$I_1 = I_{1\uparrow} - I_{1\downarrow} \quad (3.2)$$

where $I_{1\uparrow}$ is the long wave radiation emitted by the city surface and $I_{1\downarrow}$ is the long wave atmospheric radiation absorbed by city structure.

Absorbed solar radiation is a direct function of the mean albedo of city. The albedo α is defined, with reference to a spherical coordinate system, as (3.3):

$$\alpha = \frac{\int_{\lambda_1}^{\lambda_2} \int_0^{2\pi} I \uparrow \cos(\theta) d\omega d\lambda}{\int_{\lambda_1}^{\lambda_2} \int_0^{2\pi} I \downarrow \cos(\theta) d\omega d\lambda} \quad (3.3)$$

where I is the radiant intensity [W/m^2], θ is the zenith angle, defined as the angle between the normal to a surface and the incident beam, λ is the wavelength and ω is solid angle, defined as the ratio of a partial spherical area of interest to the square of the sphere radius. The up and down arrows indicate the reflected and incident radiation respectively.

Use of high albedo materials reduces the amount of radiation absorbed through building envelopes and urban structures and thus, keeps their surfaces cooler.

In the atmosphere, clouds reflect about 19% of the mean annual energy back to space and absorb about 5%. Atmospheric constituents scatter and reflect about 6% to space and absorb about 20%. The remainder of the original beam is transmitted to the Earth's surface, where approximately 3% is reflected back into space and the remaining 47% is absorbed. Way of solar radiation through the atmosphere can be seen in Figure 3.4.

Extra-terrestrial solar radiation is modified when passing through the atmosphere. The portion of the incoming radiation that is reflected and scattered, together with the portion that is reflected between the surface and the atmosphere, gives the diffuse solar radiation. Finally, the portion of incoming solar radiation that arrives at the Earth's surface, without being absorbed or diffused, is called direct beam short wave radiation.

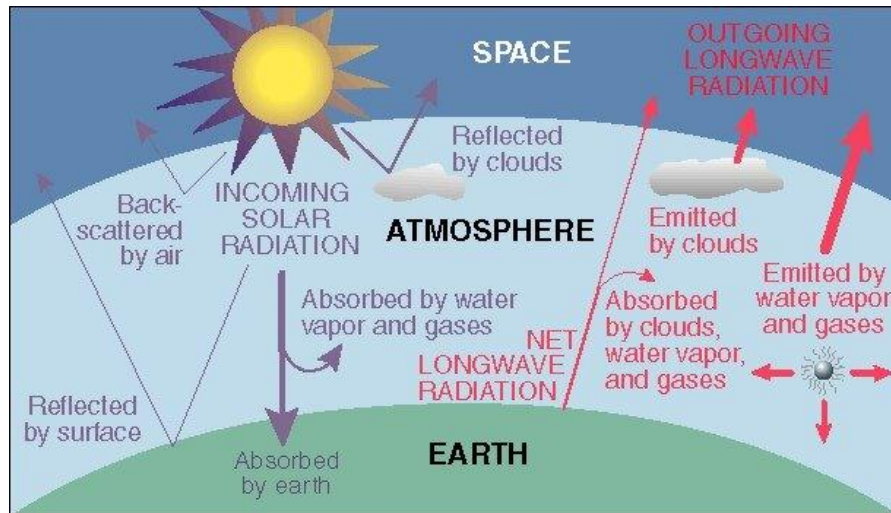


Figure 3.4 : Way of solar radiation through the atmosphere (Markewich et al., 2001).

3.3.1 Urban form characterisation for solar evaluation

In order to study the solar distribution at the surface of an urban canyon, one should identify the basic units of structures that are repeated in the urban area. There are probably no truly representative urban surfaces, such as those that can be identified as characteristic of rural and other natural terrains. Urban units that can be formed consist of the more or less geometric combinations of horizontal and vertical surfaces arising from the block-like arrangement of buildings and streets. These units reflect the essentially three dimensional nature of the urban canopy.

The importance of urban geometry has been demonstrated by using observations and both numerical and scale models in different research projects. The characterisation of the urban form is defined by different variables: number of floors, building depth to frontal length, grid azimuth, base block dimension and the aspect ratio on both orientations.

Martin and March (1972) examined a number of simplified or archetypal forms (Figure 3.5) in order to limit the complexities found in real urban textures, at a time when the abilities of computer software were limited.

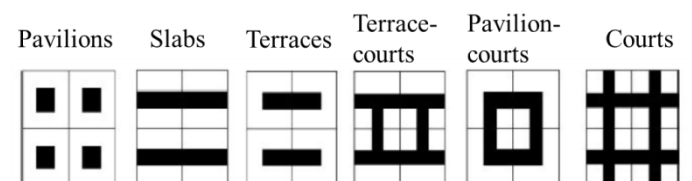


Figure 3.5 : Generic urban forms, based on Martin and March (Ratti et al., 2003).

Oke (1981) proposed the height-to-width ratio of street canyons (the aspect ratio). Now this approach is generally accepted as a quantitative geometry of the urban canopy layer (UCL) used to work on microclimatic issues. As stated by Ratti et al., “The adoption of Martin and March's archetypal urban forms has been extensive during the last three decades in various kinds of researches, specifically those aiming at assessing aspects of the environmental behaviour of urban form” (Ratti, Raydan and Steemers, 2003). Meir et al. (Meir, Pearlmutter and Etzion, 1995) used the semi-enclosed courtyards typology in their research on the microclimatic behaviour in hot dry regions (Meir, Pearlmutter and Etzion, 1995). For example, Gupta (1987) examined three building forms (pavilion, street canyon and courtyard) and attempted to investigate the link between the solar exposure and thermal performance of buildings with respect to some form parameter. Again utilizing generic urban forms, Martin and March's simplified forms have influenced various scholars to employ simple forms, thus eliminating the complexities found in real the urban structure.

Moreover, the generic street forms are used in Shashua-Bar et al.'s (Shashua-Bar, Tzamir and Hoffman, 2004) work to evaluate the thermal effects. In recent studies of Shashua-Bar et al.'s (Shashua-Bar, Hoffman and Tzamir, 2006) the urban form is specified quantitatively by three generic variables: defined by geometric ratios (see Figure 3.6) for definition of length components, spacing distance to frontal length (L_1/L_2) and building depth to frontal length (D/L_2), aspect ratio (H/W).

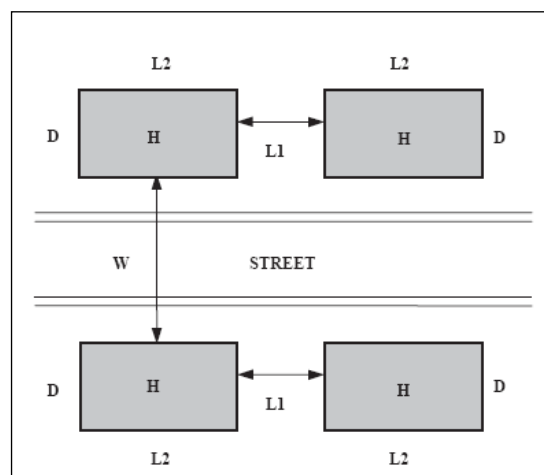


Figure 3.6 : The separated form structure.

H, D, L_2 , refer to the height, depth, and frontal length of each unit. L_1 refers to the spacing between the units and W refers to the width of the street.

3.3.2 Shading effects from nearby buildings

Shading has major influence on the illuminance of a plane that is exposed to sunlight. At windows, particularly of non-domestic buildings, shading is necessary to avoid overheating. Shading of facades, however, reduces the solar gain for winter season and should be avoided.

Shading arrangement should be analysed during the design process because it can significantly affect thermal and visual comfort. The key issues in urban planning for solar availability are: understanding the shadow patterns of the proposed design, to assess its impact on the solar availability of areas surrounding buildings and the protection of future buildings by not locating the structure in the shade.

Several techniques can be used for determining the impact of the proposed building on surrounding buildings and/or for estimating the shading caused by surrounding structures. One of the techniques is a shading factor technique. The shading factor is the ratio of the “illuminated area of the façade” to the “total area of façade”, which is determined by the sun and changes throughout a day. The sunlight availability can also be calculated by finding probable sunlight hours received at any point in a building. The sun path indicator can be used to find the times of the day and year for which sunlight is available on a window. Those techniques are constructed on the basis of the solar location at different latitudes and the heights of the obstruction that might block the light.

When a plane is shaded by an obstacle, not only the direct light is affected but also the diffuse irradiance. This comes from the complete sky dome, but the obstacle may block a part of it.

To determine the fraction of the unobstructed sky that is seen at an observation point, the “view factor” is used in several researches. The view factor is the ratio of the “solid angle of visible sky” to the sum of the “solid angle of visible sky” and the “solid angle of the obstructed” sky. The sky view factor remains constant throughout the year and does not depend on the sun position. The diffuse irradiation is permanently reduced by this factor. However, one problem with this method is that the view factor is valid for one point of the facade only. It does not represent all the transparent area of the space. Two points situated apart from each other will have different sky view factors.

The sky view factors of urban surfaces have been shown to be associated with microclimatic conditions such as the level of daylighting and radiant cooling potential. Traditionally, a fish-eye lens is used to capture a sky view in a real urban setting. The sky view factor can then be measured from the image. With computer aided design software, it is now possible to obtain fish-eyes images from computer models and therefore, the sky view factors of design schemes or imaginative urban forms can be measured. It is, however, time consuming to make such measurement for the whole urban area since the average of numerous points is required. Ratti developed an image processing technique to calculate the sky view of an urban area based on digital elevation models, which expedites the process of calculating the average sky view factors of the ground (Ratti, Raydan and Steemers, 2003). Teller et al. define sky opening as an indicator of "the perceptive confinement felt by an observer located in the open space" (Teller and Azar, 2001). An example of sky view factor of a district is given by Figure 3.7.



Figure 3.7 : Sky view factor of a district.

Trying to maximize the indoor daylight use in urban contexts, Leder proposed the Preferable Sky Window parameter (Leder, Pereira, Claro, 2007). The Preferable Sky Window has been applied to provide design constraints that would guarantee certain levels of daylight availability in the urban environment. The Preferable Sky Window parameter consists of a sky zone; see Figure 3.8, which identifies the sky section that has the greatest daylight potential in a horizontal plan located in the indoor environment. The zone is defined by horizontal limits of 45° to the left and 45° to the right, and vertical limits from 15° to 60° from the horizon line.

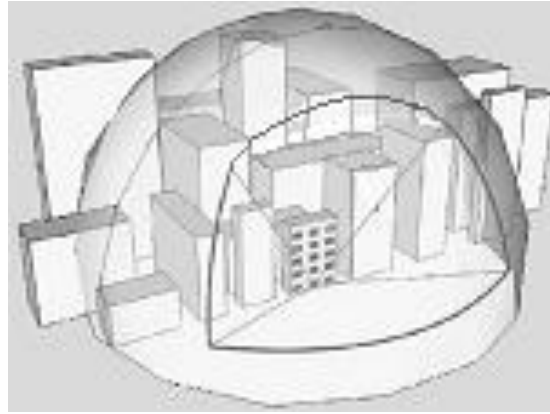


Figure 3.8 : The concept of the preferable sky window zone.

The Preferable Sky Window sky portion has a visible sky factor of 32%, while the remaining area, or the sky outside the Preferable Sky Window zone, and has a visible sky factor of 68%. A comparison between Preferable Sky Window zone and the remaining sky area showed that the Preferable Sky Window impacted the daylight availability in interior rooms 1.5 to 2 times more than the remaining sky area (Leder, Pereira, Claro, 2007).

It is difficult to decide on the position of windows in the urban design stage, but it is suggested to check the sunlight availability at some specific points on the building within different recommendation and standards. The British standards (Littlefair, 1991) recommend that sun light availability be checked at the point 2 m above the lowest storey level of each main window wall faces within 90 degrees to the south. The building facade as a whole should have good sunlighting potential that meets the British Standard criterion for probable sunlight hours. The probable sunlight hours is defined as the total number of the hours in the year that the sun is expected to shine on unobstructed ground, allowing for average levels of cloudiness for the location in question. The standard advice is that the interiors where the occupants expect sunlight should receive at least one quarter of annual probable sunlight hours, including at least 5% of annual probable sunlight hours during winter months between 21 September and 21 March (BS-8206, 1992).

The recommendation included in the German DIN 5034 on daylight provision is that at least four hours of possible sunlight should fall on the middle of the window on 20 March (DIN 5034-1, 1999).

3.4 Methods for the Calculation of Solar Energy and Daylight Access

Nowadays, much research is continuing in a number of areas, including the development of solar radiation modelling, energy impact of solar radiation, lighting energy savings from daylight.

For characterisation of interaction between building elements and the radiation they receive directly from the sun and from the sky and ground it is important to understand the circumstances of solar energy (whether for daylighting, heating or the prevention of overheating), designers need to know when and where, and what form solar radiation might contribute or effect on the building performance and occupant comfort.

In the design process of buildings, the assessment of the energy-related impacts of sunlight and skylight are often linked to other domains of the building design, such as the artificial lighting design, envelope and HVAC design or the verification of compliance with thermal regulations. This impact can harm the final conditions, in particular in what refers to the comfort requirements of the occupants and their preferences regarding the indoor environment.

3.4.1 Methods to analyse solar radiation in urban settings

The first simple computer models of solar radiation in urban settings to assist with site layout planning were developed in the 1980's. More recent work has focussed on modelling the availability of solar radiation for solar energy conversion (using solar thermal collectors or photovoltaic cells) or to offset demands for applied energy for heating or lighting buildings (passive design). Mardaljevic and Rylatt (2000) (Figure 3.9) used the ray tracing program RADIANCE and developed a method for simulating annual solar irradiation (Wh.m^{-2}) incident on urban surfaces.

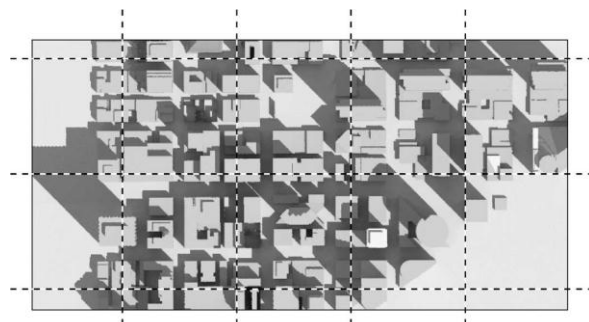


Figure 3.9 : User specified grid for automated irradiation mapping of city model (San Francisco).

In order to achieve solar access, the solar envelope was first proposed by Ralph L. Knowles in 1999 as a zoning device. He applied the obstruction angle rule into the 'solar envelope' (Knowles, 2003). Obstruction angle is defined as the smallest angle with the horizontal plane under which the sky can be seen from the lower edge of a point; usually an opening in a building. Within 'solar envelope' solar access is guaranteed, thus, shadow will not affect the buildings during critical energy-receiving periods of the day and year.

Compagnon (2004) developed an analogous method, but this time based on pre-processing the sky radiance distribution – creating a cumulative sky radiance distribution ($\text{Wh.m}^{-2}.\text{Sr}^{-1}$) – rather than post-processing results for individual skies / suns. Moreover, Compagnon produced irradiation results for individual (r-trace) points within the urban scene which could later be analysed to determine to the proportion of urban surfaces that exceed specific thresholds relating to the viability of passive and active solar energy technologies (Figure 3.10).

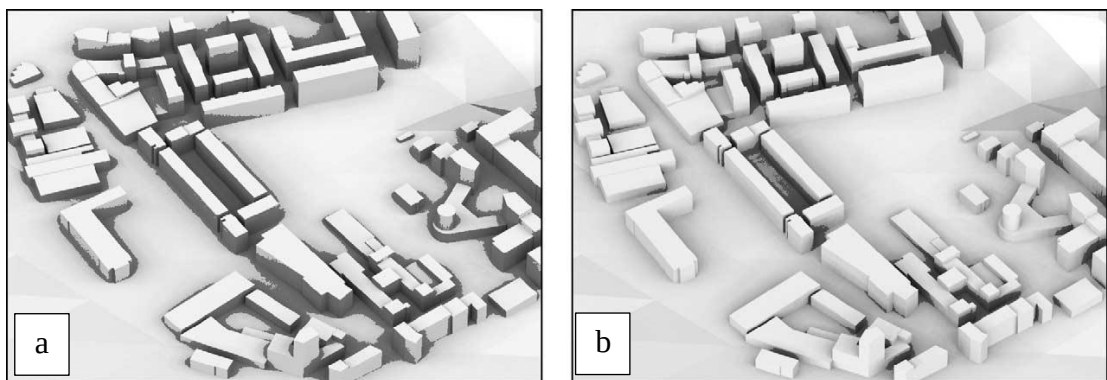


Figure 3.10 : (a) visualisation of building facades suitable for photovoltaic systems
(b) visualisation of facades suitable for passive solar systems are shaded in grey.

Robinson and Stone (Robinson, Campbell, Gaiser, Kabel, Le-Mouel, Morel, Page, Stankovic and Stone, 2007) developed a slightly more computationally accurate way of simulating irradiation using a cumulative sky (by discretising the sky rather than using individual light sources). External surface illuminance may be solved in a similar way, given the solar illuminance and a sky luminance distribution. Views to the external sources may then be determined from renderings taken at internal points to calculate the sky and externally reflected contributions to internal illuminance. These are also inputs to a low resolution conventional radiosity calculation to solve

for internally reflected contribution to internal illumination in an accurate but quick way.

3.4.2 Methods to investigate daylight availability in urban environment

Paul Littlefair explained first site layout planning for daylight and sunlight and published as guidance in the BRE (Building Research Establishment) Report in 1991 (Littlefair, 1991). The BRE guidance is centred on the concept of action obstruction (obstruction building). The guidance states where reduction in heights necessary. BRE report is based on British standard code of Practice for daylighting, BS 8206 (BS-8206, 1992).

The British standard (BS- 8206) recommends criterion to judge sunlight availability in urban areas. This criterion is met when either of the following is true: the window walls face within 90° of due south and there is no obstruction, measured in the section perpendicular to the window wall, at an angle of more than 25° from the horizontal (Figure 3.11); or the window wall faces within 20° of due south and the reference point has a vertical sky component of 27% or more. Obstructions within 90° of the reference point do not need to be taken into account here. For new buildings, the 25° are measured from 2 m above ground; for existing buildings, the angle is measured at the centre of the window.

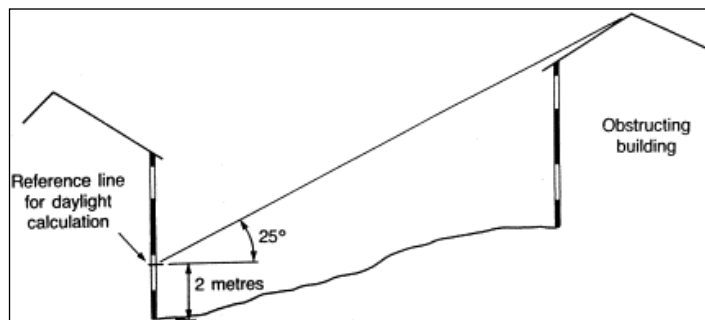


Figure 3.11 : Section of building showing 25° obstruction angle.

British standard “BS 8206-1 Lighting for buildings and Code of practice for daylighting” was first published in 1985 confirmed in 1992. It is replaced by BS ISO 8995 in 2002 and this standard is also withdrawn in 2007. In 2008, “BS 8206-2 Lighting for buildings Code of practice for daylighting” was published (BS-8206 - 2, 2008). The current gives recommendations regarding design for daylight in buildings. It includes recommendations on the design of electric lighting when used in conjunction with daylight. BS 8206-2 describes good practice in daylighting

design and presents criteria intended to enhance the well-being and satisfaction of people in buildings, recognizing that the aims of good lighting go beyond achieving minimum illumination for task performance. This revision of BS 8206-2 has been prepared to take account of the publication of BS EN 12464-1 and BS EN 15193 . In particular, some of the manual calculations that appeared in the 1992 edition have been omitted and a new annex on climate-based daylight modelling has been added. There is also a new clause on daylighting and health. Then in 2011 BRE published the second edition of the “Site layout planning for daylight and sunlight” guidance (Littlefair, 2011). This guide is intended to be used in conjunction with the interior daylight recommendations in the British standard Code of practice for Daylighting, BS8206-2. It contains guidance on site layout to provide good natural lighting within a new development; safeguarding of daylight and sunlight within existing buildings nearby; and the protections of daylighting of adjoining land for future development.

Traditional solar laws are based on simple angular criteria, such as obstruction angle rules. From the Roman period to the present, urban studies had tried to take advantage of solar energy. Those planning works were based on road width and building height in the town. The first local zoning law was made in 1832 in the United Kingdom. The case of New York’s Zoning Law of 1916 is symbolic. It was enacted as a reaction against the negative environmental effects caused by excessive building height and density in central Manhattan (Figure 3.12). A similar law based on an obstruction angle of 60° is applied to the city of Milan.

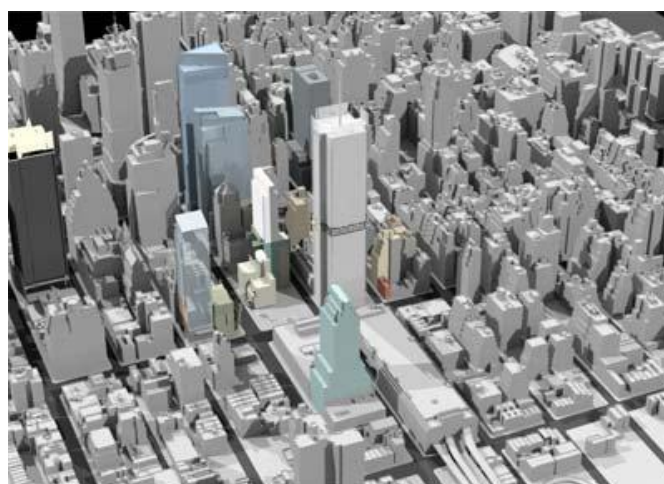


Figure 3.12 : 2009 The Lawrence Berkeley National Laboratory radiance model of Time headquarters in its urban context of Manhattan.

Daylight performance in an urban context relates to a combination of direct sunlight, diffused skylight and reflector of light from the facades and the ground. Daylight literature identifies a number of technical variables that are related to the characteristics of space configuration that impact daylight performance. The physical configuration of the space, according to an explanation by Baker et al. could be a morphological composition of vertical planes and horizontal ones (Baker, Fanchiotti and Steemers, 1993),

Based on this morphological technique, the technical variables of the space configuration can be classified in three levels: vertical configuration variables, horizontal configuration variables, and space configuration variables (Al-Maiyah and Elkadi, 2006).

Studies concerned with the morphological definition of the space introduced a set of geometrical variables to evaluate the enclosure quality of the space. A number of morphological variables, such as the width to height or the height to 1/2 length ratios, have an influence on the daylight propagation of the space. Dekay (1992), has recommended that the height and width relationships be between 1:1 and 3:1 in the built urban environment to obtain adequate daylight. Sky opening (sky view) factor, an urban quality factor, is also used in previous works as a measure of daylight availability in the urban setting (Ratti, 2004). This ratio represents the percentage of the sky visible from a point (Teller, 2003) (Teller and Azar, 2001).

Legislation should guarantee a certain amount of daylighting access for each building. In many countries there are land use laws, which define the occupation percentage, building heights and easements. However, this may not assure daylight access. Hopkinson proposed a graphic method based on the geometric relationship between building height and spacing. The objective of this method is an acceptable level of daylighting in indoor environments, while controlling the amount of sky obstruction (Hopkinson, Petherbridge and Longmore, 1966). Ng has conducted studies of the city of Hong Kong using different urban scenarios in order to introduce new alternatives that would provide access to daylight in the context of a high-rise urban environment (Ng, Wong, 2004; Ng, 2005; Ng, 2005).

3.4.3 Methods which analyse the impacts of solar radiation and daylight on the building energy performance

In reaching energy efficient design solutions, it has become important to consider the integrated management of visual and thermal requirements and to take into account the luminous and thermal implications of daylighting strategies. Integrated energy analysis models and lighting energy saving models (due to the use of daylight) will be examined individually in this section. There are some notable and important methods, which are shortly described below.

BREEAM (Building Research Establishment Environmental Assessment Method) is a measurement rating tool for green buildings that was established in the UK (BREEAM, 1990). The equivalence of those tools in other regions are; LEED (Leadership in Energy and Environmental Design) in North America, Green Star in Australia and HQE (High Quality Environmental standard) in France (LEED, 1998; Green Star, 2002; HQE, 1992).

To measure the sustainability of new non-domestic building in the UK, BREEAM was established in 1990. The last update was done in 2008 and called BREEAM 2011 (BREEAM, 2011). The standard covers the main buildings types such as; retail, offices, education, prisons, courts, healthcare, industrial and multi residential buildings. The specialized buildings are assessed under then BREEAM Bespoke method. BREEAM consist of ten rating groups; managing, health and wellbeing, energy, transport, water, materials, waste, land use and ecology, pollutions and innovation.

Daylighting theme is part of health and wellbeing under the visual comfort topic. The assessment criteria that ensure visual comfort are split into five parts; pre-requisite, Daylighting (1-2 credits) - building type dependent, glare control and view out (1-2 credits) - building type dependent internal and external lighting (1 credit) and visual arts- healthcare building types only. Good practice daylighting criteria are defined as: uniformity ratios of at least 0,4 or a minimum point daylight factor of at least 0,8% , a view of sky from desk height (0,7 m) should be achieved and the room depth criterion should be stratified.

All the similar rating systems offer some methods for the evaluation of daylight in buildings, but they are basically based on rules of thumb. As a summary rating

system methodologies are not efficient to evaluate the solar radiation and daylighting on building performance.

LT-Urban (Lighting and Thermal Energy Model) predicts building energy consumption using a modified version of the lighting and thermal (LT) energy model. Parameters that describe the building fabric (for example, orientation of facades and angles of obstruction of the sky) are derived using image processing techniques based on digital elevation models (DEMs) (Ratti, Robinson, Baker and Steemers, 2000).

In the UK Jones et al.'s EEP (Williams and Lannon, 2000) (The Energy and Environmental Prediction) estimates the energy demands and associated emissions for a municipality's stock of buildings based on extrapolation of results from representative building typologies. The model has a statistical clustering method that is deployed to estimate standard assessment procedure (SAP) energy ratings for domestic properties.

Thus far, the characterisation of the energy impacts of daylighting in buildings has been addressed in different ways by different authors. The proposed methodologies take into consideration the effect of daylight-linked controls in savings of electric lighting energy and also incorporate a behavioural model that translated the probability of switching the lights on as function of the time of the day and of the minimum daylight factor in the work plane. But models do not include the surrounding (shading) effect on the energy impacts of daylighting in buildings.

The "Energy Performance of Buildings" Directive (EPBD) requests the accounting of the lighting energy demand in the overall building energy balance. The European Committee for Standardization (CEN) developed a set of standards covering the requirements of the EPBD to maintain good quality levels of lighting and also promote energy efficient artificial lighting systems and the efficient use of daylight.

EN 15193 provides a useful umbrella framework, with a calculation method that is both simple and general. Except for the determination of the installed power in new buildings, the standard allows stand-alone calculation, and thus, the energy analysis and optimization of lighting installations. It integrates artificial lighting, daylighting and lighting controls.

3.5 Evaluation of the Methods and Necessity of a New Approach

This review primarily indicates the parameters that are relevant to the problem of daylight and sunlight planning in order to create a sustainable design. The following shortcomings of the existing evaluation methods illustrate why a new approach toward daylighting and solar planning in the urban context, and particularly its relationship to energy use and comfort level, is a necessary and valid research endeavour:

On the urban level:

- Urban energy models generally are based on the buildings stock's energy performances and those models are not suitable for architects and planners.
- The contribution of reflected radiation and modelling of the effects of adjacent buildings on reducing diffuse sky is either absent or partial.
- The effects of the urban meso / micro-climate on the energy balance of buildings are ignored.

On the building level:

- Suggested methodologies that would allow the designer to explore a number of options are not easy to use.
- Some of the energy parameters such as artificial lighting load or luminaire efficiency are considered as average values to calculate the energy consumption.
- Methodologies related to dynamic skies approaches are either restricted or many of their integrated daylight control implementations are insufficient.
- The potential for energy savings and improved internal comfort is apparent, but the way to reach this target is less obvious.
- The energy balance of a building includes all energy systems. Due to manifold interactions between the various systems, a realistic prediction of the energy consumption without calculation is not possible.
- In EN 15193 to determine the impact of daylight on lighting energy, the daylight factor is used as a classification criterion, which cannot provide precise results all the time.

The ability to simulate accurately a wider range of buildings in the urban context would undoubtedly help to establish those criteria.

The studies and research described above indicate that the use of proper urban planning tools in combination with help from accurate methodologies can elevate energy savings, in addition to optimising visual and thermal comfort. The holistic collaboration between these existing methodologies generated by various scientific influences is necessary to set up effective integrated planning and strategy of development for this thesis.

In summary, urbanisation is a global trend resulting in an ever increasing number of people living in urban areas along with increasing urban densities. The development of the urban environment is generally associated with an of energy consumption by cities and their inhabitants, which in turn is associated with serious effects on local and global air quality, energy balances and heat island effects, weather patterns, biodiversity, and the rate of raw material use. As the main component of the urban structure, buildings consume the most energy in an urban area, representing close to 40 % of the world's total energy use, including climate control and energy used for appliances, lighting and other installed equipment. Land use zoning is tool that can be implemented on the local, state, or national level that guides the development of communities by stipulating the types of buildings, uses, densities, heights, ratios, and lot coverage - among other distribution characteristics - that are permissible in a community. Daylighting is a free and abundant source of lighting for buildings in urban areas and currently much research is being conducted in the development of solar radiation modelling, energy impact of solar radiation in urban context, and lighting energy savings from daylighting. The effect of the surrounding urban context, particularly shading from adjacent structures, is not always considered in many contemporary models. This thesis proposes to develop a new method that attempts to integrate current sky luminance modelling, energy modelling and thermal comfort assessment techniques, while incorporating the effects of shading by surrounding structures as an important parameter when designing for energy efficiency and maximisation of daylighting use.

4. PRINCIPLES OF THE APPROACH TO THE EVALUATION OF DAYLIGHT IMPACT AND CONTRIBUTION TO THE ENERGY DEMAND OF OFFICE BUILDINGS IN THE URBAN CONTEXT

Designing urban forms in an environmental friendly way in order to preserve health, and comfort, as well as to optimise the use of resources and energy is a complicated task. In the urban context, buildings closely packed together decrease the availability of the natural elements (sun, daylight, wind). There are various design variables like building height, distance between buildings, and the light reflectance of the facades, which affect daylight availability in the space.

The study aims to predict the energy demand of office buildings in the urban context depending on daylight contribution. This approach is developed in order to assess the total energy demand considering the lighting, heating and cooling loads of existing office buildings for retrofitting purposes or at the design stage to optimise the energy performance of building.

The space should be defined and users of the space clearly identified before the daylighting performance analysis is done. Therefore, the space should be primarily lit with natural light combining thermal and visual comfort conditions with overall energy use for lighting, heating and cooling. Hence, it is important to evaluate daylight availability, especially in urban areas.

The research is based on daylighting analysis and proposes an integrated building energy calculation approach using different tools. The proposed approach presents integration of computer-based analysis techniques, which can be effectively used during the design and evaluation of day-lit spaces. In the description of principles of a new approach, recent advances in dynamic daylight computation, daylighting metrics, electric lighting design, control systems for electric lighting and shading options are discussed. The integrated analysis method considering effects of neighbouring buildings in the urban context (within specified urban geometry) is introduced. This method simultaneously considers annual daylight availability, visual comfort and energy use. Annual daylight illuminance profiles are combined with

visual comfort condition limitations in order to determine annual shading profiles throughout a space.

The principles of the new approach to assess energy demand of office buildings are explained in this chapter. The basic steps of the approach can be seen in the Figure 4.1. Details of each step of the methodology will be explained in the following sections.

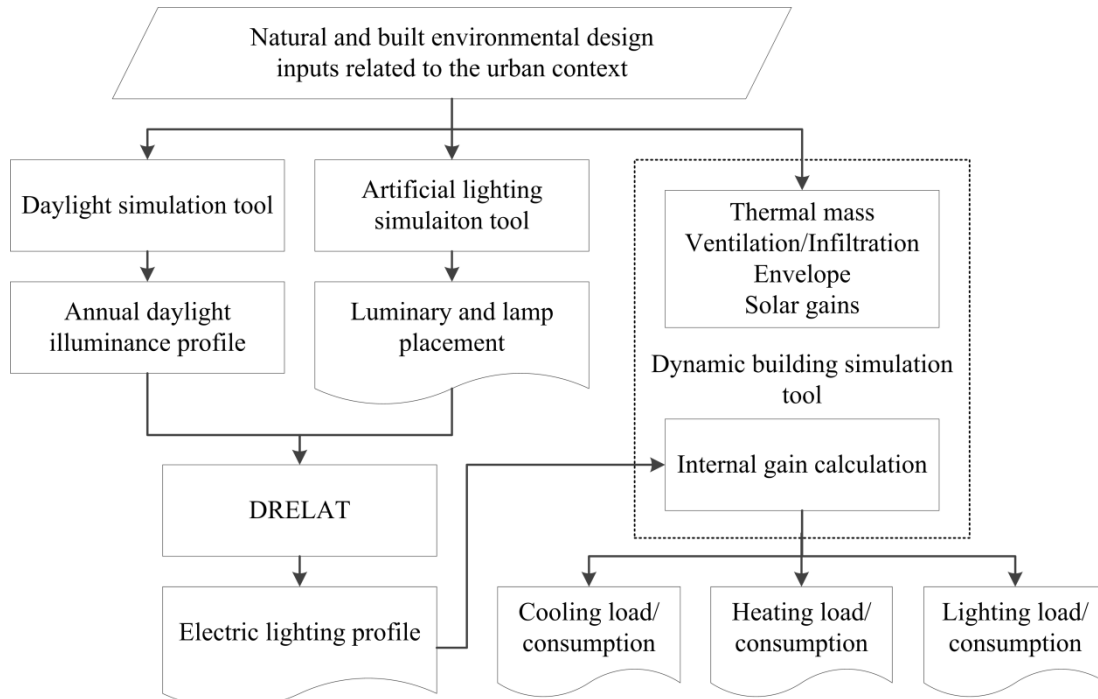


Figure 4.1 : Schematic description of an approach to the evaluation of daylight impact and contribution to the energy demand of office buildings in the urban context.

To quantify the influences of urban structure on the energy demand is complex. Hence, in the concept of this thesis, energy demand analyses are done considering both the lighting and thermal behaviour. During the calculation of the energy demand, it is vital to provide comfort conditions in the indoor environment. To ensure the permanence of a healthy environment for the occupant, building properties should be determined to provide the thermal and visual comfort conditions. Standards and recommendations which are already explained in detail in Chapter 2 are taken into consideration for determination of the properties.

Daylight contributes to reduce electrical energy demand for lighting and decreases internal gains. The total energy demand of the building, including the internal gains from artificial lighting and artificial lighting energy demand are predicted.

4.1 Determination of Natural Conditions

To satisfy the comfort conditions in the indoor environment, the first step is to determine the values of the parameters related to the outdoor environment. Those parameters that are related to thermal comfort such as; outdoor air temperature; solar radiation, outdoor humidity, wind and velocity have been explained in Section 2.1.1. Parameters that are related to visual comfort such as outdoor illuminance level, solar position, sunshine duration and sky type have been explained in Section 2.2.1.

Values of local environmental conditions are obtained from geographic, meteorological and topographical data, with due consideration to the data specifying the position of the building within a particular urban quarter.

4.2 Determination of Built Environment Conditions

Built environment conditions are determined in different stages considering the thermal and visual comfort effects in the space. Taking the right decisions in the various stages of the design phase, a certain comfort for the user can be achieved.

The main parameters related to the built environment were defined under different scales by Oral et al. Parameters on the settlement unit scale were given as; dimension and orientation of external obstacle, solar and light reflectivity of surrounding surfaces and soil cover and nature of the ground. Parameters on the building scale were noted as orientation and form of the building. The room scale design parameters were specified as; position of the room within the building, dimension of the room and its shape factor, absorption coefficient of the room for solar radiation entering through the transparent component and light reflection coefficient of the surfaces inside the room (Koclar Oral, Koknel Yener and Tamer Bayazit, 2004).

To determine the built environment conditions, a bottom up method is used in this methodology. It is defined starting from room properties, including building element properties and window location, then building properties and then finally ending up with urban space properties. In

Figure 4.2, the relation between built environment elements can be seen.

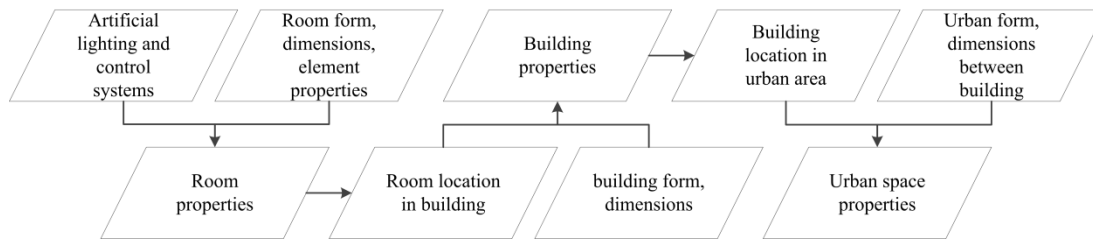


Figure 4.2 : Schematic description of built environment conditions determination.

The daylight availability in the urban area is essential for daylight performance due to environmental controls such as shading devices and electric lighting controls, in addition to it having an influence on energy loads. To investigate the energy performance of the space considering daylight availability and contribution to the energy loads, the space is defined as a room within a building.

Each room of the building can have different characteristics (dimensions, electric lighting, shading devices, occupancy schedule, surfaces reflectance etc.) and be affected by shading from the nearby buildings in the urban context. The shading effect changes according to the position of the room in the building and therefore, the results for annual energy demand vary.

For the evaluation of the energy related implications of a daylighting concept, the calculations are done first in a defined room. Then the integrated approach can be applied to other rooms within the building and the overall energy load is calculated. If the building is consisting of many rooms of the same type, some assumptions and simplifications is made to receive quick results of the overall energy use of the building.

4.2.1 The office room properties

The properties of the office room are important to examine. Heating, cooling and electric lighting energy is determined or defined in this section whether the room already exists or is about to be designed.

4.2.1.1 Room form, dimensions and building elements properties

The main source of heat transfer is radiant energy and the primary source is the sun. Solar gain differs according to orientation. Thus, the definition of orientation is essential to calculate the heat transmission. With the aim to calculate the energy demand of the room ensuring the comfort conditions, the room's orientation should be determined first. In order to set up a definition of the room, the following

properties related to the room and window(s) must be determined. Definition of the dimensions can be seen in Figure 4.3.

- l - room width [m]
- d - room depth [m]
- h - room height [m]
- l_w - window width [m]
- H_w - window height [m]
- p_h - height of the wall part between floor and window [m]
- l_h - height of the wall part between window and ceiling [m]

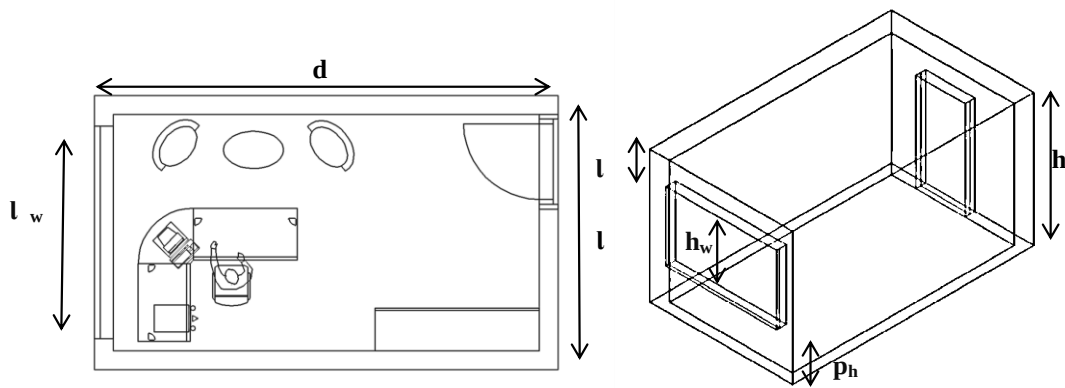


Figure 4.3 : Room and window dimensions.

In order to achieve thermal and visual comfort in rooms, it is necessary to determine building element properties such as transparency and opaqueness property. Element layer should be checked as single or multiple layers. Then total mass and heat conduction coefficients of the materials have to be defined. The other factors that should be determined for opaque building elements are:

- density
- total heat conduction coefficient of the component
- the total weight of the opaque element
- total stiffness factor of the opaque element

If the proposed approach will be used for new design, then certain decisions must be taken to ensure the limits for the values are not exceeded. When the approach is used as evaluation for existing system, it is also important to define the building element properties mentioned above.

The transparent component of the envelope has certain objectives, like maximisation of the daylight entrance, controlling direct sunlight, minimising the heat gain during overheated period and providing glare control and view to the outdoor environment.

The glazing type to be used for the windows is determined with respect to its transmission, absorption and reflection for heat and light. Since the window frames are manufactured from different materials with different thicknesses, their specific construction has an influence on heat loss or conservation and on the amount of daylight level. In Section 2.2.2, different glazing types, advantages and disadvantages in the context of energy conservation are discussed. Moreover, switchable windows which could readily adapt in response to changing climatic conditions or occupant preferences are explained in the same section. A choice of appropriate windows can be determined with a market research of the available products with respect to their heat and light transmission values related to their thickness, structural properties, functionality, aesthetic appeal and price.

4.2.1.2 Electric lighting, control system and solar shading

The selection of the artificial lighting system including lamp types, shape of the luminaries and lamps, reflector, diffuser, ballast and starter is defined at this stage of the proposed approach. The geometrical position of the artificial lighting system in the room is also determined in here.

Control system is part of lighting system. The control system properties such as dimmable features, standby power of control system must also be taken into account.

The function of solar shading systems is to obstruct the entry of direct sunlight into the space, to prevent glare and control the direct solar radiation to decrease overheating. Light shelves, roller textile blinds and venetian blinds can be used in side-lit office spaces to prevent the direct sunlight and optimise the light distribution in the space. The determination of the shading system is done in this instance.

4.2.2 The office building properties

The office building properties definition or determination is also essential for the evaluation methodology. The building form, dimensions, orientation and the location of the sample room are set in to this phase.

4.2.2.1 Building form and dimensions

The placement of a building form in relation to its immediate site and neighbouring buildings is another crucial aspect. This aspect must be considered in order to analyse or design an architectural form, including shape, mass size, scale, proportion, texture and colour of building. In this case rectangular (orthogonal) geometries were considered as an office building form.

For evaluation purposes, the following building properties should be predicted.

- L_2 Building width [m]
- D Building depth [m]
- H Building height [m]

The position of the room in the building and the dimensions to the building reference point that is used for definition of the room position is illustrated in Figure 4.4

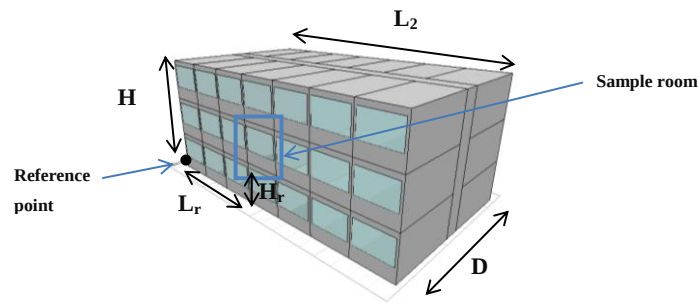


Figure 4.4 : Building dimensions H , L_2 , D and room location illustration with L_r and H_r .

4.2.2.2 The sample office room location in the building

The office room location, which will be analysed for heating, cooling and electric lighting energy demand, is defined within the building. The room that is selected for evaluation is defined according to a reference point (right bottom corner) of building model. The illustration of the distance L_r and H_r can be seen in Figure 4.4.

4.2.3 Urban space characterisation

In order to investigate the daylighting and thermal performance of the building, it is important to define the urban geometry and the position of the room in that urban structure considering not only the direct and diffuse sunlight, but also reflected light (solar gain) from neighbour facades and ground (albedo). Some archetypes were defined to limit the definition of the complex urban structure for the limited abilities of computer software and these simplified types are used especially for energy use

studies (Ratti, Raydan and Steemers, 2003). On the other hand, some other researchers use site coverage percentage for their studies (Ng, 2005; Li and Wong, 2007).

Mainly, the characterisation of urban form is explained by distance between buildings in the two dimensions (x, y), number of floors, block dimensions and street width.

4.2.3.1 Urban form and dimensions

The presenting evaluation methodology is developed for “pavilion” type of urban generic form, but it can be applicable for “slabs” and “terraces”, which can be seen in the Figure 4.5.

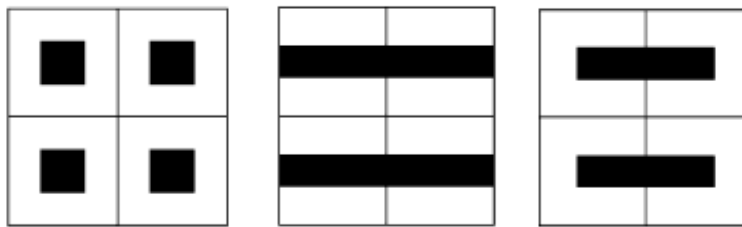


Figure 4.5 : From left to right: pavilions, slabs, terraces. Generic urban forms, based on Martin and March (1972).

For evaluating or designing of the urban form, the legal framework of land use zoning should be taken in to consideration. In the Section 3.1 this issue is explained in detail.

The following properties related to urban geometry is determined:

- number of building blocks in the urban area
- L_1 distance between buildings in the x direction - spacing between units [m]
- W distance between buildings in the y direction and/or width of the street [m]

The distances that specify the urban geometry and buildings relations can be seen in the Figure 4.6. The other ratios which are used in building configuration are valid for urban geometry specifications. It is assumed that all the building forms and heights in the urban area are equal to each other and buildings are located in the face to face position.

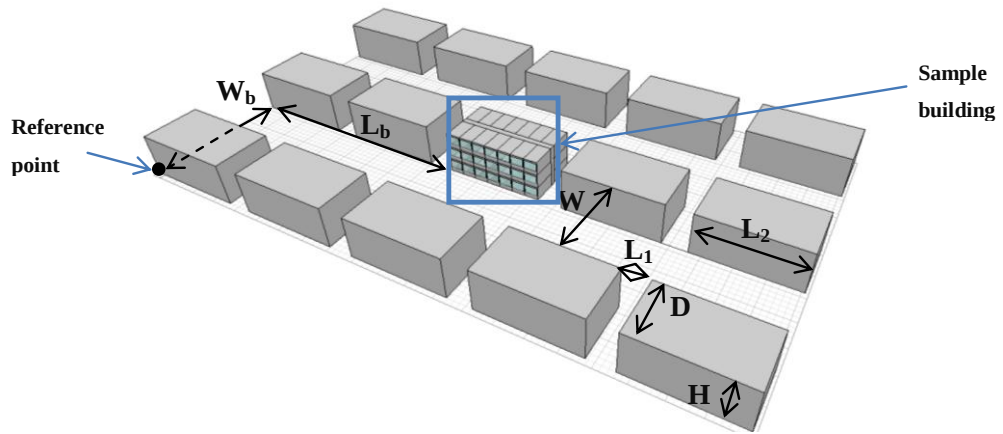


Figure 4.6 : Urban geometry specifications with distances between building units and sample office building location in the urban area.

4.2.3.2 The sample office building location in urban area

The location of the sample office building should be specified in the urban area with distances between other buildings. The number of the surrounding buildings must be also considered for this specification. The same system that is used for determination of sample room location in the building can be applied to define the sample building location. The reference point that can be seen in the Figure 4.6 is the left bottom corner of the first building in the investigated urban area. The distances between reference point and the sample building left bottom corner, W_b and L_b , should be defined.

4.3 Sub-methodologies to Calculate Daylight Responsive Electric Lighting Demand

In this section, calculation methodologies related to the lighting are explained in 3 stages: daylighting calculation, artificial lighting calculation and daylight responsive electric lighting energy demand calculation.

4.3.1 Methods and tool assignment for calculation of daylight distribution

Daylight calculation methodologies can be divided in to static and dynamic depending on whether they consider single or series of consecutive sky conditions. The results of a static daylight simulation are commonly expressed in the form of photo realistic images or in the form of illuminance values at certain points of interest in a building under a reference sky.

The static and dynamic daylight calculation methods (which are used for evaluation) is determined in this stage of proposed approach. Determination of daylight simulation tool alternatives can be seen as flow chart on Figure 4.7. The user of the approach should know beforehand what kind of output she/he wants to have as result of daylight distribution calculation. For instance, if the photorealistic image is wanted as an output, one of the static daylight simulation tool alternatives have to be chosen. To calculate the daylight responsive electric lighting demand with proposed approach, it is important to produce annual illuminance profiles which are a time series of the indoor illuminance at points of interest in a room. To fulfil this requirement, proper dynamic daylight simulation alternatives should be selected. After producing the annual illuminance profile, the user can select an appropriate method to assess results. On the other hand, for demand calculation supplementary illuminance profile, which is provided by artificial lighting system, can be calculated according to annual daylight illuminance profiles. The supplementary illuminance profiles are produced based on required illuminance level on points of interest.

The methods most commonly used in static simulations of illuminance distribution in 3D space such as split flux, radiosity and raytracing were described in the third chapter. The split-flux and radiosity methods require a shorter calculation time, however, they have limitations in dealing with complex geometries. On the other hand, the ray-tracing method offers advantages for simulating the physical performance of light rays and the material spectral properties for any building complexity.

In order to obtain good quality photorealistic images and reliable illuminance level on the determined points, the static simulation tool alternative should be selected. Within the concept of the proposed approach, the RADIANCE daylighting simulation tool, which calculates based on the physical performance of light functioning using the ray-tracing method, is selected.

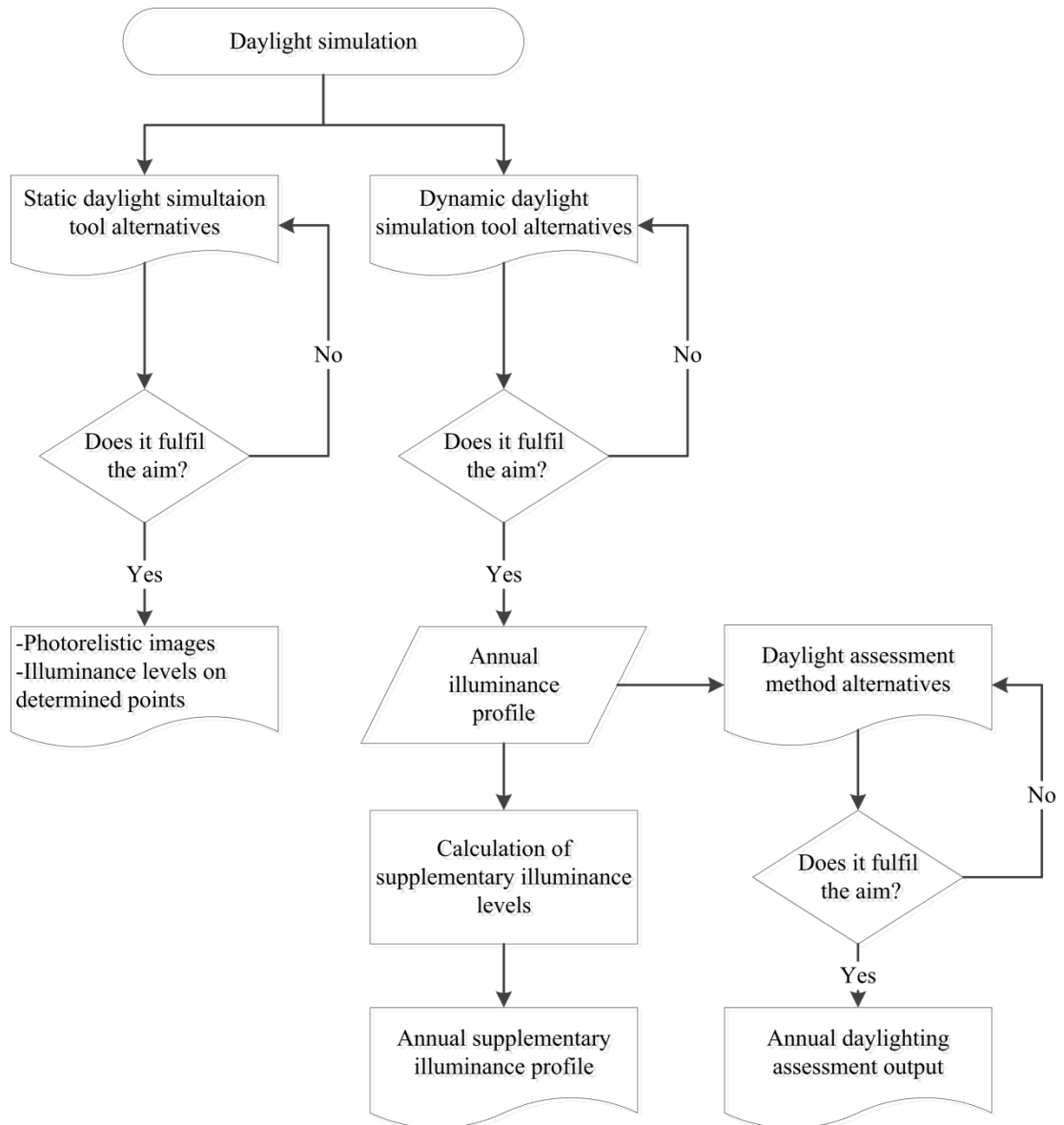


Figure 4.7 : Determination of daylight simulation tool alternatives.

The dynamic daylight calculation tool should be decided upon for efficient calculation of the internal illuminance and the luminance of a zone in the period of the year. The daylight simulation program DAYSIM is selected to calculate annual daylighting in the space. DAYSIM integrated the method of the RADIANCE program into Daylight Coefficient Method.

The Daylight Coefficient is a method to calculate the internal illuminance levels in relation to the daylighting under the defined sky conditions. This method divides the celestial hemisphere into segments and calculates the contribution of each segment to obtain the total illuminance. As a result, once the values for the points of interest have been calculated, the illumination levels can be easily calculated for any sky

condition. The use of this method in DAYSIM enables the simulation time for all hours of the year, avoiding the necessity to simulate all sky conditions to obtain the annual daylighting conditions.

Useful Daylight Illuminance (UDI) is selected as daylight performance method in the approach. Useful daylight is defined as providing ambient light at the work plane at illuminance levels between 100 lux to 2000 lux in occupied times of the year (Nabil and Mardaljevic, 2005; Nabil and Mardaljevic, 2006). Accordingly, the upper limit for preferred/tolerated daylight illuminance used for Mardaljevic's study was 2000 lux and he grouped the UDI as:

- The illuminance is less than 100 lux, i.e. UDI 'fell-short' (or UDI_f).
- The illuminance is greater than 100 lux and less than 500 lux, i.e. UDI supplementary (or UDI_s).
- The illuminance is greater than 500 lux and less than 2000 lux, i.e. UDI autonomous (or UDI_a).
- The illuminance is greater than 2000 lux, i.e. UDI exceeded (or UDI_e).

The UDI categorization proposed by Mardaljevic is used in the concept of the PhD study for dynamic daylight performance evaluation metrics.

4.3.2 Tool assignment for calculation of electric lighting energy demand

In order to design a proper artificial lighting system and fulfil the illuminance and uniformity requirements, average illuminance level and illuminance level at a given point need to be calculated. Calculation of illuminance at specific points is often done in a computer environment using calculation tools. For indoor lighting situations, the lumen method is generally used with data from a coefficient of utilization table.

It is also important to develop the artificial lighting calculation methodology and a tool that can serve the aim of this part of this work. Within the scope of the proposed approach, the most common used simulation tool in Europe, RELUX, is used to calculate the electric lighting energy and placement of lamps and luminaires in the room. RELUX is also a radiosity-based program like RADIANCE (point to point method) where both artificial lighting and daylighting simulations can be conducted (RELUX, 1998). Luminaire photometry can be imported and luminaire dimensions can be set manually.

If the room is in the design stage, the decision regarding the luminary placement and lamp selection should be done according to the recommendations and the specifications set into the simulation program (EN 12464, 2002). If the evaluation is done for an already existing room, all conditions related to the electric lighting system can be specified in the selected computer program.

One step further, the electric energy demand can be calculated related to occupancy time of the space, control type and user preferences of lighting. The schematic presentation of the electric lighting simulation process within the proposed approach can be seen in Figure 4.8.

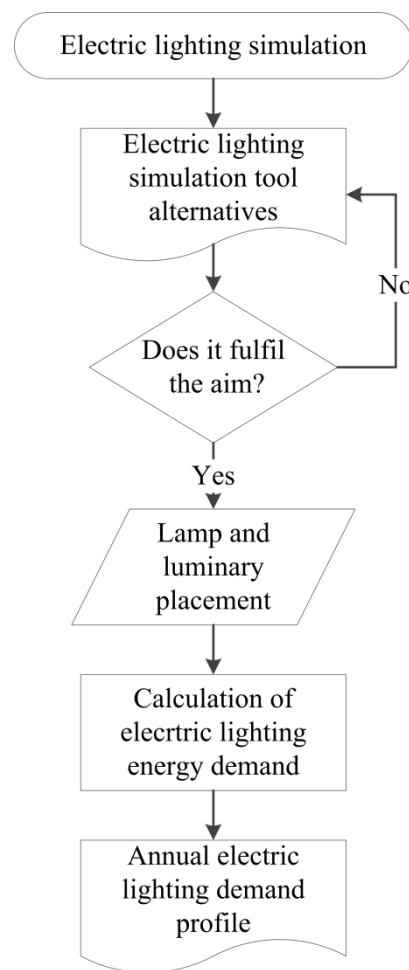


Figure 4.8 : Schematic presentation of electric lighting simulation process within the proposed approach.

4.3.3 Daylight responsive electric lighting analysis tool DRELAT

To quantify the energy saving potential from daylight availability, the systems should be examined properly. In the previous two sections, the daylighting and electric lighting calculation method and simulation tools were investigated and

selected for evaluation methodology. In this phase, the electric lighting power to reach the desired level of illumination based on daylighting illuminance is determined. DRELAT (Daylight responsive electric lighting analysis tool) simulation module is developed by author during this research.

First, the principles of the methodology will be described and then the DRELAT tool will be explained with considered assumptions and system details.

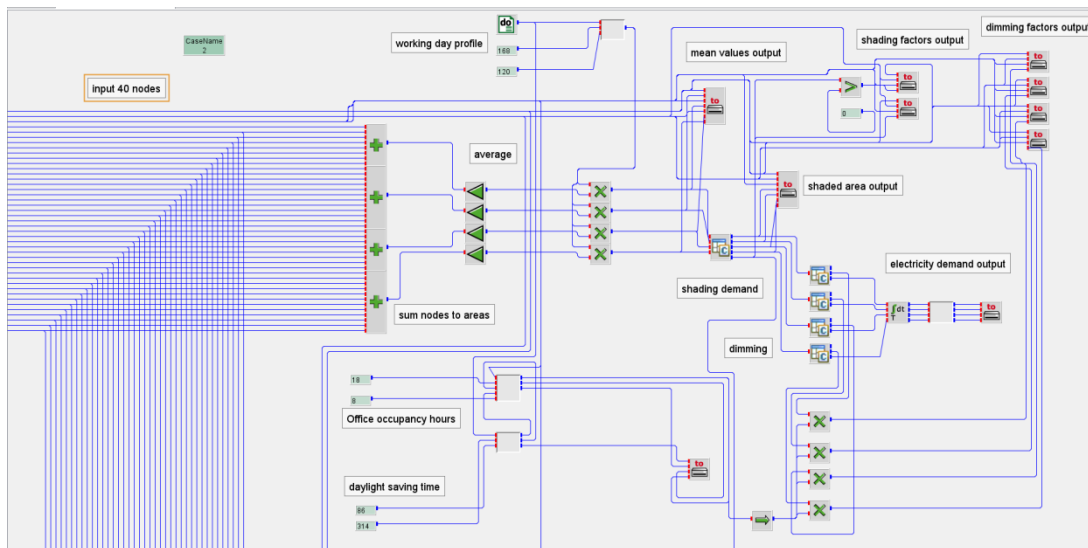


Figure 4.9 : DRELAT in simulation environment in InSEL8.

In Figure 4.9, a screen shot of the simulation environment of DRELAT is shown. The annual illumination profile shows the need for supplementary lighting to reach the required illuminance level of the space. To understand the need, the annual illuminance profile that contains all hours of the year should be checked based on threshold illuminance level. When the illuminance levels are sufficient, there is no need for supplementary lighting to reach required level. However, if there is a need, it should be supported with electric lighting to ensure visual comfort conditions.

Nabil and Mardaljevic (2005) noted that when the daylight illuminance level exceeds 2000 lux, it might lead to visual and/or thermal discomfort. The 2000 lux upper limit was based on the reported behaviour of occupants in day-lit buildings. It was around the 2000 lux threshold when blinds were drawn and/or dissatisfaction was noted. The values are based on surveys (Roche, Dewey and Littlefair, 2000) (Roche, 2002) carried out in non-residential, largely office buildings where daylight-originated glare on visual display devices is a common problem. Many of these surveys were carried out before LCD display panels became common. Thus, it seems reasonable to

recommend the higher reported values as the upper limit of 2000 lux. In other words, the shading device alternatives (with controlling units) should be applied to satisfy the comfort need. Consequently, the upper limit for preferred/tolerated daylight illuminance used for this study is 2000 lux.

After the electric lighting need is comprehended, the control mechanism of the lamps should be determined to calculate the energy demand and annual electric lighting profile. When the system has no control, it is assumed that the electric lighting is on during the occupancy time while the office users are in the space, such as all weekdays between 08:30 and 18:30. However the developed analysis tool is flexible and can easily adjust to arrange the occupancy hours, with or without weekends. If the system is controlled or the designer wants to implement a control system, the specifications of the control system should be done in this stage. Taking different control method alternatives into account, supplementary electric lighting demand can be calculated.

In the concept of the thesis, the control system is assumed as daylight responsive electric lighting control system. Photo sensor controlled dimmed lighting controls are used. The photocell dims the activated lighting until the total work plane illuminance (daylight & electric light) reaches the minimum illuminance threshold, in this case 500 lux. The energy demand depends on the momentary dimming level of the system.

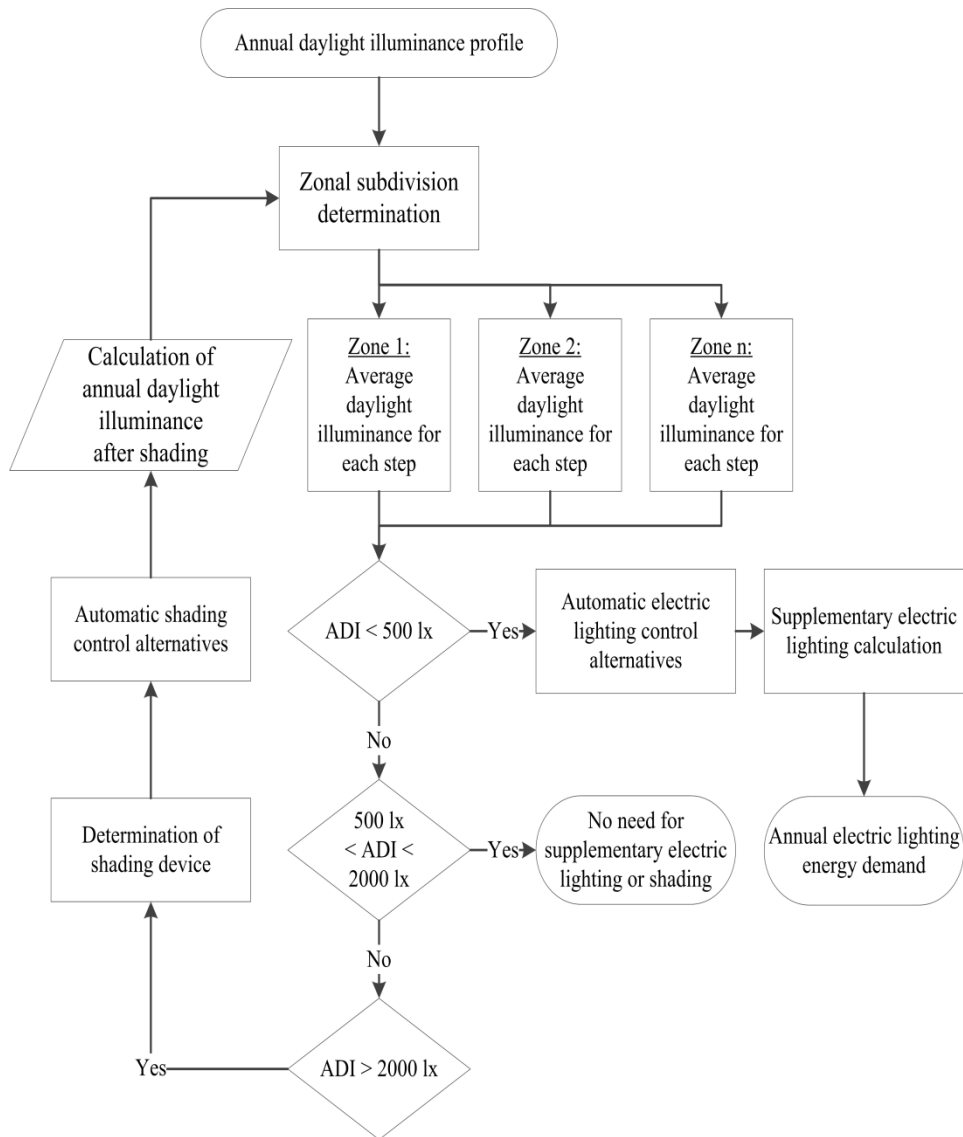


Figure 4.10 : The methodology principles to analysis daylight responsive electric lighting calculation.

A flowchart that illustrates the principles can be seen in Figure 4.10. The necessary steps include: zonal subdivision, activation of shading system, shading system activation followed by calculation of illuminance levels on grid, supplementary artificial lighting system activation and last, annual electric energy demand calculation can be seen. The detailed explanation is given in each stage of DRELAT.

The stages of DRELAT are:

1. Determination of a grid system
2. Determination of the time steps
3. Determination of zones for control

4. Average daylight illuminance calculations for the determined zones and for each time step of the year
5. Supplementary electric lighting need calculation
6. Dimming levels and energy demand calculation
7. Annual electric lighting calculation
8. Analysis for the shading to provide visual comfort
9. Output files preparation for thermal calculation

1. Determination of a Grid System:

It is necessary to configure the analysis grid for use in daylight calculations in the proposed approach. The analysis grid is assumed as a sensor grid system. RADIANCE and DAYSIM sensor point files are both based on the analysis grid system definition. The adjustment of the grid system should be done according to CIE (1986; 110-111) recommendations, both in terms of size and grid divisions. The vertical height of the grid should be 80 cm, which corresponds to the height of desks. The sample grid placement can be seen Figure 4.11. Outer surrounding area of the grid system is 50 cm from the room's walls as it stays in standard (EN 12464-1, 2002).

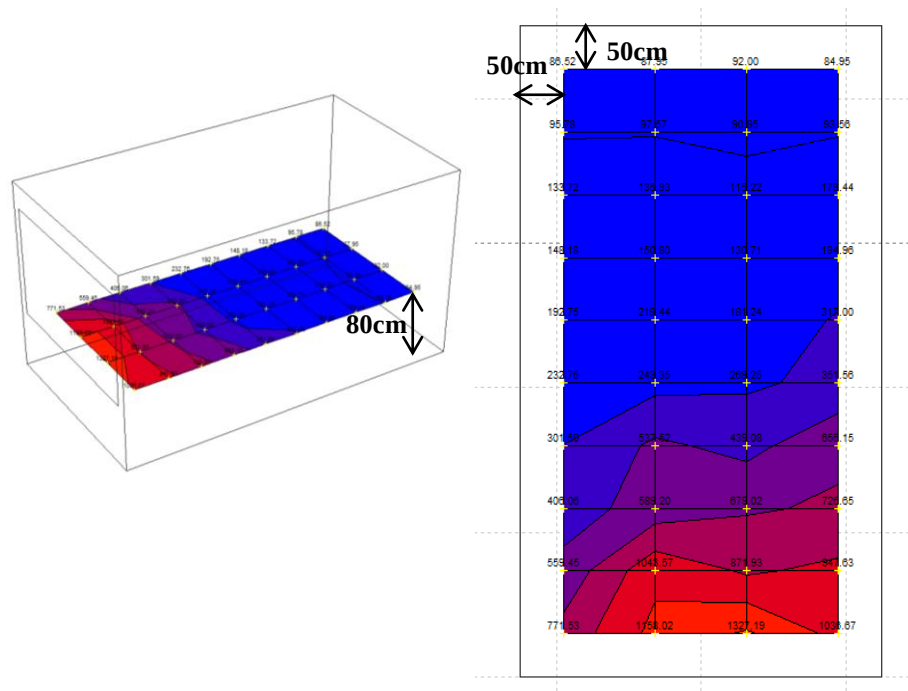


Figure 4.11 : The placement of the grid system in the room.

2. Determination of the time steps: The calculation time steps are determined in this stage of the tool development. This tool determines the energy impact of daylight responsive electric lighting based on analysis of daylight availability, site condition, shading device management in response to visual comfort and dimming control. In conjunction with the thermal analysis the calculations are done hourly. The important part of the time step determination is working times (i.e. each working days between the hours 09:00- 18:00). Users can be define the time period and also create their own working schedules. Daylight savings time is also considered in the tool and it is set as optional.
3. Determination of zones for control:

In order to implement the control mechanism into the electric lighting and shading system, it is suggested to divide the room into subzones. The room is divided parallel to window direction, which can also correspond to the electric lighting equipment arrangement. The number of the subzones, placement and analysis grid definition can be made according to room dimensions and the other geometrical specifications of the room. In the example (Figure 4.12), the room is divided into 4 subzones and each zone has one representative luminary that controls responsively the detected average level of daylight in the subzone. In this way, each luminary (lamps) can provide supplementary illumination when the daylight level is not sufficient.



Figure 4.12: Zoning for daylight responsive electric lighting control.

4. Zone average daylight illuminance level calculation for each time step of the year:

For daylighting evaluation, an hourly report with daylighting illuminance values are processed in the tool (DRELAT), based on the simulation environment insel8. The evaluation is done for each point of the analysis grid system.

After definition of the subzones in the room, each subzone's average daylight illuminance (ADI) level is calculated by DRELAT for each defined time step of the year and analysed according to the conditions given below:

- If the ADI is below 500 lux, the subzone needs supplementary illumination from electric lighting, which is supplied by the luminaries in the same subzone
- If the ADI is between 500 lux and 2000lux, it is perceived as desirable or at least as tolerable. There is no need for supplementary illumination or protection with shading devices.
- If the ADI exceeds the 2000* lux threshold, there is a need for a shading device to provide comfort conditions and protection against the glare.

DRELAT also provides reports (.txt files) for UDI values for each point on the analysis grid as a percentage of the annual period. UDI values are grouped such as: less than 100lux, between 100 and 500 lux, between 500 and 2000 lux, and exceeded 2000 lux. The calculation file can be seen in Figure 4.13. Those outputs enable daylight performance assessment to be made and compare the results in different conditions.

*Examples of Climate-Based Daylight Modelling, Paper No. 67, John Mardaljevic.

The 2000 lux upper limit was based on the reported behaviour of occupants in day-lit buildings. It was around the 2000 lux mark that blinds were drawn and/or dissatisfaction was noted. Further, it seems plausible that the occurrence of UDI exceeded (i.e. >2000 lux) is likely to be related to the building's propensity for excessive solar gain. In other words, this simple scheme can provide useful information on the intrinsic shading effectiveness of the building as well as on the daylight.

```

1 require 'fileutils'
2
3 ills = Dir["input/**/*"].select{|f| File.file?(f)}
4
5 - class Array
6 -   def categories
7     h={}
8     h[0]=count{|i| i<=0}
9     h[100]=count{|i| i>0 && i<100}
10    h[500]=count{|i| i>100 && i<500}
11    h[2000]=count{|i| i>500 && i<2000}
12    h[2001]=count{|i| i>2000}
13    h
14  end
15
16 - def dilay_output
17   h=categories
18   zeroes = h[0]
19   t=0
20   h=h.sort
21   h.shift
22   - lh=h.sort.map{|c, v|
23     i = (v.to_f/(size-zeroes)*100)
24     t += i
25     "% .2f" % i
26     #v.to_f/(size-zeroes)
27   }
28
29   # Comment this line to remove "Control" column
30   #l.push("% .2f" % t)
31   l.join(",")
32 end
33 end
34
35 - ills.each{|ill_file|
36   out_filename = ill_file.sub('input', 'output').sub('.', '_udi.')
37   FileUtils.mkpath(File.dirname(out_filename))
38
39   puts "#{ill_file} -> #{out_filename}"
40
41   content=File.readlines(ill_file)
42
43   - File.open(out_filename, 'w+'){|out_file|
44     nodes = content.first.split.size-3
45     - content.map{|l|
46       l.split.last(nodes).map{|i| i.to_i}
47     }.transpose.each_with_index{|v,i|
48       out_file.puts "#{i+1};#{v.dilay_output}"
49     }
50   }
51 }

```

Figure 4.13 : Useful daylight illumination (UDI) evaluation of DRELAT.

Using the time-varying illuminance derived from clime files, UDI during the year is calculated at each of the grid points. Average useful daylight illuminance of each zone (in here 4 zones) expressed in terms of percentage of determined working year. The result of the useful daylight illumination evaluation can be seen in Figure 4.14.

```

1 1;0.00;0.48;88.58;10.94
2 2;0.00;0.00;81.87;18.13
3 3;0.00;0.00;78.07;21.93
4 4;0.00;0.00;79.52;20.48
5 5;0.00;8.58;87.61;3.44
6 6;0.00;2.24;92.08;5.56
7 7;0.00;0.91;93.35;5.68
8 8;0.00;2.96;89.43;7.55
9 9;0.00;43.02;54.62;2.30
10 10;0.00;31.12;64.71;3.99
11 11;0.00;30.63;64.89;4.23
12 12;0.00;30.45;65.08;4.41
13 13;0.00;74.98;24.59;0.18
14 14;0.00;65.08;34.44;0.18
15 15;0.00;64.41;35.35;0.18
16 16;0.00;65.50;33.90;0.06
17 17;0.00;89.61;10.21;0.00
18 18;0.00;86.04;13.90;0.06
19 19;0.00;85.98;13.90;0.06
20 20;0.00;87.85;12.02;0.06
21 21;1.27;94.62;3.81;0.00
22 22;2.11;93.96;3.75;0.00
23 23;0.06;95.83;3.93;0.00
24 24;0.97;95.47;3.20;0.00
25 25;10.94;88.82;0.00;0.00
26 26;12.21;87.37;0.00;0.00
27 27;12.21;87.67;0.00;0.00
28 28;12.75;86.83;0.00;0.00
29 29;22.66;76.56;0.00;0.00
30 30;20.48;70.03;0.00;0.00

```

Figure 4.14 : Useful daylight illumination evaluation results of DRELAT.

5. Supplementary electric lighting need calculation:

It is assumed that each lighting zone is controlled by one sensor that represents the calculated average daylight illuminance level of each time step. Once the average illuminance level of each subzone is calculated, the decision of the control is made according to the level. For instance, when the average daylight illuminance level of the subzone is below 500 lux, it is assumed that the sensor calculates the need and sends the information to dim the lamps according to the requirement. The number of luminaries or lamps can be changed with the purpose of design, need and existing situation implementation.

6. Dimming levels and energy demand calculation:

The electric lighting control system is simulated to determine the lighting energy need to make up the difference between the daylighting illuminance level and the design illuminance level. To perform this, the zone lighting electric reduction factor is calculated.

Dimming factor “DIMFAC” is set according to the required amount of artificial light at a certain daylight level G_{IN} . The dimming stage and the electric light output are defined via:

Dimming factor **(4.1)**:

$$DIMFAC = 1 - \left(\frac{G_{in}}{LIMIT} \right) \quad (4.1)$$

Lamp power **(4.2)**:

$$P_{LAMP} = DIMFAC \cdot P_{max} \quad (4.2)$$

The C-code which deploys the formula and create the dimming factors can be seen Figure 4.15.

```

94 // Standard call -----
95 float dimfac
96 ;
97
98 if (in[0] <= BP[0] && in[0] >=0)
99 {
100     dimfac = 1 - (in[0]/BP[0]);
101     out[0] = in[0];
102     out[1] = dimfac;
103     out[2] = dimfac*BP[1];
104 }
105
106 else
107 {
108     out[0]=in[0];
109     out[1]=0;
110     out[2]=0;
111 }
112
113
114 }

```

Figure 4.15 : C-Code for the dimming calculation.

7. Annual electric lighting energy calculation:

As explained in the previous section, each electric lighting system that is responsible to provide supplementary illuminance, is dimmed according to the detected average daylight illuminance level. Once the dimming level is determined, the electricity consumption is calculated according to the design power of the lamps. The calculation is done for each defined time step of the year. The annual daylight responsive electricity lighting consumption, considering shading and solar protection when it is necessary, can be taken as a result. In order to get total consumption of the system, the control units' system power and ballast efficiency etc. should be considered. The annual electric lighting calculation of the DRELAT can be seen in Figure 4.16. With this electric lighting calculation processor; the photocell controlled dimmer dims ideally luminaries up to required illuminance level and gives electricity demand as a result.

```

103 // Standard call -----
104 if (in[0]<0 && in[1]<0 && in[2]<0 && in[3]<0)
105 {
106     out[0]=-1;
107     out[1]=-1;
108     out[2]=-1;
109     out[3]=-1;
110     out[4]=0;
111     goto Ende;
112 }
113 if (in[0]==0 && in[1]==0 && in[2]==0 && in[3]==0)
114 {
115     out[0]=0;
116     out[1]=0;
117     out[2]=0;
118     out[3]=0;
119     out[4]=0;
120     goto Ende;
121 }
122 if (in[0] <= BP[0] && in[1] <= BP[0] && in[2] <= BP[0] && in[3] <= BP[0] )
123 {
124     out[0]=in[0];
125     out[1]=in[1];
126     out[2]=in[2];
127     out[3]=in[3];
128     out[4]=0;
129     goto Ende;
130 }
131 if (in[0] > BP[0] || in[1] > BP[0] || in[2] > BP[0] || in[3] > BP[0])
132 {
133     if (in[0] < BP[1] && in[1] < BP[1] && in[2] < BP[1] && in[3] < BP[1] )
134     {
135         out[0]=in[0]*BP[2];
136         out[1]=in[1]*BP[2];
137         out[2]=in[2]*BP[2];
138         out[3]=in[3]*BP[2];
139         out[4]=BP[2];
140     }
141     else if (in[0] || in[1] || in[2] || in[3] >= BP[1] )
142     {
143         out[0]=in[0]*BP[3];
144         out[1]=in[1]*BP[3];
145         out[2]=in[2]*BP[3];
146         out[3]=in[3]*BP[3];
147         out[4]=BP[3];
148     }
149 }
150 }
151
152 Ende;
153 }
154

```

Figure 4.16 : The annual electric lighting calculation processor of DRELAT.

8. Analysis for the shading to provide visual comfort:

Occupants can interact with the operation of lighting controls and shading devices manually or the system can be controlled automatically. The automatic control mechanism can be set according to the work plane illuminance level or the appearance of direct sunlight at the workspace. A key assumption of the model is that the electric lighting and shading system is controlled automatically depending on average illuminance level of the defined subzones. When the average daylight illuminance of the defined subzone on work plane level exceeds 2000 lux, the shading system is activated. In order to determine the shading control mechanism settings and conditions, the daylight illuminance levels are calculated again and evaluated a second time.

9. Output files preparation for thermal calculation:

DRELAT analysis tool produces 2 types of output files for integration of thermal calculation. The first type of file is a shading control output file, which consist on/off (1/0) positions of the interior shading devices. The second file type is a dimming level output file, which consists of dimming levels of luminaries as fraction (0-1). Both types of files are generated for 8760 hours of year to integrate the thermal analysis. In this stage of the tool, the annual total daylight responsive electric lighting energy demand is calculated.

4.4 Thermal Energy Demand Calculation in Urban Context

The thermal interactions between a building and its environment are complex. To account for the complexities of the energy transfer processes occurring between the external environment and the building and among its various components and systems, several building energy simulation tools are designed. With building energy simulation tools, the possibility of a prediction of a future reality at the design stage can now be realised and can lead to a more energy efficient building stock.

Building energy simulation tools can be employed to design the building to the requirements of local building regulations, codes, and standards. Subsequently, tools can supplement energy auditing to check the energy performance of the as-built building.

As different building energy simulation codes vary in complexity, calculation algorithms, ease of use and cost, the codes have their advantages and disadvantages. The user's experience and computer skills also play an important role in performing building energy simulation. It can be foreseen that tools will be applied more frequently and widely in building design and analysis as costs decrease and usability improves.

The calculation algorithms for thermal energy demand and heat balance solutions were examined in Chapter 5.4. The determination of the thermal energy calculation (simulation) tool decision will be made in this chapter and integration of the proposed approach will be explained.

Among various aspects of energy conscious design, energy performance of the building deserves great attention, especially for office buildings. Study of the factors

affecting the energy performance of office buildings and the energy characteristics of the building systems is essential for a better understanding of the energy conserving design principles and operational strategies. With the help of computer programs for detailed building energy simulation, it is possible to examine these factors extensively and systematically.

To investigate how the energy demands in an office building vary under changing conditions of surrounding buildings and building properties itself, an energy simulation program should be used. The analysis of the interactions between different conditions of heating/cooling loads in office buildings in various climatic zones can be evaluated with the dynamic energy simulation program. The effect of parameters such as the climatic conditions (location), urban geometric ratios, insulation and thermal mass, colour of external surfaces, window systems including window area and glazing system, and daylight responsive artificial lighting control strategies on annual building energy requirement is examined and the results are presented for each location.

The proposed study involved heating and cooling load calculations of office buildings. For this aim, EnergyPlus, simulation software developed by the US Department of Energy (2011) is used. EnergyPlus calculates thermal loads of buildings by the heat balance method (Crawley, Lawrie, Winkelmann, Buhl, Huang, Pedersen, et al., 2001). The heat balance method takes into account all heat balances of outdoor and indoor surfaces and transient heat conduction through building construction. It is more accurate than the weighting factor methods, since it allows for the variation of properties with time steps (Strand, Winkelmann, Buhl, Huang, Liesen, Pedersen, et al., 1999).

4.4.1 Calculation methodology of EnergyPlus simulation tool

EnergyPlus is an integrated simulation. This means that all three of the major parts, building, system and plant, must be solved simultaneously. In programs with sequential simulation, the building zones, air handling systems and central plant equipment are simulated sequentially with no feedback from one to the other. The sequential solution begins with a zone heat balance that updates the zone conditions and determines the heating/cooling loads at all times. This information is fed to the air handling simulation to determine the system response, but that response does not influence the zone conditions. Similarly, the system information is passed to the

plant simulation without feedback. This simulation technique works well when the system response is a well-defined function of the air temperature of the conditioned space (The US Department of Energy, 2011).

To obtain a simulation that is physically realistic, the elements have to be linked in a simultaneous solution scheme. The entire integrated program can be represented as a series of functional elements connected by fluid loops as shown in Figure 4.17. In EnergyPlus, all the elements are integrated and controlled by the Integrated Solution Manager. The loops are divided into supply and demand sides, and the solution scheme generally relies on successive substitution iteration to reconcile supply and demand.

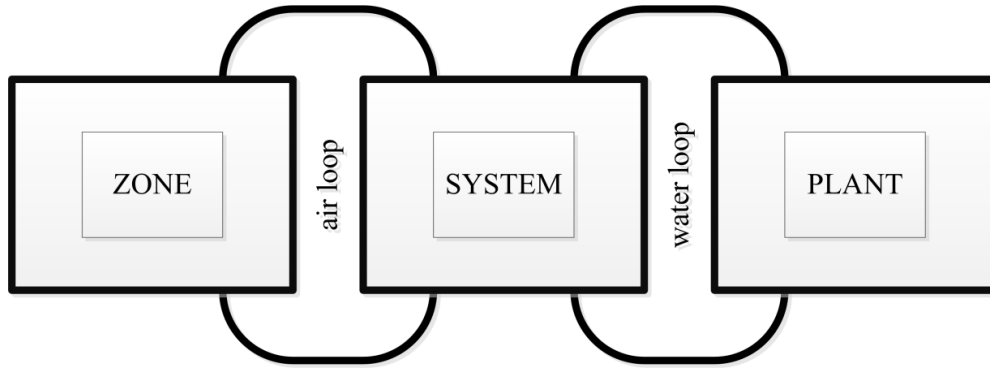


Figure 4.17 : Schematic of simultaneous solution scheme in EnergyPlus (The US Department of Energy, 2011).

The basis for the zone and air system integration is to formulate energy and moisture balances for the zone air and solve the resulting ordinary differential equations using a predictor-corrector approach. The formulation of the solution scheme starts with a heat balance of the zone air.

Heat balance of the zone air **(4.3)**:

$$c_z \frac{dT_z}{dt} = \sum_{i=1}^{N_{si}} \dot{Q}_i + \sum_{i=1}^{N_{surf}} h_i A_i (T_{si} - T_z) + \sum_{i=1}^{N_z} \dot{m}_i c_p (T_{si} - T_z) + \dot{m}_{\infty} c_p (T_{\infty} - T_z) + \dot{Q}_{sys} \quad (4.3)$$

With:

$\sum_{i=1}^{N_{si}} \dot{Q}_i$	sum of the convective internal loads
$\sum_{i=1}^{N_{surf}} h_i A_i (T_{si} - T_z)$	convective heat transfer from the zone surfaces
$\sum_{i=1}^{N_z} \dot{m}_i c_p (T_{si} - T_z)$	heat transfer due to inter-zone air mixing

$$\dot{m}_{\infty} c_p (T_{\infty} - T_z)$$

heat transfer due to infiltration of outside air

$$\dot{Q}_{sys}$$

air systems output

$$C_z \frac{dT_z}{dt}$$

energy stored in zone air

Air systems provide hot or cold air to the zones to meet heating or cooling loads. The system energy provided to the zone $\dot{Q}_{sys}$ can be formulated from the difference between the supply air enthalpy and the enthalpy of the air leaving the zone. If the mechanical system is defined as the ideal loads air system, there is no need to give the system definitions like efficiency and plant size.

The EnergyPlus integrated solution manager manages the surface and air heat balance modules and acts as an interface between the heat balance and the building systems simulation manager. The surface heat balance module simulates inside and outside surface heat balance, interconnections between heat balances and boundary conditions, conduction, convection, radiation, and mass transfer effects. The air mass balance module deals with various mass streams such as ventilation air, exhaust air, and infiltration. It accounts for thermal mass of zone air and evaluates direct convective heat gains.

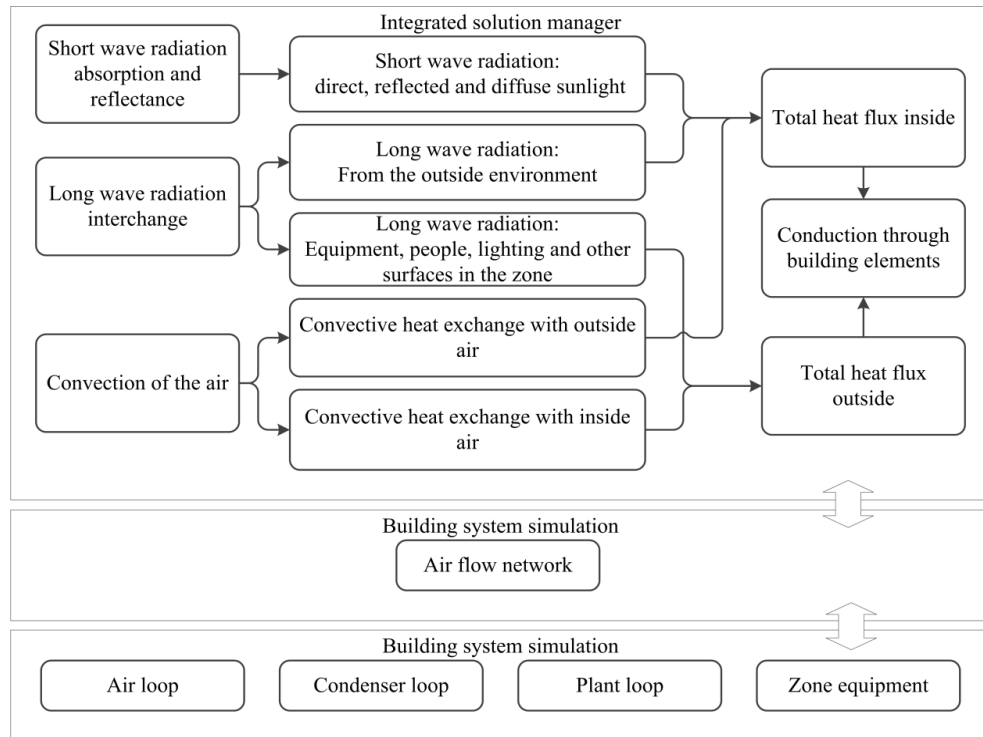


Figure 4.18 : Heat balance and building system simulation interaction in EnergyPlus.

As it is illustrated in Figure 4.18, EnergyPlus is consisting of integrated solution manager and building system simulation managers. The simulation manager controls the interactions between all simulation loops through the user selected time step and simulation period. The integrated solution manager manages the surface and air heat balance modules that simulates inside and outside surface heat balance and interconnections between heat balances and boundary conditions, conduction, convection, radiation, and mass transfer effects. The integrated solution module also deals with air mass balance such as ventilation air, exhaust air and infiltration.

4.4.1.1 Heat balance model

As noted earlier, the underlying building thermal zone calculation method in EnergyPlus is a heat balance model. The fundamental assumption of heat balance models is that air in each thermal zone can be modelled as well as stirred with uniform temperature throughout. Although this does not reflect physical reality well, the only current alternative is Computational Fluid Dynamics (CFD), which is a complex and computationally intensive simulation of fluid movement. The other major assumption in heat balance models is that room surfaces (walls, windows, ceilings, and floors) have the following:

- uniform surface temperatures,
- uniform long and short wave irradiation,
- diffuse radiating surfaces, and
- internal heat conduction [26]

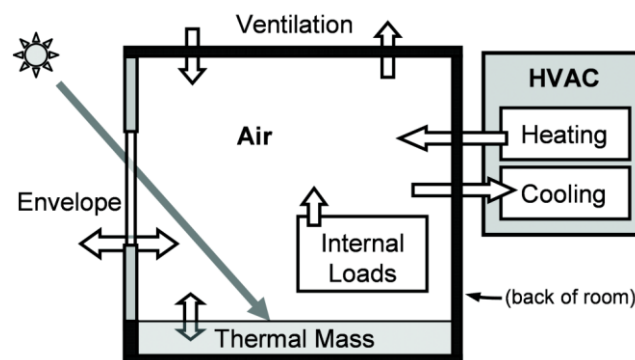


Figure 4.19 : Energy exchange with the air in a room. Arrows indicate possible directions of heat flow (The US Department of Energy, 2011).

The walls of the building space act as a thermal mass, absorbing the sunlight at the surface and converting it into heat, which is slowly transmitted to the inside of the

building space. Furniture in a zone has the effect of increasing the amount of surface area that can participate in the radiation and convection heat exchanges. It also adds participating thermal mass to the zone. These two changes affect the response to temperature changes in the zone and also affect the heat extraction characteristics. The proper modelling of thermal mass with the heat balance formulation allows the effect to be modelled in a realistic manner by including the furniture surface area and thermal mass in the heat exchange process.

4.4.1.2 Energy exchange computation

Energy exchanges occur via several channels like; internal loads, ventilation, envelope, thermal mass, and HVAC. As can be seen in Figure 4.19, all possible directions of heat flow are taken into account for calculation of air exchange in the building space. Internal loads depend on the occupancy conditions in the building and are assumed to be constant during any given hour. Ventilation and envelope loads are proportional to the indoor-outdoor temperature difference and their magnitude can vary within a single hour as the room's air temperature floats between the upper and lower thermostat bounds. Thermal mass loads are more complicated and variation depends on the instantaneous indoor temperature, the incident heat flux, and the temperature distribution within the mass itself.

One way of solving large thermal systems is to assign each surface a temperature node, generate a system of energy balance equations, and use matrix inversion to solve the system of equations. Because some of the heat transfer coefficients are non-constant, it would be necessary to frequently invert the large matrix, and this is impractically slow. Instead, all of the loads Q_i (in units of W) are computed independently for each room for the various channels of energy exchange. The computations are made only as frequently as needed; once per hour for internal loads, and times steps per hour for envelope, thermal mass, and ventilation loads (Urban and Glicksman, 2010).

4.4.1.3 Solar radiation calculation

When assessing heat gains in buildings due to solar radiation, it is necessary to know how much of each part of the building is shaded and how much is affected by direct sunlight. The sunlit area of each surface changes as the position of the sun changes during the day. The purpose of the EnergyPlus shadow algorithm is to compute such

sun lit areas. The shadow algorithm is based on coordinate transformation methods similar to Groth and Lokmanhekim (1969) and the shadow overlap method of Walton (1983).

EnergyPlus has also an option to calculate beam and diffuse solar radiation that is reflected from exterior surfaces and then strikes the building. The reflecting surfaces fall into three categories; shadowing surfaces, exterior building surfaces, and the ground surface. Examples of solar reflection from shadowing surfaces can be seen in Figure 4.20. Solid arrows are beam solar radiation; dashed arrows are diffuse solar radiation. (a) Diffuse reflection of beam solar radiation from the top of an overhang. (b) Diffuse reflection of sky solar radiation from the top of an overhang. (c) Beam-to-beam (specular) reflection from the facade of an adjacent highly-glazed building represented by a vertical shadowing surface (Engineering Reference of Energy Plus, 2011).

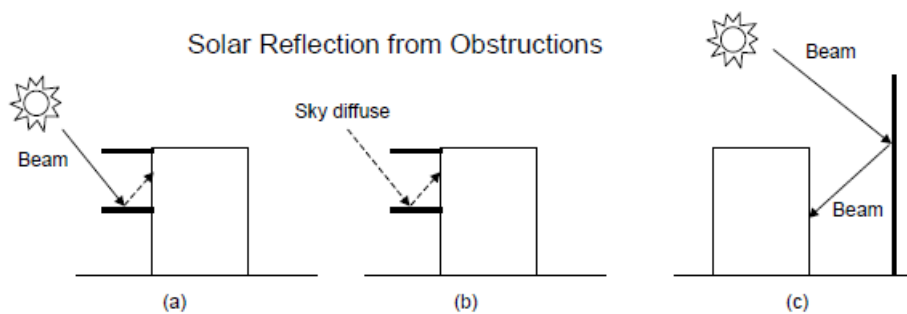


Figure 4.20 : Examples of solar reflection from shadowing surfaces (The US Department of Energy, 2011).

A ray-tracing method is used to calculate beam solar and sky solar radiation that is diffusely reflected onto each of a building's exterior surfaces (walls, roofs, windows and doors), called here "receiving surfaces." The calculation begins by generating a set of rays proceeding into the outward hemisphere at each receiving point on a receiving surface. Then it determinates whether each ray hits the sky, ground or an obstruction. The radiance at the hit point from reflection of incident beam or sky solar is determined and the contribution of this radiance to the receiving surface is calculated, added to the contribution from other hit points, and averaged over the receiving points. Separate calculations are done for beam-to-diffuse and sky solar reflection from all obstructions and beam-to-diffuse and sky solar reflection from the ground (Engineering Reference of Energy Plus, 2011).

At each time step, the transmitted fraction of incident radiation is computed. Multiple reflections are considered to determine the energy absorbed, reflected, and transmitted by all elements of a multi-layered facade. Spectrally selective materials are modelled with a tri-band radiation model; IR, visible, and solar-thermal radiation are considered separately.

4.4.1.4 Ventilation and infiltration modelling

Buildings interact with the atmosphere through convective heat transfer between the outdoor air and the exterior surfaces of the building envelope, and through the exchange of air between the outside and inside of the building via infiltration and ventilation.

Infiltration is the unintended flow of air from the outdoor environment directly into a thermal zone. Infiltration is generally caused by the opening and closing of exterior doors, cracks around windows, and even in very small amounts through building elements which is assumed to be immediately mixed with the zone air. The determination of the amount of infiltration air is quite complicated and subject to significant uncertainty. EnergyPlus contains three models for infiltration. The first is the “Design Flow Rate”, the second is “Effective Leakage Area” and the third is “Flow Coefficient” model (Engineering Reference of Energy Plus pdf, 2011, Air Heat Balance Manager / Processes).

Ventilation is the purposeful flow of air from the outdoor environment directly into a thermal zone in order to provide some amount of non-mechanical cooling. Ventilation as specified by this input context is intended to model “simple” ventilation as opposed to the more detailed ventilation investigations that can be performed with the Airflow Network model. Simple ventilation in EnergyPlus can be controlled by a schedule and through the specification of minimum, maximum and delta temperatures (Engineering Reference of Energy Plus pdf, 2011, Air Heat Balance Manager / Processes). EnergyPlus contains two models for ventilation; the “Design Flow Rate” model and the “Wind and Stack with Open Area” model.

4.4.1.5 Daylight calculation in EnergyPlus and comparison with RADIANCE

The goal of this study is mainly to calculate the heating, cooling and lighting (daylight responsive) loads through the year while providing daylighting information given surrounding buildings in the urban context. EnergyPlus had also a module to

calculate the illuminance level of interiors DELight calculation module uses, specified reference points for the interior daylighting illuminance calculations and then it determines how much the electric lighting can be reduced while still achieving a combined daylighting and electric lighting illuminance target. In the concept of the PhD work, EnergyPlus lighting calculation module was not selected because of some specific reasons that are described below.

- DELight uses radiosity method to calculate realistic images, while Radiance uses Raytracing Method. (The difference between radiosity and raytracing approaches is described in 4.3.1.)
- With DELight the Artificial lighting system specifications, as lamp and luminary selection and placement cannot be described.
- Up to 100 reference points can be defined within a DELight daylighting zone. One or more of these reference points must be included in the control of the electric lighting system in the zone. There is no limit for reference point definition in Radiance neither for illuminance level detection nor electric and control.
- DELight uses Perez luminous efficacy model to calculate mean luminance of the diffuse and direct sunlight for considered sky condition (Perez, 1990). This model is a combination of four sky luminance models; (1) the standard CIE cloudless sky, (2) a high turbidity formulation of the latter, (3) a realistic formulation for intermediate skies proposed by Nakamura and (4) the standard CIE overcast sky. However, the Radiance based DAYSIM uses the Perez sky luminous distribution model first to convert irradiances into illuminances and then into a series of sky luminous distributions of the celestial hemisphere for all sky conditions of the year.

To compare the DELight and Radiance results, two identical rooms are designed in two different programs. Dimensions of the test case room can be seen in Figure 4.21.

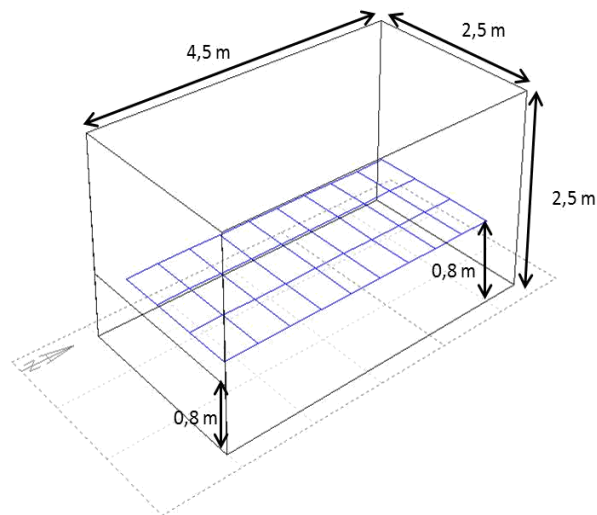


Figure 4.21 : Dimension of the test case room.

Simulations were done in same location, day and times of the day under the same sky conditions to compare the daylight simulation results obtained by Radiance and EnergyPlus through the methods of the evaluation (Kesten, 2011). The results can be seen in

Figure 4.22. Radiance programme algorithm calculates the internal illuminance and luminance of a zone efficiently based on the physical performance of the light functioning with the raytracing method. This program predicts illuminance distribution in buildings under defined sky conditions. However, EnergyPlus DE-light determines the daylighting based on radiosity method.

To analyse the natural illumination through the programs Radiance and EnergyPlus DE-Light a model is defined that represents an office of $11,25\text{m}^2$ ($2,5\text{m} \times 4,5\text{m}$) with a floor to ceiling height of $2,5\text{ m}$. the model has a window to the exterior in the south facade of $4,25\text{ m}^2$ (Figure 4.21).

Daylighting evaluation is done on 21st of January with clear sky condition and compared in 4 time steps with daylighting illuminance values on grid points.

Figure 4.22 indicates that EnergyPlus DE-Light results are overestimated compared to Radiance results. The reason is caused by the previously mentioned limitations of the radiosity method that is used by EnergyPlus program.

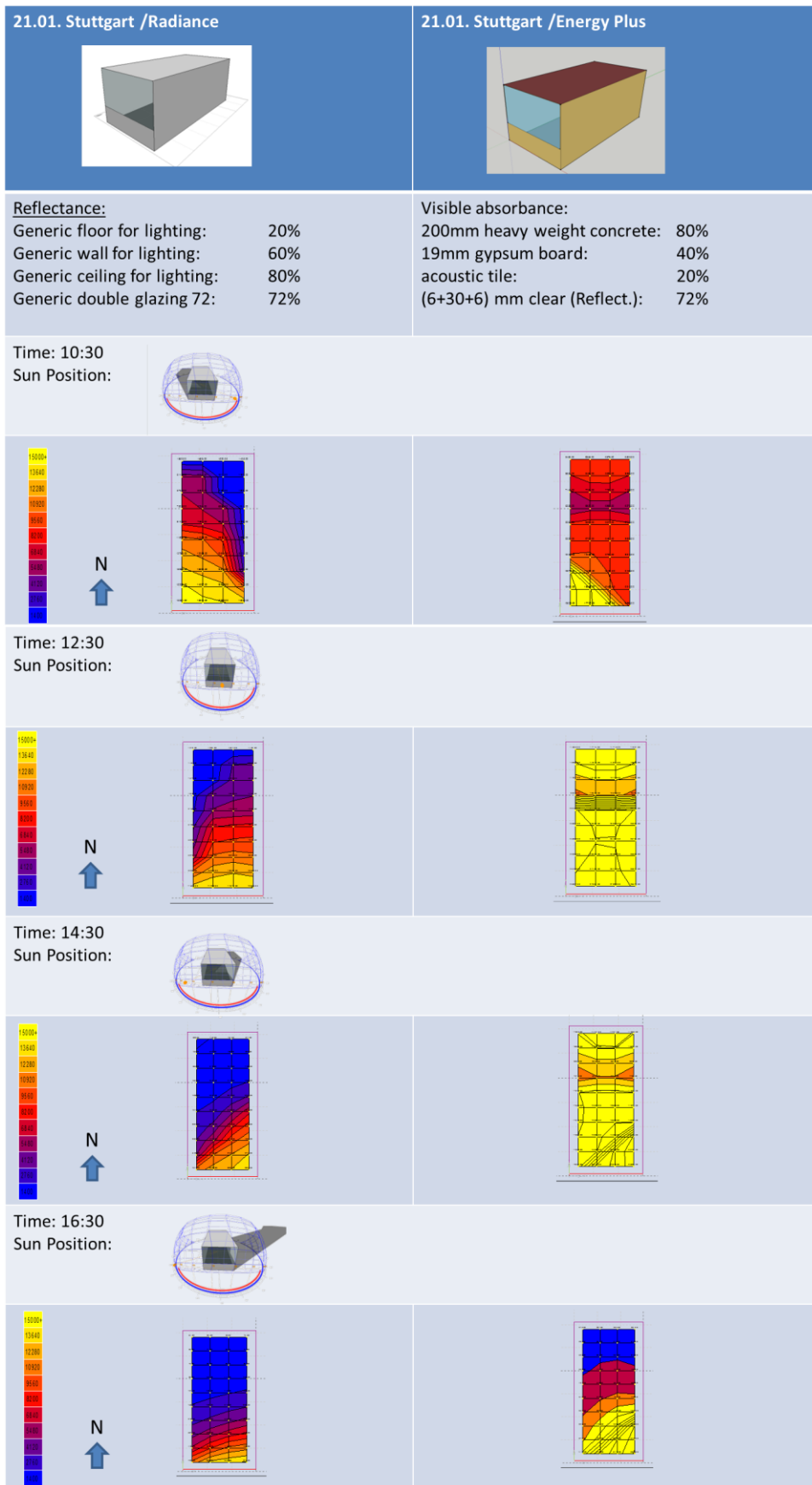


Figure 4.22 : Daylighting simulation result comparison between Radiance and EnergyPlus.

The results also indicate the importance of the right daylighting and artificial lighting tool in the proposed approach in this work.

Versage et al. (2010) examine the influence of modelling daylighting in EnergyPlus and DAYSIM. Different controls of the daylighting system were tested and the results were based on the total building energy consumption. The daylighting results from the EnergyPlus program show limitations for zones that have great depth as it overestimates the illuminance values in areas far from the window. Thus, the modelling of daylighting using DAYSIM was combined with the EnergyPlus program to estimate the whole building energy performance. These results demonstrated higher accuracy and the influence of the use of the DAYSIM daylighting result.

4.4.2 Input of required data for thermal simulation

Computer-based building-energy simulations have proven useful in analysing thermal schemes. Detailed building-energy simulation programs incorporate sets of mathematical models that seek to explain quantitatively how each component of a building behaves under given circumstances. An hour-by-hour, full year, multiple-zone numerical analysis for modelling building energy performance is required to illustrate the alternatives in detail. The computer simulations conducted and the energy results generated are considered valuable design aids and provide a comprehensive picture of the proposed building's energy-behaviour. The simulation tool employed in the present study for thermal calculation is the EnergyPlus building-energy simulation program (EnergyPlus simulation tool input - output options can be seen in the Appendix A).

4.4.2.1 Natural conditions' definition for Energy Plus

Natural factors affecting energy performance and user comfort requirements can be separated into the parameters related to climatic and geographical factors, which were specified as the input data in the simulations for characterizing the outdoor environment. The climatic factors may include: daily solar radiation, outdoor dry bulb temperature, barometric pressure, wind pressure and direction, sky clearness and outdoor humidity ratio. The geographical factors include: longitude, latitude, direction, elevation, terrain and ground reflectivity.

Weather data should be relatively stable for building design and energy use analysis. The key climatic variables affecting the thermal design of buildings and building services systems should be defined primarily on the basis of the simulation tool requirements. All building simulation programs employ some means of representing local climatic conditions relative to the building modes. The widely used energy simulation programs use climate representations. These data often include “typical” data derived from hourly observations at specific locations provided by national weather service or meteorological offices. Examples of these typical data include: Typical Meteorological Year 2 (TMY2) and The Weather Year for Energy Calculations 2 (WYEC2) in the United States and Canada and Typical Meteorological Year (TRY) in Europa (Crawley, Hand and Lawrie, 1999). Radiation and illumination data are becoming increasingly necessary in simulation programs. The TMY2 and WYEC2, typical weather years contain more solar radiation and illumination data than other formats such as TMY, WYEC and TRY. In EnergyPlus simulation, TMY2 weather data is used for calculations.

4.4.2.2 Built environment conditions’ definition for Energy Plus

The built environmental factors that affect energy and the user comfort performance of building include; Position and size of the exterior obstacles (solar radiation reflectivity of the surrounding surfaces); users (numbers, activity level, thermal insulation value of clothing, schedule of building, general properties of the building, volume, size and orientation, function, usage schedule, air movement/temp/humidity); and building components (opaque, transparent, thermal/optical properties). Each of these factors can be determined in order to calculate the thermal performance of the building.

In specifying the building components, the thermal and optical properties of the components should be defined in the required format. For example, the window specifications such as Heat Transmission Coefficient (U value), SHGC (Solar Heat Gain Coefficient) and T_{vis} (Visible Transmittance) are used in EnergyPlus as input data files for identifying thermal and optical properties of glazing systems. The properties of building components are that impact energy calculations such as dimension, position, joint, colour and material should be taken into consideration in the design or definition of existing system.

4.4.3 Thermal simulation process

Heating and cooling energy load calculations can be estimated by determining heat gain and losses that result from: heat transmission, solar radiation; air infiltration; and mass effect and gain resulting from internal heat gains. These calculations are performed by using EnergyPlus, which is a collection of many program modules that work together to calculate the energy required for heating and cooling a building using a variety of systems and energy sources. The details of each calculation are described in Section 4.4.1.

In EnergyPlus, the heat transfer by radiation, convection and conduction is calculated at each time step. The U-values are not constant through the simulation because heat transfer is calculated by algorithms that take into account parameters such as the temperature difference between the surface and the air. In this case, building construction should be defined as composed layers; for example, sand plaster layer, 13 mm gypsum plaster with paint on the indoor side. The properties of the materials used in building are specified.

For the thermal simulation of the room, it is assumed that the space is bordered on five sides by similar space conditions. Hence, interior walls, floor and ceilings are modelled adiabatically.

The easiest way to find out the space's hourly total cooling and heating load in EnergyPlus to maintain the specified thermostat set points is to use the purchased air simulation with no capacity limits and include outside air if applicable. This will also provide a rough approximation of latent load requirements. If the thermostat set points are being met, then the system is providing enough cooling and heating. This is the measure of performance and output files show whether the set points are being met. The heating and cooling set points and setbacks are 21°C / 24°C and 25°C / 30°C, respectively. Annual hourly schedules for electric lighting (including roller blinds action necessary) is generated in DRELAT and read as simulation input into Energy Plus.

4.5 Integration of Lighting and Thermal Calculations

External obstructions affect the building's energy-performance in two main ways. Shading will, on the one hand, result in less cooling requirements due to a decrease in solar heat. On the other hand, shading will admit less natural daylight, increase

electric-lighting consumption and can cause an increase in associated cooling requirements under daylighting controls.

In order to evaluate energy-related implications of a daylighting concept, the simulation assumptions from the daylighting analysis need to be synchronised with the thermal analysis. In the proposed approach, this synchronisation was realised through DRELAT, writing out hourly schedules that include the status of the electric lighting. This schedule file was then read into the EnergyPlus model of the space. Figure 4.23 summarises the overall simulation approach. The space must be modelled twice to apply the proposed methodology; once for the daylight simulations and once for thermal simulation.

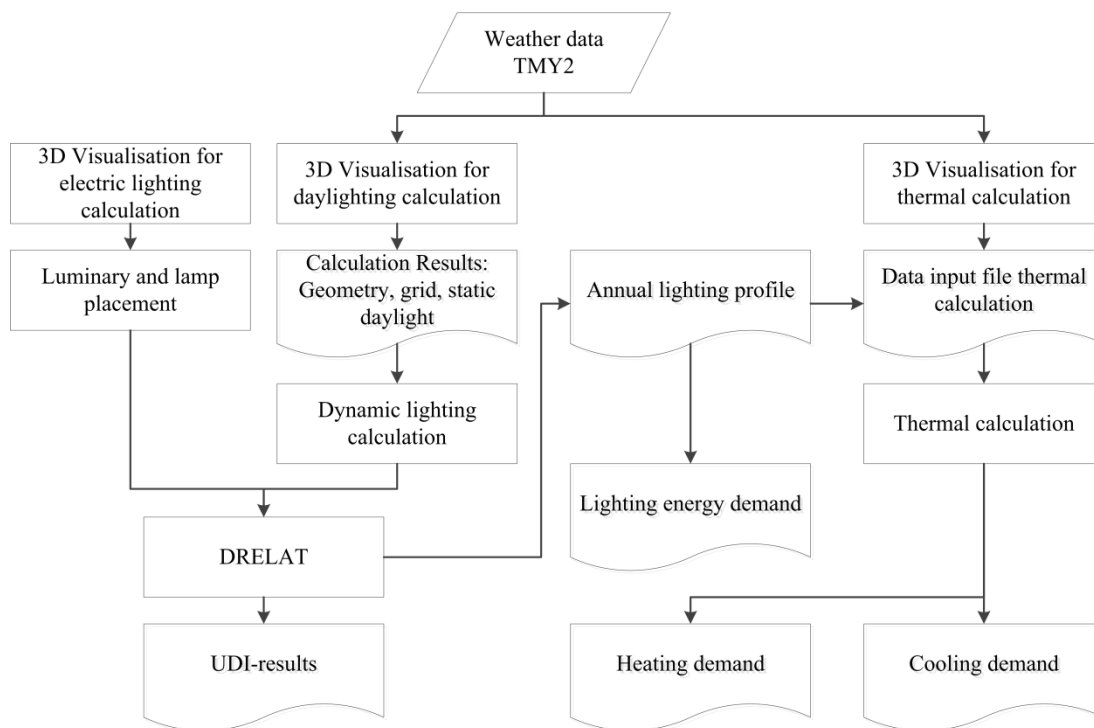


Figure 4.23 : Integration approach thermal and lighting simulations used in the concept of thesis.

The objective is to provide relevant information regarding daylighting and overall energy use considering the effect of neighbouring buildings. The comparison between the energy implications of different urban geometries is made easier when the monthly (daily, hourly) energy use patterns are obvious. .

The proposed approach can play important role in helping design teams (urban designers, architects) make more informed design decisions. Regarding the use of energy saving components, the method can be applied at the design stage when key

decisions are generally made. When the approach is used as evaluation method, it can also help designers understand the energy impacts of existing conditions and provide a chance to test refurbishment options. Furthermore, the approach provides a variety of climate-based daylight performance outputs. The designer can use those metrics to enhance design practises that still largely rely on rules of thumb and experience from previous work.

In summary, the principles of the new integrated design analysis method considering effects of neighbouring buildings in the urban context (within specified urban geometry) is introduced and explained in this chapter. The basic steps of the approach are illustrated in a flow chart and include input from various simulation models taking into consideration natural and built environments, the office building and room properties, urban geometry, daylight responsive electric lighting demand, thermal energy demand, and the integration of these calculations. Details of each step of the methodology are explained including integrated use of computer-based analysis techniques related to DRELAT and EnergyPlus programs. This proposed method simultaneously considers annual daylight availability, visual comfort and energy use. Annual daylight illuminance profiles are combined with visual comfort condition limitations in order to determine annual shading profiles throughout a space. The shading profiles are then used to calculate useful daylight illuminance performances in four levels (less than 100lx, between 100lx and 500 lx, between 500lx and 2000lx, and exceeding 2000lx). After implementation of the shading profiles, the daylight responsive electric lighting profile is constituted and lighting, heating and cooling energy loads are calculated respecting the profile of electric lighting. This chapter serves to set forth the basic theoretical approach to the proposed evaluation method. The next chapter will describe the implementation of this approach using an example of a side-lit test office room wherein a series of simulations for are carried out and described with room orientation and area of the external obstruction being changed systemically.

5. IMPLEMENTATION OF THE PROPOSED APPROACH

The urban geometry and interactions between all parameters should be examined in detail when studying the daylight and energy performance of a building. Integrated building energy simulations can provide analysis of daylight schemes, but as explained in the previous chapters, it is not sufficient to show qualitatively and quantitatively how each component of the urban system, building and room behaves under given circumstances. This PhD study proposes a daylight performance and numeric analysis approach for the evaluation of a building's energy performance within the urban context. The implementation of the proposed approach is explained in this chapter.

A simplified scenario is used in this study. The focus is then reduced to the main mechanisms of the problem, baring the disadvantage that obtained results may not directly related back to real problems. In most cases, results can only indicate the potential sensitivity of the performance due to the variable.

5.1 Determination of Natural Conditions

The example of a simple side lit office space is provided to analyse visual performance including the heating, cooling and lighting energy load. The space is located in Stuttgart, Germany, geographically located at 48°68'N latitude and 9°22'E longitude.

Based on recent data sets from the German Weather Service, Stuttgart is located in the Cfb Zone. Cfb Zone can be defined as: *C* stands for warm moderate climate, wherein the average temperature of the coldest month lies between +18 und -3°C; *f* stands for humid, wherein all months are humid; and *b* stands for warm summers wherein the average temperature of the warmest month lies under +22°C and at least four months of average temperatures of at least +10° C.

Stuttgart's climate is mild with an average annual temperature of around 10 °C in the basin of the city and 8.4 °C in the more elevated outskirts situated approximately 400 m asl (above sea level). July is the hottest month with an average temperature of 18.8

°C, while the temperature in January averages only 1.3 °C (See Figure 5.1). Nearly 150 days of the year are below freezing temperature (Jendritzky, 1993).

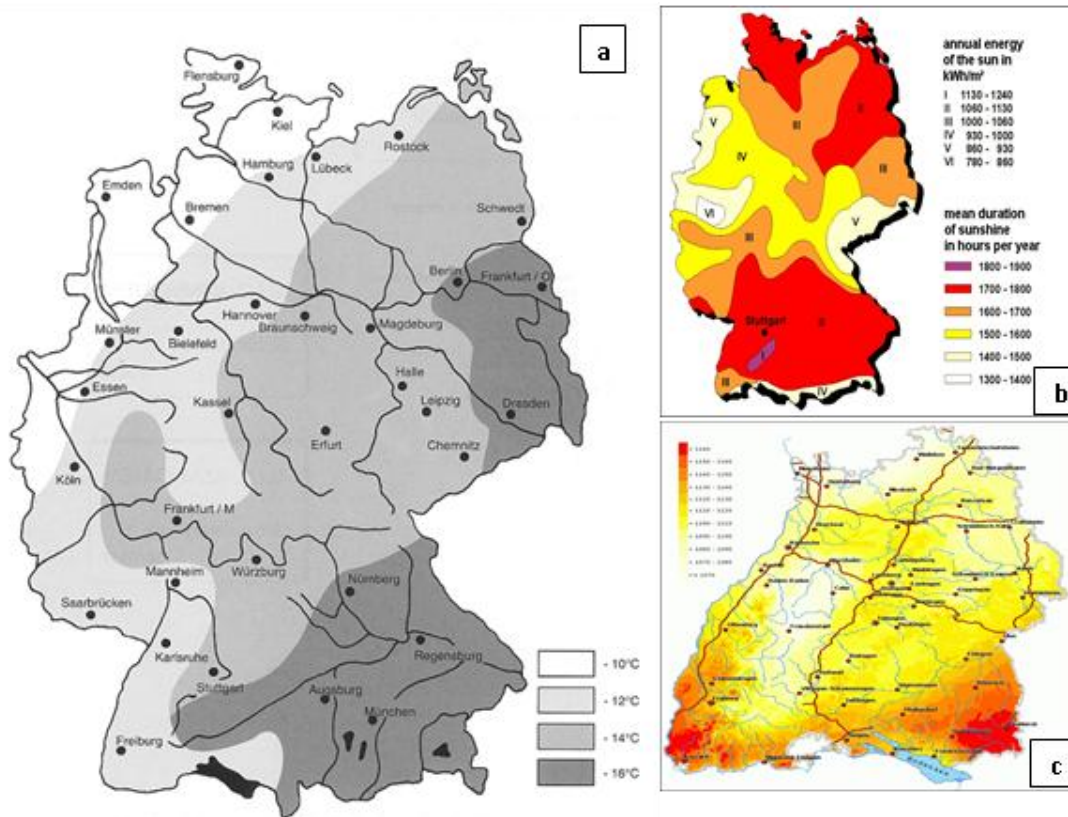


Figure 5.1 : Average temperature in the Federal Republic of Germany (a) average annual duration of sunshine and global radiation in the Federal Republic of Germany (Schirm, 1995), middle annual solar irradiation (kWh/m²) in Baden-Württemberg.

The most frequent and also strongest winds in the region of northern Württemberg, as a long-term average, come from the west to southwest (prevailing wind direction). The average wind speed in the climatic region is only 2.5 m/s. This means that Greater Stuttgart is a region with relatively low wind speeds. The above-mentioned very low wind speeds of up to 1.5 m/s (including lulls) have an average annual frequency of about 44 %. The frequency of low wind speeds increases slightly during the winter half year and reaches 46 %. The predominant wind direction, wind probability and average wind speed of Stuttgart can be seen in Table 5.1.

Table 5.1 : The predominant wind direction, wind probability and average wind speed of Stuttgart

Statistic relies on data collected between 11/2001 and 04/2005 (07:00-19:00)													
Month	1	2	3	4	5	6	7	8	9	10	11	12	Year
Predominant wind direction	↗	↗	→	←	↗	↓	→	←	←	←	↗	↗	↗
Wind probability ≥ 4 Beaufort [%]	16	29	15	20	12	15	20	9	8	18	9	16	15
Average wind speed [km/h]	11	17	13	15	13	11	13	9	11	13	9	13	11

5.2 Determination of Built Environment Conditions

The built environment conditions of the case study are determined in this stage.

5.2.1 The office room properties

The office room properties are determined in following subtitles.

5.2.1.1 Room form, dimensions and building elements properties

The method is applied for an office room (required illumination level 500 lux) in Stuttgart. The specifications of the room are as follows:

- The width, l, depth, d, height, h of the room are 2,5m, 5m and 2,5m, respectively.
- The light reflectance of the room surfaces are: ceiling 80%, walls, 60%, floor 30%.
- Window dimensions: window width, l_w : 2,25m and window height, h_w : 1,40m with 0,80m sill height (p_h) above the floor. The height of the wall part between window and ceiling (l_h) is 0,30m.
- Working plane and window have the same height above the floor.
- The window has a spectrally selective double glazing with the normal visual transmittance of 72% and solar heat coefficient of 62%.
- The office is occupied on weekdays from 08:30 to 18:30.
- The heat transfer coefficients (U value) of the construction are selected according to minimum requirement contained in EnEV 2009 (the construction layers, material names, thickness, density and conductivity values can be seen in the Appendix B).

The room and window dimensions can be seen in Figure 5.2.

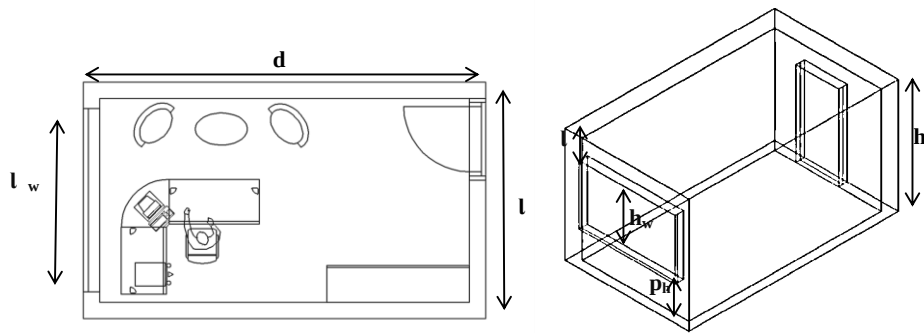


Figure 5.2 : Room and window dimensions.

5.2.1.2 Electric lighting, control system and solar shading

The electric lighting of sample the office space is designed to meet the requirements of the space function and visual comfort of the users.

The selecting and positioning of luminaires and lamps was done in ReluxSuite by Relux Informatik A.G. The proper combination of lamp and luminaire was found after the testing of cases. The selected lamp for the simple office is a 35W TL5 fluorescent lamp with a colour temperature of 3000 K. For the selection of the luminaire, prevention of glare has been considered.

The positioning of the artificial lighting system can be seen in Figure 5.3.

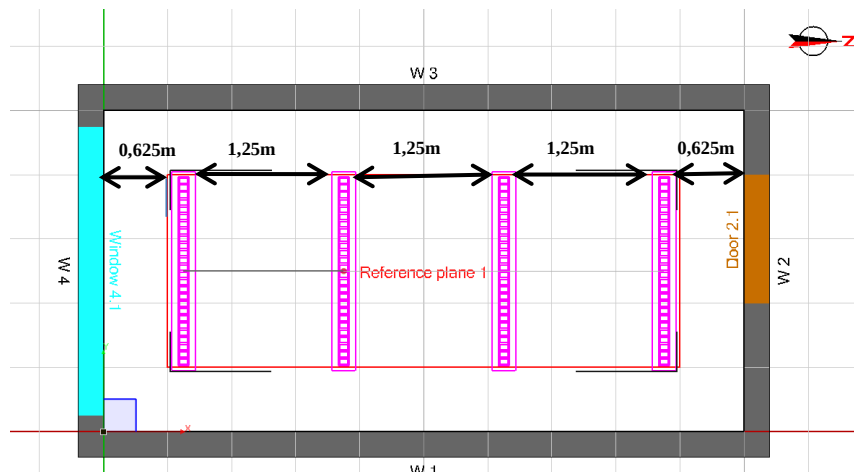


Figure 5.3 : Luminaire placement of sample room.

Each luminaire has one 35W TL 5 fluorescent lamp. The lamps in the electric lighting system can be dimmed by electronic ballasts. The luminaire that is used for electric lighting and its polar diagram can be seen in Figure 5.4.

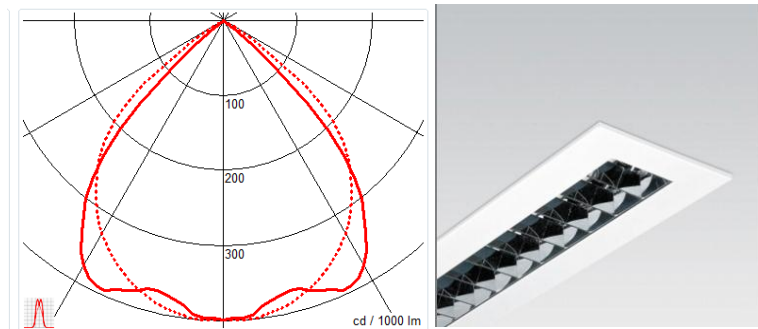


Figure 5.4 : The selected luminaire and its polar diagram.

The length of selected recessed luminaire is 1547 mm, the width is 184 mm and has an efficiency of 72.8%. The luminaire efficiency is 61.6 lm/W (A60, ↓ 100.0% ↑ 0.0%) and CIE Flux Codes are 73 99 100 100 73. Its total system power and total luminous flux are 39 W and 3300 lm, respectively. The protection degree of the luminaire is IP20 with the protection class of “T”.

Daylight responsive dimmable electronic control gear is added to electric lighting system in the room. Illuminance sensors of lamps are controlled according to their position in the room so that the predefined illuminance level, 500 lux, is maintained in the whole working area.

The sensors mounted on the luminaries measure the illuminance density of the area below. Therefore, the sensor sends dimming values (0-100 %) to the control algorithm and sets the artificial lighting level. Even though daylight may change rapidly, the current control systems follow these changes quickly.

Shading is used not only to balance daylighting requirements and ensure the visual comfort, but also prevent thermal discomfort. In this sample office room, the determined shading device is the textile roller blind. The roller blind is controlled based on daylighting considerations. At the same time the cooling energy consumption is calculated as a function of transmittance, taking operation of the blinds and control of electric lighting into account.

The used roller blind has two layers with different transmitting properties. The optic and thermal properties of the textile roller blinds are given below:

The first layer consists of 84% polyester and 16% linen. It is translucent and both sides are white. Thickness is 0,35mm and openness factor is 14%. It has 30% visible transmittance.

The second layer consists of 25% polyester and 75 % PVC on polyester. Both sides are white. Thickness is 0,35mm and openness factor is 5%. It has 50 % visible transmittance. Both roller blinds have high solar reflectance values (80%) and a conductivity of 0.5W/mK.

5.2.2 The office building properties

The building form dimensions and location of the sample room are defined in this section.

5.2.2.1 Building form and dimensions

The sample office building form is square with a 12.5m building depth, D , and 12.5m building width, L_2 (Figure 5.5). The building has 3 floors with a total height (H) of 9 m. It has two main facades with a total 21% window-wall ratio. The office building has a central corridor that serves offices on both sides. The width of the corridor is 2.5 m. On each side of corridor there are 5 identically sized cell offices comparable to the sample office room.

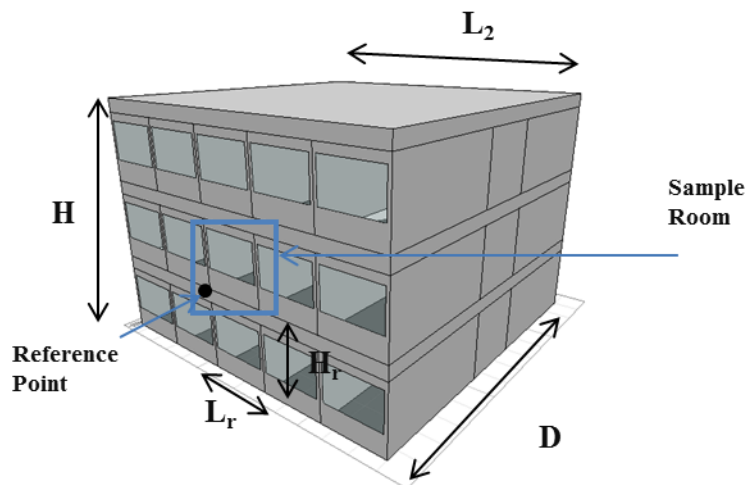


Figure 5.5 : Building dimensions H , L_2 , D and room location illustration with L_r and H_r .

5.2.2.2 The sample office room location in the building

The sample room is located in the middle axis of the building in the second floor. The reference point of the room is located at 5 m distance and at the 3 m height from the reference point. The location can be defined as: $L_r=5$ m and $H_r=3$ m. The placement of the sample room can be seen in Figure 5.5.

5.2.3 Urban space characterisation

Each basic urban form is obtained according to the building depth ratio (L_2/D). Pavilion building depth ratio is 1, short slab between 2 and 5, long slab between 6 and 9, and terrace building depth ratio is more than 10 (Oliveira Pana, Gonc-alvesa and Ferra, 2008).

As mentioned in Chapter 4, with in the proposed approach, three generic urban forms are considered (pavilion, slabs and terraces).

5.2.3.1 Urban form and dimensions

The first case implementation is applied to the pavilion urban form. The dimensions between each building are determined based on current environmental law dealing with spatial planning and zoning in Germany the municipal level (Stuttgart).

It is assumed that this urban form is located in the core (centre) of the city. The coverage type, plot areas, which may or may not be built on, and the location of the physical structures are determined according to German building code (Baugesetzbuch - BauGB). The Land Utilization Ordinance, which offers the upper limits of the degree of building and land use, include the maximum limits of the site occupancy index (GRZ) and plot ratio (GFZ) (Baunutzungsverordnung, BauNVO) (Oliveira Pana, Gonc-alvesa and Ferra, 2008). The permissible site occupancy index (GRZ) is 1.0 and the plot ratio (GFZ) is 3.0 in city centres. In terms of distance and space, secondary structures like balconies, loggias and terraces are arranged according to federal state law.

Based on the Federal State Building Ordinance of Baden-Württemberg (LBOBW), the distance between buildings in the city centre can be arranged using the ratios of building height to street width, as seen in Figure 5.6.

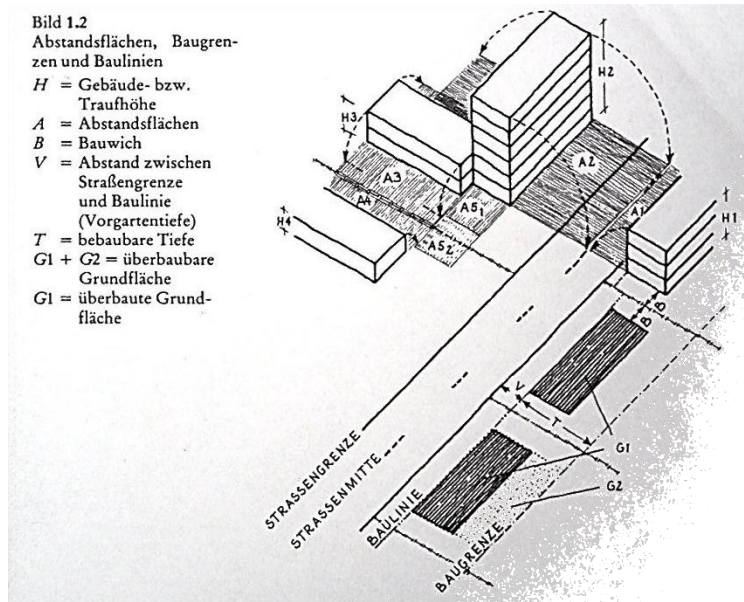


Figure 5.6 : Distance space, construction line and building line illustration according to German Building Code.

The permissible space distances, which are given in the LBOBW for the city centre constructions, are: $0.4 H$ (building height, see Figure 5.7), in the narrow privilege conditions; it can be either $0.3H$ or minimum 2,5m from the building line.

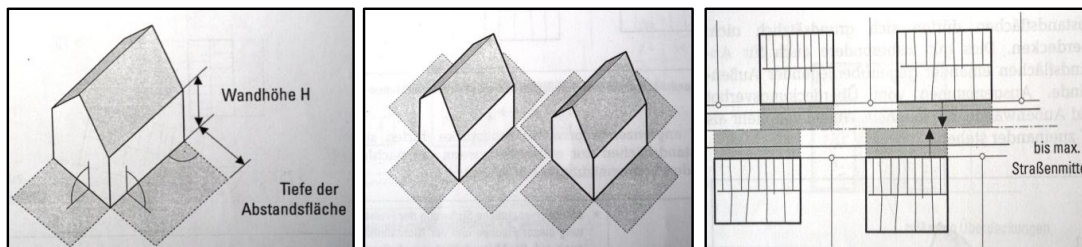


Figure 5.7 : Building height and distance space relation according to LBOBW.

In the sample urban configuration, the distance between buildings in the y-axis direction, so called W , is considered with street (road) application. The different scenario configurations are selected also according to German permissible street width dimensions, which can be seen in Figure 5.8.

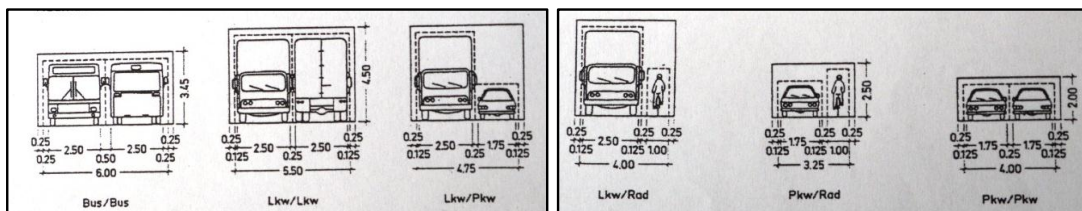


Figure 5.8 : The street design standards in Germany.

The sample urban area is designed in order to meet the minimum permissible dimensions between buildings in Stuttgart city centre. Urban geometry specifications with distance between building units and sample office can be seen in Figure 5.9. The applied distances between office blocks are given below:

- The urban form used is the pavilion form, with the ratio of $L_2/D = 1$. Building heights are the same as the sample building height H , 9 m, same building depth $D=12,5$ m and building width $L_2=12,5$ m.
- Number of building blocks in the urban area is 9.
- L_1 distance between buildings in the x direction - spacing between units is 5 m. The minimum permissible space distance of the building is 2,5m and $L_1=2,5\text{m} + 2,5\text{m} = 5\text{m}$
- W distance between buildings in the y-direction and/or width of the street is 9 m. The minimum street dimension for 2 cars is given 4 m in the German street planning standards. The minimum permissible space distance of building is 2,5 , $W= 2,5\text{m} + 4\text{m} + 2,5\text{m} = 9\text{m}$

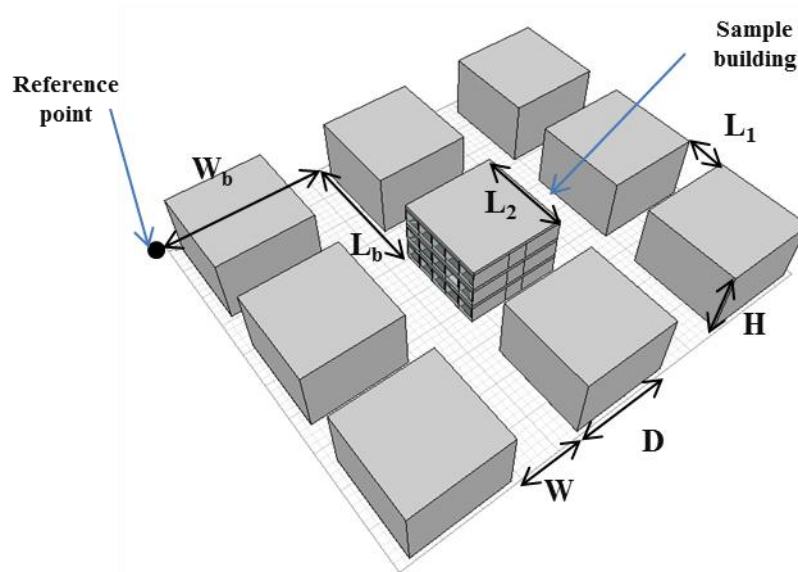


Figure 5.9 : Urban geometry specifications with distances between building units and sample office.

5.2.3.2 The sample office building location in urban area

The sample office is located in the centre of the pavilion type urban area. From the reference point of the urban area to the reference point of the building area, the distance in the y-direction (L_b) is 21,5m and the distance in the x-direction (W_b) is 21,5m.

5.3 Daylight Responsive Electric Lighting Energy Demand Calculation in the Urban Context

In this chapter, the steps of the daylight responsive electric lighting demand calculation are given according to the proposed approach with the implementation of the urban, building and room configuration.

5.3.1 Calculation of daylight availability

The simulation-based daylighting performance analysis and illuminance distribution in the sample office room with surrounding buildings is calculated in this section.

As already determined in the Chapter 4, the RADIANCE simulation tool is used for static daylight performance calculation. The sample structure with all components (surrounding buildings, sample building and sample room) and properties is visualised in ECOTECT. ECOTECT is a software package with a unique approach to conceptual building design. It couples an intuitive 3-D design interface with a comprehensive set of performance analysis functions and interactive information displays (Autodesk Ecotect Analysis, 2011). The ECOTECT visualization and setting of the building element properties can be seen in Figure 5.10 and Figure 5.11. The visual diffuse reflectance of surfaces and visual transmittance of the glazing is defined as explained in the previous sections.

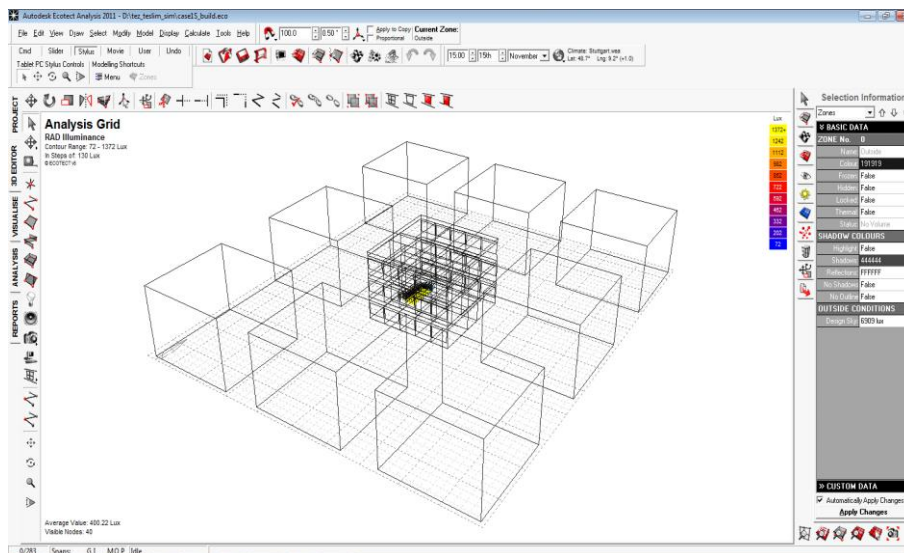


Figure 5.10 : The visualization in ECOTECT.

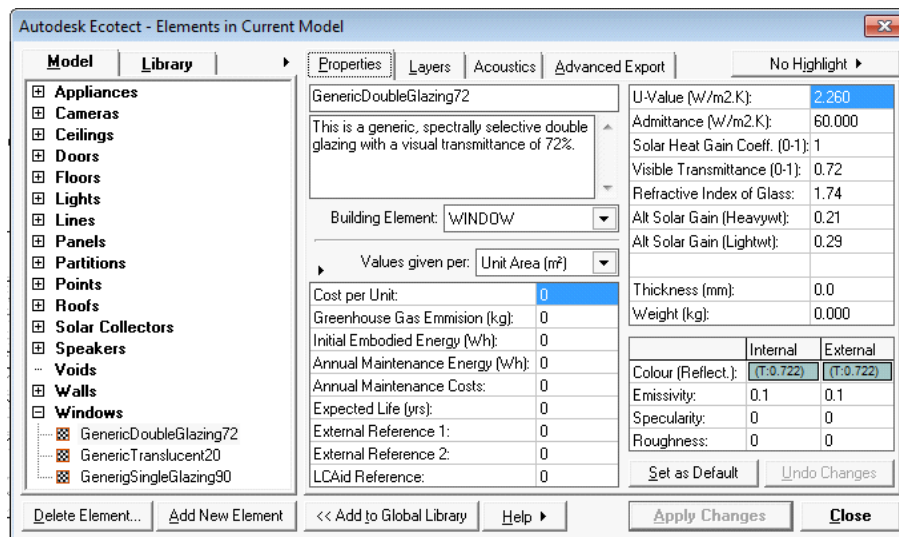


Figure 5.11 : Building element properties setting in ECOTECT.

The luminance images are generated with the backward raytracer tool RADIANCE. Luminance is based on the amount of light reflected by objects, so such images display the colour and reflectance of each surface. RADIANCE can also generate illuminance images in the given day and time of the year with a defined sky luminance distribution. These are based on the amount of light falling on the objects and therefore, do not represent surface colours and reflectance. This results in light levels on each surface being affected by colour and reflectance of surfaces that surround them.

RADIANCE parameters are a set of parameters that have a major impact on the results. The parameters guide Radiance how to carry out a simulation. Ambient bounces parameter describes the number of diffuse inter-reflections that will be calculated before a ray path is discarded. An ab-value of 5 is already sufficient for a standard room without any complicated facade elements. The ambient division parameter determines the number of sample rays that are sent out from a surface point during an ambient calculation. An ambient sampling parameter is greater than zero determines the number of extra rays that are sent in sample areas with a high brightness gradient. The combination of ambient accuracy and ambient resolution with the maximum scene dimension provides a measure of how fine the luminance distribution in a scene is calculated. Direct threshold switches off the selective source testing, i.e. each light source is equally considered during each shadow testing (Ward, and Shakespeare, 1998).

The RADIANCE parameters that are used for daylight simulations are given below:

- ambient bounces:5
- ambient division: 1000
- ambient sampling: 20
- ambient accuracy: 0.1
- ambient resolution: 300
- direct threshold: 0

The example static daylight performance analysis results can be seen in Figure 5.12. The simulation is given as an example on 15 November at 15:00 under sunny sky conditions.

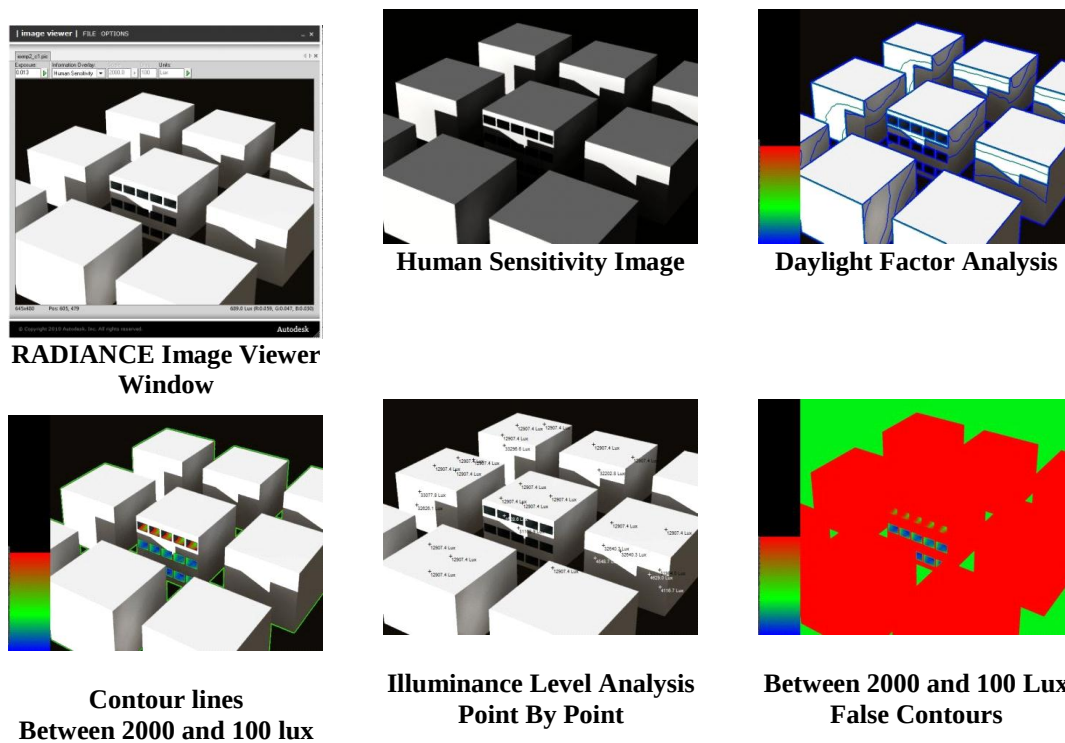


Figure 5.12 : The static daylight performance analysis example.

The DAYSIM simulation tool is used to calculate annual illuminance profiles based on local climate data and daylight coefficient. DAYSIM is validated daylighting analysis software that calculates the annual daylight availability in arbitrary buildings based on the Radiance backward raytracer. DAYSIM can calculate daylighting metrics and uses specific occupant behaviour models to mimic occupant use of personal controls, such as light switches and venetian blinds, and to predict energy savings from automated lighting controls, such as occupancy sensors and photocell

controlled dimming systems. The simulation tool is used only for annual illuminance profile calculation. As indicated in the description, DAYSIM has a predefined occupant behaviour model definition that is not very flexible and a predefined shading device, assumed to be venetian blinds. Because these restrictions are too narrow for the work presented here, the analysis part of DAYSIM is not used in the proposed approach. Instead of DAYSIM, DRELAT is used in the proposed approach.

For an annual simulation, the sensor points of interests (grid system) need to be specified in the room. In the sample office, the grid system is defined on the work plane. As described in the EN12464, the grid system has a distance of 0.5 metres from the room's wall. The grid system has 4 points on the y-axis (parallel to the window direction) and 10 points on the x-axis (perpendicular to the window direction). The total sensor point number is 40. The DAYSIM simulation's graphical user interfaces can be seen it the Figure 5.13.

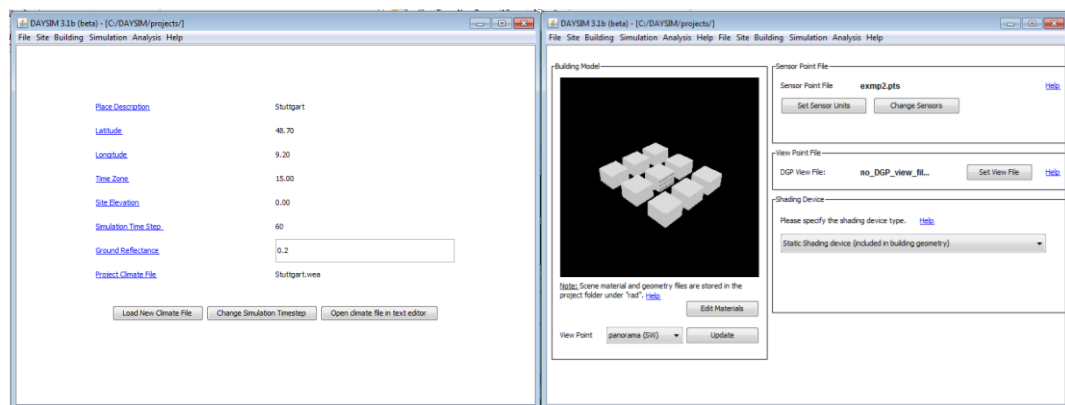


Figure 5.13 : DAYSIM's graphical user interface.

5.3.2 Calculation of electric lighting demand

Computational analysis using the RELUX software has helped to evaluate the performance of the electric lighting in the office room. The existing lighting scheme is applied in the simulation tool environment. The scheme was already designed for a service illuminance of 500 lux using RELUX. The illuminance distribution of the office room can be seen in Figure 5.14.

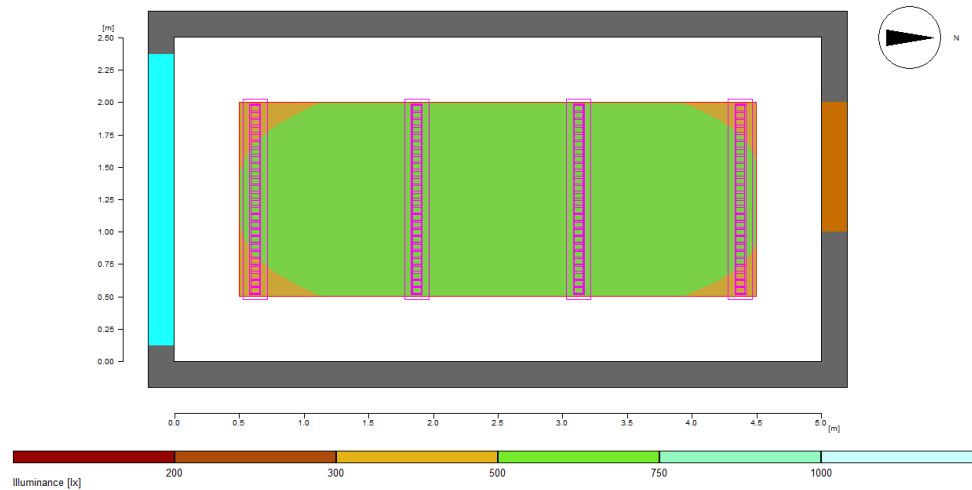


Figure 5.14 : The illuminance distribution of the electric lighting system in the sample office room.

5.3.3 Implementation of “DRELAT” daylight responsive electric lighting analysis tool

With the DRELAT analysis tool, the annual amount of daylight in the space was quantified with dynamic daylight metrics as explained in Chapter 4. Useful daylight illuminance metrics are used within the study with 4 groups. UDI values are grouped as follows: less than 100 lux, between 100 and 500 lux, between 500 and 2000 lux, and exceeded 2000 lux. DRELAT provides reports (.txt files) for UDI values for each point on the analysis grid as a percentage of the annual period. Those outputs can be visualised in the ECOTECT environment which can be seen in Figure 5.15. With the help of these files, daylight performance assessment can be compared in different conditions.

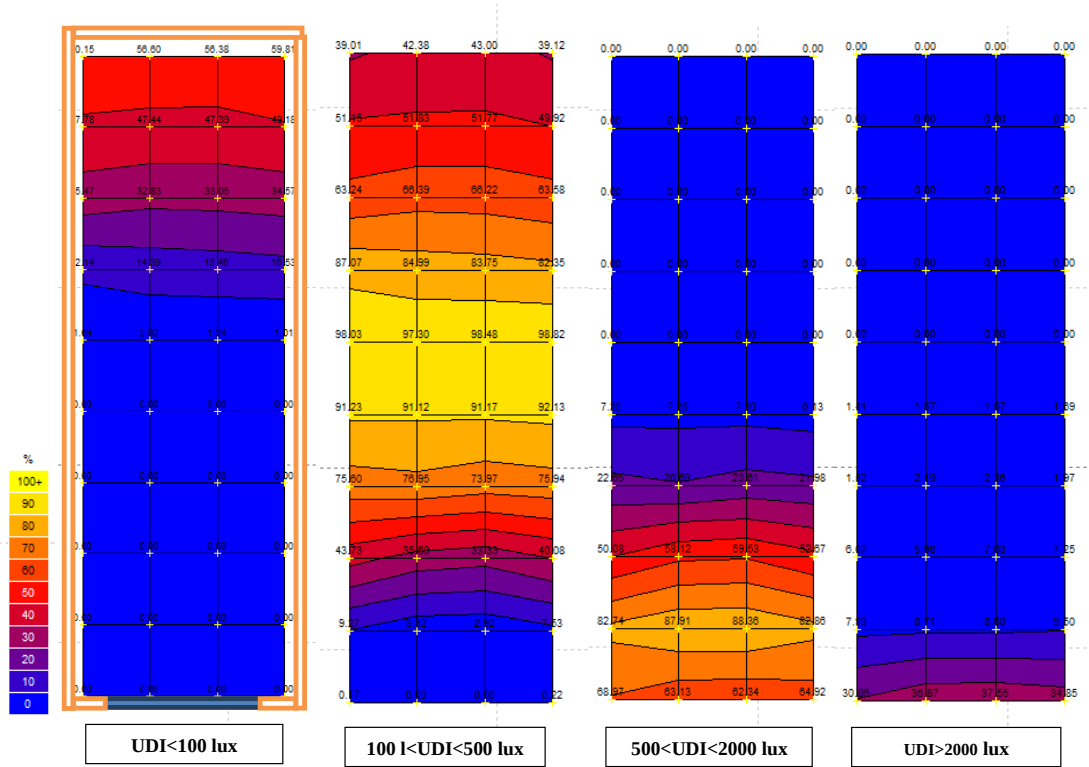


Figure 5.15 : Useful daylight illuminance distributions in the sample side lit office room with the given urban configuration.

The shading device and roller blinds properties are described in the previous sections. The control of the roller blinds and the activation rules are also defined in DRELAT. When the average daylight illuminance of the defined subzone on the work plane level exceeds 2000 lux, the shading system is activated.

As described in Chapter 4, in order to implement control mechanisms into electric lighting and shading systems, the room is divided into 4 zones parallel to window direction (Figure 5.16). Each zone has one representative luminaire that is controlled responsively to the detected average level of daylight in the subzone. This way, each luminaire (lamps) can provide supplementary illumination when the daylight level is not sufficient. The dimming factor is calculated by the DRELAT tool dimming section according to the required amount of artificial light at a certain daylight level.

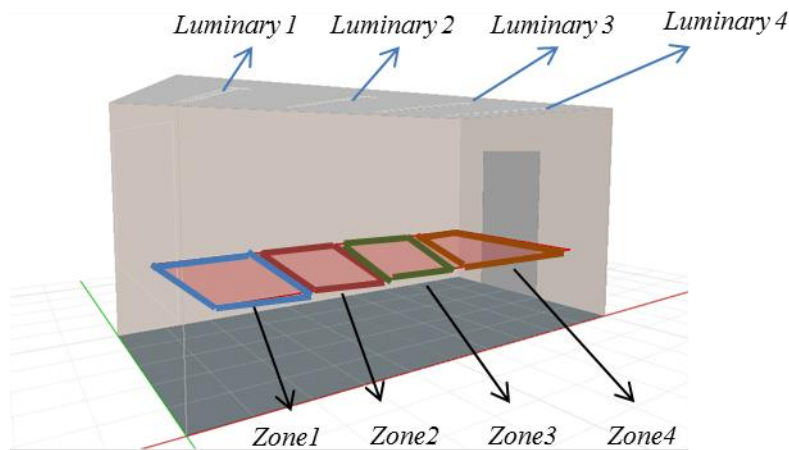


Figure 5.16 : Sub-zoning illustration in the sample room.

With the DRELAT analysis tool, two types of output files are generated for integration into the thermal calculation. The shading control output file consists of on/off (1/0) positions of the interior shading devices. The dimming level outputs files consist of dimming levels of luminaries as fractions (0-1). For this case study, types of files, 4 dimming and one shading output file, are generated for 8760 hours of a year and integrated into the thermal analysis.

5.4 Thermal Energy Demand Calculation in the Urban Context

EnergyPlus has already been defined as a simulation tool for thermal energy demand calculations in Chapter 4. The calculation methodologies were explained and discussed to illustrate the energy performance of an office building that is influenced by neighbouring buildings.

The OpenStudio Plug-in for Google SketchUp is used to create and edit the building geometry for EnergyPlus input files. The thermal zones and surfaces are created in the SketchUp environment. The screenshot of Google SketchUp with the OpenStudio Plug-in of sample the urban configuration with the sample building and office room can be seen in Figure 5.17.

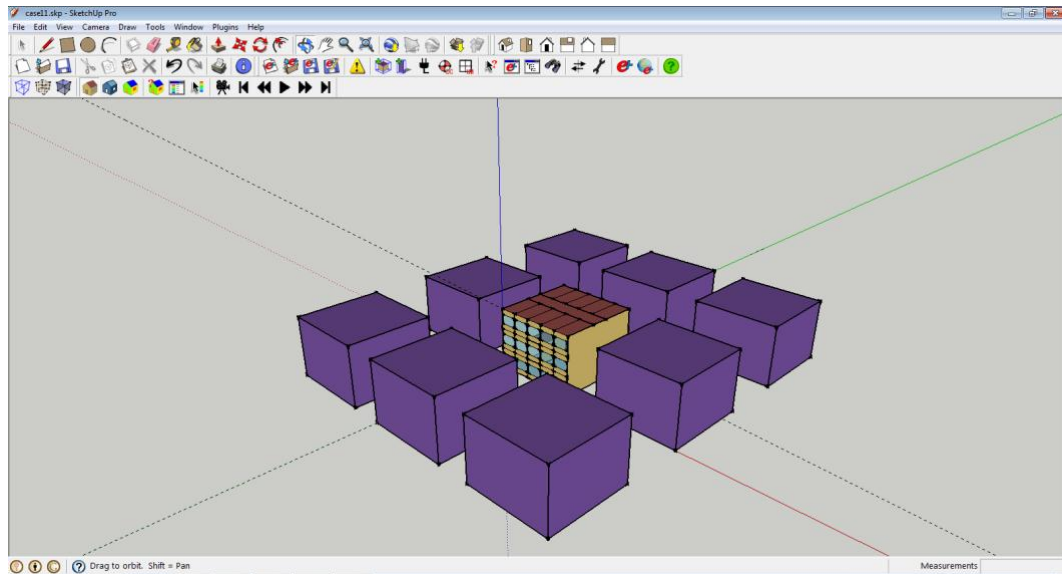


Figure 5.17 : Screenshot of Google SketchUp with the OpenStudio Plug-in.

Based on the building specifications which were described in the previous sections, the building's physical environment with surrounding buildings, building form, construction elements, materials and system definitions are entered into the EnergyPlus .idf input file. The simulation tool then calculates the heating and cooling loads to maintain thermal control set points. The EnergyPlus user interface can be seen in the

Figure 5.18.

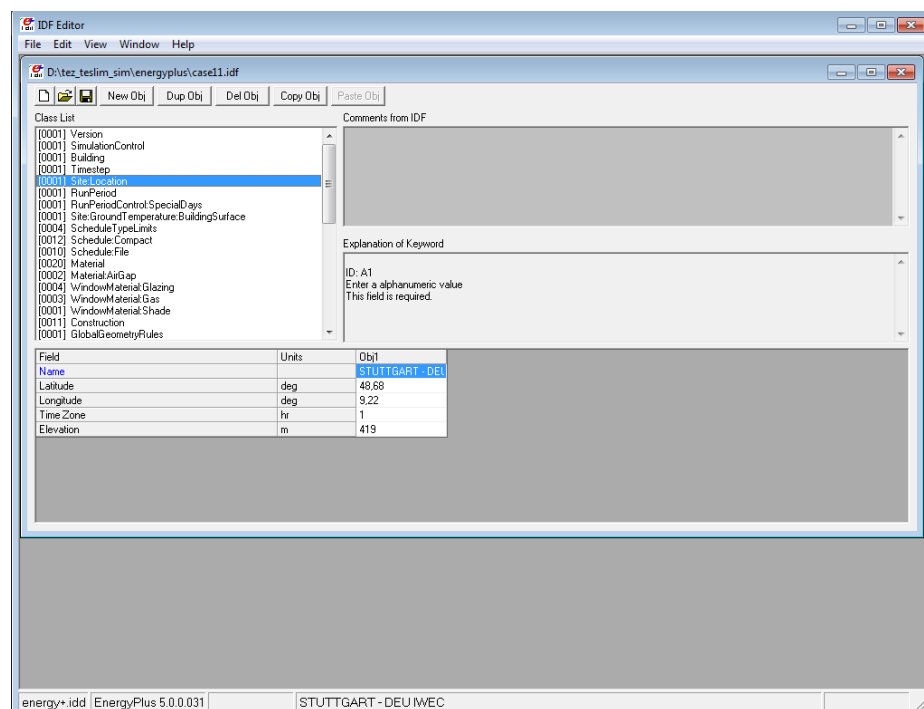


Figure 5.18 : The screenshot of EnergyPlus simulation tool.

A sample building is developed to serve a base line for the comparison and evaluation. Description of the base case model is then established for use in the building energy simulations of other cases. The base case reference building, as described above, is a square (12,5 m x 12,5 m) 3 storey (9 m) office building designed with the construction elements that have heat transfer coefficients selected according to minimum requirement EnEV 2009. The total window-wall ratio of the building is 21%. The building, in the base case, is facing south and north. Those windows of these facades have spectrally selective double glazing. Equipment power density and occupant density are 18 W/m² and 8 m² per person, respectively.

The mechanical system (HVAC) is defined as ideal loads air system. This is the easiest way to find out the space's hourly total cooling and heating load in EnergyPlus to maintain the specified thermostat set points. When the thermostat set points are being met, then the system is providing enough cooling and heating. In general, brief description of the base case office building is shown in Table 5.2 to Table 5.4.

Table 5.2 : Description of base case office building

Use of Building:	cellular (private) plan office
Daily profiles:	Weekdays 08:00 to 18:00 (no lunch breaks regarding internal gains)
People sensible gain:	150 W/person
Occupancy density:	10 m ² /person
Appliances sensible heat gain:	10 W/m ²
Infiltration maximum flow:	0,2 h ⁻¹ (air exchange)
Auxilliary ventilation:	0,8 h ⁻¹ (natural)

Table 5.3 : Description of base case building properties

Construction details	U-value (W/m ² K)	Thickness (mm)	Reflectance (%)	Vis. Transmit.
Exterior Walls	0,28	0,34	0,6	-
Roofs	0,2	0,36	-	-
Ground Floors	0,2	0,36	0,3	-
Internal ceilings / Floors	-	0,15	0,8	-
Windows	1,4	0,04	-	0,72

Table 5.4 : Energy schedules of base case office

Heating schedule		Cooling schedule		Lighting schedule	
Weekdays:		Weekdays:		Weekdays:	
00:00- 08:30	16°C	00:00- 07:00	off	00:00 - 08:30	off
08:30- 18:30	21°C	07:00- 18:00	25°C	08:30 - 18:30	on
18:30- 24:00	16°C	00:00- 24:00	off	18:30 - 24:00	off
Weekends:		Weekends:		Weekends:	
00:00- 24:00	16°C	00:00- 24:00	off	00:00 - 24:00	off
Summer Period:		Winter Period:			
00:00- 24:00	off	00:00- 24:00	off		

The sample office room (placement definition was done in the previous sections), is described as a different thermal zone to implement daylight responsive artificial lighting and roller blind shading schedules. For thermal and lighting calculations integration in the EnergyPlus environment, the schedule files have to be integrated.

5.5 Integration of Lighting and Thermal Calculations

Fully integrated (with full accuracy) daylight thermal simulation tools are not available. Part of the problem may be that different technical advances have been realised in different simulation environments and without appropriate graphical user interfaces.

In order to evaluate energy-related implications of a daylighting concept, the simulation assumptions from the daylighting analysis need to be synchronized with the thermal analysis. For the present study, this synchronization was realized through DRELAT, writing out hourly schedules that include the status of the electric lighting and blinds. This schedule file is then read into the EnergyPlus model of the space, which is described as a flow chart in Chapter 4.

The definition of the luminaries in the sample office room is done in the “Lights” tabs of Energy Plus. Each luminary is defined with its name and the reference zone and its schedule. The power of the luminaries is also defined in here. The return air fraction, radiant fraction, visible fraction, replaceable fractions are defined with the help of the manufacturer’s documentation. The user interface of the “Lights” tabs of EnergyPlus can be seen in Figure 5.19.

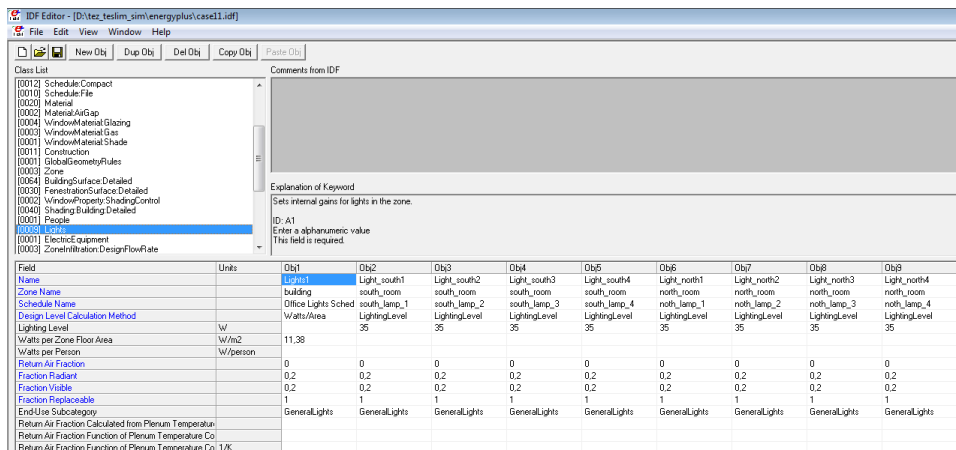


Figure 5.19 : The user interface of the “Lights” tabs of EnergyPlus.

The schedule of the each luminary (lamp) should be defined in the “Schedule: File”-section of EnergyPlus. The output schedules of luminaries, which are created by DRELAT, should be placed in this section as a .csv-file. The dimming level is defined as fraction. It should be noted that the .csv-files should consist of 8760 hours per year. The lighting schedule file definition can be seen in the Figure 5.20.

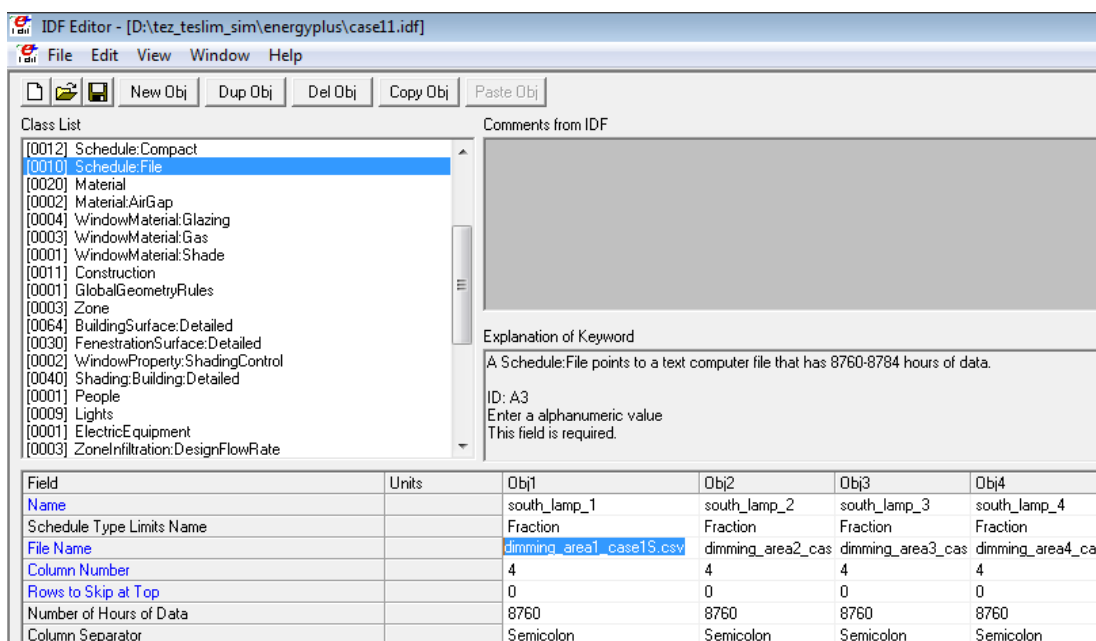


Figure 5.20 : The lighting schedule files definition.

The shading schedules must also be defined in the EnergyPlus environment. The properties of the roller blind being used in the sample office room are defined in the “WindowMaterial:Shade” section. The solar transmittance, reflectances, thermal hemispherical emissivity, thermal transmittance thickness and conductivity are the

main parameters of the roller shadings that must be defined correctly. Shading control schedules are defined in the “Schedule:File” section, which is the same as lighting schedules. The roller blind schedule is also connected with the DRELAT .cvs shading output file, which are consist of 8760 hours of on/off control data.

With the integration of the hourly schedules of electric lighting and roller blind schedules, the annual energy uses for heating cooling and lighting is calculated in EnergyPlus.

In summary, this chapter details the implementation of the new approach to the numeric analysis of a building’s energy and lighting performance within the urban context that is proposed by this thesis. A simplified scenario using a side-lit office space is provided to analyse performance including the heating, cooling and lighting energy load. The theoretical methodology generally described in Chapter 4 is closely followed in the simulation of a side-lit office room including: the determination of natural conditions, the characterisation of built conditions, including the office building and room properties, and urban geometry. In addition, the amount of daylight availability is determined using the RADIANCE tool, the electric lighting availability is determined using RELUX tool, and the annual amount of daylight in the space is quantified using DRELAT. DRELAT produces two types of output files for input into the thermal calculation simulation using EnergyPlus. The thermal zones and surfaces are created in Google SketchUp and the OpenStudio Plug-in for SketchUp is used to create and edit the building geometry for EnergyPlus input files. The lighting and thermal calculations were then finally integrated in EnergyPlus, producing the annual energy uses for heating cooling and lighting. The integration of the shading parameter back into the EnergyPlus tool is innovative feature of the proposed approach because it links the lighting calculations that consider the influential shading parameter of the urban context with the energy modelling tool, making the energy simulation more valid and relevant for use in urban design.

6. COMPARATIVE TESTING AND EXPERIMENTAL VALIDATION OF PROPOSED APPROACH

The purpose of this chapter is to evaluate the accuracy of the proposed approach, which is able to predict illumination levels, electric lighting, and heating and cooling energy use of an office space in the urban context.

The accuracy of the predictions for illumination level, artificial lighting demand, heating and cooling demand of the space are evaluated by comparing predicted values with values measured in a test room. The accuracy of predictions for artificial lighting illuminance and energy use is evaluated by comparing simulation results using the data provided by manufacturers. The artificial lighting control system is tested by using current dimming mechanism equipped with a luminary.

Over a typical one week period in winter 2010 and in summer 2009, the heating and cooling energy consumptions were measured along with the indoor air temperature of a test room and the surrounding rooms, outside temperature and global radiation.

6.1 Experimental Methodology

The major aim of the methodology is to assess the performance of the proposed approach, which considers illuminance levels, electric energy use for lighting, cooling and heating energy use of a sample office room. This procedure allows analysis of the source of errors by comparing measurements in a test room to a computer designed test room model. Figure 6.1 shows the scheme of the experimental procedure in this study.

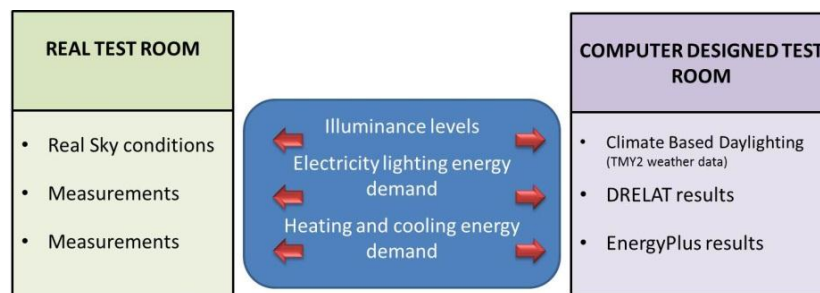


Figure 6.1 : Scheme of the experimental methodology.

The first measurements of work plane illuminance are taken under different sky conditions and different days of the year. The luminance distribution of the sky and the direct horizontal illuminance (in case of direct sunlight) at the time of every single measurement are recorded with a luminance camera and illuminance sensors. Simulation based daylighting analysis is done to calculate annual illuminance level profiles based on local climate data and the daylighting coefficient approach (Bourgeois, Reinhart and Ward, 2008).

Sunlight or daylight contribution into the room makes it difficult to measure the behaviour of the control system. Thus, in order to understand the sensitivity and dimming reaction of the daylight responsive control system, the measurement was done at night around 22:00. The torch was used as a light source. When the torch was close to the sensor, the control systems dims itself. If the torch came too close, the artificial lighting system was totally turned off. The sensor was also shaded with a plastic opaque disk. When the sensor was completely covered, lamps were working at full power, which means control systems dims lamps on.

The lighting control system of the test office is based on threshold illuminance dimming. With three threshold illuminance levels, lights are turned on when the illuminance falls below the first threshold level, lights are dimmed 50% when the illuminance level rises above the second threshold and lights are turned off when the level of illuminance rises above the third threshold. The power consumption of the test room lighting system can be seen in Figure 6.2.

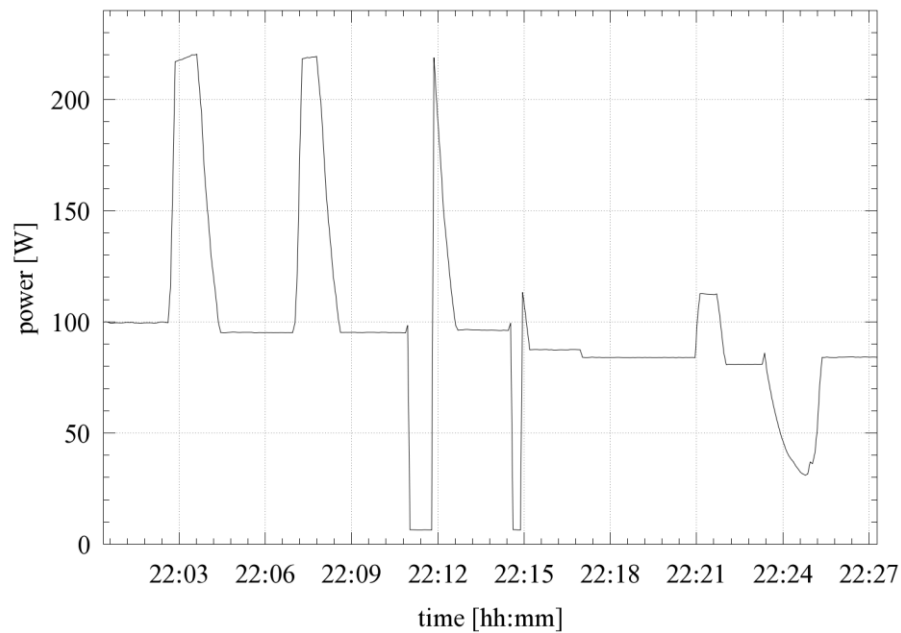


Figure 6.2 : Power consumption of daylight responsive lighting of test room.

In a second step, the electric energy consumption of daylight responsive artificial lighting system is tested. Within a specific time period, electricity consumption of the system is monitored and recorded using LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench).^{*} Over the same time period, computer-designed test room electricity lighting demand is calculated with DRELAT.

As a third step, the heating and cooling energy demand of the test room are also monitored and stored by LabVIEW. In this case thermal simulation of the test room is done in EnergyPlus. All the simulation parameters, details of the room, building and surroundings will be described in the next sections.

6.1.1 Test room and its surroundings

The test room is located in an office building near the city centre of Stuttgart, Germany. The two-storey building is commonly used by the University of Stuttgart and the Stuttgart University of Applied Sciences. The test room is located on the ground floor and facing the parking area. The facade is orientated towards South-

^{*}LabVIEW is a platform and development environment for a visual programming language from National Instruments.

South-East (154.5° from North). The site plan and a sample bird's eye view can be seen in Figure 6.3.

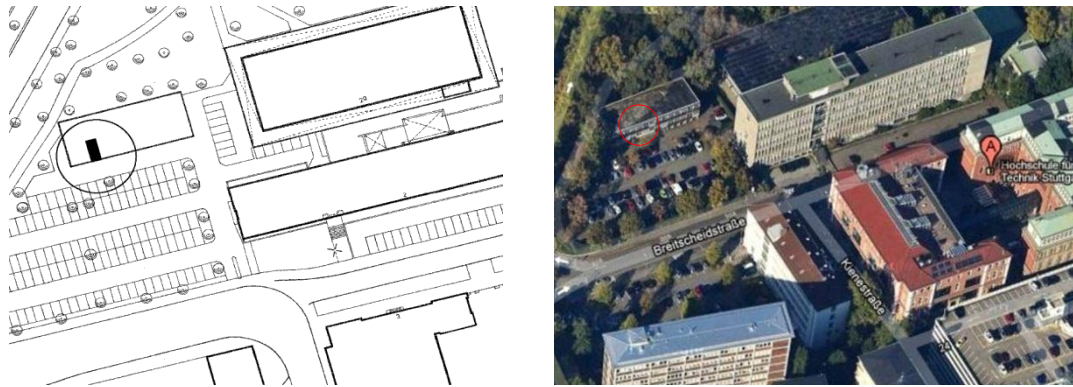


Figure 6.3 : Site plan (Test room in circle).

Originally, the interior of the test room was very inhomogeneous, which would have complicated the model building and caused additional errors in the measurements. Therefore, the test room was remodelled (see Figure 6.4). The original surfaces of the walls and ceilings, which were profiled metal sheeting and timber panels, were covered with plasterboard and painted white. The heavily soiled linoleum floor was covered with a blue-grey carpet and the window frames and the door were painted white.

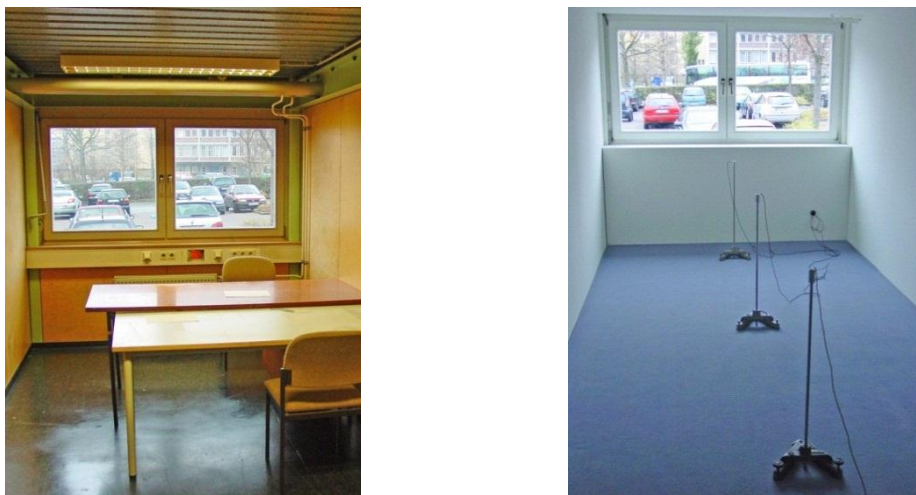


Figure 6.4 : Photos of room condition: (a) before the renovation; (b) after the renovation.

After remodelling, the test room dimensions were 2,31 m x 5,84 m x 2,08 m (w/d/h). The floor plan, section and elevation can be seen in Figure 6.5.

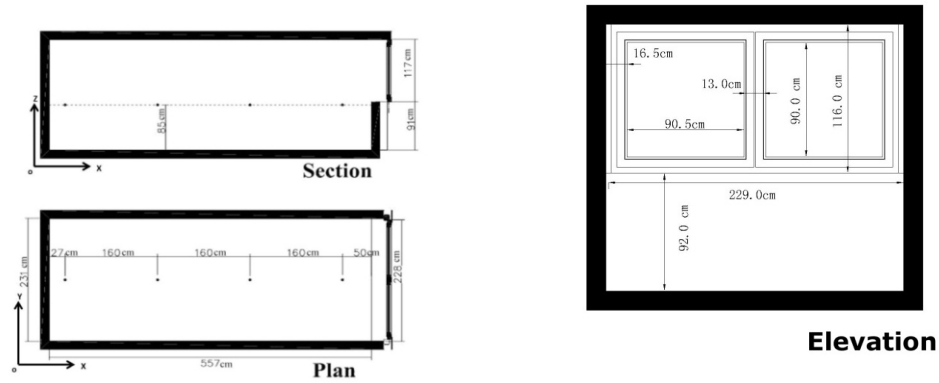


Figure 6.5 : Floor plan, section and elevation of the test room.

All building materials were carefully selected and the photometric properties of materials (the reflectance and transmittance) were then determined with a Perkin Elmer Type Lambda 19 spectrometer. Table 6.1 shows all materials used in the test room and their photometric properties.

Table 6.1 : Photometrical properties of test office room.

Component	Material	Scale	ρ_{tot} [%]	ρ_{dif} [%]	ρ_{dir} [%]
Wall, Ceiling	White paint on plaster board (RAL 9010)	original	89,97	89,79	0,18
Window frame, Door	White paint on wood	original	89,42	88,45	0,97
Carpet	Carpet, grey-blue	original	19,44	19,42	0,02

The transmittance of the glazing was measured before every measurement series with a Gossen Mavolux lux-meter. Two photometers were mounted on the window pane to determine the transmittance. The one placed outside the glazing measured the total vertical radiation (Eges,vert.1), and one inside the glazing measured the total vertical radiation coming through the glass (Eges,vert.2). The installation can be seen in Figure 6.6.

Both measurements were simultaneously recorded in intervals of 60 seconds. The transmittance value of the window glazing was obtained by dividing the measured value of the photometer that lies behind the window glass, by the measured value of the photometer in front of the window glass. The calculation of transmittance was repeated for each time period after the measurements. Thus, the angle dependent transmittance could be considered as a correction factor in the analysis of measurements.



Figure 6.6 : Measurement setup for determining the transmittance of the window glass.

6.1.2 Experimental set up

Different equipment and installations as well as monitoring tools were used during the measurements. The sky luminance distribution was recorded with a TechnoTeam LMK mobile luminance camera (Figure 6.7.(a)) and a Nikon FC-E8 fisheye converter. Since the view angle of the luminance camera was restricted to approximately 150° , it was not possible to measure the luminance distribution of the whole sky vault with one picture. Therefore a series of four pictures per measurement had to be taken, which took approximately 1 min. 20 seconds.

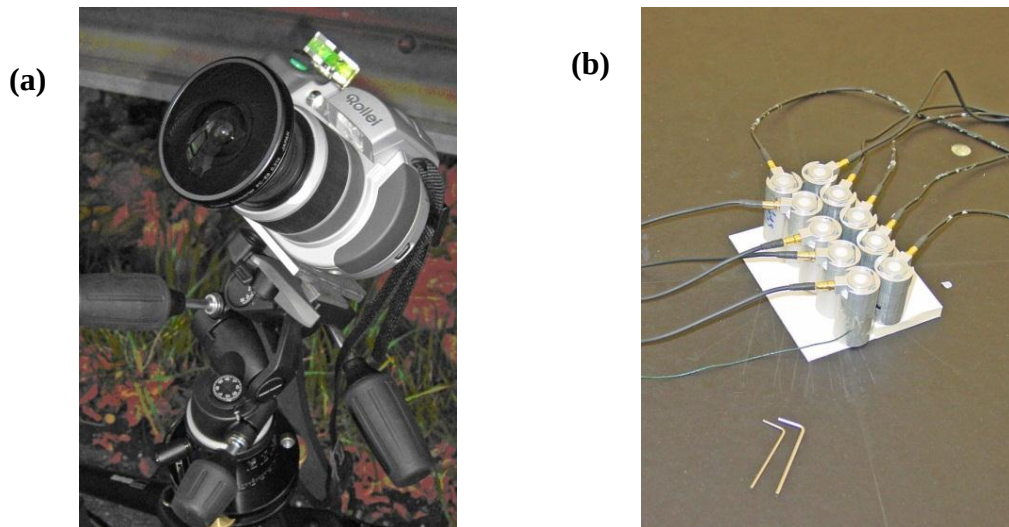


Figure 6.7 : (a) TechnoTeam LMK mobile luminance camera (b) PRC Krochmann illuminance sensors.

All illuminance measurements were taken with PRC Krochmann illuminance sensors Type MI (see Figure 6.7. (b)). The dimensions of the sensors, approximately 25 x 25 x 7 mm (width x depth x height), are very small, which makes them particularly

suitable for measurements. The sensors were carefully calibrated under the artificial sky. Since the SI-photocells in the sensors are temperature-sensitive the calibration was done for different temperature profiles. The temperature-dependent measurement errors were eliminated by recording the temperature of the sensors and using correction factors when analysing the measured data.

The room was equipped with a daylight responsive artificial lighting system. The artificial lighting is provided by two direct dimmable luminaries each with 2x54 W lamps 4450 lumen (OSHRAM FQ 54W/840 HO Luminux Cool White). At full capacity, this system delivers average 550 lux illuminance onto the work plane. This comparatively high illuminance level has total power of 236 W and total luminous fluxes of all lamps are 8900 lm. The photo sensors (2 sensors) were placed on the luminary facing down to the working area / floor. The placement of the sensors and the dimension of the luminary can be seen in Figure 6.8.

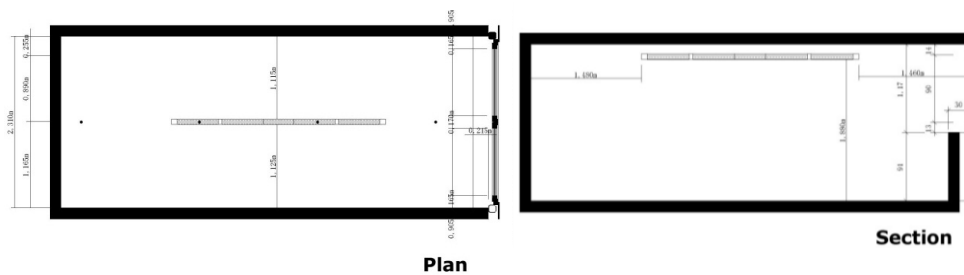


Figure 6.8 : Placement of the artificial lighting system in the test room.

The photo sensor control system dims the lamps according to three step thresholds (full: 100% on, half: 50% on, and off: 0% on). The sensors' positions and the artificial lighting system of the room are shown in the Figure 6.9.

During the day, lighting levels are automatically dimmed via a mounted illuminance sensor that is connected to ballast. The level of the natural illuminance is high and lights are not turned on until late afternoon when the level of the natural illumination falls. On the other hand, on some other days the level of the natural illumination level is much lower; lights are switched on and remain on all day.

For the comparison between the real room and the computer-designed office room within the PhD study, no shading devices and/or blinds were used.



Figure 6.9 : The artificial lighting system and the photo sensor placement on the lamp with the connection of dimming ballast.

To understand the thermal behaviour and the performance, as well as the interrelation between daylighting and daylight responsive artificial lighting system, temperature sensors were installed in the room and surrounding spaces (left room, right room, the room at the upper floor, corridor and outside each had 1 temperature sensor, test room had two temperature sensors). In Figure 6.10, the location of the temperature sensors and the monitoring room with computer equipment can be seen.

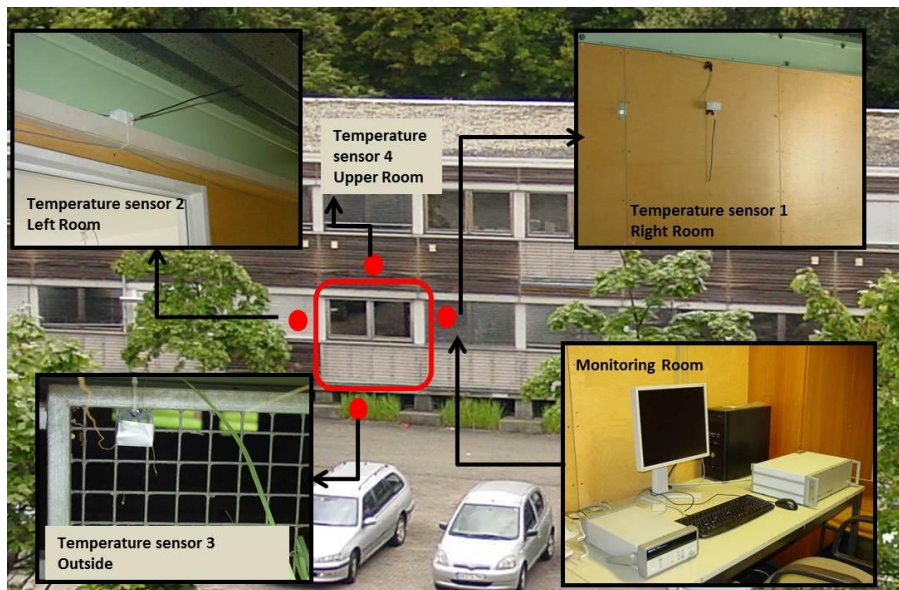


Figure 6.10 : Locations of temperature sensors and monitoring room.

For data acquisition a HP 34970-A Data logger and the software LabView were used. All the sensors were connected with the data logger, which communicates with a LabView data acquisition software package. Data logger modules allow flexibility in instrumentation; additionally, channels can easily be added or removed. A total of 24 channels were used to collect data (twelve channels for the temperature, two for electricity consumption and ten for illumination levels). The measured data (with

different intervals: 1 minute to fifteen minutes) were displayed by using LabView in the form of numbers and graphs on the computer screen are shown in Figure 6.11.

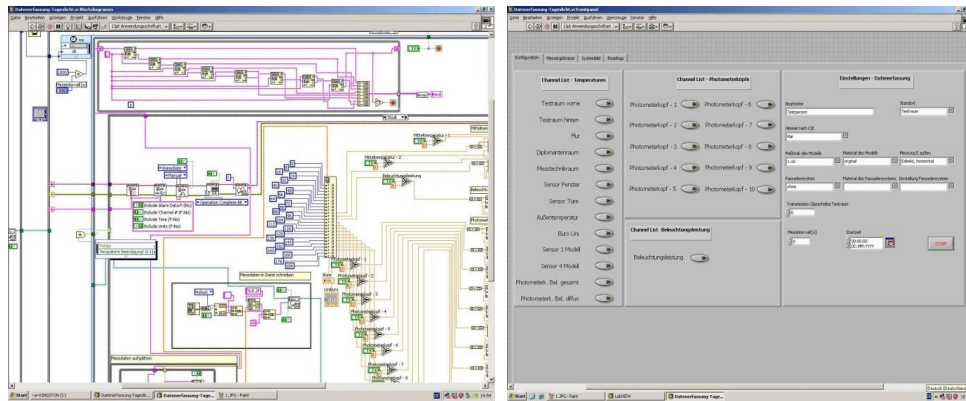


Figure 6.11 : Screenshots of LabView data acquisition system.

The list of physical quantities, which are recorded by monitoring set-up, is given Table 6.2.

Table 6.2 : The list of physical quantities which are recorded by monitoring set-up.

Quantity	Units	interval
Illuminance level	lux	minute / 15 minutes
Temperature	Degree Celsius ($^{\circ}\text{C}$)	minute / 15 minutes
Consumption of artificial lighting	Watt	15 minutes
Consumption of heating system	Watt	15 minutes
Consumption of cooling system	Watt	15 minutes

6.2 Illuminance Measurements and Computer Simulation Modelling

The illuminance was measured at four points on the middle axis of the test room. In the cases of direct sunlight on the test room facade, the horizontal direct illuminance was recorded. This was done by measuring the horizontal total and the diffuse illuminance with unshaded and shaded illuminance sensors, respectively. The difference of these two values is the horizontal direct illuminance.

Radiance and DAYSIM were used to determine the interior space illumination in the computer simulation. DRELAT was used for the daylight controlled artificial

lighting electric demand calculation. The measured performance of the full scale mock-up office and simulation models were compared.

The accuracy of the simulated natural illuminance is evaluated by comparing simulated illuminance values with values measured in a test room. The accuracy of simulated electricity consumption is evaluated by the operation of the lighting system in the test room.

6.2.1 Daylight illuminance measurement and comparison

For doing a comparison, a simulation-based daylighting analysis model was built and the results were visualized in Autodesk Ecotect (Marsh, 2010). The Radiance simulation parameters used for daylight simulations were $ab=5$, $ad=1000$, $as=20$, $aa=0.1$ and $ar=300$. The dynamic daylight computing capability, which provides climate-based daylighting metrics, was also utilised for comparison. The dynamic or so-called climate based metrics are basically used to quantify the annual amount of daylighting. Here, a part of the annual simulation (hourly data) was used.

The test room (building) was built including its surroundings in a 3D computer environment. The computer model can be seen in Figure 6.12. To make a lighting analysis, the model was built again in Autodesk Ecotect and this simplified 3D model can be seen Figure 6.13. In the simplified model, just the surrounding building geometries were simplified, but the dimensions and distance between the buildings remained the same. All the materials used in the test room and their photometric properties were defined in the model as in the reality.

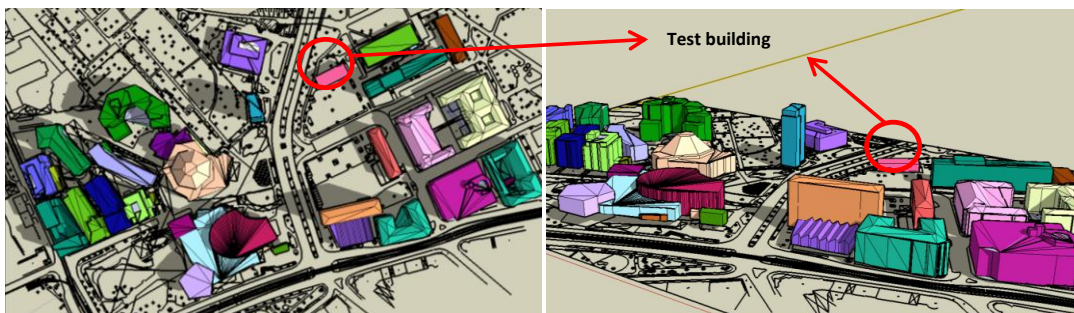


Figure 6.12 : Three dimensional computer model of test room with its surroundings.

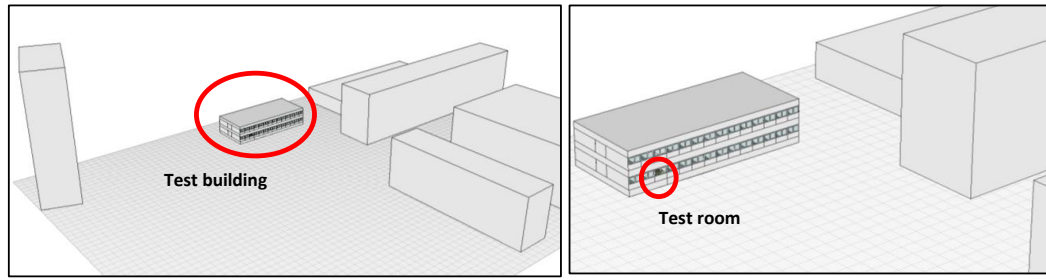


Figure 6.13 : Simplified Autodesk Ecotect 3D-model.

Radiance and DAYSIM were used to calculate the resulting illuminance at the four measurement points in the test room; the calculated values were then compared with the measured values. The same day time and sky condition were used in the simulations. The resulting simulation values of illuminance were compared with the values in the test room in a deviation calculation.

The deviation between simulated and measured values were calculated for each measurement point and used to show distribution of the magnitude of errors. The deviation for each simulation is given by the equation (6.1):

$$\sigma(\%) = 100 \cdot \frac{\text{simulated illuminance}}{\text{measured illuminance}} - 1 \quad (6.1)$$

The following describes potential errors that may result due to the size of illuminance sensors and a typical Test Reference Year (TRY) weather data.

176 test cases were compared with values in the test room with clear glazing. Some of the measurements were done using different daylighting systems, such as venetian blinds, louvers and light shelves together with scale models (scales: 1/10, 1/20), in the course of the research project “Optimization of facade systems for improved daylight use and reduction of summer cooling loads of building”, which was carried out at HFT-Stuttgart as a cooperation of the Department of Architecture and the Centre for Applied Research- Sustainable Energy technology (zafh.net) (Kesten, Thumm, Fiedler, Löffler and Eicker, 2009). In the concept of this thesis, the measurement values without any facade system were taken in to consideration and compared with simulation results.

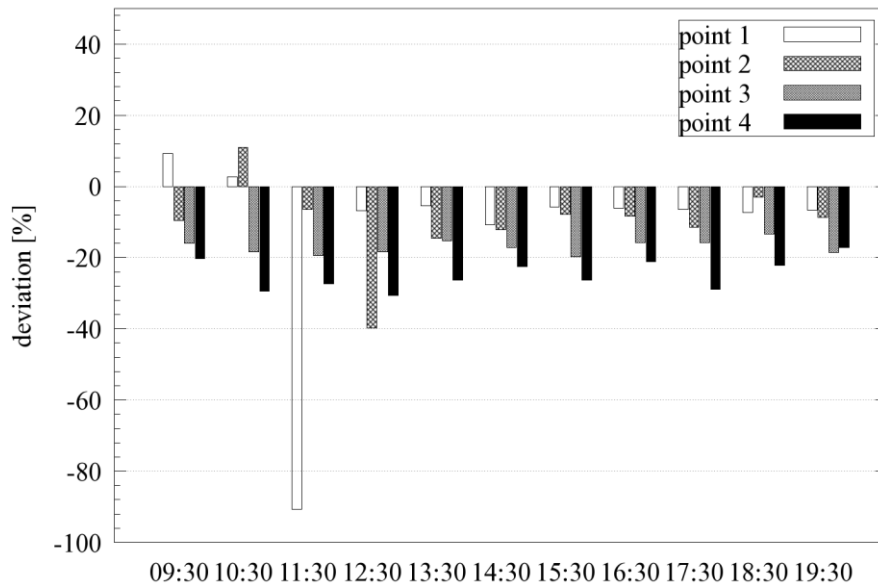


Figure 6.14 : Deviation of illuminance levels between measurements and radiance simulation under clear sky conditions.

In Figure 6.14, the simulated Radiance values are compared with the measured values. The columns show the deviation values under clear sky conditions. All measurements and simulations were done on the test room site, with obstruction by the surrounding buildings. While all measurements show an underestimation of illuminance levels when comparing Radiance results, the deviation of the measurements are lower than simulation illuminance values. Underestimation of radiance measurements has a tendency to increase with the distance from the measurement point to the window.

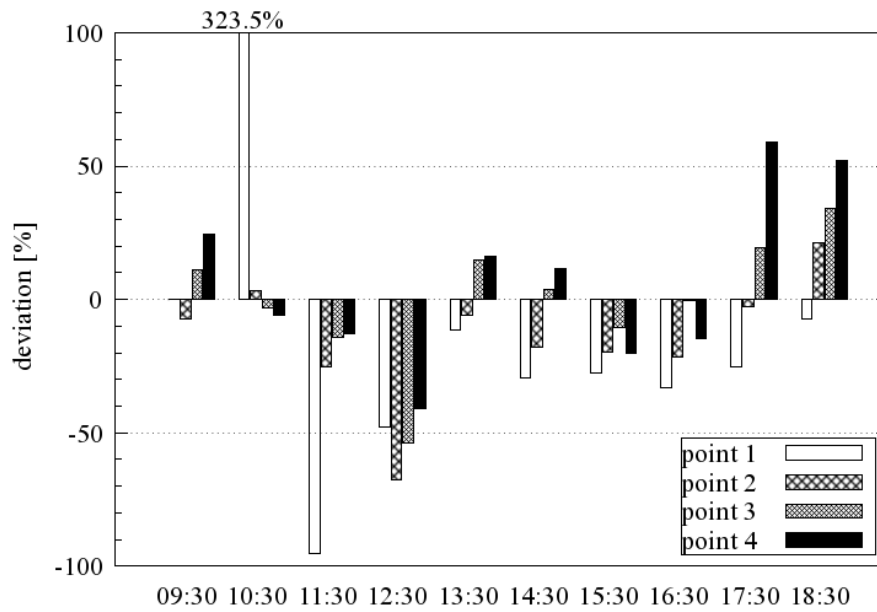


Figure 6.15 : Deviation of illuminance levels between measurements and DAYSIM simulation under clear sky condition.

In Figure 6.15, the deviation of illuminance levels between measurements and DAYSIM simulation illuminance values under clear sky conditions can be seen. DAYSIM uses daylight coefficient methods to calculate time series of illuminances and luminances in the room. These time series were produced using direct and diffuse irradiance from weather files, luminous efficacy models (Perez et al., 1990), and luminous distribution models (Perez et al., 1993). For this simulation, TMY Stuttgart weather file was used. Given the simulation's data requirements, the deviation observed can possibly be attributed to the use of test reference year data.

The first set of measurements and simulations were done on 20th of August under a clear sky condition. To investigate illuminance levels under overcast sky conditions, the measurements were taken during different times of the year when overcast sky conditions were observed.

Figure 6.16 represents the illuminance level deviation between measurements and Radiance simulation results. In overcast sky conditions the measurements did not show much deviation from the radiance simulation results. However, the illuminance sensor size can also influence the illuminance level. Deviations are mainly due to shading effects on sensors, which have non-negligible surface areas, whereas the simulation tool calculates illuminance at infinitely small points. This effect can be seen in Figure 6.17. Under clear sky, the sensor can be partly affected by the

sunlight. Considering the fact that the illuminance sensor dimension is always same, but the simulation model takes the illuminance sensor as a point, different results may be achieved.

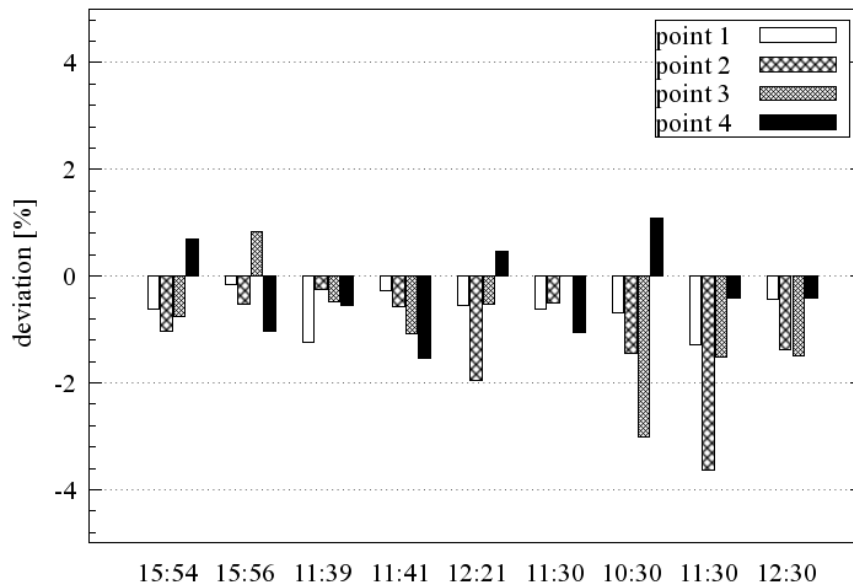


Figure 6.16 : Deviation of illuminance levels between measurements and radiance simulation under overcast sky conditions.

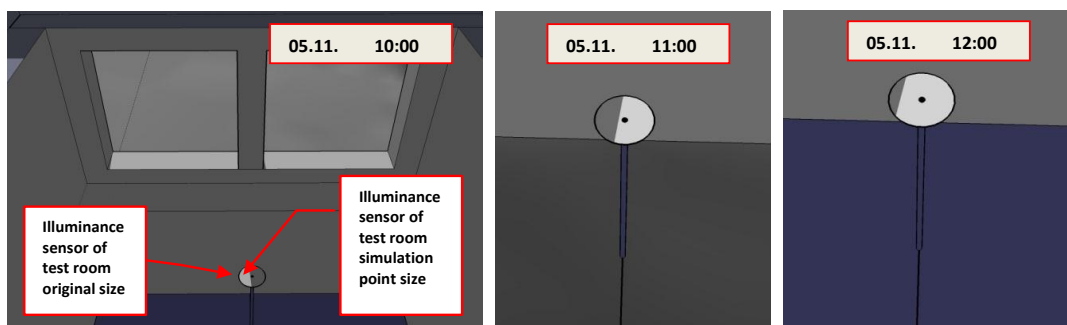


Figure 6.17 : Shading effects on illuminance sensors.

When no direct light occurs, the deviation between the measurements and simulation of the simplified model is small. This means that under overcast conditions, good agreement between the simulation and monitoring can be achieved (Figure 6.18). The illuminance level deviation between measurements and Radiance simulation results never exceeded 30 %. According to previous studies on daylight simulation program accuracy, the test results seem to be in a reasonable range (Bodart et al., 2007; Thanachareonkit et al., 2006; Cannon-Brookes, 1997; Thanachareonkit et al., 2005)

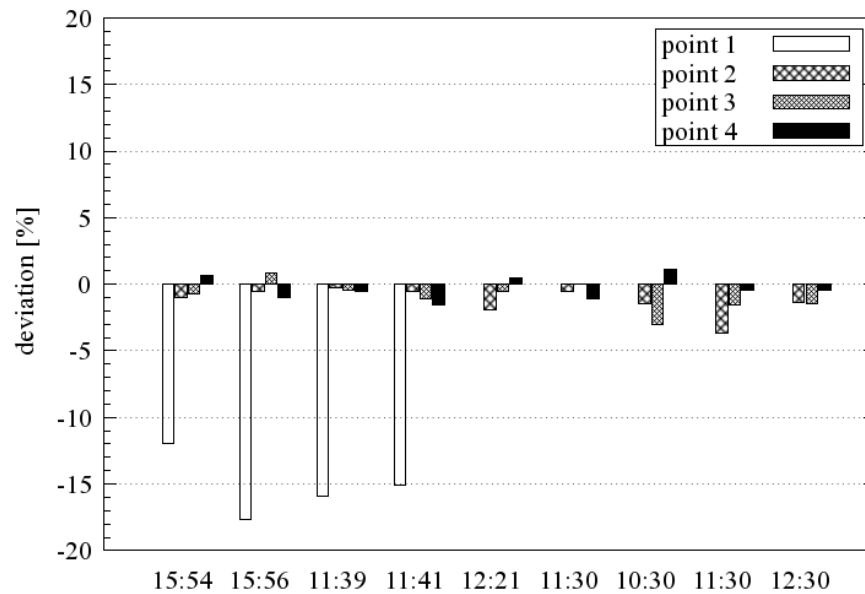


Figure 6.18 : Deviation of illuminance levels between measurements and DAYSIM simulation under overcast sky conditions.

6.2.2 Daylight controlled electric energy measurement and comparison

The monitored field study was done to understand dimmable daylighting control system performance and lighting energy consumption under unoccupied conditions in a small cell office. The measurements have also been compared with simulation results. The artificial lighting system, luminaries, lamps and the fixtures were already described in section 6.1.2. The daylighting control system was designed to dim each luminary in response to daylight, so as to maintain the design illuminance set point range of (450-500 lux). The photo sensors are integrated directly into a light fixture by attaching them to the lamp via a clip and to the fixtures dimmable ballast via low voltage vires. The dimming ballast that was used in the system has the light output dimming range of 5-100%.

Daylighting control is a closed-loop system. This system measures the combined contribution to light level from both daylight and the electric lighting system and then adjusts the light output to maintain the desired level of illumination. The closed-loop system has an advantage; the system measures actual light level and can also respond to shading device positions (opening- closing blinds).

Data were recorded every 15 minutes from August 21, 2009 09:10 to August 22, 2009 09:30, a full 24 h period. All data were taken from the illuminance sensors, which were located along the middle axis of the room. Data included illuminance level and total electric energy consumption from the luminaires.

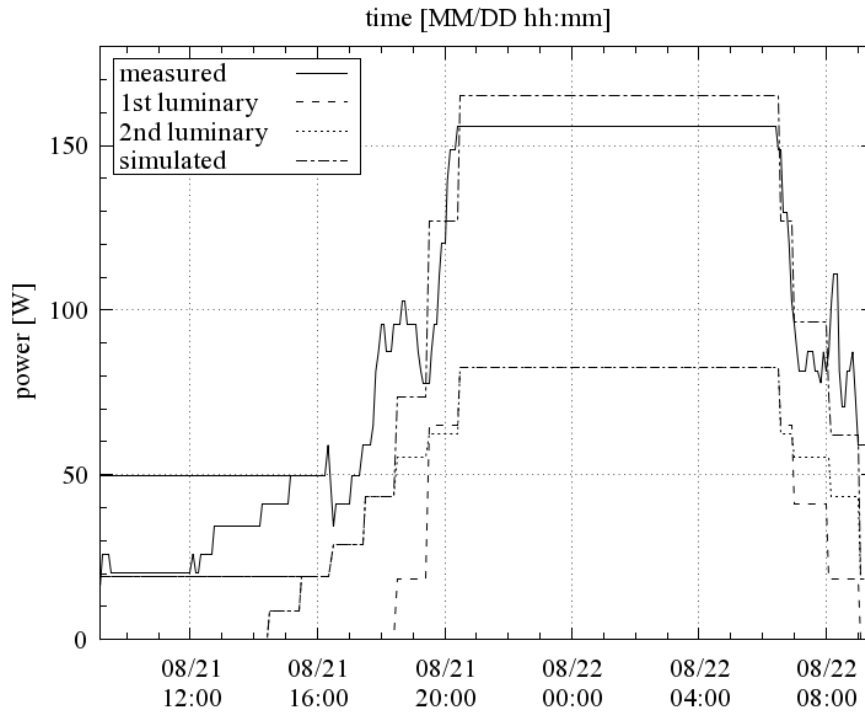


Figure 6.19 : Comparison of measured daylight controlled lighting energy consumption and simulated energy consumption of test room.

Figure 6.19 shows the daylight controlled lighting energy consumption comparison. The fluorescent lights were dimmed down and up gradually to maintain the target illuminance level. The electric energy was recorded as total consumption from two luminaries. The sum of the measured electric energy consumption was 24464 Wh by the end of the measurement period. The electricity consumption for lighting was simulated directly using the results of the daylighting illumination levels. Depending on the lighting system definition, the simulation was done in DRELAT. For each luminary, lighting (electric) energy consumption was calculated. Lighting energy consumption for the first and second luminary was calculated at 12077 Wh, 14259 Wh, respectively. The total lighting energy consumption that resulted from the simulation is 26336 Wh. Both simulation and measurement results showed a similar dimming profile for total energy consumption. During the night, time lamps are dimmed up to provide sufficient illuminance levels. The lighting power density of the system is $41,23\text{W/m}^2$, which is more than necessary to provide 500 lux average illuminance level in the test room. This is the reason that almost 70% of maximum power was needed during the night time.

Smooth changes instead of stepped changes were observed in the simulation plots. This view was mainly caused by time steps differences. The simulation time step is

hourly compared to the 15 minute intervals of the physical measurements. Moreover, minimum power for the dimming system was assumed to be zero in the simulation, although minimum power is 3,5 W for each luminary for the existing system. In the DRELAT calculation, the daylight control system was responsive to changes in daylighting levels; however, the system overrates the electric lighting dimming level when the daylight reference is not available. This additional lighting results in an almost 8% higher electric energy consumption in a one day time period.

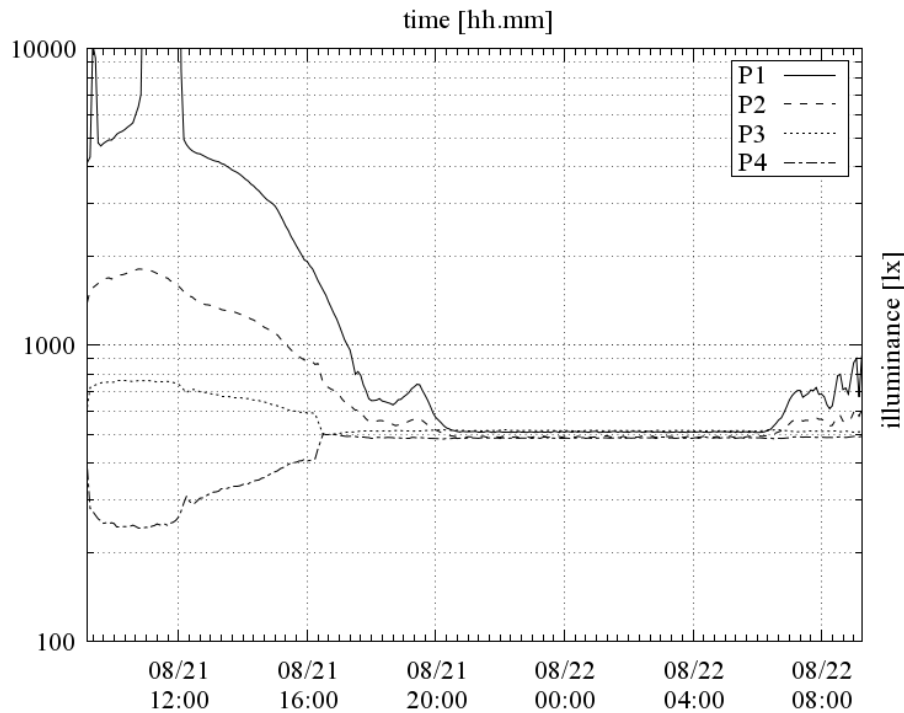


Figure 6.20 : Total illuminance levels of the measurement points of the test room (sunrise= 05:28 / sunset: 20:24).

Four sensors located in the room recorded the illuminance levels during 24 hours. At measurement point 1, illuminance levels are greater than 2000 lux (direct sun beam) until 15:00 in the afternoon. This similar tendency was observed at the second measurement point as well, however, the illuminance levels were not as high as at the first point. The illuminance sensor that was attached to the second luminary to control the electric lighting system and it took average illuminance level of the rear part of the room. The control system's illuminance sensor assumed a high level of illuminance and did not provide enough artificial lighting contribution to the rear part. This effect can be seen In Figure 6.20. Good control system performance was achieved during daytime, especially at high illuminance level conditions over the

monitored period. The control system maintained total illuminance levels above 93% during all hours at all sensor locations.

6.3 Thermal Measurements and Computer Simulation Modelling

In this section, overall thermal energy requirements of the test room are measured and simulated in an existing situation.

The climate-based dynamic daylight analysis should be not only part of the general building energy performance modelling, but also part of the urban energy modelling. In the context of the suggested methodology, the building performance evaluation of the day-lit spaces considers annual daylight availability of the room (building) with the shading situation due to surrounding buildings and landscape, thermal definition, weather conditions, thermal and visual comfort of the occupants.

To quantify the thermal energy performance, experimental investigations were carried out in a test office. Heating and cooling energy consumption was measured at different time periods of the year.

6.3.1 Heating energy consumption measurement and comparison

The heating energy consumption was measured in the test room using measurement equipment described in Table 6.2. The heating system of the test room was an electrical heater, which delivered power from 0 to 2000 W. The room was equipped with the temperature sensors to measure the indoor and outdoor temperature of the test room, as well as the adjacent rooms and corridor. Also, the outside temperature and global radiation were measured at the weather station on the roof of The University of Applied Sciences Stuttgart's third building (Kesten, Tereci, Strzalka and Eicker, 2011). The list of equipment are given below:

- Heater: 2000W electric fan type
- Temperature sensors in each attached thermal zone (5), plus one outside
- Powermeter, measuring the current to the heater
- LabView for data acquisition

The measurements considered in the analysis were taken from 8th (10:00) until 11th (16:00) of February 2010. These values were then used to validate the simulated heating energy demand. The thermal simulation was done in EnergyPlus. The

thermal simulation parameters that were used in simulation model were based on construction materials of the test building and can be seen in Table 6.3.

Table 6.3 : Thermal simulation parameter.

Use of Building:	Cellular (private) plan office	
Daily profiles:	February 8 th to 11 th	
Infiltration flow:	0,2	1/h
Auxiliaire ventilation:	1	1/h
Heating set point:	21 °C	
Cooling set point:	25 °C	
Construction details	U (W/m ² K)	Thickness (m)
Exterior Wall	0,449	0,140
Interior Walls	0,488	0,110
Exterior Floor	0,257	0,215
Internal ceiling	0,488	0,200
Window	2,670	-

After it was modelled in Autodesk Ecotect for the daylight simulations (especially the visualization and graphical interface for static and dynamic lighting simulation), the test room building and its surrounding was modelled once again in SketchUp Open Studio for EnergyPlus simulations. The SketchUp Open Studio model can be seen Figure 6.21.

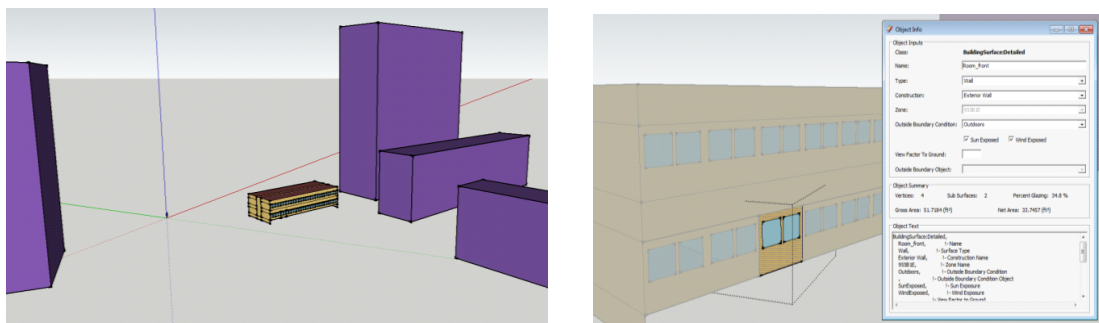


Figure 6.21 : SketchUp Open Studio model for thermal energy simulation in EnergyPlus.

The simulation model of the heating system was built in EnergyPlus and ZONEHVAC:UnitHeater was used as the input object. This object provides a model for unit heaters that are zone equipment and contain only a fan and heating coil. This model was suitable for the test room heating unit and validation test. The unit heater in the model requires the names and specification of the fan, heating coil, availability schedule and maximum airflow rate. The heating model specifications can be seen in Table 6.5. The unit was connected to the zone inlet and exhaust node. The control of the heating unit and fan are on/available. The heating coil is modulated (constant fan

speed) to meet heating load. Control of the heating coil and its flow rate is identical to the fan coil unit and unit ventilator. The flow rate of air through the unit is controlled by the user input and schedules.

Table 6.4 : Heating model specifications.

Zone HVAC system:	unit heater
Availability schedule:	always
Maximum supply air flow rate:	0,84 m ³ /s
Fan Control type:	on/off
Heating coil object Type:	coil : heating: electric
Fan efficiency:	0,5
Motor efficiency:	0,9
Pressure rise:	75 Pa

The heating unit (2000W) and temperature measurement instruments of the test room can be seen in Figure 6.22.



Figure 6.22 : Temperature measurement instruments and heating unit of test room.

The model simulation used Stuttgart TMY2 weather file. The hourly measured temperature data from HFT Stuttgart weather station and hourly ambient temperature data of TMY weather file were compared and the most realistic period was used for simulation. The measured ambient temperature and the model's ambient temperature can be seen in the Figure 6.23(a).

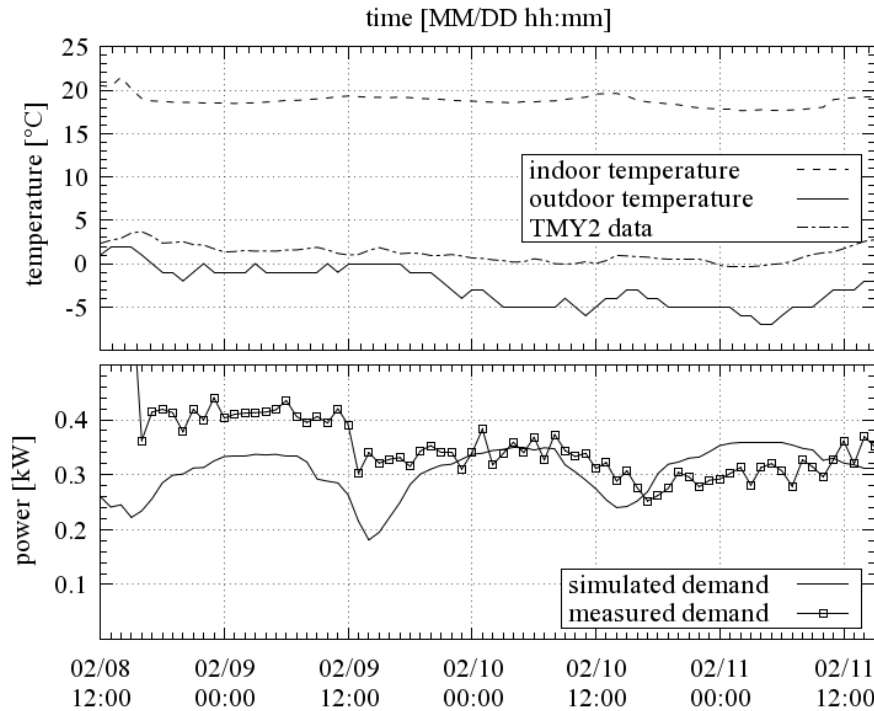


Figure 6.23 : (a) Hourly outdoor dry bulb temperature comparison between TMY Stuttgart weather data and HFT-Stuttgart weather station (08.02.2010-12.02.2010). (b) Heating energy demand comparison of the test room.

The comparison of the dynamic heating energy simulation values and measured values shows reasonable agreement. The comparison of the hourly measured and simulated values can be seen in Figure 6.23(b).

The differences between three days (76 hours: 08.02.2010 13:00 - 11.02.2010 16:00) of monitored data and simulated data for the total heating energy consumption were demonstrated at almost 17%. Measured energy demand was relatively higher than simulation results, which is likely a consequence of the weather data used in the simulation model. As can be seen in Figure 6.23(a), the average measured ambient temperature was 4 degree less than the average TMY average outdoor dry bulb temperature within the same time period.

6.3.2 Cooling energy consumption measurement and comparison

Different conventional types of air condition systems exist. Window air conditioners, also known as room air conditioners, and are self-contained cooling systems to cool one zone at a time. A window air conditioner contains the three basic parts: a compressor, a condenser coil and an evaporator coil. To cool the zone air, window air conditioners use refrigerant, a chemical compound used in cooling systems to absorb heat from its surrounding.

Portable air conditioners serve as an alternative to window or wall air conditioners or as a supplement to central air conditioning. Unlike traditional window air conditioners, portable air conditioners do not sit in the window. They typically sit on the floor within the space which is required to be cooled. All portable air conditioners exhaust hot air as part of the cooling process. This hot air is usually directed out of the cooled space using a hot air discharge hose, also known as an exhaust hose. This air hose is often vented out of a window, into a drop ceiling, or through a wall to an adjacent space. When air is cooled, moisture is removed from the air. Therefore, all portable air conditioners remove water from the air while they are cooling. There are many different ways that various portable air conditioners deal with this condensate water.

A 7600 BTU portable air conditioner (Carrier KCA081P 7600 BTU Thru-Wall/Window Air Conditioner) unit was installed and measured on 20th August 2009. The portable air conditioner unit was placed as a window air conditioner (direct connection to the outdoor for exhaust hot air and condense water) in the test room. The cooling system simulation module predictions are verified by comparison with monitored data for this period. The cooling machine picture, information and parameter settings can be seen in the Table 6.5 and Figure 6.24.

Table 6.5 : The cooling machine specifications.

Name and Model	ALASKA KL7600
Running Temperature	15 ~ 30
Net Weight	35 kg
Dimensions (WxHxD)	38.5 cm x 47 cm x 85.5 cm
Power Input	950 W
Cooling Capacity	2,23 kW
Air Flow Volume	260 m ³ /h
Refrigerant:	R407c
Power supply	230 V ~ 50 Hz



Figure 6.24 : The cooling system of the test room.

The simulation model of the cooling system was built in EnergyPlus and as input object ZONEHVAC:WindowAirConditioner was used. In this model, the window air conditioner contains a fan, a DX cooling coil and an outdoor air mixer. The coil meets the cooling load by cycling on/off. The fan can operate continuously, but in this case, turns on/off in conjunction with the coil.

The model must be described by inputting names of the outdoor air mixer, the fan, and the cooling coil. The placement of the fan, blow through or draw through an operation, cooling coil type can also be defined. The connectivity of the unit must also be specified: a recirculated air node, an air outlet node, an outdoor air inlet node, or a relief air node. The air conditioner flow rate and the outdoor air flow rate, as well as an availability schedule for the unit (this is an on/off schedule), should also be defined.

Simulation control is provided by on /off control. The first step is to decide whether the unit is on for the current time step. For a unit with a cycling fan, the entire unit is assumed to be off if there is no cooling load; if the cooling load is very small, the unit is scheduled off. For a unit with a continuous flow, the fan operates if the unit is scheduled on, whether or not there is a cooling demand. The coil, however, only operates if there is a cooling demand. Cooling model specifications can be seen in

Table 6.6.

Table 6.6 : Cooling model specifications.

Zone HVAC system: WindowAirConditioner
Availability schedule: always
Maximum supply air flow rate: Autosize
Fan Control type: on/off
Cooling coil object Type: Coil:Cooling:DX:SingleSpeed
Rated COP: 3
Fan efficiency: 0,5
Motor efficiency: 0,9
Pressure rise : 150 Pa
Total Cooling Capacity Function of Temperature Curve: Biquadratic
Total Cooling Capacity Function of Flow Fraction Curve: Quadratic
Energy Input Ratio Function of Temperature Curve: Biquadratic Curve
Energy Input Ratio Function of Flow Fraction Curve: Quadratic Curve
Part Load Fraction Correlation Curve: Quadratic Curve

To verify the simulation model, the calculated results, i.e. total cooling energy, power consumption of the system, and the room temperature are compared against monitored data. Figure 6.25 gives the comparison between room temperature results calculated by the simulation model and experimental measurements in one day with outdoor temperatures.

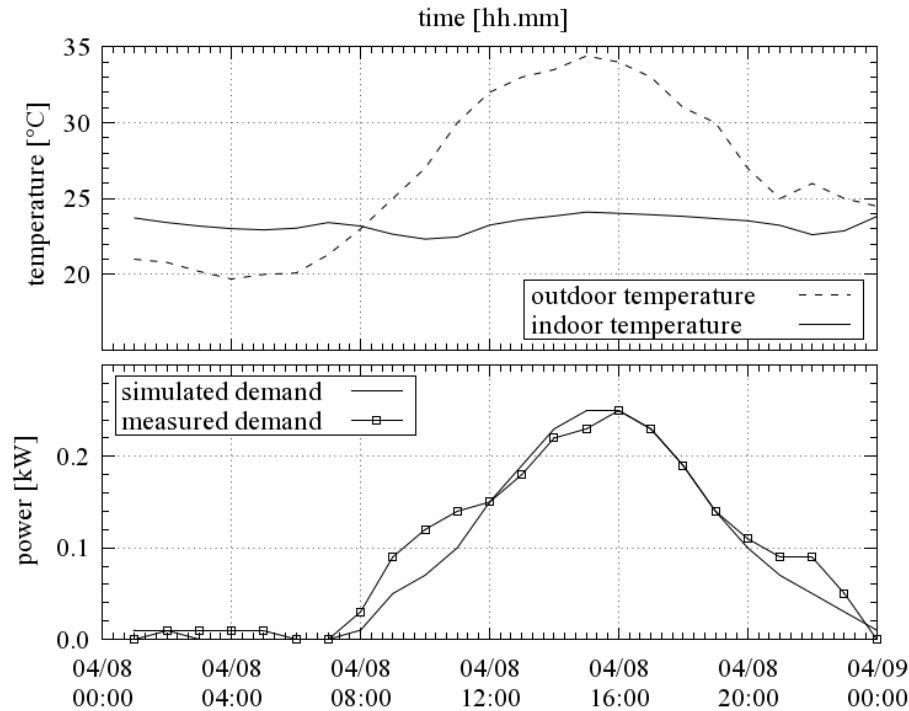


Figure 6.25 : Cooling energy demand comparison.

In order to compare and validate the cooling system simulation model in EnergyPlus, the experimental study was performed in the same test room. The difference between averaged monitored and predicted data for the daily total energy use is demonstrated to be 14,5 %.

In summary, this chapter describes the accuracy of the proposed approach to be able to predict illumination levels, electric lighting, and heating and cooling energy use of an office space in the urban context. A real world test office room was constructed and heating and cooling energy consumptions were measured along with the indoor air temperature of and the surrounding rooms, outside temperature and global radiation. The test room and including its surroundings was also built within a 3D computer environment. Predicted values derived from the simulation models were compared to values measured in the test room. In addition, the accuracy of predictions for artificial lighting illuminance and energy use were evaluated by comparing simulation results to data provided by manufacturers. The artificial lighting control system was also tested by using current dimming mechanism equipped with a luminary. Measurements of illuminance levels, electric energy use for lighting, cooling and heating energy use of a sample office room were taken and compared with results from simulation models. One source of deviation between the measured energy demand and the simulation results is likely the weather data used in

the simulation models, as the actual weather conditions on the days measurements were taken of the test room differed from the average temperature that was inputted into the simulation.

7. SIMULATION RESULTS AND REGRESSION ANALYSIS

EnergyPlus software was used to quantify the impact of the surrounding buildings on the daylight responsive artificial lighting energy performance of a sample office building. The real urban texture is highly complex to compute. In order to limit these complexities, some archetypes that are specifically used for energy studies were re-defined from previously definitions in 3.3.1 (Ratti et al. 2003).

7.1 Office building and office room distance parameters in defined urban areas

The characterisation of the urban form can be defined by following variables: number of floors (building height), building depth to the frontal length (building depth ration), base block dimension (building length and depth), and aspect ratio on both orientation (building height to street width). Office building and office room distance parameters are included in defined urban areas.

Three dimensional distances between the single office building units were varied within the range of current environmental law dealing with spatial planning in Germany. Each office in the urban area has a similar building volume and construction, occupation and equipment pattern.

The sample space was varied in terms of building type and urban density. The geometrical distance definitions that are used in the parametrical analysis are listed in Table 7.1. Some of the parameters are calculated using other parameters; for example, H_{dif} is the difference between building height (H) and sample office room height (H_{room}). The building simulations were done using the definition of the parameters that most affect the lighting consumption of an office. The spread sheet view of the model parameters can be seen in Appendix C.

Table 7.1 : Parameter definitions.

Site Coverage Percentage (%)	
Cardinal Directions: North, East, South, West	
H:	Height of the surrounding buildings (m)
W:	Distance between buildings in the y direction and/or width of the street (m)
D:	Building depth (m)
L₁:	Distance between buildings in the x direction (spacing between units) (m)
L₂:	Building width (m)
L_r:	Distance between left bottom corner of room to the left bottom corner of the building in the x direction (m)
W_b:	Distance between left bottom corner of room to the left bottom corner of the urban system in the y direction D+W (m)
L_b:	Distance between left bottom corner of building to the left bottom corner of the urban system in the X direction L ₁ +L ₂ (m)
H_{room}:	The height of the left bottom corner of room from the ground level (m)
H_{dif}:	The difference of building height from room height (m)
H_{dif}/W:	The difference of building height from room height to Distance between buildings in the y direction (m)
D/L₂:	Building depth to the Building width (m)
L₁/L₂:	Distance between buildings in the x direction to the Building width (m)
L_t	(L ₁ +L ₂ +L _r)Distance between buildings in the x direction plus building width plus distance between left bottom corner of room to the left bottom corner of the building in the x direction
L_{mid}:	[(L ₂ /2)- (L _r +1,25)] The distance between building`s midpoint and room midpoint on x axis. (Right side positive direction, left side negative direction)

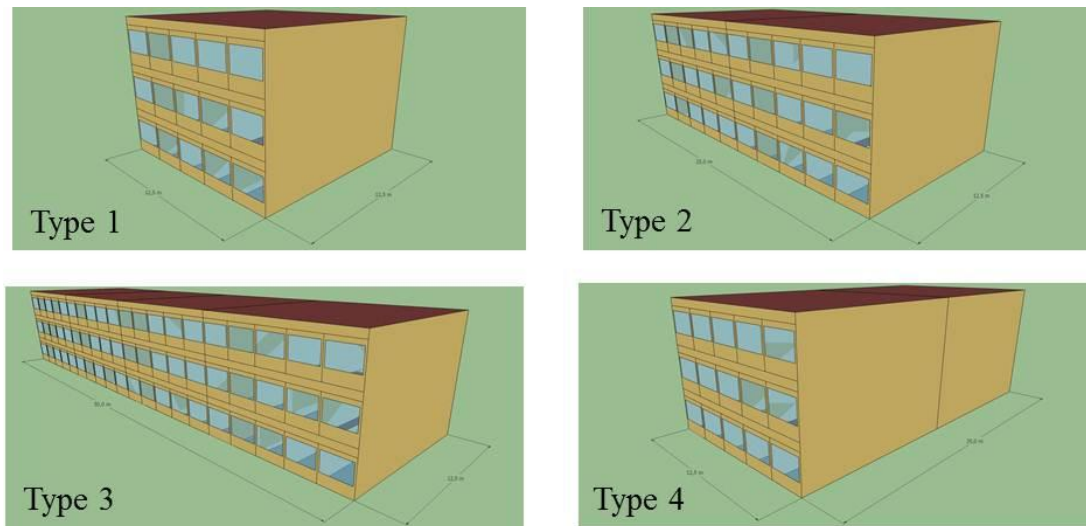


Figure 7.1 : Office building types.

Office building models have four basic geometrical forms (Figure 7.1). All are cellular side lit with two main glazed facades and have the following characteristics:

- Type 1: 12,5 m length x 12,5 m depth

- Type 2: 25,0 m length x 12,5 m depth
- Type 3: 50,0 m length x 12,5 m depth
- Type 4: 12,5 m length x 25,0 m depth

Each building type has a different building height in different cases. The main variables which are used for urban form definitions are shown in Figure 7.2.

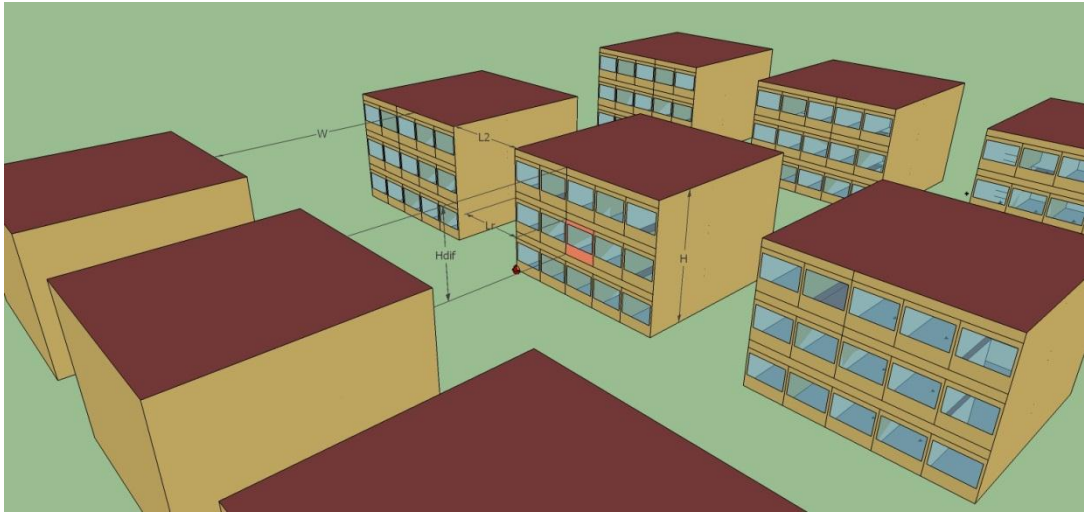


Figure 7.2 : Urban form definition.

In order to represent a large range of existing buildings constructed during the past decade, as well as the new buildings (according to the German building code), these four building forms were placed in different urban configurations. They can be defined by site coverage percentage¹, as well as by the distance between buildings. In some cases, even the urban forms have the same site coverage percentage; however, they can be defined with different L_1 , W , H_{dif} and L_r dimensions. Four levels of L_1 spacing were included in the study: 5,0 m, 10,0 m, 12,5 m, 20,0 m and 25,0 m. Furthermore, three values of W were considered as options: 6,0 m, 9,0 m and 18,0 m. Height differences between surrounding buildings and sample office rooms were also implemented as a possible variable in order to analyse daylight responsive electric artificial lighting consumption. In addition to the height differences, the horizontal locations of the sample office space are important to assess the energy demand. For

¹ Site coverage here means the area of all buildings measured along the outermost external walls expressed as a percentage of the net site area.

this purpose, 21 different L_m distances were used in the analysis. Finally, the orientation of buildings was also investigated by rotating the buildings by 90 degree intervals in the cardinal directions.

7.2 Distance parameters in urban areas to evaluate overall heating, cooling and lighting energy demand

The first stage of the research was to evaluate the total energy demand, including heating, cooling and lighting of the sample office room. The building and room constructions were defined in Chapter 5. Identical definitions and methodology (DRELAT + EnergyPlus) were used to calculate energy demand in the varied urban areas.

Table 7.2 : Annual heating, cooling and lighting energy demand of reference office room without surrounding obstructions.

Reference Office Room	Heating energy demand (kWh/m ² a)	Cooling energy demand (kWh/m ² a)	Lighting energy demand (kWh/m ² a)
North (shading + dimming)	58,51	5,59	11,70
North (without)	57,08	9,75	6,07
East (shading+ dimming)	52,32	17,74	11,82
East (without shading)	49,69	29,01	5,22
South (shading+ dimming)	39,62	20,44	12,06
South (without shading)	33,79	33,64	5,51
West (shading + dimming)	53,20	17,84	11,82
West (without shading)	50,23	29,07	6,14

Table 7.2 shows the dynamic simulation results of the reference office room without surrounding obstructions in two different control devices. The first option was calculated considering automatic shading and dimming mechanism. As it was explained in previous chapters, the roller blinds were used as an indoor shading device and the activation rules of the blinds were defined in DRELAT (when 20% of the sensor points on the work plane monitoring daylight illuminance exceed 2000 lux). Supplementary electrical lighting was used in order to provide required average level of lighting in the sub-zone.

The north-oriented sample office space, which is equipped with shading and electric lighting dimming system, had the highest annual heating demand value (58,51 Wh/m²a) and the lowest annual cooling demand value (5,59 kWh/m²a). On the other hand, the north-oriented office space also had the third highest annual electrical

lighting demand with 11,70 kWh/m²a. The high electricity demand was caused by activation of the shading device during the direct sunlight hours. The minimum heating demand occurred in south-facing offices, which had no shading device, but rather an electrical lighting dimming mechanism. This option resulted in the highest cooling energy demand with 33,64 kWh/m²a. The lighting energy demand of the south oriented non-shaded office was 5,51 kWh/m²a. The minimum annual lighting energy demand was observed in the east-facing non-shaded office space. As a general tendency, the offices that were equipped with a shading device and dimming system required higher heating and lighting energy than the ones without a shading device. In spite of this, the higher cooling energy requirement and lower heating and lighting energy requirement were observed in the non-shaded office. The lowest total energy demand occurred in the north-facing non-shaded office room; 72,12 kWh/m²a. The highest total energy demand occurred in the west-facing non-shaded office room; 85,44 kWh/m²a.

Annual energy demands of the sample office space were calculated and analysed in 28 different dimensional parametric cases under Stuttgart's climatic conditions. The parameters are summarised in Figure 7.3. Site coverage percentages are illustrated in different grey scales. In each case dimension parameters and site coverage percentages are visualized in Figure 7.3. The parameters' values of each case are given in Appendix C.

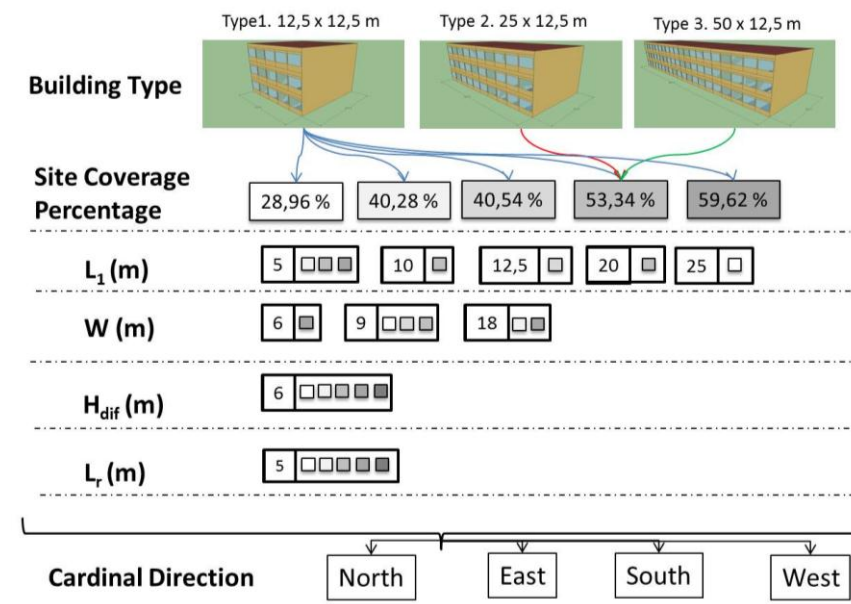


Figure 7.3 : Tree view of model parameters to calculate heating, cooling and daylight responsive artificial lighting energy demand.

Office buildings within the urban environment were evaluated according to the suggested methodology and analysed according to geometrical ratio effects such as the aspect ratio (H_{dif}/W), building depth to the frontal length (D/L_2) and distance between buildings (x-direction the spacing distance) to building frontal length (L_1/L_2). In order to better understand the shading effect of the surrounding building on heating, cooling and lighting energy demand; all simulations were done without automatic a shading device system. Although the sample office had no shading system within the set of simulations, it was equipped with daylighting responsive electrical dimming mechanism.

7.2.1 Aspect ratio effect

Heating and cooling energy demand of the sample office room under different height and spacing configurations were evaluated to find an understanding of the aspect ratio (H_{dif} : building height / W : street width) effect. The office room is evaluated in three different aspect ratios:

- $H_{dif}/W=0,33$ - 40,28% site coverage
- $H_{dif}/W=0,67$ - 53,34% site coverage
- $H_{dif}/W=1$ - 59,62% site coverage

facing each cardinal direction. While aspect ratios are changing, the D/L_2 and L_1/L_2 ratios remain the same, as 1 and 0,4, respectively. **Hata! Başvuru kaynağı bulunamadı.** shows the heating, cooling and lighting demand of the office room in three different aspect ratios.

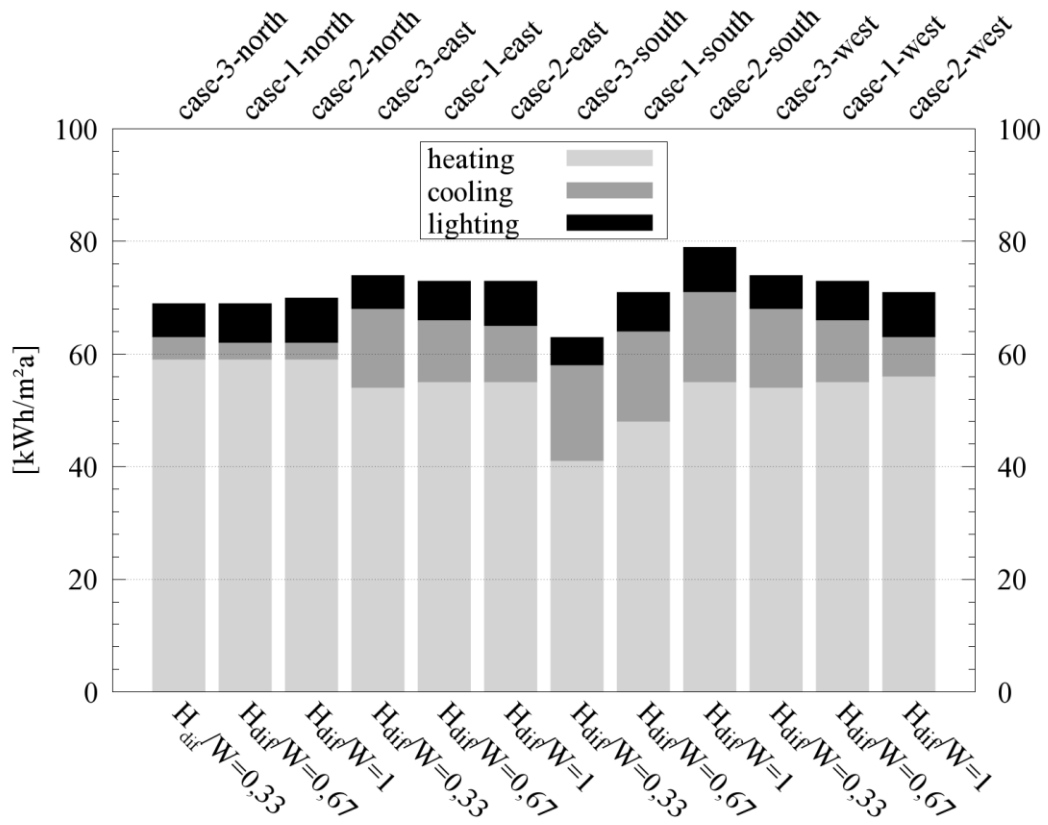


Figure 7.4 : Annual energy demand simulation results as a function of aspect ratios ($H_{dif}/W = 0,33, 0,67, 1, D/L_2=1$ and $L_1/L_2=0,4$).

Without any surrounding shading effect, the heating energy demand of the north-facing office was 57,08 kWh/m²a. With the additional shading variables from the urban area, the heating demand can be 4% higher ($H_{dif}/W=1$). This is 12% higher in the east-facing office and 13% higher in the west-facing office. The maximum increase on heating demand can be observed in the south-facing office with a 64% increase. The opposite situation was observed in the cooling energy demand. The required cooling energy decreased by almost one third in the north- and west-facing offices, and almost by half in south-facing office. The lighting energy demand showed a similar tendency as the cooling energy demand. With the higher H_{dif}/W -ratios, the electric energy demand was increased by between 40 and 66%.

7.2.2 Effect of the building depth to the frontal length ratio

The energy demands of the office room with different building depth to frontal length (D/L_2) were investigated in terms of total annual energy demand. While ratios of building depth to the frontal length are changing, the H_{dif}/W and L_1/L_2 ratios remain the same as 0,67 and 0,4 respectively. The site coverage remains the same as

well with the percentage of 53,34 in each option. The office room is evaluated in three different building depth to frontal length ratios:

- $D/L_2=0,25$
- $D/L_2=0,50$
- $D/L_2=1$.

As it can be seen in Figure 7.5 the annual heat demand decreases by 3% in the south-facing office and 7% in west-facing office with the influence of increasing D/L_2 ratios. Compared to the annual heating energy demand of south-facing office without any surrounding shading effect, the increase can be up to 48% depending on the D/L_2 ratios. The heating energy demand has the opposite tendency. Therefore, as the building geometry becomes more compact, the heating energy demand declines. For the north-facing office options, the effect of the building depth to the frontal length ratios was not noticeable on heating, cooling as well as daylight responsive lighting energy demand. On the other hand, the increase of the energy demand was just up to 5% in the north-facing offices.

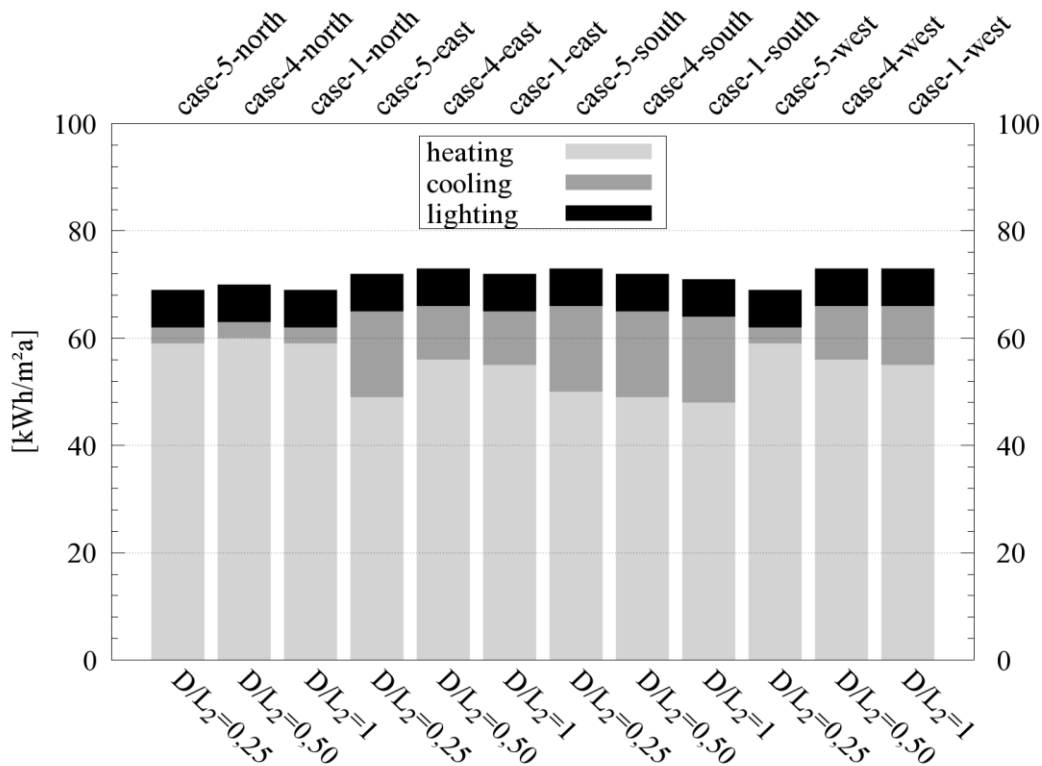


Figure 7.5 : Annual energy demand simulation results as a function of building depth to the frontal length ratio ($D/L_2= 0,25, 0,50, 1$, $H_{dif}/W=0,67$ and $L_1/L_2=0,4$).

The highest heating energy demand was observed in the north-facing office with a ratio of 0,5. The lowest was observed in south-facing office with a ratio of 1. The annual cooling demand of the south-facing office with $D/L_2=0,25$ ratio showed the maximum value in comparison to other alternatives. The minimum cooling energy can be seen in 0,25 ratio in the west-facing office with the 3,38 kWh/m²a. In addition to the cooling energy demand, the highest lighting energy demand was observed in the south-facing office with the 0,25 D/L_2 ratio (7,71 kWh/m²a).

The maximum total energy demand per square meter of office room was calculated in the west-facing office with the ratio of 0,50 (74,58 kWh/m² a). In spite of this, the simulation of the north-facing office with the $D/L_2=1$ ratio showed the minimum total energy demand.

Total energy demand of heating, cooling and lighting of the office room can be decreased up to 13% in the east-facing direction and 18% in the north facing direction. In the south-facing and north-facing directions, the total energy savings is not so notable. A maximum of 4% saving can be reached in the north-facing direction and almost 1% in the south-facing direction, as a function of building depth to the frontal length ratios.

7.2.3 Effect of the spacing distance to the frontal length

Annual heating, cooling and lighting energy demand of sample office room were evaluated in different ratios of spacing distance to the frontal length. The office room is evaluated in three different ratios of spacing distance to frontal length:

- $L_1/L_2=0,40$ - 53,34% site coverage
- $L_1/L_2=1$ - 40,54% site coverage
- $L_1/L_2=2$ - 28,96% site coverage

facing each cardinal direction. While L_1/L_2 ratios are changing, the H_{dif}/W and D/L_2 ratios remain the same as 0,67 and 1 respectively. L_1/L_2 ratios can also be defined as site coverage percentages. Figure 7.6 shows the heating, cooling and lighting demand of office room in three different ratios of spacing distances to frontal length (L_1/L_2).

Without any shading effect of surrounding buildings, the heating energy demand of the office room was 57,08 kWh/m²a for north-facing direction, 49,69 kWh/m²a for east-facing direction, 33,79 kWh/m²a for south-facing direction and 50,23 kWh/m²a

for west-facing direction. The annual heating demand of the office room increases between 5% (north-facing direction) to 44 % (south-facing direction) as a function of spacing distance the frontal length ratios (L_1/L_2). The annual heating demand slightly decreases with higher L_1/L_2 in each cardinal directions. The annual daylight responsive electric lighting energy demand has similar tendency as the heating energy demand.

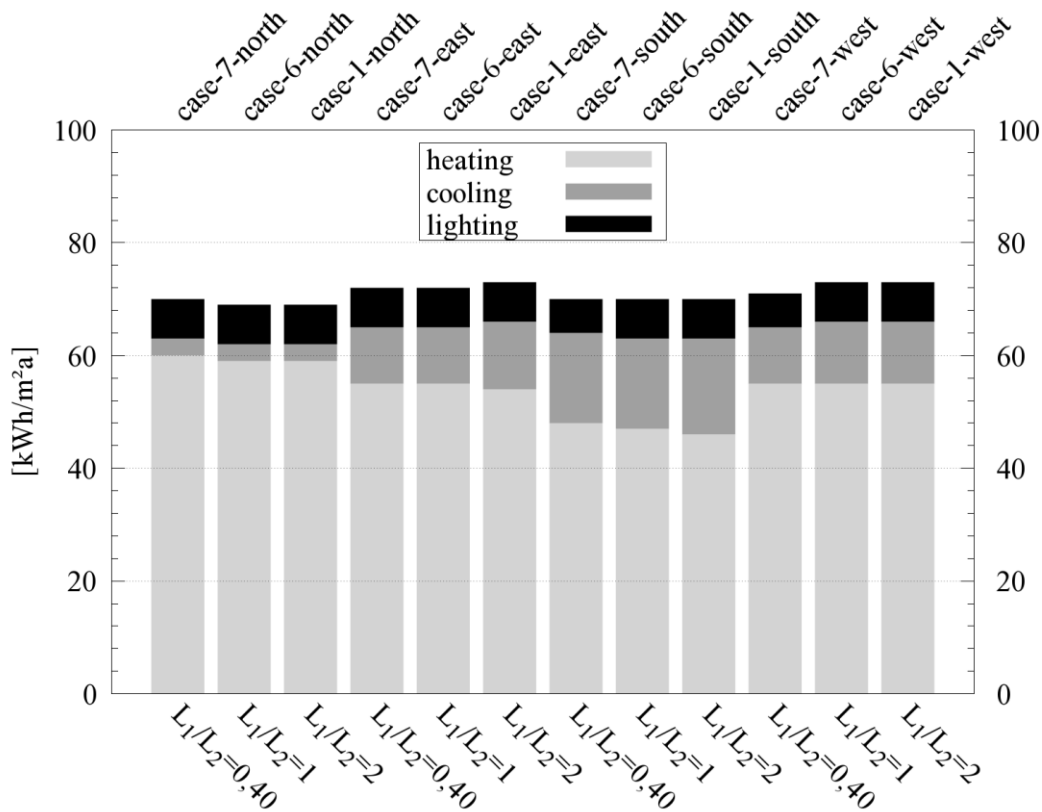


Figure 7.6 : Annual energy demand simulation results as a function of spacing distance to the frontal length ($L_1/L_2=0,4, 1, 2$, $H_{dif}/W=0,67$ and $D/L_2=1$).

Contrary to the heating energy and lighting demand, cooling energy demand increases with the decreasing site coverage and increasing spacing to frontal length ratios.

The highest heating energy demand can be observed for the north-facing office with a ratio of 0.4 and the lowest for south-facing office with a ratio of 2. The maximum annual cooling energy demand with 17,50 kWh/m²a was observed for the south-facing office room with the L_1/L_2 -ratio of 2. The minimum cooling demand can be seen for north-facing office with 3,39 kWh/m²a.

Heating and cooling energy demand of the sample office room varies according to the direction the building faces. On the other hand, a similar trend cannot be observed for the daylight responsive electric lighting energy demand. Heating energy demand varies up to 25% and cooling energy demand can reach almost 4 times the energy requirement per square metre in different orientations, as a function of the spacing distance to the frontal length ratio. It shows that the shading effect is more relevant for heating and cooling energy demand than lighting energy demand in terms of changing L_1/L_2 -ratios. The minimum total energy demand can be seen with the north-facing office room ($L_1/L_2=1$) at 70,41 kWh/m²a and maximum for the east-facing office room ($L_1/L_2=2$) with 74,40 kWh/m²a.

7.2.4 Discussion: effects of distance parameters to total energy demand

Many aspects of the urban design from the layout of the roads to the building shape significantly affect the energy performance of the buildings. Consequently, the urban configuration has significant effects on the site energy performance. The lighting electricity demand of commercial buildings with daytime operation can be decreased by the urban design strategy and daylight responsive artificial lighting system. Therefore, first the possible solar gains for the site design need to be investigated and then building construction and envelope design have to be optimised by considering this analysis.

Within this work, the total annual energy performance of buildings under spacing distance to the frontal length ratios (L_1/L_2) and building depth to the frontal length ratios (D/L_2) and aspect ratios (H_{dif}/W) effects were evaluated.

The combined detailed daylighting analysis and dynamic thermal simulations of office rooms show that in a moderate to cold climate, the heating energy demand increases with H_{dif}/W ratio increase by about 34% (worst case: south facing) and the cooling demand drops by 53% (worst case: west facing). The daylight responsive electric lighting demand rises from 5,94 kWh/m²a at a $H_{dif}/W= 0,33$ ratio to 8,85 kWh/m²a at a $H_{dif}/W= 1$ ratio. If no daylight responsive strategy were used, the electric lighting demand would be 36 kWh/m²a, which is almost six times higher than the case of $H_{dif}/W=0,33$ ratio. The heating and daylight responsive electric lighting energy demand changes were not so significant with the increase of D/L_2 -ratios. In west-facing office rooms, the heating energy demand decreases by just 4% and lighting energy demand increase is 3 % with increasing building depth to the

frontal length ratio. On the other hand, the cooling energy demand increases by 3 times with the increase of D/L_2 -ratios. By increasing spacing distance to the frontal length ratios (L_1/L_2), the heating and lighting energy demand increase and cooling energy demand decrease. The decline of the heating demand is almost 5% and the decrease of the lighting energy demand is almost 8% in all directions. Cooling energy demand increases by increasing of L_1/L_2 -ratios by between 5% and 8%. Consequently, lighting and thermal energy demand should be investigated together and the overall energy consumption should be optimised considering primary energy.

If solar access is taken into account at the earliest planning stages, it is usually possible to ensure that the majority of buildings on a site are orientated to have good solar access for daylighting and have a reduced heating demand. For summer dominated climate conditions, the site design should focus on reducing the cooling load, but the daylighting illuminance level and the electric lighting loads should also be considered.

7.3 Distance parameters in urban areas to evaluate daylight responsive artificial lighting energy demand

One of the main aims of the thesis is to define the most important distance parameters in urban areas that impact the daylight responsive artificial lighting energy demand calculation. To evaluate daylight responsive electrical lighting demand of the sample office room, identical definitions and methodology (DRELAT + EnergyPlus) were used in varied urban areas. Figure 7.7 presents all scenarios derived by these parameters. Site coverage percentages are illustrated in different grey scales. In each case dimension parameters and site coverage percentages are visualized in Figure 7.7. The parameters' values of each case are given in Appendix C.

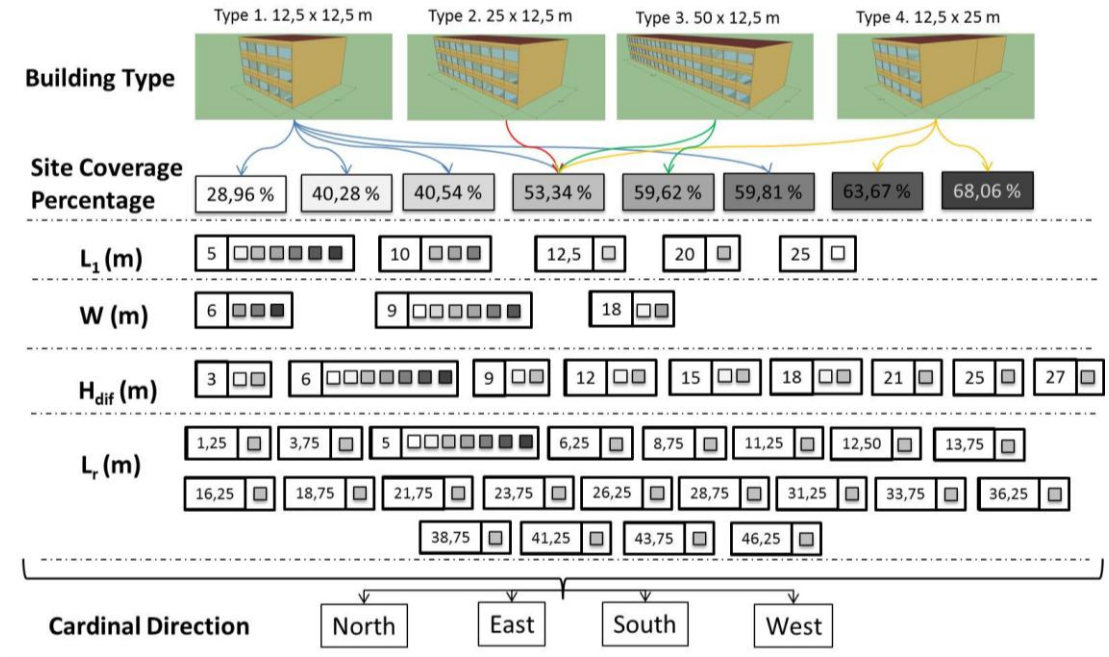


Figure 7.7 : Tree view of model parameters to calculate daylight responsive artificial lighting energy demand.

7.3.1 Aspect ratio effect

To find an understanding of the aspect ratio effect on daylight responsive electric lighting energy demand, different height and spacing configurations were evaluated. The lighting demand of the office room was calculated in nine different aspect ratios:

- $H_{dif}/W=0,17$
- $H_{dif}/W=0,33$
- $H_{dif}/W=0,50$
- $H_{dif}/W=0,67$
- $H_{dif}/W=0,83$
- $H_{dif}/W=1$
- $H_{dif}/W=1,17$
- $H_{dif}/W=1,33$
- $H_{dif}/W=1,50$

As it is indicated in Figure 7.8, the D/L_2 and L_1/L_2 ratios remain the same, as 1 and 0.4, respectively. The site coverage percentage also remains the same as 40,28%.

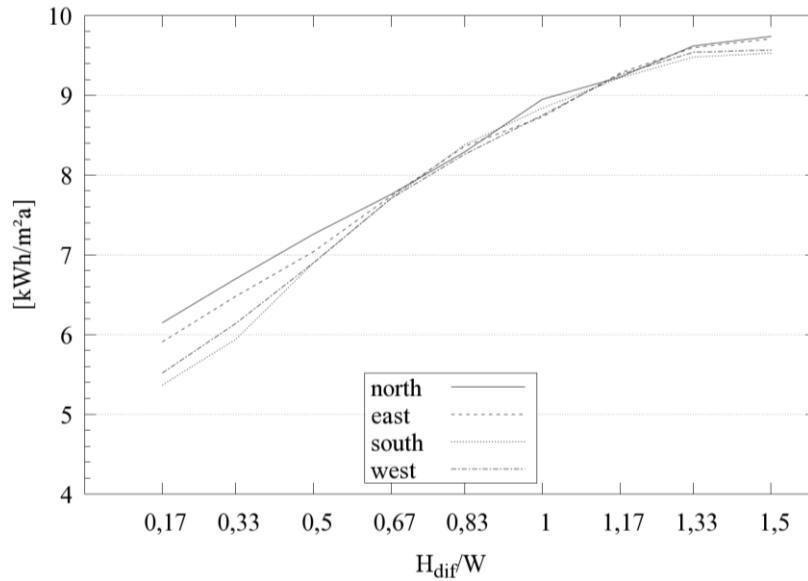


Figure 7.8 : Annual lighting energy demand simulation results as a function of aspect ratios ($H_{dif}/W = 0,17, 0,33, 0,50, 0,67, 0,83, 1, 0,17, 1,33, 1,50$ $D/L_2=1$ and $L_1/L_2=0,4$).

The lighting energy demand is considerably enhanced by aspect ratio. The simplest and the most effective way get more daylight is to have less aspect ratio but less dense urban geometry configuration also causes glare problems and visual discomfort. In this part of the research, the aim was to learn how significant the aspect ratio and the orientation are for the lighting energy demand of an office space. As it is realised in the figure, the orientation does not have such a great impact on lighting energy demand of the office space. The shading factor from the obstruction by buildings has similar effect in each orientation and has no significant influence on each other. When we check the impact of the H_{dif}/W ratios with the other fixed conditions, the south-facing direction results has slightly more effect than other directions on lighting energy performance under the Stuttgart's altitude and latitude conditions.

The north-facing office has 36,92% worse lighting energy performance with increasing H_{dif}/W ratios. The ratio is 39,13% in east direction, 43% in the south and 42% in west-facing direction.

7.3.2 Effect of the building depth to the frontal length ratio

The simulated daylight responsive electric lighting energy demand of the office room with different building depth to frontal length (D/L_2) were investigated in terms of total annual energy demand. The office room is evaluated in three different building depth to frontal length ratios:

- $D/L_2=0,25$
- $D/L_2=0,50$
- $D/L_2=1$
- $D/L_2=2$

As it can be seen in Figure 7.9, while ratios of building depth to the frontal length are changing, the H_{dif}/W and L_1/L_2 ratios remain the same at 0,67 and 0,4 respectively. The annual lighting demand decreases by 3,7% in the south-facing office and 2,5% in west-facing office with the influence of increasing D/L_2 ratios. The decrease is 2,3% in east-facing office and 1,6% in north-facing office. In spite of all increasing D/L_2 ratios having the same decreasing tendency for the lighting energy demand, different directions do not have significant energy demand changes between each other.

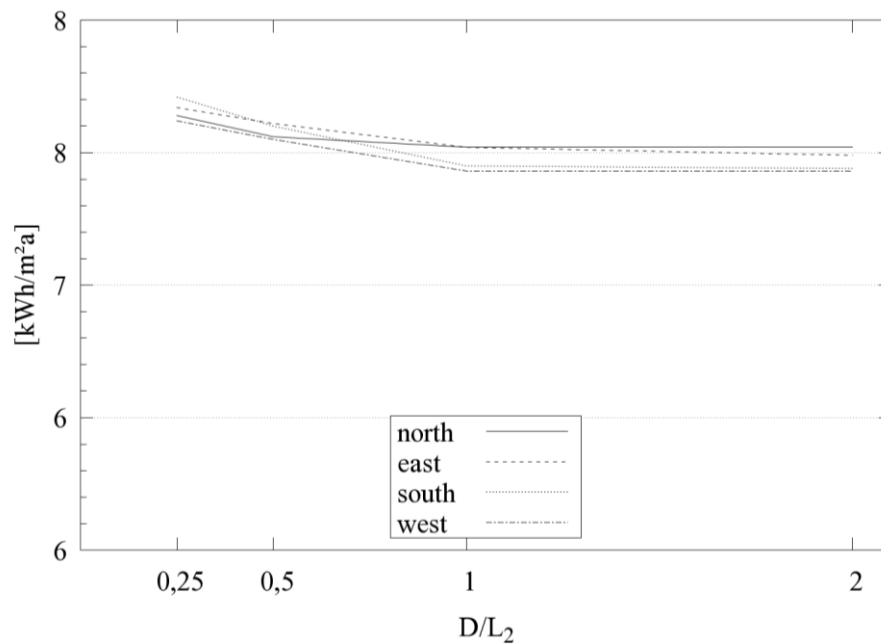


Figure 7.9 : Daylight responsive artificial lighting energy demand of building depth to frontal length ratio effect ($D/L_2= 0,25, 0,50, 1$ and 2 , $H_{dif}/W=0,67$, $L_1/L_2=0,4$).

7.3.3 Effect of the spacing distance to the frontal length

Annual lighting energy demands of sample office room were evaluated in different ratios of spacing distance to the frontal length. The office room is evaluated in three different ratios of spacing distance to frontal length:

- $L_1/L_2=0,40$ - 53,34% and 40,28% site coverage
- $L_1/L_2=1$ - 40,54% site coverage
- $L_1/L_2=2$ - 28,96% site coverage

The H_{dif}/W and D/L_2 ratios remain the same as 0,67 and 1, respectively, while L_1/L_2 ratios are changing. Two outputs of the simulation resulted in an L_1/L_2 ratio of 0,4, however, the same ratios correspond to different site coverage percentages of 56% and 68%, respectively. Figure 7.10 shows the heating, cooling and lighting demand of office room in three different ratios of spacing distances to frontal length (L_1/L_2).

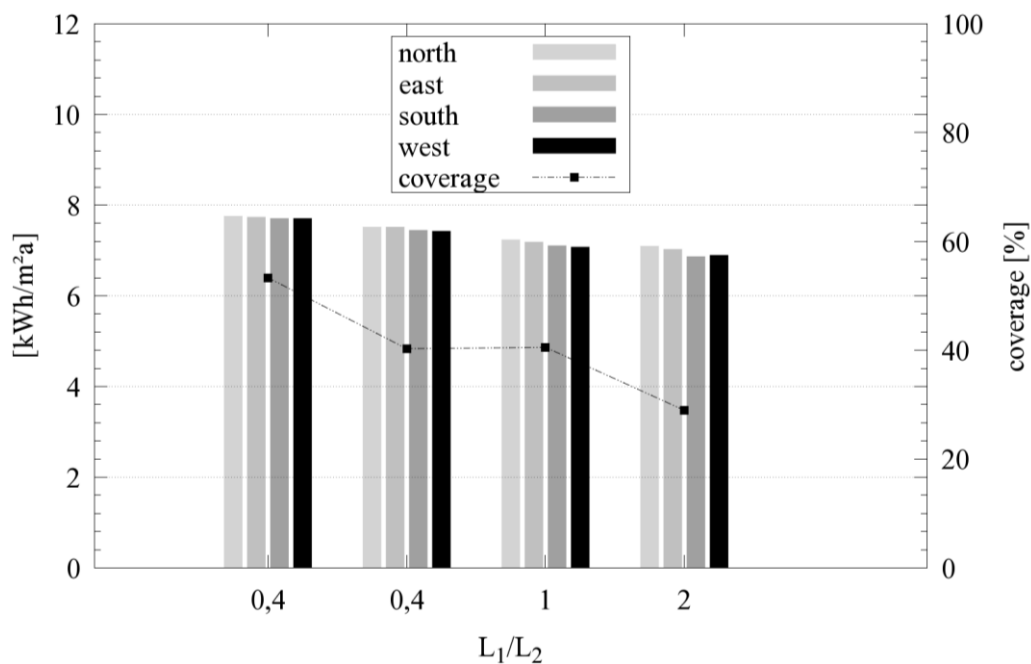


Figure 7.10 : Daylight responsive artificial lighting energy demand of spacing distance to the frontal length ($L_1/L_2=0,4, 1, 2$, $H_{dif}/W=0,67$ and $D/L_2= 1$).

The annual lighting energy demand slightly decreases with higher L_1/L_2 in each cardinal directions. The highest lighting energy demand can be observed for the north-facing office with ratio of 0,4 (53,34% site coverage) and the lowest for south-facing office with the ratio of 2. The decrease of electric energy demand based on lighting is 8,40% in the north-facing office, 9,23% in the east-, 10,87 in the south- and 10,51 in the west-facing facade.

7.3.4 Effect of the office room position on horizontal axis in the building

In order to understand the relationship between office room position on horizontal axis in the building and daylight responsive artificial lighting energy demand,

simulations were done with DRELAT. In each simulation the position of the office room was changed on the 2,5 m right and/or left side (to the positive and negative direction according to middle point of the room). Graphical explanation can be seen in Figure 7.11.

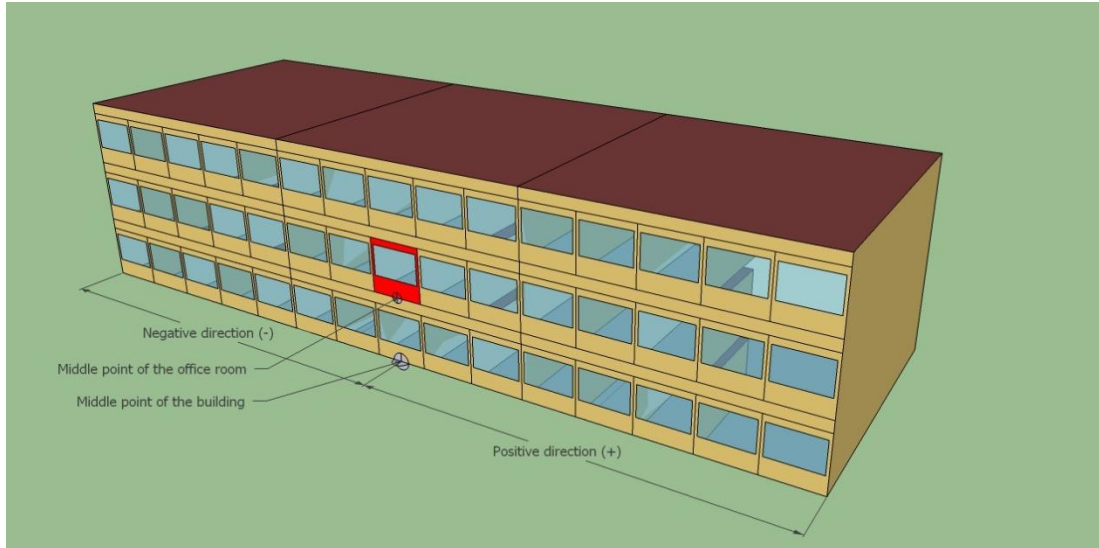


Figure 7.11 : The office room position on horizontal axis in the building.

The simulated daylight responsive electric lighting energy demand of the office room in different position on horizontal axis (L_{mid}) were investigated in terms of total annual energy demand in Figure 7.12. While the position of the office room is changing in both directions (to the left and right), the H_{dif}/W , L_1/L_2 , D/L_2 ratios and site coverage percentage remain the same 0,67, 0,40, 0,25 and 53,34 %, respectively. The annual lighting demand decreases by almost 8% in the north-facing office in both the negative and positive horizontal axis directions. The general tendency is similar in the south-facing office, with a decreasing demand of 14% in both directions. Regardless of south or north orientations, the lighting demand decrease is almost 8% in the negative direction and 12% in the positive direction for the east-facing office. The decrease of annual lighting energy demand of the west-facing office is 15% in the negative direction and 10% in the positive direction along the horizontal axis.

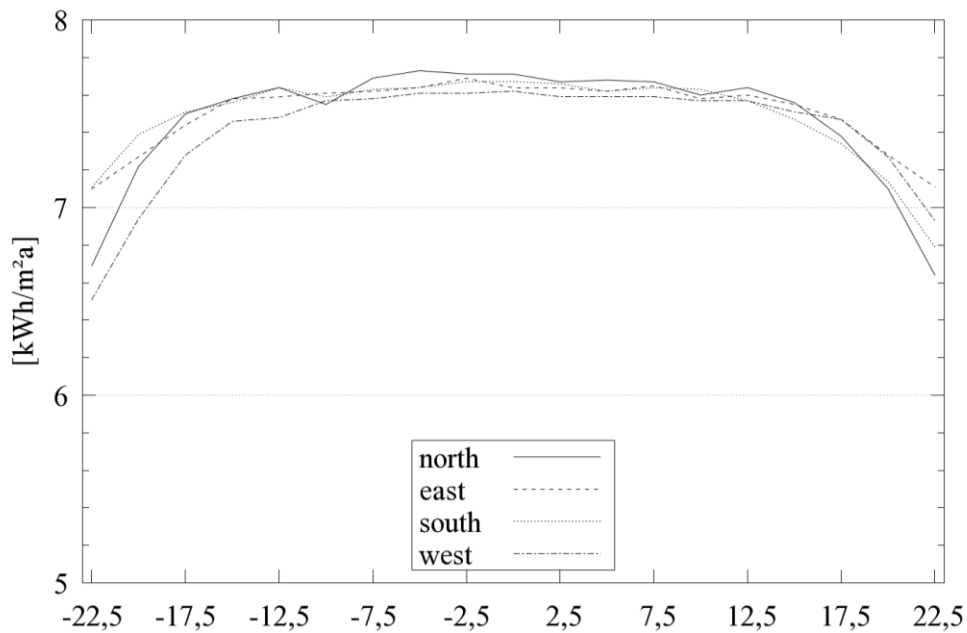


Figure 7.12 : Effect of the office room position on horizontal axis in the building on daylight responsive artificial lighting energy demand $L_{mid} = -22,5, -20, -17,5, -15, -12,5, -10, -7,5, -5, -2,5, 0, 2,5, 5, 7,5, 10, 12,5, 15, 17,5, 20, 22,5$ ($L_1/L_2=0,4$, $H_{dif}/W=0,6$, $D/L_2=0,25$ and Site coverage 53,34 %).

The effect of the position on horizontal axis on lighting energy demand was investigated in addition to another set of simulations that has $H_{dif}/W = 0,67$; $L_1/L_2 = 0,4$ and $D/L_2 = 0,5$. The results can be seen Figure 7.13. In the first set of simulations, the office buildings' frontal length were 25 m and in the second set of simulation office buildings' frontal length were 10 m.. Also, distances between buildings were different in each set. Even though there are some differences between the two urban and building geometries, the position of the office room on the horizontal axis affects lighting energy demand in similar way. The lighting demand decrease is almost by 2% in a negative direction and by 8% in a positive direction of east-facing office. The decrease of annual lighting energy demand of west-facing office is by 12% in a negative direction and by 8% in a positive direction on the horizontal axis. The results of the second sets of simulations are slightly less than first set of simulations. This can be explain primarily by the building geometry (longer frontal length) and then by the urban geometry (D/L_2 is 0,5 instead of 0,25).

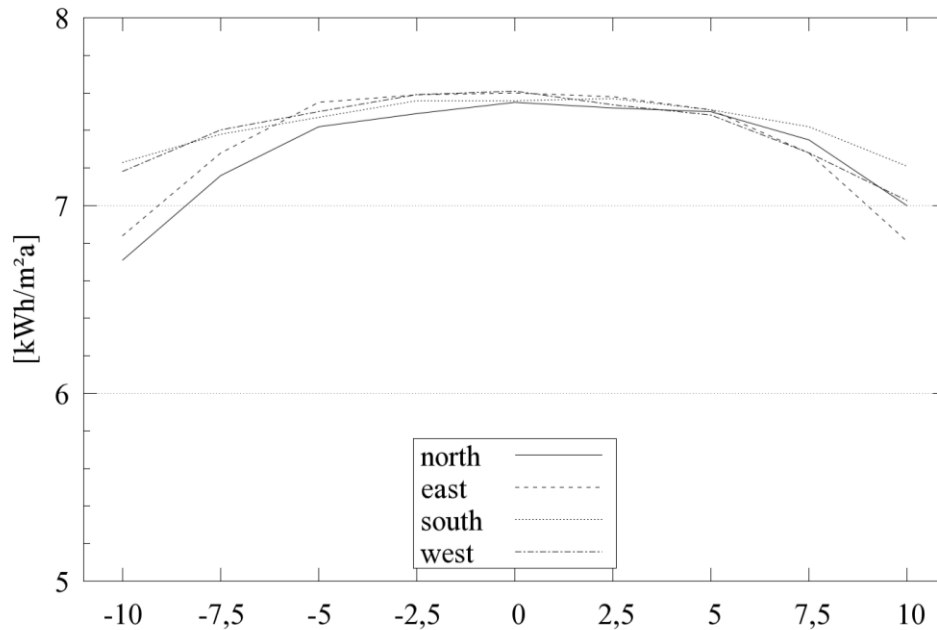


Figure 7.13 : Effect of the office room position on horizontal axis in the building on daylight responsive artificial lighting energy demand ($L_1/L_2=0,4$, $H_{dif}/W=0,67$, $D/L_2=0,5$ and Site coverage 53,34%).

7.3.5 Discussion: effects of distance parameters to lighting energy demand

The eventual source of all daylighting is the sun. Weather conditions, building orientation and time of the day can prohibit sunlight access to buildings. In these situations, building interiors depend on daylighting originating from the sky and reflected by surrounding surfaces instead of direct sunlight. In urban areas, buildings can pose obstructions to daylight access by reducing the skylight contribution and blocking the sunlight. However, reflected sunlight from the obstructions and/ or ground play an important role in the illumination of buildings.

Brotas and Wilson took physical measurements in an urban canyon in Lisbon and made computer simulations with Radiance. They showed the contribution of the reflected sunlight from obstructions and the ground to the illumination of buildings and also at times when the sun behind the building (Brotas and Wilson, 2006). In the scope of Brotas and Wilson's work, illuminance on the building facade was examined in different orientations within an obstructed surrounding. It was indicated that although the percentage of the contributions to the illuminance of a north facade may vary significantly throughout the day and year, the reflected light from the obstruction and ground is higher than the contribution of the sky.

Within this part of the work, the lighting energy performance of buildings' under spacing distance to the frontal length ratios (L_1/L_2) and building depth to the frontal length ratios (D/L_2) and aspect ratios (H_{dif}/W) effects were evaluated.

The daylighting responsive artificial lighting energy demand of office rooms show that rises in a mild climate between 37 to 43% with increasing H_{dif}/W ratio at each cardinal direction. On the other hand, the lighting demand decreases between 1,5 % to 3,5% with increasing D/L_2 ratio at each cardinal direction. While the spacing distance to the frontal length (L_1/L_2) increasing, the lighting energy demand is sinking by 8-11 % in each cardinal direction.

To analyse the effect of the position on horizontal axis on lighting energy demand, the sample room was simulated with different distances to the middle axis of the building. The distance was changed in the negative and positive detections. While the building moves away from the middle point of the building, independent from direction, the energy demand is decreasing. The decrease has a range between 5-10 % of electric lighting energy demand.

As it is also shown with the results, the most important effect on lighting energy performance in urban context is H_{dif}/W . Other ratios such as building depth to the frontal length ratio (D/L_2) or the spacing distance to the frontal length (L_1/L_2) have not much effect on lighting energy performance. At the same time, the position of the room in the building has great importance for lighting energy calculations because of daylight availability in the urban context.

One of the most important findings of the calculations are that the orientation of the room is not so effective for daylight responsive artificial lighting calculation. This finding is also provides further support of Brotas and Wilson's research, indicating refracted light from obstructions has a good contribution to illuminance of interiors.

7.4 Statistical analysis

It is widely accepted approach among building professionals to use the following building energy simulation tools: EnergyPlus, which can analyse building energy consumption in detail; Radiance for daylighting simulation, which can analyse lighting situations in that moment; and climate-based daylighting models such as Daysim, which was used in the PhD work. However, preparing and running

simulation tools is usually very complicated, time consuming and costly. Their complexity has been identified as the biggest obstacle. Adequate alternatives to complex building energy simulation tools are regression models which can provide results in an easier and faster way.

This research deals with the development of regression models that enable the selection of distance of the office room within the urban district and using this selection, is able to predict daylight responsible electric lighting consumption.

To better understand the interactions, a series of simulations for the reference office space were carried out with the orientation and the external obstruction being changed systemically. It was assumed that the obstructing blocks have the same height and same building length as the reference building, which was located in the middle of surrounding buildings with a defined separation distances. The obstructing building had 9 m floor-to-floor height and this was varied ranging from 18 m to 27 m at 9 m intervals. Such simulations were conducted for each of the four cardinal directions (North, South, East and North) to account for orientation effects.

In total, 228 simulation runs were conducted for the daylighting study. The sets of simulation results were used for the subsequent regression analysis. To better understand the electricity savings and the incremental electricity-reductions due to daylighting (the electricity consumption difference between the reference building with daylighting controls, without shading control), the regression analysis was computed and correlated with the variables.

A data set of office building simulation archetypes was used for the first part of the data set development for the regression analysis. The distance between buildings in both directions, the height of the surrounding buildings and the height of the sample room were changed systematically. The results clearly indicate that it is possible to form a reliable judgement about daylight responsive electric lighting demand based only on an office building. High coefficients of determination of the proposed regression models show that daylight responsive electric lighting demand in an urban system can be predicted with high accuracy. The main aim of regression analysis is to determine a simple as possible model that fits the observed data well enough (EnergyPlus simulation outputs) and calculates the daylight responsive electric lighting demand correctly. The goal is not to find the model that calculates the

requirements perfectly, if that is possible at all, since such a model would probably have too many parameters to be useful.

7.4.1 Statistical analysis steps and Linear Regression model

Linear Regression estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable. The linear regression model consists of several steps. All analysis phases done to set the linear regression model are summarised in Figure 7.14.

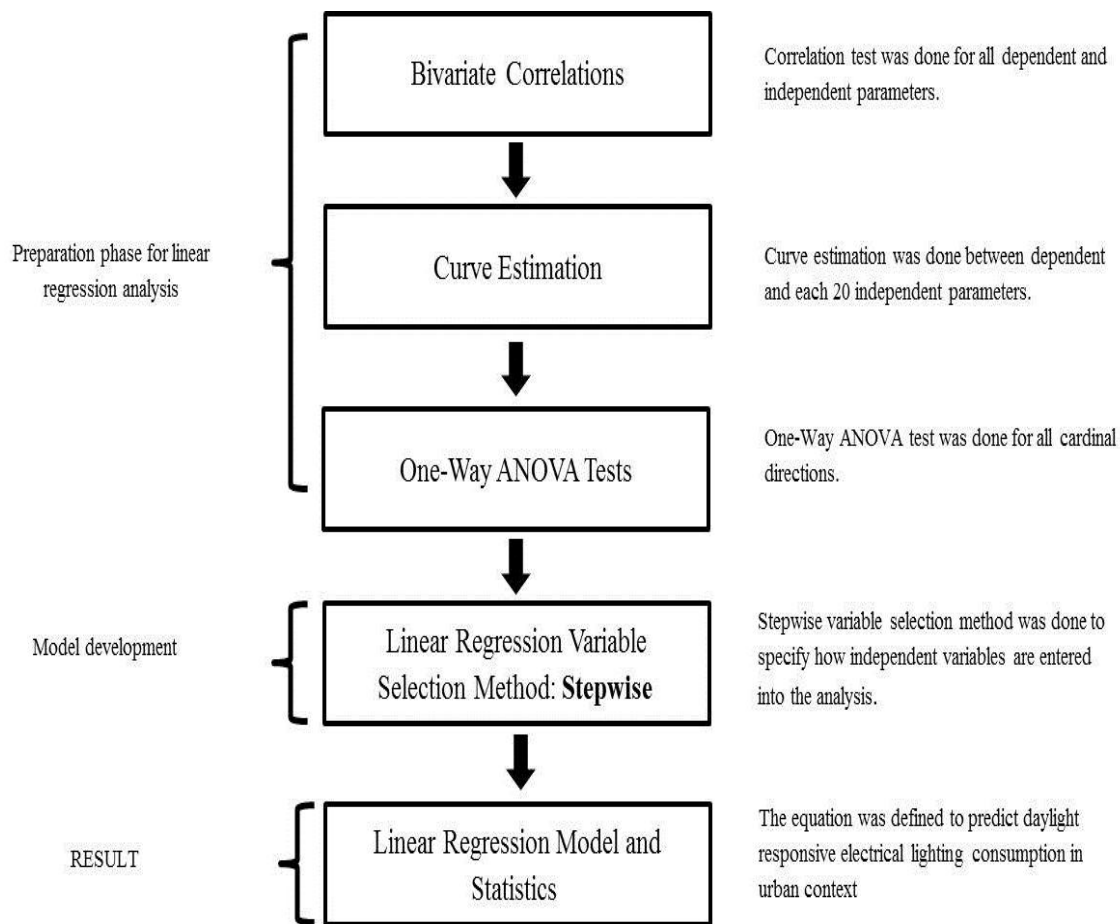


Figure 7.14 : Linear regression analysis phases.

First, the descriptive procedure was done to see the all variables. The descriptive procedure displays univariate summary statistics for several variables in a single table and calculates standardized values. The descriptive statistics table can be seen in Table 7.3.

Table 7.3 : Descriptive Statistics.

	N	Minimum	Maximum	Mean	Std. Deviation
Electricity Consumption: kWh	228	65,27	147,41	95,6021	15,18911
Electricity Consumption: kWh/m ²	228	5,22	11,79	7,6483	1,21475
Site Coverage %	224	28,96	68,06	50,5491	7,05019
H: Height of the surrounding buildings (m)	228	0	27	12,6316	6,93743
W: Distance between buildings in the y direction and/or width of the street	228	0	18	10,7895	4,13319
D: Building depth (m)	228	12,5	25	13,1579	2,79735
L₁: Distance between buildings in the x direction (m)	228	0	25	11,9737	6,54932
L₂: Building width (m)	228	12,5	50	29,386	16,00028
L_r: Distance between left bottom corner of room to the left bottom corner of the building in the x direction (m)	228	1,25	46,25	13,6184	11,52397
W_b: Distance between left bottom corner of room to the left bottom corner of the urban system in the y direction D+W (m)	228	12,5	43	23,9474	5,01863
L_b: Distance between left bottom corner of room to the left bottom corner of the urban system in the X direction L1+L2 (m)	228	12,5	70	41,3596	21,97851
H_{room}: The height of the left bottom corner of room from the ground level (m)	228	0	24	4,8421	4,9661
H_{diff}: The difference of building height from room height (m)	228	0	27	7,7895	5,03289
H_{diff} /W: The difference of building height from room height to Distance between buildings in the y direction (m)	224	0,17	2	0,737	0,32898
D/L₂: Building depth to the Building width (m)	228	0,25	2	0,6404	0,4428
L₁/L₂: Distance between buildings in the x direction to the Building width (m)	228	0	2	0,4281	0,23278
L_t: L ₁ +L ₂ +L _r (m)	228	17,5	116,25	54,9781	31,01131
L_{mid}: [(L ₂ /2)- (L _r +1,25)] (m)	228	-22,5	22,5	-0,1754	8,34102
E: East	228	0	1	0,25	0,43397
N: North	228	0	1	0,25	0,43397
S: South	228	0	1	0,25	0,43397
W: West	228	0	1	0,25	0,43397
Valid N (listwise)	224	-	-	-	-

Bivariate correlations have been done to determine how related variables are to each other. The Pearson correlation coefficient was chosen to analyse the correlation between variables. If correlation coefficients have a value of -1 it means it has a perfect negative relationship and $+1$ indicates a perfect positive relationship. A value of 0 indicates no linear relationship. The closer the correlation is to ± 1 , the closer to a perfect linear relationship. There is a tendency to interpret correlations in the following manner: $1,0$ to $-0,7$ strong negative association, $-0,7$ to $-0,3$ weak negative association, $-0,3$ to $+0,3$ little or no association, $+0,3$ to $+0,7$ weak positive

association, +0,7 to +1,0 strong positive association (Linear Correlation Coefficient, 2012). The correlation results can be seen in Table 7.4.

9,5 % of the coefficients (which are shown red in the Table 7.4) are greater than +/- 0,7, but in general, it can be considered that there are no correlations between variables.

Table 7.4 : Correlations.

	kWh	kWh/m ²	%	H	W	D	L ₁	L ₂	L _r	W _b	L _b	H _{room}	H _{diff}	H _{diff} /W	D/L ₂	L ₁ /L ₂	L ₁	L _{mid}	East	North	South	West
kWh	1,00	1,00	0,15	0,32	-0,05	-0,03	-0,05	-0,03	-0,01	-0,06	-0,04	-0,28	0,72	0,97	-0,05	-0,04	-0,03	-0,02	0,01	0,03	-0,02	-0,03
kWh/m ²	1,00	1,00	0,15	0,32	-0,05	-0,03	-0,05	-0,03	-0,01	-0,06	-0,04	-0,28	0,72	0,97	-0,05	-0,04	-0,03	-0,02	0,01	0,03	-0,02	-0,03
%	0,15	0,15	1,00	-0,57	-0,76	0,38	0,23	0,47	0,33	-0,39	0,41	-0,39	-0,39	0,09	-0,21	-0,47	0,41	-0,01	0,00	0,00	0,00	0,00
H	0,32	0,32	-0,57	1,00	0,72	-0,12	-0,44	-0,45	-0,30	0,52	-0,46	0,69	0,70	0,31	0,27	-0,02	-0,44	-0,01	0,00	0,00	0,00	0,00
W	-0,05	-0,05	-0,76	0,72	1,00	0,01	-0,43	-0,46	-0,33	0,83	-0,46	0,49	0,51	-0,12	0,41	0,01	-0,45	0,01	0,00	0,00	0,00	0,00
D	-0,03	-0,03	0,38	-0,12	0,01	1,00	-0,25	-0,25	-0,18	0,57	-0,26	-0,09	-0,08	-0,05	0,73	-0,03	-0,25	0,00	0,00	0,00	0,00	0,00
L ₁	-0,05	-0,05	0,23	-0,44	-0,43	-0,25	1,00	0,88	0,61	-0,50	0,94	-0,32	-0,29	-0,10	-0,71	0,30	0,89	0,01	0,00	0,00	0,00	0,00
L ₂	-0,03	-0,03	0,47	-0,45	-0,46	-0,25	0,88	1,00	0,69	-0,52	0,99	-0,32	-0,30	-0,09	-0,80	-0,16	0,96	0,01	0,00	0,00	0,00	0,00
L _r	-0,01	-0,01	0,33	-0,30	-0,33	-0,18	0,61	0,69	1,00	-0,37	0,68	-0,22	-0,21	-0,05	-0,56	-0,12	0,86	-0,72	0,00	0,00	0,00	0,00
W _b	-0,06	-0,06	-0,39	0,52	0,83	0,57	-0,50	-0,52	-0,37	1,00	-0,53	0,35	0,37	-0,12	0,74	0,00	-0,51	0,01	0,00	0,00	0,00	0,00
L _b	-0,04	-0,04	0,41	-0,46	-0,46	-0,26	0,94	0,99	0,68	-0,53	1,00	-0,33	-0,31	-0,10	-0,80	-0,03	0,96	0,01	0,00	0,00	0,00	0,00
H _{room}	-0,28	-0,28	-0,39	0,69	0,49	-0,09	-0,32	-0,32	-0,22	0,35	-0,33	1,00	-0,04	-0,34	0,19	-0,03	-0,31	-0,01	0,00	0,00	0,00	0,00
H _{diff}	0,72	0,72	-0,39	0,70	0,51	-0,08	-0,29	-0,30	-0,21	0,37	-0,31	-0,04	1,00	0,77	0,18	-0,01	-0,29	-0,01	0,00	0,00	0,00	0,00
H _{diff} /W	0,97	0,97	0,09	0,31	-0,12	-0,05	-0,10	-0,09	-0,05	-0,12	-0,10	-0,34	0,77	1,00	-0,02	-0,03	-0,09	-0,02	0,00	0,00	0,00	0,00
D/L ₂	-0,05	-0,05	-0,21	0,27	0,41	0,73	-0,71	-0,80	-0,56	0,74	-0,80	0,19	0,18	-0,02	1,00	0,12	-0,77	0,01	0,00	0,00	0,00	0,00
L ₁ /L ₂	-0,04	-0,04	-0,47	-0,02	0,01	-0,03	0,30	-0,16	-0,12	0,00	-0,03	-0,01	-0,03	0,12	1,00	-0,06	0,00	0,00	0,00	0,00	0,00	0,00
L ₁	-0,03	-0,03	0,41	-0,44	-0,45	-0,25	0,89	0,96	0,86	-0,51	0,96	-0,31	-0,29	-0,09	-0,77	-0,06	1,00	-0,26	0,00	0,00	0,00	0,00
L _{mid}	-0,02	-0,02	-0,01	-0,01	0,01	0,00	0,01	0,01	-0,72	0,01	0,01	-0,01	-0,01	-0,02	0,01	0,00	-0,26	1,00	0,00	0,00	0,00	0,00
East	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	-0,33	-0,33	-0,33
North	0,03	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,33	1,00	-0,33	-0,33
South	-0,02	-0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,33	-0,33	1,00	-0,33
West	-0,03	-0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,33	-0,33	-0,33	1,00

The curve estimation procedure was used separately for each variable to determine how the independent and dependent variables are related (linearly, exponentially, etc.). The residuals of a good model should be randomly distributed and normal.

The electricity consumption (kWh/m²) was selected as a dependent variable. Each independent variable (16 variables – except for the 4 cardinal directions) was coupled with the dependent variable to determine which plot to use to graph the data. In Table 7.5, the curve estimation model summaries can be seen. Details of each estimation model can be found in Appendix C.

Table 7.5 : Curve estimation model summaries and parameter estimates.

Dependent Variable: kWh_m²										
Independent Variables	Equation	Model Summary					Parameter Estimates			
		R²	F	df1	df2	Sig.	Constant	b1	b2	b3
Site Coverage %	linear	0,02	4,75	1,00	222	0,03	6,44	0,03	0,00	0,00
H	linear	0,10	25,24	1,00	226	0,00	6,95	0,06	0,00	0,00
W	cubic	0,08	6,07	3,00	224	0,00	5,82	1,36	-0,19	0,01
D	not fit found	x	x	x	x	x	x	x	x	x
L ₁	quadratic	0,07	8,83	2,00	225	0,00	6,51	0,25	-0,01	0,00
L ₂	quadratic	0,06	6,68	2,00	225	0,00	6,17	0,13	0,00	0,00
L _r	cubic	0,07	5,98	3,00	224	0,00	6,60	0,23	-0,01	0,00
W _b	quadratic	0,05	5,43	2,00	225	0,01	3,50	0,33	-0,01	0,00
L _b	quadratic	0,05	5,89	2,00	225	0,00	6,33	0,08	0,00	0,00
H _{room}	linear	0,08	19,46	1,00	226	0,00	7,98	-0,07	0,00	0,00
H _{dif}	linear	0,51	235,94	1,00	226	0,00	6,31	0,17	0,00	0,00
H _{dif} /W	linear	0,93	2975,20	1,00	222	0,00	5,09	3,52	0,00	0,00
D/L ₂	cubic	0,06	4,45	3,00	224	0,01	5,82	9,16	-10,90	3,39
L ₁ /L ₂	cubic	0,05	3,69	3,00	224	0,01	5,99	7,60	-9,44	2,94
L _t : L ₁ +L ₂ +L _r	quadratic	0,03	3,89	2,00	225	0,02	6,85	0,04	0,00	0,00
L _{mid} : (L ₂ /2)-(L _r +1,25)	quadratic	0,03	3,48	2,00	225	0,03	7,76	0,00	0,00	0,00

The One-Way ANOVA analysis was applied for the cardinal directions variable. The electricity consumption variance is not statically significant according to the direction of office space fenestration. The table of the One-Way ANOVA analysis provides some very useful descriptive statistics including the mean, standard deviation and 95% confidence intervals for the dependent variable (electricity consumption pro square metre: Wh/m²) for each separate group (East, North, South and West), as well as for all groups combined (see Table 7.6).

Table 7.6 : Descriptive statistics of One-Way ANOVA analysis.

Dependent Variable: kWh/m²

Cardinal direction	Mean	Std. deviation	N
East	7,6784	1,2195	57
North	7,7165	1,0904	57
South	7,6051	1,3149	57
West	7,5932	1,2514	57

The Table 7.7 shows the output of the ANOVA analysis and whether a statistically significant difference between direction means is present. In here, the significance

level is 0,940 ($P=0,940$), which is greater than 0,05, and therefore, there is a statistically not significant difference in the mean electric consumption.

Table 7.7 : Tests of Between-Subjects Effects.

Dependent variable: kWh/m ²					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0,597*	3	0,199	0,133	0,940
Intercept	13337,16	1	13337,16	8934,77	0,00
Cardinal Directions	0,597	3	0,199	0,133	0,940
Error	334,37	224	1,49	-	-
Total	13672,13	228	-	-	-

* $R^2=,002$ / adjusted $R^2 = -0,012$

In this case the most meaningful equation is sought to explain daylight responsive electric energy consumption within the urban context (different height, distance and direction of the reference office space and neighbourhood building).

Linear regression variable selection methods allow for the specification of how independent variables are entered into analysis. To set the linear regression model for this study, a stepwise model was used. At each step, the independent variable not in the equation that has the smallest probability of F is entered, if that probability is sufficiently small. Variables already in the regression are removed if their probability of F becomes sufficiently large. 18 steps in the regression analysis were applied to find the best linear equation. The applied steps can be seen in Appendix C.

SPSS generates tables in its results section for a linear regression. The first table of interest is the Model Summary, which can be seen in Table 7.8. This table provides the R and R^2 -values. The R-value is 0,971, which represents the simple correlation and, therefore, indicates a high degree of correlation. The R^2 -value indicates how much of the dependent variable can be explained by the independent variable. In this case, R^2 is 94,3%.

Table 7.8 : Model Summary.

Model	R	R ²	Adjusted R ²	Std. Error of the Estimate	Change Statistics R ² Change	Durbin-Watson F Change	df1	df2	Sig. F Change
1	0,971	0,943	0,942	0,28862	0,943	725,725	5	218	0,812

a. Predictors: (Constant), (Lr)³, (L1/L2), (Lmid), HDif /W, (Lb)²
b. Dependent Variable: kWh/m²

The next table (Table 7.9), **ANOVA**, indicates that the regression model predicts the outcome variable significantly well. Sig. column indicates the statistical significance of the regression model that was applied. Here, $P < 0,00005$ which is less than 0,05 and indicates that, overall, the model applied is significantly good enough in predicting the outcome variable.

Table 7.9 : ANOVA - the regression model predictions.

Model		Sum of squares	df	Mean square	F	Sigma
1	Regression	302,27	5,00	60,45	725,73	0 ^a
	Residual	18,16	218,00	0,08	-	-
	Total	320,43	223,00	-	-	-

a. Predictors: (Constant), $(L_r)^3$, (L_1/L_2) , (L_{mid}) , H_{Dif}/W , $(L_b)^3$
b. Dependent variable: kWh/m²

The table below (

Table 7.10), Coefficients, provides information on each predictor variable to predict office space electric energy demand (per square metre) from dependent variables such as L_r , L_1/L_2 , L_{mid} , H_{Dif}/W , L_b . Both the constant and incoming variables contribute significantly to the model and can be seen in the Sig. column. By looking at Column B under the Unstandardized Coefficients column, we can present the regression equation as:

$Y = A + B \cdot L_b^2 + C \cdot \frac{H_{dif}}{W} + D \cdot L_{mid}^2 + E \cdot \left(\frac{L_1}{L_2}\right)^3 + F \cdot L_r^3$	(7.1)
--	-------

- A=5,052
- B=0,00009
- C=3,5

- D= -0,000075
- E=0,072
- F= -0,00001

Table 7.10 : Coefficients of Linear Regression model.

Coefficients ^a										
Model	Unstandardized Coefficients		Standardized Coefficients		Sigma	Correlations			Collinearity Statistics	
	B	Std. Error	Beta	t		0-order	Partial	Part	Tolerance	VIF
(Constant)	5,052	0,055	-	91,239	0,000	-	-	-	-	-
$(L_b)^2$	0,000	0,000	0,144	5,332	0,000	-0,100	0,340	0,086	0,356	2,808
H_{Dif}/W	3,504	0,059	0,962	59,106	0,000	0,965	0,970	0,953	0,982	1,018
$(L_{mid})^2$	-0,000	0,000	-0,167	-5,179	0,000	0,000	-0,331	-0,083	0,251	3,980
$(L_1/L_2)^3$	-0,072	0,018	-0,063	-3,895	0,000	-0,086	-0,255	-0,063	0,988	1,012
$(L_r)^3$	-0,000	0,000	-0,232	-5,985	0,000	-0,106	-0,376	-0,097	0,172	5,799

a. Dependent variable: kWh/m²

The regression analysis has suggested that daylight responsive electric energy consumption can be estimated with the proposed equation. The regression equations can be applicable to various sky obstructions caused by neighbourhood buildings and predicted by regression models. Figure 7.15 indicates a strong correlation between simulated and predicted data.

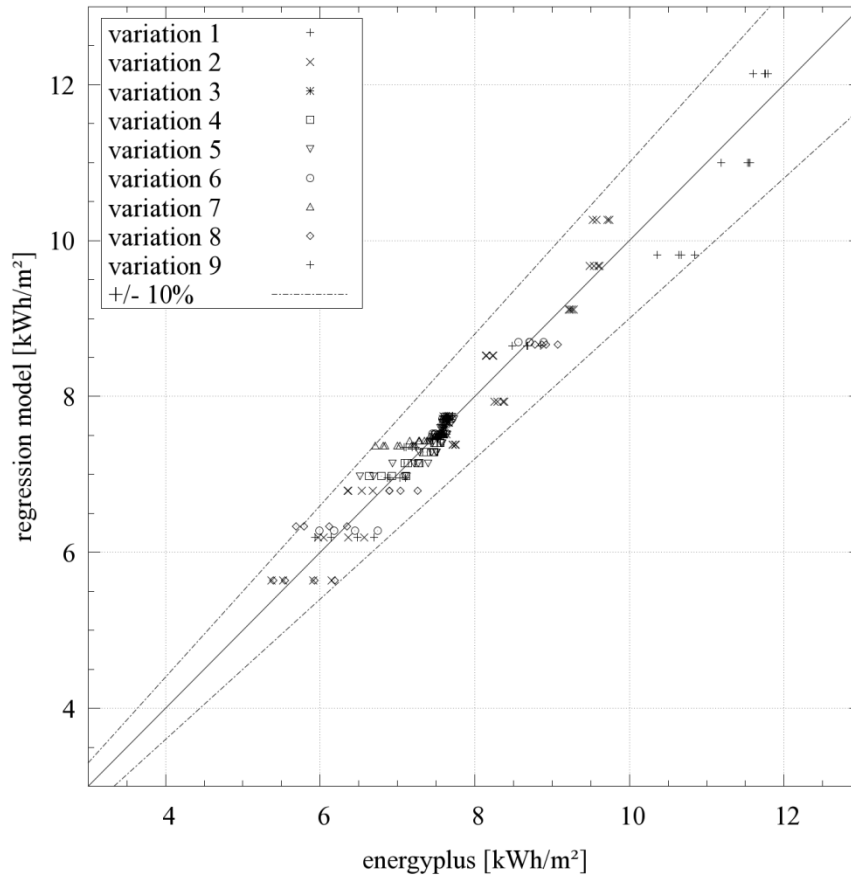


Figure 7.15 : Simulated and predicted daylight responsive electric energy consumption comparison in urban context.

The independent simulation runs to test applicability of the regression model. In this case, the same sample test room was simulated with different urban geometry, a specification that is not defined in existing cases. Obstructing building height is 45 m, distance between buildings in the x direction is 5 m, distance between buildings in the y direction is 20 m and the reference room was located at the entrance floor of the middle building (Figure 7.16). Again, the DRELAT methodology was used for the simulation chain.

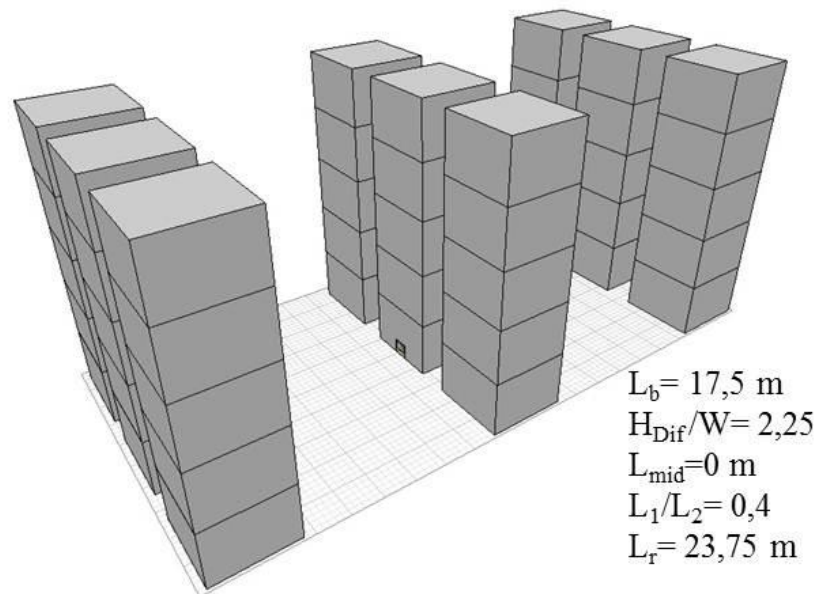


Figure 7.16 : Urban geometry specifications for comparative study.

The simulated and predicted electric energy consumptions were computed to be 14,37 and 12,81 kWh/m², respectively. The difference is 1,5 kWh/m², representing about 10 % of simulated consumption value. It shows that using proposed prediction equations, one can obtain similar simulated results.

7.5 Effects of distance parameters on overall lighting energy demand of sample office building types

Previous analyses were done in order to calculate daylighting responsive electric lighting energy consumption of one single office space in the urban context. For architects and urban planners it is also important to make comparisons and evaluations between all overall building energy demands in urban structure. Within the scope of the thesis, the lighting energy demand of each generic building type was calculated. Descriptions of the generic office buildings were already explained in Section 7.1 and three dimension models can be seen in Figure 7.1.

The electric energy consumption of daylight responsive controlled lighting system was calculated for each single office in each generic office building. The total lighting energy demand of each type of office building is defined the sum of all single office energy demand.

The analysis of simulation results of the sample case model is essential because all subsequent calculations and analyses are based on the methodology behind it. The generic office type 1 was used for the sample case.

7.5.1 Sample case

The office building Type 1 (D- building depth: 12,5 m and L_2 - building length:12,5 m) is located in the middle of the 9 same type buildings which can be define as pavilion type of urban geometric form. All generic office buildings in the urban quarter have same building height as 9 meters with 3 storeys. Dimension between buildings in x direction (L_1) is 5 m and dimension between buildings in y direction (W) is 9 m. The location of the reference building can be seen in Figure 7.17.

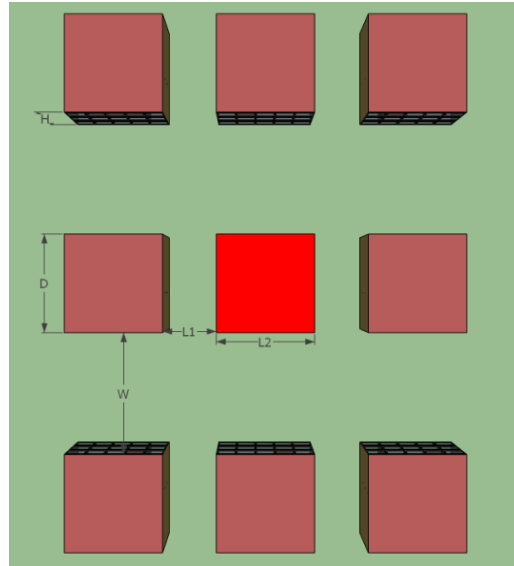


Figure 7.17 : Reference office building (Type 1- red one in the middle-) placement in the urban geometry.

The office Type 1 has 10 single office rooms (the case study office: 2,5m x 2,5m x 5 m) on each floor. Five are located right side of the middle corridor and five of them are located left side of the corridor. In total, there are 30 single offices of Type 1, 15 offices facing one direction and 15 offices facing opposite direction.. In order to arrange the simulations and analyse the results, numbers were given for each single office that faces the same direction (seen Figure 7.18).

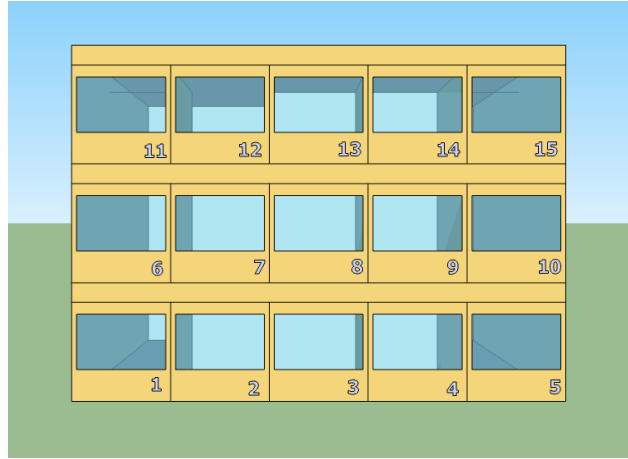


Figure 7.18 : Single office numbers and placement in office type one.

The electric energy demand of each single building was simulated using first the proposed methodology by using Ecotect, Radiance and DRELAT for both north facing and south facing facades. Then, for same single offices, electric energy demand was calculated using the suggested formulation (Equation 7.1). The simulation and calculation results of each office as well as deviation between each other can be seen for north facing offices in Table 7.11 and for the south facing offices in Table 7.12.

Table 7.11 : Lighting energy demand simulation and calculation results of each north facing single offices in building Type 1.

Number of each single offices	Simulation Results (kWh/m2)	Calculation from statistical formulation (kWh/m2)	% Deviation
1	8,69	8,58	1,25
2	8,69	8,58	1,24
3	8,67	8,58	1,01
4	8,66	8,58	0,94
5	8,64	8,57	0,79
6	7,50	7,42	1,14
7	7,51	7,42	1,26
8	7,52	7,42	1,40
9	7,51	7,41	1,31
10	7,50	7,41	1,27
11	6,32	6,22	1,66
12	6,33	6,25	1,28
13	6,33	6,25	1,29
14	6,31	6,25	1,02
15	6,30	6,24	0,98

Table 7.12 : Lighting energy demand simulation and calculation results of each south facing single offices in building Type 1.

Number of each single offices	Simulation Results (kWh/m ²)	Calculation from statistical formulation (kWh/m ²)	% Deviation
1	8,62	8,58	0,44
2	8,62	8,58	0,42
3	8,60	8,58	0,20
4	8,59	8,58	0,12
5	8,57	8,57	-0,03
6	7,43	7,42	0,19
7	7,44	7,42	0,31
8	7,45	7,42	0,46
9	7,44	7,41	0,37
10	7,43	7,41	0,33
11	6,25	6,22	0,53
12	6,26	6,25	0,16
13	6,26	6,25	0,17
14	6,24	6,25	-0,10
15	6,23	6,24	-0,15

In the sample case, the deviation between simulation result and calculation results, which are obtained from statistical formulation, never exceeds 1,5 %. Based on simulation results, the annual total lighting energy demand of the building with daylight control is 223,91 kWh/m². On the other hand, based on statistical formulation, the calculated lighting energy demand of building is 22,34 kWh/m². The deviation between two results is around 0,7 percent. This finding again shows us, instead of making complicated simulations for each single office which is located in the building; the demand can be perfectly estimated with calculation of statistical equation.

Each building type was evaluated in the similar urban structures which have same distances between buildings (L_1 : 5 m and W is 9 m). Visualization of each of the office building types in then urban geometry can be seen in Figure 7.19.

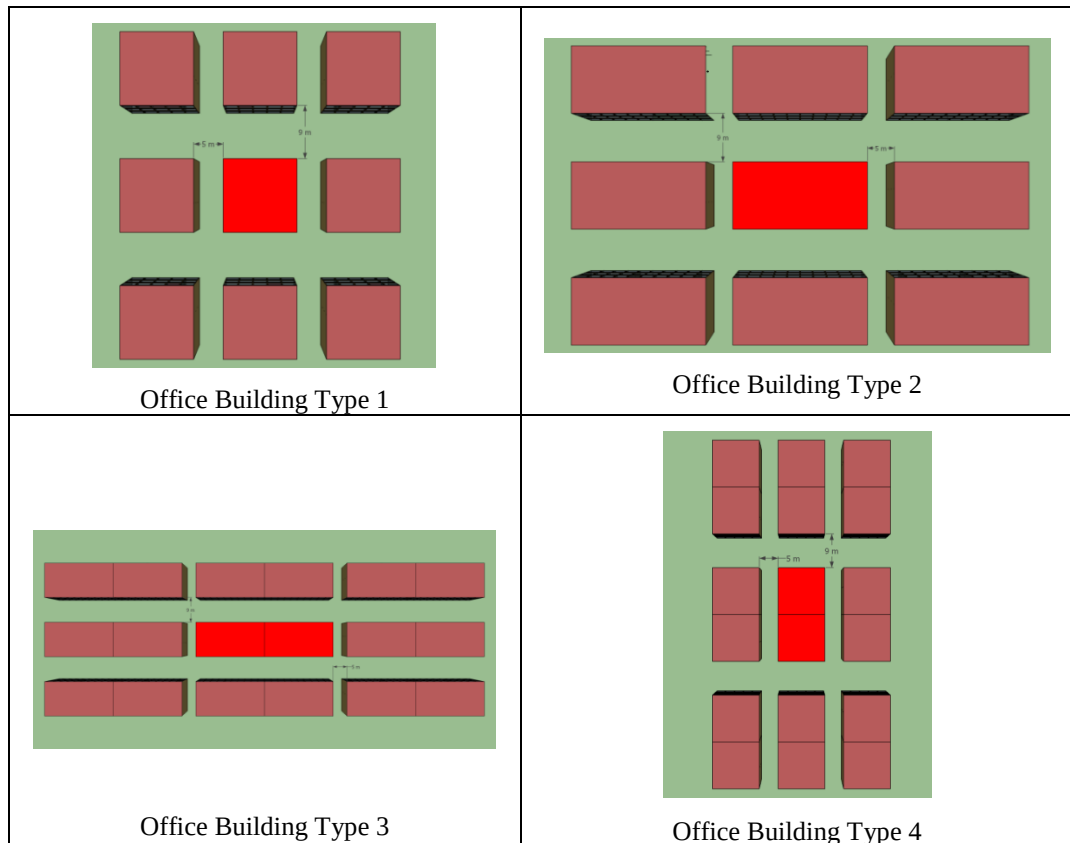


Figure 7.19 : Office building types.

The same simulation and calculation according to the statistical formula was done for each office space in each sample building type. In order to determine lighting energy demand of building in kilowatt-hours per square meter, the energy demand of each office space was multiplied by its area and then the total energy demand in kilowatt-hours was divided by all building area. Also, estimation was suggested here and compared with other determination methods. The suggested estimation methodology offers to take the middle office as a representative office space and calculate all building energy consumption according to this unit. For instance, in building type 1 office number 8 is the representative office for this type of building and is located in the middle storey and middle axis of the building (see Figure 7.19).

The annual lighting energy demand of office building types in kilowatt-hours per square meter were compared between simulation results, calculations according to the statistical formula and estimation from middle-located office. The comparison can be seen in Figure 7.20.

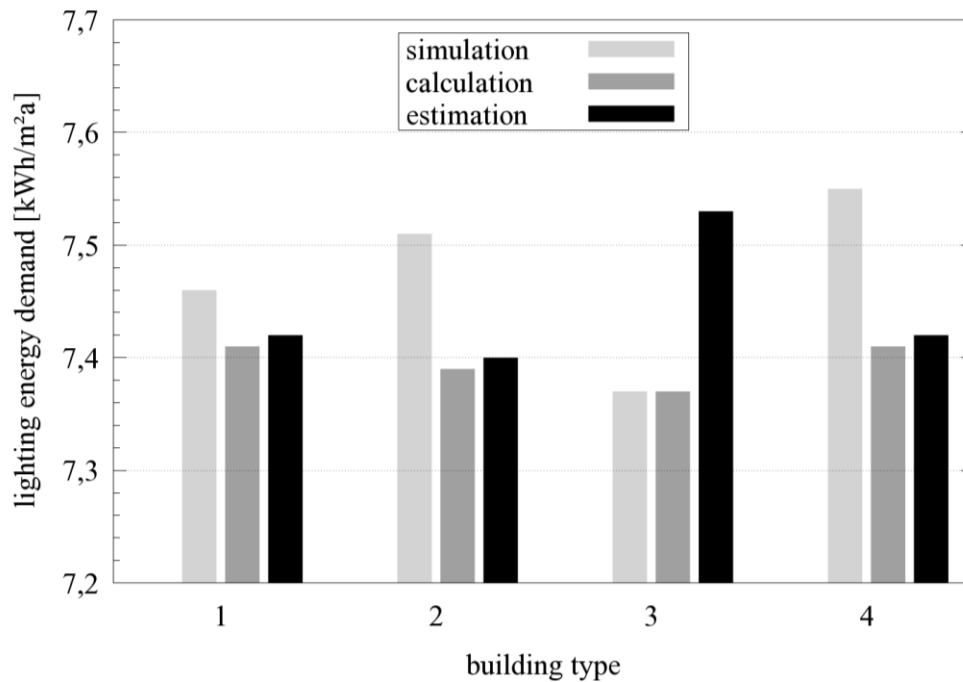


Figure 7.20 : The lighting energy demand of building types comparison between simulation, statistical formula calculation and estimation results.

Three office types (Type 1, Type 3 and Type 4) from Figure four shows, results of the simulations are higher than two other lighting energy demand estimation results. Same office types have good correlation between statistical formula results and estimated results from the middle-located office. For office building Type 1, the highest lighting energy demand was obtained from simulation results with 7,46 kWh/m²a. The calculation result from the statistical formula and the estimation result were almost 0,7 % lower than the simulation results. The building Type 2 and 4 has similar figures like Type 1. In the case of Type 2, estimation and calculation results are approximately 1,5% less than simulation results. For building Type 4 the increase is 1,75%. Sample office building Type 3 has a different character in comparison with results. The estimated lighting energy demand from the middle-located office was much higher than simulated and calculated results. This is caused by the geometrical form of the building. The length of the building Type 2 is long and the middle-located room has minimum daylight availability in the building. Accordingly, the less daylight contribution, the higher the lighting energy demand than seen in other offices which are located different positions in the office building. In this case it is not suitable to estimate the lighting energy demand according to the middle-located office room.

7.5.2 Effect of the building distances on lighting energy demand of building

The distance parameters on lighting energy demand were already evaluated in the sample single office room. Here, the effect of the distance parameters on overall lighting energy demand of each office building types were evaluated and compared with simulation results and calculation results. The effects are compared in 2 distance measures and distance between buildings in x direction (L_1).

7.5.2.1 Effect of the distance between buildings in y direction (W) on lighting energy demand of building

In order to find a relation of the distance between buildings in y direction on daylight responsible electric lighting energy demand of office building, different distance measures were evaluated for each type of office buildings. As it is indicated in Figure 7.21, the lighting demands of the office buildings were calculated in four different H/W ratios. In here H (building height) stays always the same with 9 m, and the distance between buildings in x direction is considered 5m for all cases. The H/W ratios differs as; 0,5, 0,75, 1 and 1,5 which means in this consultation, the distance between building in y direction was changed form 6 m, 9 m, 12 m and 18 m respectively.

The lighting energy demand results of each type of office building is considerably enhanced by H/W ratio in both simulation and calculation outcomes. As seen in the figure, each type of office building lighting energy demand was evaluated in simulation and statistical formula calculation methods. The shading from obstruction buildings causes similar effects for each type buildings in same H/W rations. The unit lighting energy demand per square meter in each type of building has a similar effect under each ratio conditions and is not influenced significantly by the building typology.

All sample office building types have similar lighting energy performance with increasing H/W ratios. The average lighting energy demand of all building types decreased almost 13 % with the chancing of H/W ration from 1,5 to 1. The increase between H/W=1,5 and H/W=0,75 reaches around 20 %. Finally, the difference between highest H/W ration and the lowest one is observed over 27%.

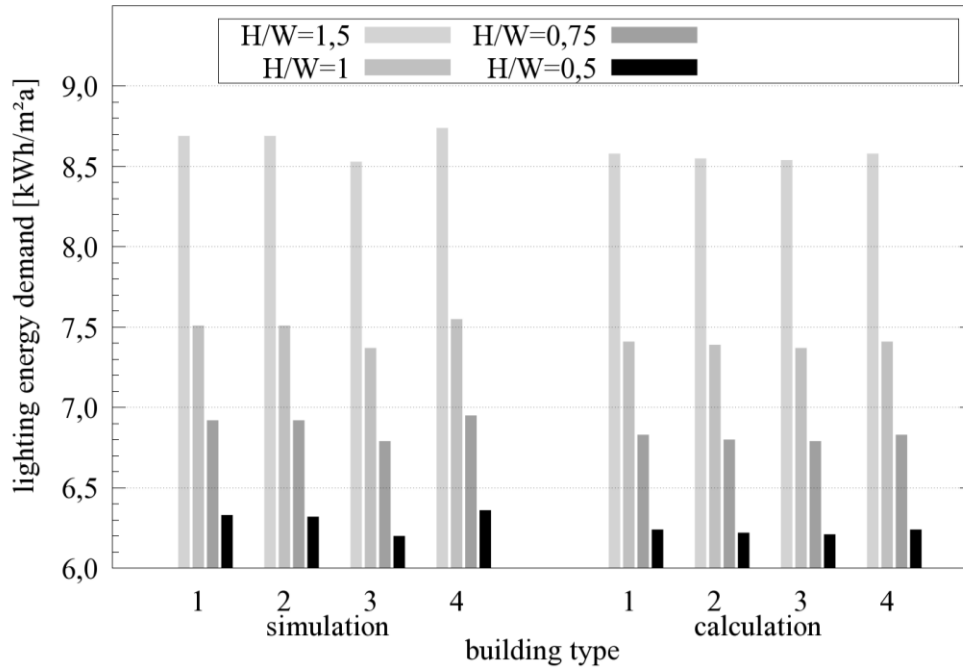


Figure 7.21 : Effect of the distance between buildings in y direction (W) on lighting energy demand of sample office building types (H/W=0,5, 0,75, 1 and 1,5)

The lighting energy demand on building scale again showed that the simplest and most effective way get more daylight is to decrease the H/W ratio. As it is already discussed in section 7.3.1., the urban geometry configuration should be well thought out and the glare problems and discomfort conditions and the design should be done considering those issues.

7.5.2.2 Effect of the spacing distance to the frontal length on lighting energy demand of building

Annual lighting energy demand of each sample office buildings was evaluated at different ratios of L_1/L_2 (L_1 : the distance between building in X direction, L_2 : the frontal length of the sample building). The Figure 7.22 shows the lighting energy demand of each sample office types in four different L_1/L_2 ratios such as; 0,4, 0,8, 1,2 and 1,6. The configuration was set using the same building height (H) of 9 m for each office building and then distance between buildings in y direction (W) was taken as also 9 m for each urban sample geometries. While the building frontal length changed according to the office building type configuration, the L_1 measure also changed in order to get defined L_1/L_2 ratio, which is indicated.

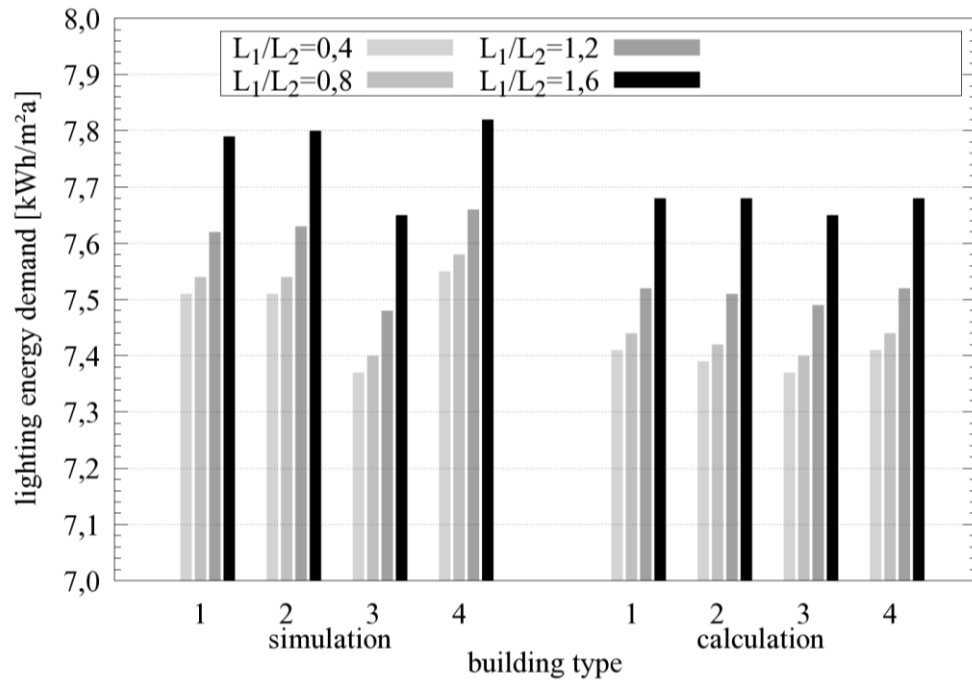


Figure 7.22 : Effect of the spacing distance to the frontal length on lighting energy demand of building ($L_1/L_2= 0,4, 0,8, 1,2$ and $1,6$).

With the higher L_1/L_2 ratio, the lighting energy demands of the all office types are higher. The annual demand increases by almost half percent with increasing of the L_1/L_2 ratio from 0,4 to 0,8 in all cases. The increase is observed just 1 % between the ratios of 0,8 and 1,2. Almost 2 % increase can be obtained by increasing other spacing distance to the frontal length ratio from 1,2 to 1,6. The maximum difference between highest and lowest L_1/L_2 ratios on energy demand never exceeds 4 % in any of building types.

7.5.3 Discussion: Effects of distance parameters on overall lighting energy demand of sample office building types

The results above have some implications for the design of the urban structure that are suited to office buildings, in which the lighting energy demand is fairly important. In the scope of this part of the thesis, the lighting energy performance of sample office building types were examined under changing H/W (H: building height, W: distance between buildings in y direction) ratios and spacing distance to the frontal length ratios (L_1/L_2). By comparison, it is understood that changing the L_1/L_2 ratios has not so much effect on lighting energy demand of office building types. In other words, these buildings cannot achieve their objective, which is to get

benefited from daylight, by decreasing the spacing distance to the frontal length ratios.

Of all urban geometries examined, that with the lowest H/W value performs the best regardless of orientation. Given that the building height is fixed, this implies that increasing the distance between buildings in y direction generally will reduce the daylight responsive electric lighting load in office buildings. The largest distance between buildings in y direction examined here (18 m) achieved an annual lighting energy demand reduction of 27 % were. For these office buildings, there is an advantage to being located in low dense built environments where the shading by other buildings is not effective and by this way the daylight contribution reduces the lighting energy demand of buildings.

Of course the lighting energy performance of the office buildings in a defined urban geometry should not be the only guiding principle for urban design although it may be the dominant concern for thermal energy performance of the building. The energy performance of the building should be examined as whole and in an integrated context.

In summary, this chapter provided a discussion of the simulation results described in previous chapters. Because in reality the urban texture is quite complex and difficult to compute, the definitions and limitations of some archetypes and parameters were provided and explained. In the simulation, the sample space was varied in terms of building type and urban density. Specifically, distance between buildings and aspect ratios were found to have an impact on total energy demand. Statistical analysis was performed to determine which of the variables introduced in the simulation has the greatest influence on the accuracy of the model. A regression analysis was then performed and an equation developed that predicts daylight responsive electric lighting consumption while simultaneously enabling the definition of the variable of distance of the office room from an adjacent building, which is perhaps the most influential parameters affecting the accuracy of the prediction. High coefficients of determination of the proposed regression model showed that daylight responsive electric lighting demand in an urban context can be predicted with high accuracy. Regression analysis also showed that orientation of the building with respect to the cardinal directions and spacing between fenestration were not statistically significant variables in determining the overall electric lighting demand. However, orientation

of the building was found to be statistically significant with regard to heating demand. These findings are likely related to the characteristics of energy source itself. Direct access to sun beams or radiation heat is usually required to heat a building structure and therefore, impact the heating and cooling demand of a building. Illuminance from the sun (daylighting), on the other hand, can be perceived by building occupants and utilised through windows regardless of building orientation and without the need for direct sun beam penetration due to the reflective qualities of the surrounding environment and general illuminance properties of light.

The main aim of regression analysis was to determine as simple as possible model that fits the observed data well enough to calculate the dependent variable (electric lighting demand) so well the results are not due to chance. The ANOVA test applied to the results indicates that the regression model indeed statistically significantly predicts the outcome of the dependent variable. Thus, the results are relevant to engineers and architects because they indicate an alternative to current computer simulation models that is less expensive, less complicated and less time consuming and still provides valid and reliable predictions of daylight responsive electrical energy consumption within the urban context. Because preparing and running simulations tools is usually very complicated, time consuming and costly, the development of the regression equation presented in this thesis is unique in that it is based on both simulation and directly observed results (the test room).

In conclusion, the lighting energy performance of individual single office room is concerned as a basis of overall lighting energy performance determination in defined office building types within several urban geometries. The energy efficiency of urban spaces (such as that of urban quarter consisting of 9 office buildings) can be assessed easily by building scale studied rather than room scale. The study presented in building scale examines the effects of distance parameters on overall lighting energy demand of sample office building types. The results show that for the sample office building types lower the H/W ratios better the annual lighting energy demand of the office buildings. Moreover, the lower spacing distance to the frontal length ratios results better lighting energy performance but not as much as the difference of the H/W ratios. All cases were examined both simulation method and the calculation according to the statistical formula. An estimation method was also suggested and

compared with simulation as and calculation results in order to estimate the lighting energy demand of office building in an urban structure.

To conclude, both room and building scale approaches are useful to designers seeking to create sustainable and energy efficient designs, which speaks directly to the demands of current policy and zoning trends governing energy efficiency and carbon footprints of buildings in the urban sector.

8. CONCLUSIONS

Many aspects of the urban design, from the layout of the roads to the building shape, significantly affect the energy performance of buildings. The lighting electricity demand in office buildings during daytime operation can especially be decreased by the urban design strategy and daylight responsive artificial lighting systems. Therefore, first the possible solar gains for the site design need to be investigated and then building construction and envelope design must be optimised considering these facts.

In the literature review, research on daylight and approaches for estimating daylight, and lighting energy savings from daylight contribution were examined. This review formed a basis to develop the proposed approach and it is useful for other fields of research to accurately calculate the interior daylight illuminance and to determine energy demand with daylight responsive light and shading controls. The findings of previous researches and studies are helpful for architects and engineers to adopt proper daylight schemes in order to improve energy efficiency in buildings, especially office-type designs.

The last decade has seen many advances in dynamic daylight computation. Climate data-based daylighting calculation methodologies, glare studies, visual comfort and energy use analysis must be mentioned in this context.

Dynamic daylight energy consumption prediction has several challenges:

- No homogenous, all-in-one simulation environment exists
- Simulations still require long computational power and time. Many environments are not optimised for multiple core CPUs. Thus, this field cannot fully participate in development
- No full integrated daylight-glare-thermal simulation process exists
- Lack of clear understanding of simulation outcomes

The recently developed computer analysis tools provide relevant information about daylight availability, occupant comfort and illuminance level for indoor spaces.

However, these innovations were obtained through a synergetic interaction of technical and computational expertise.

This study covers the principles of an approach to the elevation of daylight impact and contribution to the energy demand of office buildings in the urban context.

The aim of this research was to develop integrated dynamic daylighting and thermal analysis approach taking into consideration the effects of surrounding buildings. The daylighting evaluation steps were determined using relevant information regarding daylight availability, occupant comfort and energy. Computer-based daylighting analyses simulation results were visualised and prepared as a transferable format for thermal analysis.

Suggested simulation and calculation methodology which is based on single office energy demand, were implemented in order to determine overall daylight responsive electric energy demand determination of different office building types. The effects of the surrounding buildings were also considered in here and adapted in the building scale determinations.

There are many different tools and techniques available that estimate the natural illumination. Some of the most widely used models are based just on overcast sky conditions and some consider just direct sunlight including shading effects.

The information required for all simulation steps are defined. Required information for this purpose can be categorized as:

- building (space) geometry
- surrounding objects (including geometrical and material information)
- material
- thermal zones
- schedules of related building typology
- appliances and occupancy

The proposed approach has some constrains and limitations. For instance, the properties of the office room were the same in each case, while the location of the room in the building and the distance between buildings in the urban quarter changed.

In order to evaluate energy related consequences of a chosen daylight concept, the simulation of daylight should be coordinated with thermal analysis. In the suggested approach, this requires a different definition of the same model. For instance, the building with surroundings was first modelled in 3D using Autodesk Ecotect with all visual specification of the materials. For daylighting simulation on the other hand, Google SketchUp including Open Studio Plug-in, was used. Here, all thermal specifications for EnergyPlus thermal simulation are determined. Occupancy hours, daylight savings and different control modes are applicable to the developed model.

To examine the urban effect on the energy performance, necessary simplifications were applied in the case study. The urban form was limited to three forms (pavilions, slabs and terraces). In order to compute the urban environment, a nine-building city quarter was created, located in Stuttgart, Germany. All cases were examined with related weather conditions. This assumption is considered a sample case for a mild European climate.

The suggested procedure involving different computer simulation techniques was employed to evaluate the energy performance of a sample office space with daylighting controls shaded by neighbourhood buildings. Several studies on shading effects have shown that daylight responsive artificial lighting saves energy. The results presented here support these findings. In order to find a correlation, electricity demand and daylighting sets of simulations were also conducted.

The study has shown that in urban context there exists a strong dependency of illuminance levels and daylight distribution on height of the office space. As a result, noteworthy difference between lowest and upper floors was produced under the same conditions (window size, location, material etc.). If the architects consider those differences during early design stages, then precautions can be taken into consideration.

Sets of simulations were used for the linear regression analysis. The suggested regression model is able to predict daylight responsive electric energy demand of the sample office space in the urban context.

It has been shown that a clear correlation exists between regression model results and the simulation to predict daylight responsive lighting electric energy demand. The energy demands pro square meter can be easily determined in the early design stages

using the suggested linear regression model. The method proposed here can help architects and urban planners evaluate design options by keeping in mind the daylighting availability of the site and its implications on building and urban design.

If solar access is taken into account at the earliest planning stages, it is usually possible to ensure that the majority of buildings on a site are orientated to have good solar access for daylighting and a reduced heating demand. For summer dominated climate conditions, the site design should focus on reducing the cooling load, but the daylighting illuminance level and the electric lighting loads should also be considered.

Suggested methodology can be applicable of different design levels. The advantages and application areas of the methodology are given below.

On room level:

- With the integrated simulation methodology (by using DRELAT) would allow the designer to explore a number of options such as room geometry, material, occupancy or appliances schedules etc.
- The simulation method is not fully integrated nevertheless stress-free to use.
- Artificial lighting system such as artificial luminary efficiency, lamp properties and control mechanism can be defined by designer then simulated and compared for best solution
- The dynamic skies approaches were used for simulation process and in integrated daylight control implementations are sufficient
- All energy system can be included for then balanced energy solutions. Due to interactions between systems especially daylight responsive artificial lighting systems and its thermal effects to the system is realistically considered
- Most essentially, the single office room was considered with its surrounding in order to understand the effects of the shading effects from other buildings. Moreover, the location of the room can be also defined by designer
- With the suggested equation which is a result of statistical calculation, all the simulation procedure was reduced to some coefficient and the distance

parameters to estimate the daylight responsive electric lighting demand of a single office room in the urban context.

On building level:

- The method can be used for whole building energy demand calculation by multiplying the room based process.
- By using the suggested methodology, designer can define the ideal building shape, envelope, size and type of glazing etc. in the early design phase according to the effect of surrounding buildings.
- The location of the building in the urban quarter can be determined by using building energy demand calculation method.

On urban quarter level:

- Energy simulation methodology and statistical calculation based determination can be used at the earliest design of urban settlement to acquire a range of design options and alternative building typologies and forms
- These methods can be also used to evaluate the success of different energy conservations and energy demand reduction measures of an urban quarter
- By using the suggested methodology, designer can define the ideal urban quarter geometry. Such as; distance between buildings, height difference and orientation of the buildings.

In order to minimize energy use, adjusting then illumination and utilize the daylighting, the surrounding of the spaces are essential. The examined cases within thesis indicate that both in room and building scale the most relevant energy performance indicator is aspect ratio which can be define the height difference to the distance between buildings in y direction (H_{dif}/W).

It could be shown that in Stuttgart location and conditions, the sample office space`s heating energy demand increases with H_{dif}/W ratio increase by about 30 %. The daylight responsive electric lighting demand rises 35% with increasing H_{dif}/W ratio. The heating and daylight responsive electric lighting energy demand changes were not so significant with the increase of building depth to the frontal length ratios (D/L_2). By increasing spacing distance to the frontal length ratios (L_1/L_2), the heating

and lighting energy demand increase by almost 5 and 8 % and cooling energy demand decrease by approximately 6%.

When the methodology is applied to room, building or urban quarter energy performance determination, research findings can provide a starting point for measuring how efficiently buildings use energy familiar to the same structure.

This thesis deals with the methodologies to develop an integrated energy demand determination tool for different scales from room level to building and urban quarter level. It is well known that the building analysis is important and the major step for beginning urban analysis.

In Turkey, regulations were harmonized based on EU Energy Performance Directive of Buildings and “Turkish National Building Energy Performance Calculation Methodology (BEP-TR)” is prepared with respect to Turkey's conditions. This calculation method covers, calculating the amount of the energy need for heating and cooling of buildings, lighting energy demand and energy consumption for domestic hot water. The BEP-TR is not a dynamic, integrated methodology. Building energy performances are needed to be handled as an integrated system. Because of that the suggested methodology can also find an application area in Turkey for detailed dynamic building performance analysis.

On the other hand, Turkey has not a building stock database, yet. The certification of the energy category for buildings is not based on the existing buildings characteristic. In order to determine the building typologies and/or make an evaluation in urban quarter the suggested method can be used.

The value of the results also lies in the support of international, national, state and local established goals for designing smarter, more efficiently functioning buildings by refining a design process more in tune with its urban environment. This work, therefore, contributes to the general academic body of knowledge regarding daylighting assessment for building design while also supporting German and EU sustainability goals, along with the Kyoto protocol, for cutting CO₂ emissions, reducing energy demand and increasing efficiency of buildings. The thesis puts forth a missing key component of energy efficient design: a relatively simpler, faster, more holistic design tool compared to existing modelling options and techniques that accurately and more comprehensively predicts daylight responsive electric energy

demand of office buildings considering shading in an urban context. A clear correlation between the regression and the simulation results was demonstrated and the proposed method can help architects and urban planners consider the consequences of the site design with respect to daylighting optimisation.

In some circumstances, the simulation progress can be very complicated and the error messages that are produced by simulation models can be difficult to understand. Users who have no experience may spend much time and effort just computing the model.

The author believes that in the near future, fully integrated simulation programs can be produced through the common work of architects, engineers, building physicians and computer programmers. Many architects and engineering practices consider simulation programs too complicated, costly and time consuming. Outside of the fully integrated detailed simulation tool, there is another need to have simple methods in the forms of simple equations, charts and diagrams for designers and planners. When the different design schemes and concepts are being considered and evaluated, simple equations, diagrams tables and charts that can be easily produced can be very helpful, especially during initial design phase.

In this study, a simple equation was produced as a result of a regression analysis, with some constraints and limitations. In next step, the regression analysis can be designed to account for the limitations of each instrument involved in the analysis. The comparison of the cases can then be shown in a table or chart, which could illustrate energy performance with further accuracy in the urban context.

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APPENDICES

APPENDIX A: EnergyPlus simulation tool input – output options

APPENDIX B: The physical properties of building-materials

APPENDIX C: Model parameters (spread sheet)

APPENDIX D: Statistical analyses

APPENDIX A: EnergyPlus simulation tool input – output options

Table A.1 : Definition, input, simulation and output options of EnergyPlus simulation tool.

DEFINITION	INPUTS	SIMULATIONS	OUTPUTS
LOCATION	Longitude	Energy Analysis And Thermal Load Simulation	Annual building utility performance summary
	Latitude		Total site energy (kWh)
	Orientation		Net site energy (kWh)
	Time zone		Total source energy (kWh)
TIME STEP	Elevation	• Heat balance based calculation	Net source energy (kWh)
	Number of time steps per Hour		Energy per total building area (kwh/m ²)
MATERIALS	Name	• Transient heat conduction calculation	Energy per conditioned building area(kwh/m ²)
	Roughness		Site to source energy conversion factors
	Thickness (m)		Building area
	Conductivity (W/m K)		Total building area (m ²)
	Density (kg/m ³)		Net conditioned building area(m ²)
	Specific Heat (J/kg K)		Unconditioned building area(m ²)
MATERIAL: AIR GAP	Name	• Combined heat and mass transfer model calculation	End uses
	Thermal Resistance (m ² -K/W)		Electricity (kWh)
WINDOW MATERIAL: GLAZING	Name	• Anisotropic sky model for improved calculation of diffuse solar on tilted surfaces	Natural gas (kWh)
	Thickness (m)		Other fuel (kWh)
	Solar Transmittance at Normal Incidence		District cooling (kWh)
	Front Side Solar Reflectance at Normal Incidence		District heating
	Back Side Solar Reflectance at Normal Incidence		Water (m ³)
	Visible Transmittance at Normal Incidence		Utility use per conditioned floor area
	Front Side Visible Reflectance at Normal Incidence		
	Back Side Visible Reflectance at Normal Incidence	• Advanced fenestration calculations	Electricity intensity (mj/m ²)
	Infrared Transmittance at Normal Incidence		Natural gas intensity (mj/m ²)
	Back Side Infrared Hemispherical Emissivity		Other fuel intensity (mj/m ²)
	Conductivity (W/m-K)		District cooling intensity (mj/m ²)
			District heating intensity (mj/m ²)

WINDOW MATERIAL: GAS	Name Gas Type Thickness (m)	Water intensity (m^3/m^2) Utility use per total floor area Envelope
CONSTRUCTION	Name Outside Layer Layer 2 Layer 3, 4...	Window-wall ratio (for each cardinal direction) Gross wall area (m^2) Window opening area (m^2) Window-wall ratio (%)
GLOBAL GEOMETRY RULES: 3D DEFINITION OF BUILDING (ROOM)	Starting Vertex Position Vertex Entry Direction Coordinate System	Skylight-roof ratio Gross roof area (m^2) Skylight area (m^2)
ZONE DEFINITION	Name Direction of Relative North (deg) X,Y,Z (m)	Skylight-roof ratio (%) Opaque exterior results for each constriction element
BUILDING SURFACE: DETAILED	Name Surface Type Construction Name Zone Name Outside Boundary Condition Outside Boundary Condition Object Sun Exposure Wind Exposure View Factor to Ground Number of Vertices X,Y,Z 1 (m) X,Y,Z 2 (m) X,Y,Z 3 (m) X,Y,Z 4 (m)	U-factor ($\text{w}/\text{m}^2\text{-k}$) Reflectance Gross area (m^2) Azimuth (deg) Tilt (deg) Cardinal direction
SHADING: BUILDING: DETAILED	Name Transmittance Schedule Name Number of Vertices	Fenestration results for each window element Area of one opening (m^2) Area of openings (m^2) U-factor ($\text{w}/\text{m}^2\text{-k}$) Shgc (solar heat gain coefficient) Visible transmittance Parent surface Azimuth (deg) Cardinal direction
PEOPLE	Name Zone Name Number of People Schedule Name Number of People Calculation Method Number of People People per Zone Floor Area (person/m^2) Zone Floor Area per Person (m^2/person) Fraction Radiant Sensible Heat Fraction Activity Level Schedule Name	Shading summary Sunlit fraction on each surface: March 21 9am March 21 noon March 21 3pm June 21 9am June 21 noon June 21 3pm December 21 9am December 21 noon December 21 3pm Interior lighting Lighting power density (w/m^2)

	Mean Radiant Temperature Calculation Type Surface Name/Angle Factor List Name Work Efficiency Schedule Name Clothing Insulation Schedule Name	Total power (W) End use subcategory Schedule name Average hours/week (hr)
LIGHTS	Name Zone Name Schedule Name Design Level Calculation Method Lighting Level (W) Watts per Zone Floor Area (W/m ²) Watts per Person (W/person) Return Air Fraction Fraction Radiant Fraction Visible Fraction Replaceable End-Use Subcategory	Conditioned (y/n) Performance Zone summary Area (m ²) Conditioned (y/n) Volume (m ³) Gross wall area (m ²) Window glass area (m ²) Lighting (w/m ²) People (m ²) per person Plug and process (w/m ²) End uses Time of peak
ELECTRIC EQUIPMENT	Name Zone Name Schedule Name Design Level Calculation Method Design Level (W) Watts per Zone Floor Area (W/m ²) Watts per Person (W/person) Fraction Latent Fraction Radiant Fraction Lost	Zone cooling summary Zone/sys sensible cooling rate (maximum)(w Zone/sys sensible cooling rate (timestamp) Outdoor dry bulb (at max/min) (C) Outdoor wet bulb (at max/min) (C) Zone total internal latent gain (kWh) Zone total internal latent gain (maximum)(W) Zone total internal latent gain (timestamp) Outdoor dry bulb (at max/min) (C) Outdoor wet bulb (at max/min) (C)
ZONE INFILTRATION: DESIGN FLOWRATE	Name Zone Name Schedule Name Design Flow Rate Calculation Method Design Flow Rate (m ³ /s) Flow per Zone Floor Area (m ³ /s-m ²) Flow per Exterior Surface Area	Zone heating summary Zone/sys sensible heating energy (kWh) Zone/sys sensible heating rate (maximum)(W) Zone/sys sensible heating rate (timestamp) Outdoor dry bulb (at max/min) (C) Zone electric summary Zone lights electric consumption (kWh)

	(m ³ /s-m ²)	
	Air Changes per Hour	Zone lights electric consumption (maximum)(W)
	Constant Term Coefficient	Zone lights electric consumption (timestamp)
	Temperature Term Coefficient	Zone electric equipment electric consumption (kWh)
	Velocity Term Coefficient	Zone electric equipment electric consumption (maximum)(W)
	Velocity Squared Term Coefficient	Zone electric equipment electric consumption (timestamp)
ZONE CONTROL: THERMOSTAT	Name	Space gains
	Zone Name	Zone people total heat gain (kWh)
	Control Type	Zone lights total heat gain (kWh)
	Schedule Name	
	Control 1 Object Type	Zone electric equipment total heat gain (kWh)
	Control 1 Name	Zone gas equipment total heat gain
	Control 2 Object Type	Zone hot water equipment total heat gain
	Control 2 Name	Zone steam equipment total heat gain
THERMOSTAT SETPOINT: SINGLE HEATING	Name	Zone other equipment total heat gain
	Set point	Zone infiltration sensible heat gain (kWh)
	Temperature	
	Schedule Name	
THERMOSTAT SETPOINT: SINGLE COOLING	Name	Zone infiltration sensible heat loss (kWh)
	Set point	
	Temperature	
	Schedule Name	
ZONE HVAC: IDEAL LOADS AIR SYSTEM	Name	
	Zone Supply Air Node Name	
	Heating Supply Air Temperature (C)	
	Cooling Supply Air Temperature (C)	
	Heating Supply Air Humidity Ratio (kg-H2O/kg-air)	
	Cooling Supply Air Humidity Ratio (kg-H2O/kg-air)	
	Heating Limit	
	Maximum Heating Air Flow Rate (m ³ /s)	
	Cooling Limit	
	Maximum Cooling Air Flow Rate (m ³ /s)	
	Outdoor Air	
	Outdoor Air Flow Rate (m ³ /s)	
ZONE HVAC: EQUIPMENT LIST	Name	
	Zone Equipment 1 Object Type	

	Zone Equipment 1 Name	
	Zone Equipment 1 Cooling Sequence	
	Zone Equipment 1 Heating or No-Load Sequence	
ZONE HVAC: EQUIPMENT CONNECTIONS	Zone Name	
	Zone Conditioning Equipment List Name	
	Zone Air Inlet Node or Node List Name	
	Zone Air Exhaust Node or Node List Name	
	Zone Air Node Name	
	Zone Return Air Node Name	
	Name	
NODE LIST	Node 1 Name	

APPENDIX B: The physical properties of building-materials

This appendix describes the physical properties and configuration for the building envelope and construction elements which are walls, roof, floor and window,

Building element constructions in Energy Plus are defined by the compositions of material layers. Layers are specified by basic thermal and other material property parameters. The most important parameters are thickness, conductivity density and specific heat.

Building envelope elements in the models are; ground floor, exterior roof (flat roof), and external wall.

Figure B1.shows the cross section of the ground floor element which is composed of three layers: Reinforced (150 mm), thermal insulation (110 mm) and flooring screed plate (60 mm).

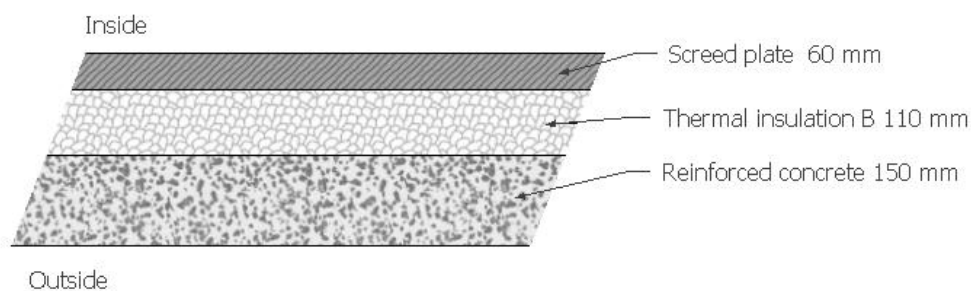


Figure B.1 : Ground floor – cross section.

Exterior roof construction element, Figure B.2, is built from following components: thermal insulation layer (190mm), reinforced concrete (200mm), interior plaster (10mm).

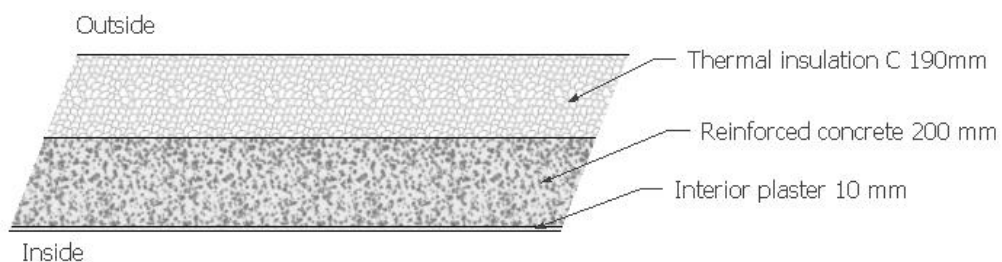


Figure B.2 : Exterior roof – cross section.

External wall, as it can be seen from Figure B.3, is also made from three layers: thermal insulation layer (130mm), limestone block (175mm), interior plaster (15mm) as surface finish.

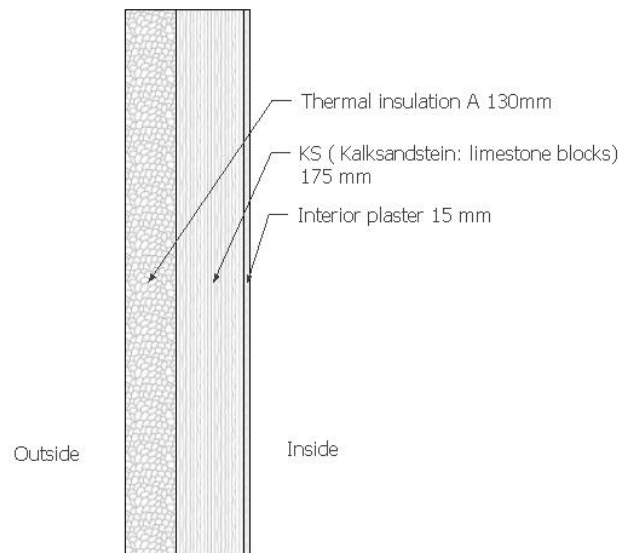


Figure B.3 : External wall – cross section.

In addition to three building envelope elements, the interior wall has to be defined. Interior walls were composed of two gypsum plasterboard (each 19mm thick) separated by 10mm air gap.

The most important properties of materials used to define building elements, are presented in Table B.1

Table B.1 : Material properties.

Material	Conductivity [W/m·K]	Density [kg/m ³]	Specific Heat [J/kg·K]
Reinforced concrete 150 mm	2,5	2400	1000
Thermal insulation B 110 mm	0,04	30	1220
Screed plate 60 mm	1,4	2400	840
Thermal insulation A 130mm	0,04	30	1220
KS (Kalksandstein: limestone blocks) 175 mm	0,83	1500	880
Interior plaster 15 mm	0,55	1800	840
G01a 19mm gypsum board	0,16	800	1090
Thermal insulation C 190mm	0,04	30	1220
Reinforced concrete 200 mm	2,5	2400	1000
Interior plaster 10 mm	0,55	1800	840
M11 100mm lightweight concrete	0,53	1280	840
F16 Acoustic tile	0,06	368	590

Air layer in the external wall element and the air gap in the interior partition are assumed to be materials with no mass and they are defined by specifying thermal

resistance only, which was set to 0.18 m²·K/W for the former and 0.15 m²·K/W for the later. The properties can be seen in Table B.2

Table B.2 : Thermal resistance properties.

Thermal Resistance[m ² ·K/W]	
F04 Wall air space resistance	0,15
F05 Ceiling air space resistance	0,18

Similar to opaque building elements, fenestration was also defined in EnergyPlus by the composition of several layers. Cross section of all glazing units can be seen in Figure A.4. The double glazed unit was made from 3 mm low emissivity glass pane (outside facing) and 6 mm clear galls pane. The cavity between two panes was 13 mm depth and the cavity was filed xenon gas.

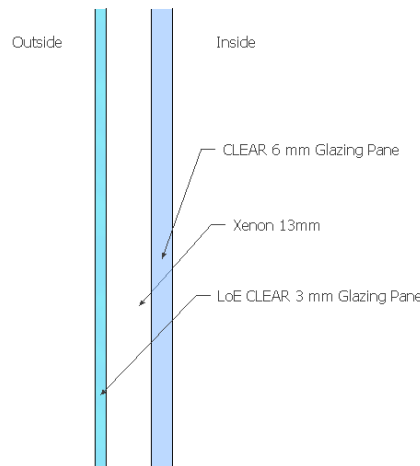


Figure B.4 : Glazing – cross section.

Properties of glazing panes used for windows in this research are presented in Table B.3. Terms “Front Side” and “Back Side” are used for the side of the layer opposite the zone in which the window is defined and the side closest to the zone respectively. This means that for exterior windows, “front side” is the side closest to the outdoors.

Table B.3 : Glazing pane properties.

	Glazing pane properties	
	LoE CLEAR 3MM Glazing Pane	CLEAR 6MM Glazing Pane
Thickness	3 mm	6 mm
Solar Transmittance at Normal Incidence	0,63	0,775
Front Side Solar Reflectance at Normal Incidence	0,22	0,071
Back Side Solar Reflectance at Normal Incidence	0,19	0,071
Visible Transmittance at Normal Incidence	0,85	0,881
Front Side Visible Reflectance at Normal Incidence	0,079	0,08
Back Side Visible Reflectance at Normal Incidence	0,056	0,08
Infrared Transmittance at Normal Incidence	0	0
Front Side Infrared Hemispherical Emissivity	0,1	0,84
Back Side Infrared Hemispherical Emissivity	0,84	0,84
Conductivity [W/m·K]	0,9	0,9

APPENDIX C: Model parameters (spread sheet)

Table C.1 : Model Parameters.

#	case	site coverage	Orientation (E:1/N:2/S:3/W:4)	H Height sur. buildings [m]	W: y spacing [m]	D: Building depth [m]	L1: x spacing between units [m]	L2: Building width [m]	Lx [m]	Wb=(D+W) [m]	Lb=(L1+L2) [m]	Hroom [m]	Hair [m]	Hbair/W	D/L2	L1/L2	Lr=(L1+L2+Lr) [m]	Lamb=[(L2/2)- (Lr+1,25)]	consumption [kWh]	consumption [kWh/m ²] (simulation)	consumption [kWh/m ²] (polynomial)
1	case 1 east	53,34	1	9,0	9,0	12,5	5,0	12,5	5,0	21,5	17,5	3,0	6,0	0,67	1,00	0,4	22,5	0,0	93,0	7,0	7,0
2	case 1 north	53,34	2	9,0	9,0	12,5	5,0	12,5	5,0	21,5	17,5	3,0	6,0	0,67	1,00	0,4	22,5	0,0	94,0	7,5	7,0
3	case 1 south	53,34	3	9,0	9,0	12,5	5,0	12,5	5,0	21,5	17,5	3,0	6,0	0,67	1,00	0,4	22,5	0,0	93,2	7,0	7,0
4	case 1 west	53,34	4	9,0	9,0	12,5	5,0	12,5	5,0	21,5	17,5	3,0	6,0	0,67	1,00	0,4	22,5	0,0	92,9	7,0	7,0
5	case 2 east	59,62	1	9,0	6,0	12,5	5,0	12,5	5,0	18,5	17,5	3,0	6,0	1,00	1,00	0,4	22,5	0,0	108,0	8,0	8,0
6	case 2 north	59,62	2	9,0	6,0	12,5	5,0	12,5	5,0	18,5	17,5	3,0	6,0	1,00	1,00	0,4	22,5	0,0	106,0	8,0	8,0
7	case 2 south	59,62	3	9,0	6,0	12,5	5,0	12,5	5,0	18,5	17,5	3,0	6,0	1,00	1,00	0,4	22,5	0,0	110,0	8,0	8,0
8	case 2 west	59,62	4	9,0	6,0	12,5	5,0	12,5	5,0	18,5	17,5	3,0	6,0	1,00	1,00	0,4	22,5	0,0	108,5	8,0	8,0
9	case 3 east	40,28	1	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	3,0	6,0	0,33	1,00	0,4	22,5	0,0	80,0	6,0	6,0
10	case 3 north	40,28	2	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	3,0	6,0	0,33	1,00	0,4	22,5	0,0	83,0	6,0	6,0
11	case 3 south	40,28	3	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	3,0	6,0	0,33	1,00	0,4	22,5	0,0	74,0	5,0	6,0
12	case 3 west	40,28	4	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	3,0	6,0	0,33	1,00	0,4	22,5	0,0	76,7	6,0	6,0
13	case 4 east	53,34	1	9,0	9,0	12,5	10,0	25,0	11,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	46,3	0,0	95,1	7,0	7,0
14	case 4 north	53,34	2	9,0	9,0	12,5	10,0	25,0	11,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	46,3	0,0	94,0	7,0	7,0
15	case 4 south	53,34	3	9,0	9,0	12,5	10,0	25,0	11,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	46,3	0,0	95,0	7,0	7,0
16	case 4 west	53,34	4	9,0	9,0	12,5	10,0	25,0	11,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	46,3	0,0	94,3	7,0	7,0
17	case 5 east	53,34	1	9,0	9,0	12,5	20,0	50,0	23,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	93,8	0,0	95,8	7,0	7,0
18	case 5 north	53,34	2	9,0	9,0	12,5	20,0	50,0	23,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	93,8	0,0	95,5	7,0	7,0
19	case 5 south	53,34	3	9,0	9,0	12,5	20,0	50,0	23,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	93,8	0,0	96,4	7,0	7,0
20	case 5 west	53,34	4	9,0	9,0	12,5	20,0	50,0	23,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	93,8	0,0	95,0	7,0	7,0
21	case 6 east	40,54	1	9,0	9,0	12,5	12,5	12,5	5,0	21,5	25,0	3,0	6,0	0,67	1,00	1,0	30,0	0,0	89,9	7,0	7,0
22	case 6 north	40,54	2	9,0	9,0	12,5	12,5	12,5	5,0	21,5	25,0	3,0	6,0	0,67	1,00	1,0	30,0	0,0	90,5	7,0	7,0
23	case 6 south	40,54	3	9,0	9,0	12,5	12,5	12,5	5,0	21,5	25,0	3,0	6,0	0,67	1,00	1,0	30,0	0,0	88,9	7,0	7,0
24	case 6 west	40,54	4	9,0	9,0	12,5	12,5	12,5	5,0	21,5	25,0	3,0	6,0	0,67	1,00	1,0	30,0	0,0	88,0	7,0	7,0
25	case 7 east	28,96	1	9,0	9,0	12,5	25,0	12,5	5,0	21,5	37,5	3,0	6,0	0,67	1,00	2,0	42,5	0,0	87,9	7,0	6,0
26	case 7 north	28,96	2	9,0	9,0	12,5	25,0	12,5	5,0	21,5	37,5	3,0	6,0	0,67	1,00	2,0	42,5	0,0	88,8	7,0	6,0
27	case 7 south	28,96	3	9,0	9,0	12,5	25,0	12,5	5,0	21,5	37,5	3,0	6,0	0,67	1,00	2,0	42,5	0,0	85,9	6,0	6,0
28	case 7 west	28,96	4	9,0	9,0	12,5	25,0	12,5	5,0	21,5	37,5	3,0	6,0	0,67	1,00	2,0	42,5	0,0	86,3	6,9	6,0

Table C.1 (Continued)

29	case tek east	-	1	0,0	0,0	12,5	0,0	12,5	5,0	12,5	12,5	0,0	0,0	-	1,00	0,0	17,5	0,0	65,3	5,0	-
30	case tek north	-	2	0,0	0,0	12,5	0,0	12,5	5,0	12,5	12,5	0,0	0,0	-	1,00	0,0	17,5	0,0	75,8	6,0	-
31	case tek south	-	3	0,0	0,0	12,5	0,0	12,5	5,0	12,5	12,5	0,0	0,0	-	1,00	0,0	17,5	0,0	68,9	5,0	-
32	case tek west	-	4	0,0	0,0	12,5	0,0	12,5	5,0	12,5	12,5	0,0	0,0	-	1,00	0,0	17,5	0,0	81,1	6,0	-
33	case 8 east 1	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	0,0	27,0	1,50	1,00	0,4	22,5	0,0	121,4	9,0	10,0
34	case 8 north 1	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	0,0	27,0	1,50	1,00	0,4	22,5	0,0	121,8	9,0	10,0
35	case 8 south 1	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	0,0	27,0	1,50	1,00	0,4	22,5	0,0	119,1	9,0	10,0
36	case 8 west 1	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	0,0	27,0	1,50	1,00	0,4	22,5	0,0	119,0	9,0	10,0
37	case 8 east 2	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	3,0	24,0	1,33	1,00	0,4	22,5	0,0	120,0	9,0	9,0
38	case 8 north 2	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	3,0	24,0	1,33	1,00	0,4	22,5	0,0	120,0	9,0	9,0
39	case 8 south 2	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	3,0	24,0	1,33	1,00	0,4	22,5	0,0	118,5	9,0	9,0
40	case 8 west 2	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	3,0	24,0	1,33	1,00	0,4	22,5	0,0	119,3	9,0	9,0
41	case 8 east 3	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	6,0	21,0	1,17	1,00	0,4	22,5	0,0	116,0	9,0	9,0
42	case 8 north 3	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	6,0	21,0	1,17	1,00	0,4	22,5	0,0	115,0	9,0	9,0
43	case 8 south 3	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	6,0	21,0	1,17	1,00	0,4	22,5	0,0	115,0	9,0	9,0
44	case 8 west 3	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	6,0	21,0	1,17	1,00	0,4	22,5	0,0	115,0	9,0	9,0
45	case 8 east 4	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	9,0	18,0	1,00	1,00	0,4	22,5	0,0	102,9	8,0	8,0
46	case 8 north 4	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	9,0	18,0	1,00	1,00	0,4	22,5	0,0	103,0	8,2	8,0
47	case 8 south 4	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	9,0	18,0	1,00	1,00	0,4	22,5	0,0	101,0	8,0	8,0
48	case 8 west 4	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	9,0	18,0	1,00	1,00	0,4	22,5	0,0	101,9	8,0	8,0
49	case 8 east 5	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	12,0	15,0	0,83	1,00	0,4	22,5	0,0	104,5	8,0	7,0
50	case 8 north 5	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	12,0	15,0	0,83	1,00	0,4	22,5	0,0	103,7	8,0	7,0
51	case 8 south 5	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	12,0	15,0	0,83	1,00	0,4	22,5	0,0	104,7	8,0	7,0
52	case 8 west 5	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	12,0	15,0	0,83	1,00	0,4	22,5	0,0	103,0	8,0	7,0
53	case 8 east 6	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	15,0	12,0	0,67	1,00	0,4	22,5	0,0	96,0	7,0	7,0
54	case 8 north 6	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	15,0	12,0	0,67	1,00	0,4	22,5	0,0	97,0	7,0	7,0
55	case 8 south 6	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	15,0	12,0	0,67	1,00	0,4	22,5	0,0	96,4	7,0	7,0
56	case 8 west 6	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	15,0	12,0	0,67	1,00	0,4	22,5	0,0	96,4	7,0	7,0
57	case 8 east 7	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	18,0	9,0	0,50	1,00	0,4	22,5	0,0	81,7	6,0	6,0
58	case 8 north 7	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	18,0	9,0	0,50	1,00	0,4	22,5	0,0	83,6	6,0	6,0
59	case 8 south 7	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	18,0	9,0	0,50	1,00	0,4	22,5	0,0	79,4	6,4	6,0
60	case 8 west 7	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	18,0	9,0	0,50	1,00	0,4	22,5	0,0	79,0	6,0	6,0
61	case 8 east 8	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	21,0	6,0	0,33	1,00	0,4	22,5	0,0	79,0	6,0	6,0
62	case 8 north 8	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	21,0	6,0	0,33	1,00	0,4	22,5	0,0	82,1	6,0	6,0
63	case 8 south 8	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	21,0	6,0	0,33	1,00	0,4	22,5	0,0	74,7	5,0	6,0

Table C.1 (Continued)

64	case 8 west 8	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	21,0	6,0	0,33	1,00	0,4	22,5	0,0	75,0	6,0	6,0
65	case 8 east 9	40,28	1	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	24,0	3,0	0,17	1,00	0,4	22,5	0,0	73,0	5,0	5,0
66	case 8 north 9	40,28	2	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	24,0	3,0	0,17	1,00	0,4	22,5	0,0	76,0	6,0	5,0
67	case 8 south 9	40,28	3	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	24,0	3,0	0,17	1,00	0,4	22,5	0,0	67,0	5,0	5,0
68	case 8 west 9	40,28	4	27,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	24,0	3,0	0,17	1,00	0,4	22,5	0,0	68,0	5,0	5,0
69	case5E2125	53,34	1	9,0	9,0	12,5	20,0	50,0	21,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	91,3	2,5	95,7	7,0	7,0
70	case5N2125	53,34	2	9,0	9,0	12,5	20,0	50,0	21,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	91,3	2,5	95,5	7,0	7,0
71	case5S2125	53,34	3	9,0	9,0	12,5	20,0	50,0	21,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	91,3	2,5	95,8	7,0	7,0
72	case5W2125	53,34	4	9,0	9,0	12,5	20,0	50,0	21,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	91,3	2,5	94,9	7,0	7,0
73	case5E1875	53,34	1	9,0	9,0	12,5	20,0	50,0	18,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	88,8	5,0	95,0	7,0	7,0
74	case5N1875	53,34	2	9,0	9,0	12,5	20,0	50,0	18,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	88,8	5,0	95,3	7,0	7,0
75	case5S1875	53,34	3	9,0	9,0	12,5	20,0	50,0	18,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	88,8	5,0	96,0	7,7	7,0
76	case5W1875	53,34	4	9,0	9,0	12,5	20,0	50,0	18,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	88,8	5,0	94,9	7,6	7,0
77	case5E1625	53,34	1	9,0	9,0	12,5	20,0	50,0	16,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	86,3	7,5	95,5	7,0	7,0
78	case5N1625	53,34	2	9,0	9,0	12,5	20,0	50,0	16,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	86,3	7,5	95,6	7,0	7,0
79	case5S1625	53,34	3	9,0	9,0	12,5	20,0	50,0	16,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	86,3	7,5	95,9	7,0	7,0
80	case5W1625	53,34	4	9,0	9,0	12,5	20,0	50,0	16,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	86,3	7,5	94,8	7,0	7,0
81	case5E1375	53,34	1	9,0	9,0	12,5	20,0	50,0	13,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	83,8	10,0	95,4	7,6	7,0
82	case5N1375	53,34	2	9,0	9,0	12,5	20,0	50,0	13,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	83,8	10,0	94,8	7,0	7,0
83	case5S1375	53,34	3	9,0	9,0	12,5	20,0	50,0	13,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	83,8	10,0	95,0	7,0	7,0
84	case5W1375	53,34	4	9,0	9,0	12,5	20,0	50,0	13,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	83,8	10,0	94,7	7,0	7,0
85	case5E1125	53,34	1	9,0	9,0	12,5	20,0	50,0	11,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	81,3	12,5	94,6	7,0	7,0
86	case5N1125	53,34	2	9,0	9,0	12,5	20,0	50,0	11,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	81,3	12,5	95,0	7,0	7,0
87	case5S1125	53,34	3	9,0	9,0	12,5	20,0	50,0	11,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	81,3	12,5	95,5	7,0	7,0
88	case5W1125	53,34	4	9,0	9,0	12,5	20,0	50,0	11,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	81,3	12,5	94,6	7,0	7,0
89	case5E875	53,34	1	9,0	9,0	12,5	20,0	50,0	8,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	78,8	15,0	93,4	7,0	7,0
90	case5N875	53,34	2	9,0	9,0	12,5	20,0	50,0	8,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	78,8	15,0	94,4	7,0	7,0
91	case5S875	53,34	3	9,0	9,0	12,5	20,0	50,0	8,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	78,8	15,0	94,4	7,0	7,0
92	case5W875	53,34	4	9,0	9,0	12,5	20,0	50,0	8,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	78,8	15,0	93,9	7,0	7,0
93	case5E625	53,34	1	9,0	9,0	12,5	20,0	50,0	6,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	76,3	17,5	91,0	7,0	7,0
94	case5N625	53,34	2	9,0	9,0	12,5	20,0	50,0	6,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	76,3	17,5	93,4	7,0	7,0
95	case5S625	53,34	3	9,0	9,0	12,5	20,0	50,0	6,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	76,3	17,5	92,2	7,0	7,0
96	case5W625	53,34	4	9,0	9,0	12,5	20,0	50,0	6,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	76,3	17,5	93,4	7,0	7,0
97	case5E375	53,34	1	9,0	9,0	12,5	20,0	50,0	3,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	73,8	20,0	89,2	7,0	7,0
98	case5N375	53,34	2	9,0	9,0	12,5	20,0	50,0	3,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	73,8	20,0	91,1	7,0	7,0

Table C.1 (Continued)

99 case5S375	53,34	3	9,0	9,0	12,5	20,0	50,0	3,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	73,8	20,0	88,0	7,0	7,0
100 case5W375	53,34	4	9,0	9,0	12,5	20,0	50,0	3,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	73,8	20,0	90,0	7,0	7,0
101 case5E125	53,34	1	9,0	9,0	12,5	20,0	50,0	1,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	71,3	22,5	84,9	6,0	6,0
102 case5N125	53,34	2	9,0	9,0	12,5	20,0	50,0	1,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	71,3	22,5	88,0	7,0	6,0
103 case5S125	53,34	3	9,0	9,0	12,5	20,0	50,0	1,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	71,3	22,5	82,0	6,0	6,0
104 case5W125	53,34	4	9,0	9,0	12,5	20,0	50,0	1,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	71,3	22,5	86,6	6,0	6,0
105 case5E2625	53,34	1	9,0	9,0	12,5	20,0	50,0	26,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	96,3	-2,5	95,8	7,0	7,0
106 case5N2625	53,34	2	9,0	9,0	12,5	20,0	50,0	26,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	96,3	-2,5	96,1	7,0	7,0
107 case5S2625	53,34	3	9,0	9,0	12,5	20,0	50,0	26,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	96,3	-2,5	96,4	7,0	7,0
108 case5W2625	53,34	4	9,0	9,0	12,5	20,0	50,0	26,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	96,3	-2,5	95,1	7,0	7,0
109 case5E2875	53,34	1	9,0	9,0	12,5	20,0	50,0	28,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	98,8	-5,0	95,5	7,0	7,0
110 case5N2875	53,34	2	9,0	9,0	12,5	20,0	50,0	28,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	98,8	-5,0	95,5	7,0	7,0
111 case5S2875	53,34	3	9,0	9,0	12,5	20,0	50,0	28,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	98,8	-5,0	96,6	7,0	7,0
112 case5W2875	53,34	4	9,0	9,0	12,5	20,0	50,0	28,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	98,8	-5,0	95,1	7,0	7,0
113 case5E3125	53,34	1	9,0	9,0	12,5	20,0	50,0	31,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	101,3	-7,5	95,4	7,0	7,0
114 case5N3125	53,34	2	9,0	9,0	12,5	20,0	50,0	31,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	101,3	-7,5	95,0	7,0	7,0
115 case5S3125	53,34	3	9,0	9,0	12,5	20,0	50,0	31,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	101,3	-7,5	96,2	7,0	7,0
116 case5W3125	53,34	4	9,0	9,0	12,5	20,0	50,0	31,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	101,3	-7,5	94,8	7,0	7,0
117 case5E3375	53,34	1	9,0	9,0	12,5	20,0	50,0	33,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	103,8	-10,0	94,8	7,0	7,0
118 case5N3375	53,34	2	9,0	9,0	12,5	20,0	50,0	33,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	103,8	-10,0	95,1	7,0	7,0
119 case5S3375	53,34	3	9,0	9,0	12,5	20,0	50,0	33,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	103,8	-10,0	94,4	7,0	7,0
120 case5W3375	53,34	4	9,0	9,0	12,5	20,0	50,0	33,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	103,8	-10,0	94,6	7,0	7,0
121 case5E3625	53,34	1	9,0	9,0	12,5	20,0	50,0	36,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	106,3	-12,5	95,0	7,0	7,0
122 case5N3625	53,34	2	9,0	9,0	12,5	20,0	50,0	36,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	106,3	-12,5	94,9	7,0	7,0
123 case5S3625	53,34	3	9,0	9,0	12,5	20,0	50,0	36,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	106,3	-12,5	95,5	7,0	7,0
124 case5W3625	53,34	4	9,0	9,0	12,5	20,0	50,0	36,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	106,3	-12,5	93,5	7,0	7,0
125 case5E3875	53,34	1	9,0	9,0	12,5	20,0	50,0	38,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	108,8	-15,0	94,0	7,0	7,0
126 case5N3875	53,34	2	9,0	9,0	12,5	20,0	50,0	38,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	108,8	-15,0	94,8	7,0	7,0
127 case5S3875	53,34	3	9,0	9,0	12,5	20,0	50,0	38,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	108,8	-15,0	94,8	7,6	7,0
128 case5W3875	53,34	4	9,0	9,0	12,5	20,0	50,0	38,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	108,8	-15,0	93,2	7,0	7,0
129 case5E4125	53,34	1	9,0	9,0	12,5	20,0	50,0	41,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	111,3	-17,5	93,9	7,0	7,0
130 case5N4125	53,34	2	9,0	9,0	12,5	20,0	50,0	41,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	111,3	-17,5	93,0	7,0	7,0
131 case5S4125	53,34	3	9,0	9,0	12,5	20,0	50,0	41,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	111,3	-17,5	93,8	7,5	7,0
132 case5W4125	53,34	4	9,0	9,0	12,5	20,0	50,0	41,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	111,3	-17,5	91,0	7,0	7,0
133 case5E4375	53,34	1	9,0	9,0	12,5	20,0	50,0	43,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	113,8	-20,0	92,4	7,0	7,0

Table C.1 (Continued)

134 case5N4375	53,34	2	9,0	9,0	12,5	20,0	50,0	43,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	113,8	-20,0	90,9	7,0	7,0
135 case5S4375	53,34	3	9,0	9,0	12,5	20,0	50,0	43,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	113,8	-20,0	90,2	7,0	7,0
136 case5W4375	53,34	4	9,0	9,0	12,5	20,0	50,0	43,8	21,5	70,0	3,0	6,0	0,67	0,25	0,4	113,8	-20,0	86,0	6,0	7,0
137 case5E4625	53,34	1	9,0	9,0	12,5	20,0	50,0	46,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	116,3	-22,5	88,9	7,0	6,0
138 case5N4625	53,34	2	9,0	9,0	12,5	20,0	50,0	46,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	116,3	-22,5	88,7	7,0	6,0
139 case5S4625	53,34	3	9,0	9,0	12,5	20,0	50,0	46,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	116,3	-22,5	83,7	6,0	6,0
140 case5W4625	53,34	4	9,0	9,0	12,5	20,0	50,0	46,3	21,5	70,0	3,0	6,0	0,67	0,25	0,4	116,3	-22,5	81,0	6,0	6,0
141 case4_5E	59,00	1	9,0	9,0	12,5	10,0	50,0	23,8	21,5	60,0	3,0	6,0	0,67	0,25	0,2	83,8	0,0	95,4	7,0	7,0
142 case4_5N	59,00	2	9,0	9,0	12,5	10,0	50,0	23,8	21,5	60,0	3,0	6,0	0,67	0,25	0,2	83,8	0,0	95,1	7,6	7,0
143 case4_5S	59,00	3	9,0	9,0	12,5	10,0	50,0	23,8	21,5	60,0	3,0	6,0	0,67	0,25	0,2	83,8	0,0	96,4	7,0	7,0
144 case4_5W	59,00	4	9,0	9,0	12,5	10,0	50,0	23,8	21,5	60,0	3,0	6,0	0,67	0,25	0,2	83,8	0,0	94,7	7,0	7,0
145 case9E	63,00	1	9,0	9,0	25,0	5,0	12,5	5,0	34,0	17,5	3,0	6,0	0,67	2,00	0,4	22,5	0,0	93,6	7,0	7,0
146 case9N	63,00	2	9,0	9,0	25,0	5,0	12,5	5,0	34,0	17,5	3,0	6,0	0,67	2,00	0,4	22,5	0,0	94,4	7,0	7,0
147 case9S	63,00	3	9,0	9,0	25,0	5,0	12,5	5,0	34,0	17,5	3,0	6,0	0,67	2,00	0,4	22,5	0,0	93,0	7,0	7,0
148 case9W	63,00	4	9,0	9,0	25,0	5,0	12,5	5,0	34,0	17,5	3,0	6,0	0,67	2,00	0,4	22,5	0,0	93,1	7,0	7,0
149 case10E	68,00	1	9,0	6,0	25,0	5,0	12,5	5,0	31,0	17,5	3,0	6,0	1,00	2,00	0,4	22,5	0,0	108,8	8,0	8,0
150 case10N	68,00	2	9,0	6,0	25,0	5,0	12,5	5,0	31,0	17,5	3,0	6,0	1,00	2,00	0,4	22,5	0,0	107,0	8,0	8,0
151 case10S	68,00	3	9,0	6,0	25,0	5,0	12,5	5,0	31,0	17,5	3,0	6,0	1,00	2,00	0,4	22,5	0,0	111,1	8,0	8,0
152 case10W	68,00	4	9,0	6,0	25,0	5,0	12,5	5,0	31,0	17,5	3,0	6,0	1,00	2,00	0,4	22,5	0,0	108,9	8,0	8,0
153 case10E	53,34	1	9,0	18,0	25,0	5,0	12,5	5,0	43,0	17,5	3,0	6,0	0,33	2,00	0,4	22,5	0,0	80,6	6,0	6,0
154 case10N	53,34	2	9,0	18,0	25,0	5,0	12,5	5,0	43,0	17,5	3,0	6,0	0,33	2,00	0,4	22,5	0,0	84,3	6,0	6,0
155 case10S	53,34	3	9,0	18,0	25,0	5,0	12,5	5,0	43,0	17,5	3,0	6,0	0,33	2,00	0,4	22,5	0,0	74,0	5,0	6,0
156 case10W	53,34	4	9,0	18,0	25,0	5,0	12,5	5,0	43,0	17,5	3,0	6,0	0,33	2,00	0,4	22,5	0,0	77,3	6,2	6,0
157 case 4E1375	53,34	1	9,0	9,0	12,5	10,0	25,0	13,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	48,8	-2,5	94,0	7,0	7,0
158 case 4N1375	53,34	2	9,0	9,0	12,5	10,0	25,0	13,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	48,8	-2,5	94,0	7,0	7,0
159 case 4S1375	53,34	3	9,0	9,0	12,5	10,0	25,0	13,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	48,8	-2,5	94,9	7,0	7,0
160 case 4W1375	53,34	4	9,0	9,0	12,5	10,0	25,0	13,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	48,8	-2,5	93,6	7,0	7,0
161 case 4E1625	53,34	1	9,0	9,0	12,5	10,0	25,0	16,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	51,3	-5,0	93,0	7,0	7,0
162 case 4N1625	53,34	2	9,0	9,0	12,5	10,0	25,0	16,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	51,3	-5,0	93,0	7,0	7,0
163 case 4S1625	53,34	3	9,0	9,0	12,5	10,0	25,0	16,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	51,3	-5,0	94,4	7,0	7,0
164 case 4W1625	53,34	4	9,0	9,0	12,5	10,0	25,0	16,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	51,3	-5,0	92,0	7,0	7,0
165 case 4E1875	53,34	1	9,0	9,0	12,5	10,0	25,0	18,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	53,8	-7,5	92,0	7,0	7,0
166 case 4N1875	53,34	2	9,0	9,0	12,5	10,0	25,0	18,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	53,8	-7,5	92,0	7,0	7,0
167 case 4S1875	53,34	3	9,0	9,0	12,5	10,0	25,0	18,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	53,8	-7,5	91,0	7,0	7,0
168 case 4W1875	53,34	4	9,0	9,0	12,5	10,0	25,0	18,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	53,8	-7,5	89,0	7,0	7,0

Table C.1 (Continued)

169 case 4E2125	53,34	1	9,0	9,0	12,5	10,0	25,0	21,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	56,3	-10,0	89,8	7,0	7,0
170 case 4N2125	53,34	2	9,0	9,0	12,5	10,0	25,0	21,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	56,3	-10,0	90,4	7,0	7,0
171 case 4S2125	53,34	3	9,0	9,0	12,5	10,0	25,0	21,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	56,3	-10,0	85,6	6,0	7,0
172 case 4W2125	53,34	4	9,0	9,0	12,5	10,0	25,0	21,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	56,3	-10,0	83,9	6,0	7,0
173 case 4E875	53,34	1	9,0	9,0	12,5	10,0	25,0	8,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	43,8	2,5	94,0	7,0	7,0
174 case 4N875	53,34	2	9,0	9,0	12,5	10,0	25,0	8,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	43,8	2,5	94,7	7,0	7,0
175 case 4S875	53,34	3	9,0	9,0	12,5	10,0	25,0	8,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	43,8	2,5	94,7	7,0	7,0
176 case 4W875	53,34	4	9,0	9,0	12,5	10,0	25,0	8,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	43,8	2,5	93,9	7,0	7,0
177 case 4E625	53,34	1	9,0	9,0	12,5	10,0	25,0	6,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	41,3	5,0	93,5	7,0	7,0
178 case 4N625	53,34	2	9,0	9,0	12,5	10,0	25,0	6,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	41,3	5,0	93,9	7,0	7,0
179 case 4S625	53,34	3	9,0	9,0	12,5	10,0	25,0	6,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	41,3	5,0	93,9	7,0	7,0
180 case 4W625	53,34	4	9,0	9,0	12,5	10,0	25,0	6,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	41,3	5,0	93,7	7,0	7,0
181 case 4E375	53,34	1	9,0	9,0	12,5	10,0	25,0	3,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	38,8	7,5	91,0	7,0	7,0
182 case 4N375	53,34	2	9,0	9,0	12,5	10,0	25,0	3,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	38,8	7,5	92,8	7,0	7,0
183 case 4S375	53,34	3	9,0	9,0	12,5	10,0	25,0	3,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	38,8	7,5	91,0	7,0	7,0
184 case 4W375	53,34	4	9,0	9,0	12,5	10,0	25,0	3,8	21,5	35,0	3,0	6,0	0,67	0,50	0,4	38,8	7,5	91,9	7,0	7,0
185 case 4E125	53,34	1	9,0	9,0	12,5	10,0	25,0	1,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	36,3	10,0	87,8	7,0	7,0
186 case 4N125	53,34	2	9,0	9,0	12,5	10,0	25,0	1,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	36,3	10,0	90,1	7,0	7,0
187 case 4S125	53,34	3	9,0	9,0	12,5	10,0	25,0	1,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	36,3	10,0	85,0	6,0	7,0
188 case 4W125	53,34	4	9,0	9,0	12,5	10,0	25,0	1,3	21,5	35,0	3,0	6,0	0,67	0,50	0,4	36,3	10,0	87,0	7,0	7,0
189 case 4E_h6	53,34	1	9,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	6,0	3,0	0,33	0,50	0,4	47,5	-1,3	76,0	6,0	6,0
190 case 4N_h6	53,34	2	9,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	6,0	3,0	0,33	0,50	0,4	47,5	-1,3	79,0	6,0	6,0
191 case 4S_h6	53,34	3	9,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	6,0	3,0	0,33	0,50	0,4	47,5	-1,3	71,0	5,0	6,0
192 case 4W_h6	53,34	4	9,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	6,0	3,0	0,33	0,50	0,4	47,5	-1,3	72,4	5,0	6,0
193 case 4E_h0	53,34	1	9,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	0,0	9,0	1,00	0,50	0,4	47,5	-1,3	111,5	8,9	8,0
194 case 4N_h0	53,34	2	9,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	0,0	9,0	1,00	0,50	0,4	47,5	-1,3	109,0	8,0	8,0
195 case 4S_h0	53,34	3	9,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	0,0	9,0	1,00	0,50	0,4	47,5	-1,3	113,4	9,0	8,0
196 case 4W_h0	53,34	4	9,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	0,0	9,0	1,00	0,50	0,4	47,5	-1,3	110,9	8,0	8,0
197 case 3E_h0	40,28	1	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	0,0	9,0	0,50	1,00	0,4	22,5	0,0	88,0	7,0	6,0
198 case 3N_h0	40,28	2	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	0,0	9,0	0,50	1,00	0,4	22,5	0,0	90,8	7,3	6,0
199 case 3S_h0	40,28	3	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	0,0	9,0	0,50	1,00	0,4	22,5	0,0	86,2	6,9	6,0
200 case 3W_h0	40,28	4	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	0,0	9,0	0,50	1,00	0,4	22,5	0,0	86,2	6,9	6,0
201 case 3E_h6	40,28	1	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	6,0	3,0	0,17	1,00	0,4	22,5	0,0	74,1	5,0	5,0
202 case 3N_h6	40,28	2	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	6,0	3,0	0,17	1,00	0,4	22,5	0,0	77,0	6,0	5,0
203 case 3S_h6	40,28	3	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	6,0	3,0	0,17	1,00	0,4	22,5	0,0	67,5	5,0	5,0

Table C.1 (Continued)

204 case 3W_h6	40,28	4	9,0	18,0	12,5	5,0	12,5	5,0	30,5	17,5	6,0	3,0	0,17	1,00	0,4	22,5	0,0	69,3	5,0	5,0
205 case 4E_h00	53,34	1	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	0,0	18,0	2,00	0,50	0,4	47,5	-1,3	147,4	11,8	12,0
206 case 4N_h00	53,34	2	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	0,0	18,0	2,00	0,50	0,4	47,5	-1,3	145,0	11,6	12,0
207 case 4S_h00	53,34	3	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	0,0	18,0	2,00	0,50	0,4	47,5	-1,3	146,9	11,0	12,0
208 case 4W_h00	53,34	4	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	0,0	18,0	2,00	0,50	0,4	47,5	-1,3	147,0	11,0	12,0
209 case 4E_h3	53,34	1	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	3,0	15,0	1,67	0,50	0,4	47,5	-1,3	144,0	11,6	10,0
210 case 4N_h3	53,34	2	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	3,0	15,0	1,67	0,50	0,4	47,5	-1,3	139,9	11,2	10,0
211 case 4S_h3	53,34	3	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	3,0	15,0	1,67	0,50	0,4	47,5	-1,3	144,3	11,5	10,0
212 case 4W_h3	53,34	4	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	3,0	15,0	1,67	0,50	0,4	47,5	-1,3	144,1	11,5	10,0
213 case 4E_h6	53,34	1	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	6,0	12,0	1,33	0,50	0,4	47,5	-1,3	133,0	10,0	9,0
214 case 4N_h6	53,34	2	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	6,0	12,0	1,33	0,50	0,4	47,5	-1,3	129,5	10,4	9,0
215 case 4S_h6	53,34	3	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	6,0	12,0	1,33	0,50	0,4	47,5	-1,3	135,6	10,0	9,0
216 case 4W_h6	53,34	4	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	6,0	12,0	1,33	0,50	0,4	47,5	-1,3	133,4	10,0	9,0
217 case 4E_h9	53,34	1	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	9,0	9,0	1,00	0,50	0,4	47,5	-1,3	108,8	8,0	8,0
218 case 4N_h9	53,34	2	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	9,0	9,0	1,00	0,50	0,4	47,5	-1,3	106,0	8,0	8,0
219 case 4S_h9	53,34	3	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	9,0	9,0	1,00	0,50	0,4	47,5	-1,3	110,2	8,0	8,0
220 case 4W_h9	53,34	4	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	9,0	9,0	1,00	0,50	0,4	47,5	-1,3	108,4	8,0	8,0
221 case 4E_h12	53,34	1	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	12,0	6,0	0,67	0,50	0,4	47,5	-1,3	97,4	7,0	7,0
222 case 4N_h12	53,34	2	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	12,0	6,0	0,67	0,50	0,4	47,5	-1,3	96,6	7,0	7,0
223 case 4S_h12	53,34	3	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	12,0	6,0	0,67	0,50	0,4	47,5	-1,3	97,3	7,8	7,0
224 case 4W_h12	53,34	4	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	12,0	6,0	0,67	0,50	0,4	47,5	-1,3	96,0	7,0	7,0
225 case 4E_h15	53,34	1	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	15,0	3,0	0,33	0,50	0,4	47,5	-1,3	77,0	6,0	6,0
226 case 4N_h15	53,34	2	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	15,0	3,0	0,33	0,50	0,4	47,5	-1,3	79,0	6,0	6,0
227 case 4S_h15	53,34	3	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	15,0	3,0	0,33	0,50	0,4	47,5	-1,3	71,6	5,0	6,0
228 case 4W_h15	53,34	4	18,0	9,0	12,5	10,0	25,0	12,5	21,5	35,0	15,0	3,0	0,33	0,50	0,4	47,5	-1,3	73,5	5,0	6,0

APPENDIX D: Statistical analyses

Table D.1 : Model development: Step 1.

Model Name:

MOD_5

Dependent Variable:

kWh/m²

Independent Variable:

%

Constant:

Included

Variable Whose Values Label Observations in Plots:

Unspecified

Tolerance for Entering Terms in Equations:

0,0001

a. The model requires all non-missing values to be positive.

Equation		Model Summary	Parameter Estimates							
type	#	R ²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,021	4,747	1	222	0,030	6,437	0,025	-	-
Logarithmic	2	0,020	4,574	1	222	0,034	3,279	1,125	-	-
Inverse	3	0,019	4,375	1	222	0,038	8,679	-49,329	-	-
Quadratic	4	0,022	2,455	2	221	0,088	7,492	-0,020	-	-
Cubic	5	0,022	2,494	2	221	0,085	7,288	-	-	4,86E-06
Compound	6	0,030	6,786	1	222	0,010	6,34	1,004	-	-
Growth	7	0,030	6,786	1	222	0,010	1,847	0,004	-	-
Exponential	8	0,030	6,786	1	222	0,010	6,34	0,004	-	-

Table D.2 : Model development: Step 2.

Model Name:

MOD_6

Dependent Variable:

kWh/m²

Independent Variable:

Height of the surrounding buildings (m)

Constant:

Included

Variable Whose Values Label Observations in Plots:

Unspecified

Tolerance for Entering Terms in Equations:

0,0001

a. The model requires all non-missing values to be positive.

Equation		Model Summary	Parameter Estimates							
type	#	R ²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,100	25,237	1	226	0	6,947	0,055	-	-
Logarithmic	2	-	-	-	-	-	-	-	-	-
Inverse	3	-	-	-	-	-	-	-	-	-
Quadratic	4	0,232	33,944	2	225	0	4,442	0,440	-0,011	-
Cubic	5	0,296	31,428	3	224	0	5,822	0,004	0,027	-
Compound	6	0,084	20,799	1	226	0	6,985	1,006	-	-
Growth	7	0,084	20,799	1	226	0	1,944	0,006	-	-
Exponential	8	0,084	20,799	1	226	0	6,985	0,006	-	-

Table D.3 : Model development: Step 3.

Model Name:	MOD_7									
Dependent Variable:	kWh/m²									
Independent Variable:	Distance between buildings in the y direction and/or width of the street									
Constant:	Included									
Variable Whose Values Label Observations in Plots:	Unspecified									
Tolerance for Entering Terms in Equations:	0,0001									
a. The model requires all non-missing values to be positive.										
Equation		Model	Parameter							
		Summary	Estimates							
type	#	R²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,003	0,655	1	226	0,419	7,819	-0,016	-	-
Logarithmic	2	-	-	-	-	-	-	-	-	-
Inverse	3	-	-	-	-	-	-	-	-	-
Quadratic	4	0,036	4,172	2	225	0,017	6,358	0,254	-0,011	-
Cubic	5	0,075	6,070	3	224	0,001	5,822	1,359	-0,185	0,01
Compound	6	0,005	1,161	1	226	0,282	7,775	0,997	-	-
Growth	7	0,005	1,161	1	226	0,282	2,051	-0,003	-	-
Exponential	8	0,005	1,161	1	226	0,282	7,775	-0,003	-	-

Table D.4 : Model development: Step 4.

Model Name:	MOD_8									
Dependent Variable:	kWh/m²									
Independent Variable:	Building depth (m)									
Constant:	Included									
Variable Whose Values Label Observations in Plots:	Unspecified									
Tolerance for Entering Terms in Equations:	0,0001									
a. The model requires all non-missing values to be positive.										
Equation	Model	Parameter								
	Summary	Estimates								
type	#	R²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,001	0,146	1	226	0,702	7,794	-0,011	-	-
Logarithmic	2	0,001	0,146	1	226	0,702	8,159	-0,199	-	-
Inverse	3	0,001	0,146	1	226	0,702	7,379	3,451	-	-
Quadratic	4	0,001	0,146	1	226	0,702	7,702	-	-	-
Cubic	5	-	-	-	-	-	7,648	-	-	-
Compound	6	0,001	0,117	1	226	0,732	7,683	0,999	-	-
Growth	7	0,001	0,117	1	226	0,732	2,039	-0,001	-	-
Exponential	8	0,001	0,117	1	226	0,732	7,683	-0,001	-	-

Table D.5 : Model development: Step 5.

Model Name:

MOD_9

Dependent Variable:

kWh/m²

Independent Variable:

Distance between buildings in the x direction (m)

Constant:

Included

Variable Whose Values Label Observations in Plots:

Unspecified

Tolerance for Entering Terms in Equations:

0,0001

a. The model requires all non-missing values to be positive.

Equation		Model	Parameter							
		Summary	Estimates							
type	#	R ²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,002	0,528	1	226	0,468	7,755	-0,009	-	-
Logarithmic	2	-	-	-	-	-	-	-	-	-
Inverse	3	-	-	-	-	-	-	-	-	-
Quadratic	4	0,073	8,827	2	225	-	6,508	0,254	-0,010	-
Cubic	5	83,000	6,761	3	224	-	5,992	0,449	-0,030	0,001
Compound	6	-	0,002	1	226	0,962	7,567	1	-	-
Growth	7	-	0,002	1	226	0,962	2,024	-7,33E-05	-	-
Exponential	8	-	0,002	1	226	0,962	7,567	-7,33E-05	-	-

Table D.6 : Model development: Step 6.

Model Name:

MOD_10

Dependent Variable:

kWh/m²

Independent Variable:

Building width (m)

Constant:

Included

Variable Whose Values Label Observations in Plots:

Unspecified

Tolerance for Entering Terms in Equations:

0,0001

a. The model requires all non-missing values to be positive.

Equation		Model	Parameter							
		Summary	Estimates							
type	#	R²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,001	0,226	1	226	0,635	7,719	-0,002	-	-
Logarithmic	2	-	0,027	1	226	0,87	7,575	0,023	-	-
Inverse	3	0,003	0,639	1	226	0,425	7,767	-2,520	-	-
Quadratic	4	0,056	6,678	2	225	0,002	6,172	0,127	-0,002	-
Cubic	5	0,056	6,678	2	225	0,002	6,533	0,077	-	-2,31E-05
Compound	6	-	0,029	1	226	0,865	7,537	1,000	-	-
Growth	7	-	0,029	1	226	0,865	2,02	-	-	-
Exponential	8	-	0,029	1	226	0,865	7,537	-	-	-

Table D.7 : Model development: Step 7.

Model Name:	MOD_11									
Dependent Variable:	kWh/m²									
Independent Variable:	Distance between left bottom corner of room to the left bottom corner of the building in the x direction (m)									
Constant:	Included									
Variable Whose Values Label Observations in Plots:	Unspecified									
Tolerance for Entering Terms in Equations:	0,0001									
a. The model requires all non-missing values to be positive.										
Equation	Model	Parameter								
type	#	Summary	Estimates	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	-	0,009	1	226	0,924	7,657	-	-	-
Logarithmic	2	0,009	2,130	1	226	0,146	7,330	0,140	-	-
Inverse	3	0,024	5,611	1	226	0,019	7,838	-1,303	-	-
Quadratic	4	0,051	6,075	2	225	0,003	7,135	0,085	-0,002	-
Cubic	5	0,074	5,980	3	224	0,001	6,599	0,225	-0,010	-
Compound	6	-	0,100	1	226	0,752	7,532	1,000	-	-
Growth	7	-	0,100	1	226	0,752	2,019	-	-	-
Exponential	8	-	0,100	1	226	0,752	7,532	-	-	-

Table D.8 : Model development: Step 8.

Model Name:	MOD_12									
Dependent Variable:	kWh/m²									
Independent Variable:	Distance between left bottom corner of room to the left bottom corner of the urban system in the y direction D+W (m)									
Constant:	Included									
Variable Whose Values Label Observations in Plots:	Unspecified									
Tolerance for Entering Terms in Equations:	0,0001									
a. The model requires all non-missing values to be positive.										
Equation	Model	Parameter								
type	#	Summary	Estimates	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,003	0,774	1	226	0,380	7,987	-0,014	-	-
Logarithmic	2	-	0,099	1	226	0,753	8,059	-0,130	-	-
Inverse	3	0,001	0,149	1	226	0,700	7,811	-3,755	-	-
Quadratic	4	0,046	5,431	2	225	0,005	3,496	0,332	-0,006	-
Cubic	5	0,055	4,308	3	224	0,006	-1,194	0,875	-0,027	-
Compound	6	0,005	1,164	1	226	0,282	7,957	0,998	-	-
Growth	7	0,005	1,164	1	226	0,282	2,074	-0,002	-	-
Exponential	8	0,005	1,164	1	226	0,282	7,957	-0,002	-	-

Table D.9 : Model development: Step 9.

Model Name:

MOD_13

Dependent Variable:

kWh/m²

Independent Variable:

Distance between left bottom corner of room to the left bottom corner of the urban system in the X direction L1+L2 (m)

Constant:

Included

Variable Whose Values Label Observations in Plots:

Unspecified

Tolerance for Entering Terms in Equations:

0,0001

a. The model requires all non-missing values to be positive.

Equation		Model Summary	Parameter Estimates							
type	#	R²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,001	0,316	1	226	0,574	7,734	-0,002	-	-
Logarithmic	2	0,000	0,019	1	226	0,890	7,579	0,020	-	-
Inverse	3	0,004	0,885	1	226	0,348	7,784	-4,098	-	-
Quadratic	4	0,050	5,889	2	225	0,003	6,331	0,081	-	-
Cubic	5	0,048	5,632	2	225	0,004	6,677	0,047	-	-7,39E-06
Compound	6	-	0,012	1	226	0,913	7,545	1,000	-	-
Growth	7	-	0,012	1	226	0,913	2,021	-	-	-
Exponential	8	-	0,012	1	226	0,913	7,545	-	-	-

Table D.10 : Model development: Step 10.

Model Name:

MOD_14

Dependent Variable:

kWh/m²

Independent Variable:

The height of the left bottom corner of room from the ground level (m)

Constant:

Included

Variable Whose Values Label Observations in Plots:

Unspecified

Tolerance for Entering Terms in Equations:

0,0001

a. The model requires all non-missing values to be positive.

Equation		Model	Parameter							
		Summary	Estimates							
type	#	R ²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,079	19,455	1	226	-	7,982	-0,069	-	-
Logarithmic	2	-	-	-	-	-	-	-	-	-
Inverse	3	-	-	-	-	-	-	-	-	-
Quadratic	4	0,086	10,583	2	225	-	7,808	-	-0,003	-
Cubic	5	0,111	9,287	3	224	-	8,202	-0,229	0,025	-
Compound	6	0,096	23,922	1	226	-	7,910	0,991	-	-
Growth	7	0,096	23,922	1	226	-	2,068	-0,009	-	-
Exponential	8	0,096	23,922	1	226	-	7,910	-0,009	-	-

Table D.11 : Model development: Step 11.

Model Name:

MOD_15

Dependent Variable:

kWh/m²

Independent Variable:

The difference of building height from room height (m)

Constant:

Included

Variable Whose Values Label Observations in Plots:

Unspecified

Tolerance for Entering Terms in Equations:

0,0001

a. The model requires all non-missing values to be positive.

Equation		Model Summary	Parameter Estimates				Sig.	Constant	b ₁	b ₂	b ₃
type	#	R ²	F	df ₁	df ₂						
Linear	1	0,511	235,944	1	226	-	6,305	0,172	-	-	
Logarithmic	2	-	-	-	-	-	-	-	-	-	
Inverse	3	-	-	-	-	-	-	-	-	-	
Quadratic	4	0,601	169,280	2	225	-	5,016	0,457	-0,011	-	
Cubic	5	0,602	113,021	3	224	-	5,210	0,390	-0,004	-	
Compound	6	0,498	223,884	1	226	-	6,420	1,021	-	-	
Growth	7	0,498	223,884	1	226	-	1,859	0,021	-	-	
Exponential	8	0,498	223,884	1	226	-	6,420	0,021	-	-	

Table D.12 : Model development: Step 12.

Model Name: MOD_16

Dependent Variable: kWh/m²

Independent Variable: The difference of building height from room height to Distance between buildings in the y direction (m)

Constant: Included

Variable Whose Values Label Observations in Plots: Unspecified

Tolerance for Entering Terms in Equations: 0,0001

a. The model requires all non-missing values to be positive.

Equation		Model Summary	Parameter Estimates							
type	#	R ²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,931	2975,259	1	222	-	5,091	3,515	-	-
Logarithmic	2	0,799	885,005	1	222	-	8,634	2,389	-	-
Inverse	3	0,475	200,655	1	222	-	9,077	-0,836	-	-
Quadratic	4	0,932	1503,093	2	221	-	4,932	3,901	-0,194	-
Cubic	5	0,933	1020,527	3	220	-	5,189	2,793	1,139	-0,444
Compound	6	0,904	2094,083	1	222	-	5,561	1,527	-	-
Growth	7	0,904	2094,083	1	222	-	1,716	0,423	-	-
Exponential	8	0,904	2094,083	1	222	-	5,561	0,423	-	-

Table D.13 : Model development: Step 13.

Model Name: MOD_17

Dependent Variable: kWh/m²

Independent Variable: Building depth to the Building width (m)

Constant: Included

Variable Whose Values Label Observations in Plots: Unspecified

Tolerance for Entering Terms in Equations: 0,0001

a. The model requires all non-missing values to be positive.

Equation		Model Summary	Parameter Estimates							
type	#	R ²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,003	0,595	1	226	0,441	7,738	-0,141	-	-
Logarithmic	2	-	0,058	1	226	0,810	7,628	-0,030	-	-
Inverse	3	0,001	0,186	1	226	0,667	7,710	-0,027	-	-
Quadratic	4	0,004	0,400	2	225	0,671	7,655	0,116	-0,134	-
Cubic	5	0,056	4,451	3	224	0,005	5,817	9,162	-10,937	3,391
Compound	6	0,006	1,263	1	226	0,262	7,684	0,975	-	-
Growth	7	0,006	1,263	1	226	0,262	2,039	-0,025	-	-
Exponential	8	0,006	1,263	1	226	0,262	7,684	-0,025	-	-

Table D.14 : Model development: Step 14.

Model Name:	MOD_18
Dependent Variable:	kWh/m²
Independent Variable:	Distance between buildings in the x direction to the Building width (m)
Constant:	Included
Variable Whose Values Label Observations in Plots:	Unspecified
Tolerance for Entering Terms in Equations:	0,0001
a. The model requires all non-missing values to be positive.	
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Table D.15 : Model development: Step 15.

Model Name:

MOD_19

Dependent Variable:

kWh/m²

Independent Variable:

L₁+L₂+L_r (m)

Constant:

Included

Variable Whose Values Label Observations in Plots:

Unspecified

Tolerance for Entering Terms in Equations:

0,0001

a. The model requires all non-missing values to be positive.

Equation		Model Summary	Parameter Estimates							
type	#	R ²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	0,001	0,188	1	226	0,665	7,710	-0,001	-	-
Logarithmic	2	0,000	0,081	1	226	0,776	7,500	0,039	-	-
Inverse	3	0,005	1,055	1	226	0,305	7,795	-5,741	-	-
Quadratic	4	0,033	3,890	2	225	0,022	6,854	0,035	-	-
Cubic	5	0,046	3,633	3	224	0,014	5,697	0,112	-0,002	-
Compound	6	-	0,038	1	226	0,845	7,534	1,000	-	-
Growth	7	-	0,038	1	226	0,845	2,019	-	-	-
Exponential	8	-	0,038	1	226	0,845	7,534	-	-	-

Table D.16 : Model development: Step 16.

Model Name:	MOD_20									
Dependent Variable:	kWh/m ²									
Independent Variable:	[(L ₂ /2)- (L _r +1,25)] (m)									
Constant:	Included									
Variable Whose Values Label Observations in Plots:	Unspecified									
Tolerance for Entering Terms in Equations:	0,0001									
a. The model requires all non-missing values to be positive.										
Equation	Model	Parameter								
type	#	R ²	F	df ₁	df ₂	Sig.	Constant	b ₁	b ₂	b ₃
Linear	1	-	0,105	1	226	0,747	7,648	-0,003	-	-
Logarithmic	2	-	-	-	-	-	-	-	-	-
Inverse	3	-	-	-	-	-	-	-	-	-
Quadratic	4	0,030	3,480	2	225	0,032	7,760	-0,003	-0,002	-
Cubic	5	0,031	2,426	3	224	0,066	7,757	-0,014	-0,002	-
Compound	6	-	0,074	1	226	0,785	7,560	1,000	-	-
Growth	7	-	0,074	1	226	0,785	2,023	-	-	-
Exponential	8	-	0,074	1	226	0,785	7,560	-	-	-

CURRICULUM VITAE



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List of Publications and Patents:

1- International Publications

a. Journal Articles (Peer Reviewed Publications)

- Di Vincenzo, M. C., **Kesten, D.**, Infield D., “Assessment of performance of building shading device with integrated photovoltaics in different urban scenarios” *Journal of Energy and Power Engineering, Volume 6, Number 3, March 2012 (Serial Number 52, ISSN:1934-8975*
- **Kesten, D.**, Tereci, A., Eicker, U. "A Method to Quantify the Energy Performance in the Urban Quarters", RSCH-00359-2010, has been received by ASHRAE Manuscript Central. *ASHRAE HVAC&R Research Journal on "Indoor air quality, ventilation and energy conservation in buildings"*, 18(1–2):100–111, 2011. ISSN: 1078-9669 print / 1938-5587 online
- **Kesten, D.**, Fiedler, S., Thumm, F., Löffler, A., Eicker, U. “Evaluation of daylight performance in scale models and a full-scale mock-up office” *Oxford Journals Mathematics & Physical Sciences International Journal of Low-Carbon Technologies* Volume5, Issue3 Pp. 158-165. Received May 7, 2010, Revision received June 1, 2010, Accepted June 8, 2010. The ISSN for International Journal of Low Carbon Technologies is 1748-1317 (print) and 1748-1325 (online).

b. Conference Papers (Published In Proceedings)

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- Tereci, A., **Kesten, D.**, Eicker U., “The impact of the urban form on heating, cooling and lighting demand of cities” *First International Conference on Sustainable Urbanization*, 15-17 December 2010, Hong Kong, China.
- **Kesten, D.**, Tereci, A., Eicker U., “A Calculation Method on the Energy Demand of Urban Districts”, METU - Department of Architecture - Building Science Graduate Program *1st. International Graduate Research Symposium* - October 15-16, 2010 - Ankara, Turkey.
- Tereci, A., **Kesten, D.**, Tahira Özkan S.E., Eicker U., “The Impact Of The Urban Form On Building Energy Demand” METU - Department of Architecture - Building Science Graduate Program *1st. International Graduate Research Symposium* - October 15-16, 2010 - Ankara, Turkey.

- Eicker U., Tereci, A., **Kesten, D.**, “Energy Performance of Buildings in Urban Areas” *SET2010 – 9th International Conference on Sustainable Energy Technologies*, August 24-27, 2010, Shanghai, China.
- **Kesten, D.**, Tereci, A., Eicker U., “A Method to Quantify the Energy Performance in the Urban Quarters” *IAQVEC 2010, 7th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings*, August 15-18, 2010 , Syracuse, New York, USA.
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- **Kesten, D.**, Icin, T., Cetegen, D., and A. Yener, “Comparison of Daylighting Systems in Traditional and Modern Houses in Hot Climate”, *LUX EUROPA 2005*, September 2005, Berlin, Germany.

c. Conference Posters

- Di Vincenzo, M. C., **Kesten, D.**, Infield D., “Assessment of performance of building shading device with integrated photovoltaics in different urban scenarios” *5th Energy Forum on Solar Building Skins*, 2-3 December 2010, Bressanone, Italy.
- Duminil, E., Tereci, A., **Kesten, D.**, Schneider, D., Strzalka, R. “Economical aspect and environmental impact of renewable trigeneration in urban areas, Scharnhauser Park case study” *CISBAT 2009 International Conference*, 2-3 September 2009, Lausanne, Switzerland.

2- National (Turkey- Germany) Publications

a. Conference Papers (Published In Proceedings)

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- Fiedler, S., **Kesten, D.**, Löffler, A., Eicker U. “The artificial sky at the HFT Stuttgart – contributions and limitations” (German), *14. Symposium Licht + Architektur*, 12.-13. February 2009, Bad Staffelstein Germany.

- **Kesten, D.**, Biesinger A. and Eicker U. “Monitoring The Performance Of Lighting And Shading Systems In The Open Planed Office Building: A Real Case Study (English), 7. *National Lighting Congress*, November 2008, Istanbul, Turkey.
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- **Kesten, D.** and A. Yener, “The Case Study of Energy Efficient Lighting Design for Primary School Buildings” (Turkish), 6. *National Lighting Congress*, October 2006, Istanbul Turkey.
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b. Articles

- **Kesten, D.** “Sustainable and Energy Efficient Education Buildings: Lighting System Design Evaluation” (Turkish), *Light World, Aydınlatma Endüstrisi Dergisi*, June – July 2008, volume 12, page 26-32.

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