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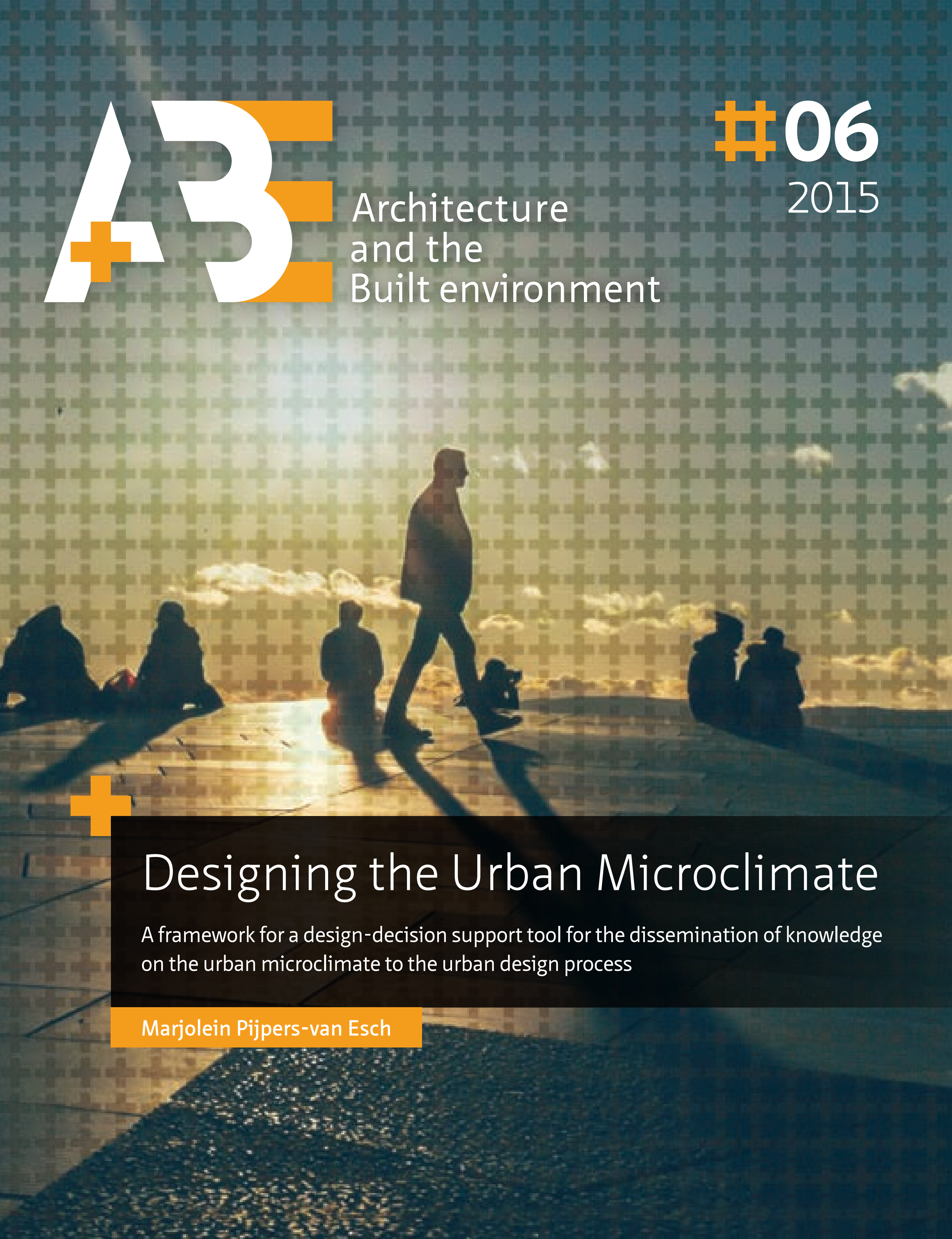

Designing the Urban Microclimate

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Marjolein Pijpers-van Esch

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Contents

Summary

This doctoral thesis presents research on the integration and transfer of knowledge from the specialized field of urban microclimatology into the generic field of urban design. Both fields are studied in order to identify crosslinks and reveal gaps. The main research question of the research is: How can the design of urban neighbourhoods contribute to microclimates that support physical well-being and what kind of information and form of presentation does the urban designer need in order to make design decisions regarding such urban microclimates? This question consists of two parts, which are addressed separately in the first two parts of the dissertation.
Part 1 concerns an assessment of relevant knowledge on urban design by literature review, followed by a field study into the use of expert information in the urban design process. Part 2 discusses the influence of the urban environment on its microclimate and, consequently, the living quality of its inhabitants – both by means of literature review.
Combined, Parts 1 and 2 serve as a basis for a framework for a design-decision support tool, which is discussed in Part 3. This tool is proposed as a means to integrate knowledge of the urban microclimate into the urban design process, bridging an observed gap.

Urban design is concerned with shaping the physical environment to facilitate urban life in all its aspects. This is a complex task, which requires the integration and translation of different stakeholder interests into a proposition for the realization of physical-spatial constructs in the urban environment. Such a proposition comprises different planning elements in the following categories: spatial-functional organization, city plan, public space design and rules for architecture. During the design process, the urban designer has to deal with incomplete, often contradictory and/or changing constraints and quality demands as well as other uncertainties. He/she handles this complexity by starting with a small selection of constraints, iteratively working to a design solution by incorporating an increasing number of constraints. The selection of constraints is subjective, depending on the design frame of the individual designer.

In order to make design decisions, the urban designer requires diverse information. To establish how urban designers collect information and which formats and information levels they prefer, field research among Dutch urban designers was carried out. This consisted of a series of exploratory interviews and an online questionnaire. The results indicate that dissemination of expert knowledge to urban design should be focused on the orientation and sketch phases of the design process and should provide different layers of detail, using mainly visual information accompanied by explanatory text.

The results furthermore show a remarkable discrepancy between the assigned significance of the urban microclimate for urban design and the frequency of inquiry on this topic; almost all interviewees and respondents consider the subject to be important, but a majority of them seldom collect information on it. This signifies a gap in the knowledge transfer process.

It is important to bridge this gap, because the urban microclimate has a significant impact on the physical well-being of people. All components of the urban microclimate – solar radiation, daylight, wind, air quality and sound – affect the physical well-being of people, whether separately or in conjunction. Some of these effects are immediate, such as heat stress and noise annoyance; others develop over a longer period of overexposure or underexposure, such as pulmonary and respiratory diseases. Some cause discomfort, for example sleep disturbance; others can be life- threatening, such as heat stroke or skin and lung cancer. It is therefore vital that the urban microclimate is given considerable attention in the urban design process.

The urban microclimate is to a large extent influenced by the city's morphology, materialization and landscaping. This influence is exerted through different physical principles, such as reflection, absorption and evapotranspiration. Basic knowledge on how and to what extent the urban environment affects the urban microclimate and of the underlying physical principles, supported by design guidelines and examples/ reference projects, will enable urban designers to estimate the effects of their design choices on the microclimate themselves better, and help them create conditions for urban microclimates that favour physical well-being.

In order to make this information available to the urban designer in a way that corresponds to his/her working process, a framework for a design-decision support tool was set up. Requirements regarding form and function were derived from the field of urban design, while requirements regarding content were derived from the field of urban microclimatology. The tool is proposed to be a web-based knowledge base, consisting of five main menu categories: "climate elements", "plan elements", "principles", "guidelines" and "example projects". Each category provides access to separate pages for underlying items, containing different layers of information, from general to detailed, that can be accessed through collapse menus or click-through functions. Hyperlinks between related items are provided to support different ways to access information. The main menu further gives access to background information on physical well-being and regulations and standards. Separate item pages can be added to a 'shopping cart', enabling customised information selection for a specific design at hand.

Providing the necessary content for the tool requires further translation of expert knowledge into design information as well as additional research regarding: the plain and simple formulation of physical phenomena related to the urban environment;

the integration of expert knowledge of separate microclimatological elements; the incongruity of parameters in microclimatological studies and urban design plan elements; and the presentation of information consistent with design and (design) communication purposes as opposed to evaluation purposes.

To illustrate how expert studies can be rendered into design information, the impact of three selected plan elements - Floor Space Index (FSI), Ground Space Index (GSI) and orientation - on solar irradiation and wind was examined with the aid of numerical simulation tools. The results of the calculations for both climate elements were integrated in order to identify conflicts and matches. The emphasis of the study lay on showing trends and generating generic knowledge. Such knowledge is required to fill the proposed design-decision support tool with content.

Answering the main research question, it can be concluded that various aspects relating to the morphology, materialization and landscaping of urban neighbourhoods can be employed to create conditions for a distinctive microclimate; urban microclimates often deviate substantially from the regional climate, and even vary within a few meters. Designing urban microclimates needs to be done with care as they affect the physical well-being of people significantly. In order to be able to do this, the urban designer needs information that ties in with his/her way of working and cognitive process. However, expert knowledge from the field of urban microclimatology does not fulfil this requirement and needs to be translated to information for urban design purposes. Aiming to give direction to this translation and facilitate the dissemination of expert urban microclimate knowledge to the urban design process, this research proposes a framework for a design-decision support tool. Requirements for the framework were derived from both the field of urban design and the field of urban microclimatology. A tool created according to the proposed framework will enable urban designers to practice climate-sensitive urban design, and, thus contribute to the physical well-being of people.

Samenvatting

Deze dissertatie presenteert onderzoek naar de integratie en overdracht van kennis uit het specialiste vakgebied van de stedelijke microklimatologie naar het generieke vakgebied van de stedebouw. Beide vakgebieden worden bestudeerd om kruisverbanden en hiaten te identificeren. De hoofdvraag van het onderzoek luidt: Hoe kan het wijkontwerp bijdragen aan microklimaten die een gunstig effect hebben op het lichamelijk welbevinden en welke informatie en informatie-presentatie heeft de stedebouwkundig ontwerper nodig om ontwerpbeslissingen te nemen aangaande zulke microklimaten? Deze hoofdvraag bestaat uit twee delen, welke ieder in een apart deel van de dissertatie worden behandeld.
Deel 1 behandelt relevante kennis over stedebouwkundig ontwerpen uit de literatuur, gevolgd door een veldonderzoek naar het gebruik van specialistische informatie in het stedebouwkundig ontwerpproces. Deel 2 beschrijft de invloed van de stedelijke omgeving op het microklimaat en de gevolgen ervan voor de leefkwaliteit – beide aan de hand van literatuurstudie.
Gecombineerd vormen Deel 1 en 2 de basis voor een raamwerk voor een hulpmiddel bij ontwerpbeslissingen, welke wordt beschreven in Deel 3. Het hulpmiddel is bedoeld om kennis over het stedelijk microklimaat te integreren in het stedebouwkundig ontwerpproces en zo een waargenomen leemte te vullen.

Stedebouw houdt zich bezig met het vormgeven van de fysieke omgeving ten behoeve van het stedelijk leven in al zijn aspecten. Dit is een complexe taak, die vraagt om de integratie van de belangen van verschillende stakeholders en de vertaling ervan naar een voorstel voor een ruimtelijk plan. Een dergelijk ruimtelijk plan bestaat uit verschillende planelementen in de volgende categorieën: de ruimtelijk-functionele organisatie van het plangebied, de stadsplattegrond, het ontwerp van de openbare ruimte en regels voor architectuur. Gedurende het ontwerpproces krijgt de ontwerper te maken met onvolledige, vaak tegenstrijdige en/of veranderende eisen en voorwaarden, en andere onzekerheden. Hij/zij maakt deze complexiteit beheersbaar door te beginnen met een beperkte selectie van criteria. In een iteratief proces worden vervolgens steeds meer criteria meegenomen tot een passende ontwerpoplossing gevonden is. De selectie van criteria is subjectief en is afhankelijk van het 'ontwerpframe' van de individuele ontwerper.

Om ontwerpbeslissingen te kunnen nemen heeft de ontwerper uiteenlopende informatie nodig. Om vast te stellen hoe stedebouwkundigen informatie verzamelen en welke vormen en mate van detail ze daarbij prefereren is een veldonderzoek onder Nederlandse stedebouwkundigen uitgevoerd. Dit onderzoek bestond uit een aantal exploratieve interviews en een online enquête. Uit de resultaten blijkt dat de disseminatie van specialistische kennis naar de stedebouw zich moet richten op de oriëntatie- en schetsfases van het ontwerpproces, het verstrekken van meerdere lagen van detail, en het gebruik van visuele informatie met bijbehorende verklarende tekst.

De resultaten wijzen verder uit dat er een opmerkelijke discrepantie bestaat tussen het belang dat de ontwerpers aan het microklimaat toekennen en de mate waarin ze erover informatie inwinnen; bijna alle ondervraagden en respondenten vinden het onderwerp belangrijk voor het ontwerp, maar een meerderheid vraagt er zelden informatie over op. Dit duidt op een leemte in de informatieoverdracht.

Het is belangrijk om deze leemte op te vullen aangezien het stedelijk microklimaat een significante invloed heeft op het fysiek welbevinden van de mens. Alle componenten van het stedelijk microklimaat – zonnestraling, daglicht, wind, luchtkwaliteit en geluid – beïnvloeden het fysiek welbevinden, separaat of in samenspel. Sommige effecten treden direct op, zoals hittestress en geluidhinder; andere ontwikkelen zich over een langere periode blootstelling (teveel of te weinig), zoals ziekten van de longen en het ademhalingssysteem. Sommige effecten leveren alleen ongemak op, bijvoorbeeld verstoring van de slaap, andere kunnen levensbedreigend zijn, zoals een hitteberoerte of huid- en longkanker. Het is daarom van het grootste belang dat er in het stedebouwkundig ontwerpproces voldoende aandacht wordt besteed aan het stedelijk microklimaat.

Het stedelijk microklimaat wordt in belangrijke mate beïnvloed door de stedelijke morfologie, materialisatie en groenvoorziening. Verschillende fysische principes, zoals reflectie, absorptie en evapotranspiratie, liggen aan deze invloed ten grondslag. Basiskennis van de manieren waarop en de mate waarin de stedelijke omgeving het microklimaat beïnvloedt, inclusief de onderliggende fysische principes en ondersteund door ontwerprichtlijnen en voorbeeld- of referentieprojecten, stelt stedebouwkundig ontwerpers in staat om de effecten van hun ontwerpkeuzes op het microklimaat beter in te schatten en helpt ze condities te creëren voor stedelijke microklimaten die het fysiek welbevinden bevorderen.

Om deze informatie beschikbaar te stellen op een manier die aansluit bij de werkwijze van de stedebouwkundig ontwerper is een raamwerk voor een hulpmiddel bij ontwerpbeslissingen opgesteld. Eisen met betrekking tot vorm en functie van het hulpmiddel zijn ontleend aan het vakgebied van de stedebouw, eisen met betrekking tot de inhoud zijn ontleend aan het vakgebied van de stedelijke microklimatologie. Voorgesteld wordt een web-based kennisbank, bestaande uit een hoofdkeuzemenu met vijf categorieën: “klimaatelementen”, “planelementen”, “principes”, “richtlijnen” en “voorbeeldprojecten”. Elk van deze categorieën geeft toegang tot aparte onderdeelpagina’s met verschillende lagen van detail – van globaal naar gedetailleerd – d.m.v. uitklapmenu’s of doorklikfuncties. Hyperlinks tussen gerelateerde onderdelen verschaffen verschillende routes door de informatie. Het hoofdmenu geeft verder toegang tot achtergrondinformatie over fysiek welbevinden en wetten en normen.

Afzonderlijke pagina's kunnen aan een "winkelwagentje" worden toegevoegd, waardoor het mogelijk is informatie te verzamelen die toegesneden is op een specifieke ontwerpopgave.

Om alle benodigde inhoud voor het hulpmiddel te kunnen verstrekken is zowel aanvullend onderzoek als een verdere vertaling van specialistische kennis naar ontwerpinformatie nodig betrekking tot de volgende aspecten: een duidelijke en eenvoudige uitleg van fysische fenomenen gerelateerd aan de stedelijke omgeving, de integratie van specialistische kennis van de afzonderlijke elementen van het microklimaat, de incongruentie tussen de parameters gebruikt in microklimatologische studies en stedebouwkundige planelementen, en de presentatie van informatie in een vorm die aansluit bij ontwerp- en (ontwerp)communicatiedoeleinden in plaats van evaluatiedoeleinden.

Om te laten zien hoe specialistische studies kunnen worden ingezet voor ontwerpinformatie, is de invloed van drie geselecteerde planelementen – Floor Space Index (FSI), Ground Space Index (GSI) en oriëntatie – op bezonning en wind onderzocht met behulp van numerieke simulatieprogramma's. De resultaten van de berekeningen voor de afzonderlijke klimaatelementen zijn geïntegreerd om conflicten en overeenkomsten bloot te leggen. De nadruk van de studie lag op het in beeld brengen van trends en het ontwikkelen van generieke kennis. Zulke kennis is nodig om het voorgestelde hulpmiddel voor ontwerpbeslissingen van inhoud te voorzien.

Om de hoofdvraag van het onderzoek te beantwoorden, kan geconcludeerd worden dat verscheidene aspecten van de morfologie, materialisatie en groenvoorziening van een wijk kunnen worden ingezet om condities te scheppen voor een eigen microklimaat; stedelijke microklimaten verschillen vaak substantieel van het regionale klimaat, en variëren zelfs binnen enkele meters. Het ontwerpen van stedelijke microklimaten moet met zorg gebeuren aangezien ze een significante invloed hebben op het fysieke welbevinden van mensen. Om dit te kunnen doen heeft de stedebouwkundig ontwerper informatie nodig die aansluit bij zijn/haar werkwijze en cognitieve proces. Specialistische kennis uit het vakgebied van de stedelijke microklimatologie is hiervoor echter niet direct geschikt, maar moet vertaald worden naar informatie voor ontwerpdoeleinden. Met het doel om richting te geven aan deze vertaling en de disseminatie van specialistische kennis van het stedelijk microklimaat naar het stedebouwkundig ontwerpproces te faciliteren, is in dit onderzoek een raamwerk voor een hulpmiddel voor ontwerpbeslissingen ontwikkeld. De eisen voor het raamwerk zijn ontleend aan het vakgebied van de stedebouw én het vakgebied van de stedelijke microklimatologie. Een hulpmiddel dat ontwikkeld wordt volgens het voorgestelde raamwerk stelt stedebouwkundig ontwerpers in staat om klimaatsensitief te ontwerpen en zo een bijdrage te leveren aan het fysiek welbevinden van de mens.

Nomenclature

Symbols

C_v	convective heat flow	[W]
C_d	conductive heat flow	[W]
d	building depth	[m]
DPI_n	daylight performance index of daylight factor of value n	[%]
E	evaporative heat loss	[W]
h	building height	[m]
H	canyon height	[m]
i	height of directly irradiated façade	[m]
k	turbulent kinetic energy	[m^2/s^2]
K_{dif}	diffuse short-wave radiation incident on the body	[W/m^2]
K_{dir}	direct short-wave radiation incident on the body	[W/m^2]
K_{ref}	indirect short-wave radiation incident on the body, reflected from surfaces	[W/m^2]
L	canyon length	[m]
L_{Aeq}	A-weighted equivalent sound level	[dB]
L_{den}	day-evening-night equivalent sound level	[dB]
L_g	geometrical length scale	[m]
L_s	long-wave radiation emitted by the body to the environment	[W/m^2]
L_{sky}	long-wave radiation incident on the body, emitted from the sky	[W/m^2]
L_{ter}	long-wave radiation incident on the body, emitted from surfaces	[W/m^2]
L_z	zenith luminance	[cd/m^2]
L_γ	luminance of a sky element	[cd/m^2]
M	metabolic rate	[W]
MRT	mean radiant temperature	[°C]
NO_2	nitrogen dioxide	[-]
NO_x	nitrogen oxides	[-]
O_3	ozone	[-]
PET	physiological equivalent temperature	[°C]
PM	particulate matter	[-]
$PM_{2,5}$	particulate matter finer component of parts > 2,5 µm	[-]
PM_{10}	particulate matter coarse component of parts 2,5 µm - 10 µm	[-]
PM_x	particulate matter components of size x	[-]

Q^*	net all-wave radiation flux	[W/m²]
Q_F	anthropogenic heat flux	[W/m²]
Q_H	sensible heat flux	[W/m²]
Q_E	latent heat flux	[W/m²]
R	reflection coefficient / albedo	[-]
RH	relative humidity	[%]
RT	reverberation time	[s]
s	street width	[m]
SO_2	sulphur dioxide	[-]
Ta	air temperature	[°C]
U	mean wind speed	[m/s]
U*	friction velocity	[m/s]
U_{H0}	mean wind speed at roof height	[m/s]
U_{loc}	hourly mean wind speed at a certain location	[m/s]
U_{thr}	threshold wind speed	[m/s]
U_z	horizontal mean wind speed at height z	[m/s]
UTCI	universal thermal climate index	[°C]
VP	vapour pressure	[Pa]
w	building width	[m]
W	canyon width	[m]
WCT	Wind Chill Temperature	[°C]
x_{obs}	street width for obstruction angle in direction of azimuth	[m]
x_{shade}	width of non-irradiated street space in direction of azimuth	[m]
z_0	aerodynamic roughness length	[m]
z_d	zero displacement length	[m]
α	sound absorption coefficient	[-]
α_{obs}	obstruction angle	[°]
α_{sun}	solar altitude	[°]
α_{thr}	threshold angle	[°]
β	solar azimuth	[°]
γ	elevation angle of a sky element above the horizon	[°]
ε	turbulent dissipation	[m^2/s^3]
ΔS	change in heat stored	[W]
ΔQ_A	change in net advective heat flux	[W/m²]
ΔQ_S	change in storage heat flux	[W/m²]
κ	Von Karman constant (0.4)	[-]
μ	thermal admittance	[$kJ/(K*m^2*s^{1/2})$]

Abbreviations

ASV	Actual Sensation Vote
BNSP	Beroepsvereniging van Nederlandse Stedebouwkundigen en Planologen (professional association of Dutch urban designers and planners)
BRE	British Research Establishment
CEN	Comité Européen de Normalisation(European Committee for Standardization)
CIAM	Congress Internationaux d'Architecture modern
CIBSE	Chartered Institution of Building Services Engineers
CIE	Commission Internationale de l'Éclairage (International Commission on Illumination)
CFD	Computational Fluid Dynamics
CRED	Centre for Research on the Epidemiology of Disasters
ERC	Externally Reflected Component (daylight factor)
FSI	Floor Space Index
GSI	Ground Space Index
H/W	Canyon height to width ratio
IPCC	Intergovernmental Panel on Climate Change
IRC	Internally Reflected Component (daylight factor)
KNMI	Koninklijk Nederlands Metereologisch Instituut (The Royal Dutch Meteorological Institute)
IRF	Isolated Roughness Flow
L/H	relative canyon length
MED	Minimal Erythemal Dosis
MEMI	Munich Energy- balance Model for Individuals
OFCM	Office of the Federal Coordinator for Meteorological Services and Supporting Research
PCI	Park Cool Island
PMV	Predicted Mean Vote
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (Netherlands National Institute for Public Health and the Environment)
SAD	Seasonal Affective Disorder
SC	Sky Component (daylight factor)
SF	Skimming Flow
SVF	Sky View factor
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organization for Applied Scientific Research)
UBL	Urban Boundary Layer
UCL	Urban Canopy Layer
UHI	Urban Heat Island
UN	United Nations
UV	Ultraviolet

VROM	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu (Ministry of Housing, Spatial Planning and the Environment)
WIF	Wake Interference Flow
WHO	World Health Organization

1 Introduction

§ 1.1 Urban microclimate & physical well-being

An urban microclimate is the distinctive climate in a small-scale urban area, and is constituted by the influence of the built environment on the larger scale climatic conditions. The atmospheric variables in a microclimate can deviate substantially from the conditions prevailing over a larger area. In other words: the design of a city and its components sets the conditions for its microclimates. This influence on climate is one of the main reasons man started building; buildings – however primitive – provide shelter from the elements.

Before the age of fossil energy use and building services man developed various passive building techniques to mitigate the negative effects of climate and utilize the positive effects. Examples of such climate-sensitive vernacular architecture can still be found around the world (Olgyay, 1963). In hot-humid climates, around the equator, a scattered layout of buildings with large open spaces between them allows for cooling breezes, while large roof overhangs provide shade from the sun. Walls are practically non-existent as they inhibit air movement and have no function as shading elements; direct radiation comes from straight above. In hot-arid climates dense layouts provide shading of buildings and outdoor spaces and large thermal masses attenuate the large diurnal temperature curve. Shaded courtyards with ponds and vegetation provide cooling. In cold climates compactness is essential in order to minimize the surface exposed to the cold. Furthermore, thermal mass is employed in combination with insulating materials to minimize heat losses. A dense but irradiated layout guarantees optimal use is made of the sun's energy and cold winds are blocked. Temperate climates allow for a relatively high degree of freedom with respect to architecture and urban design, because the thermal stresses are small. There are however some dichotomies: provision of solar access to buildings and outdoor spaces is needed in winter while solar shading is desirable in summer. Furthermore, shelter from high winds is required in winter, but cooling breezes should be promoted during the warmer months.

The above examples from vernacular design show that urban design and architecture influence microclimates and therewith also the physical well-being of human beings. Throughout history, this influence has been of concern in urban design and policy.

After 1850, the population of European cities grew dramatically as a result of the industrial revolution and increased hygiene. The enormous housing demand led to speculative housing developments and slums populated by workers. After heavy criticism against these poor living conditions by the hygienist movement, several countries started making plans and policies to improve the situation. In the Netherlands, requirements for the quality of social housing were introduced, ultimately leading to the enactment of the Dutch Housing Act (Kruseman, 1901). Other well-known examples are Haussmann's renovation of Paris and the Garden Cities concept, based on Ebenezer Howard's "Garden Cities of To-morrow" (1902), that was adopted all over the world. The modernist movement also had clear ideas on the responsibilities of architects and urban designers regarding public health; in the Charter of Athens (CIAM, 1933), they promoted several design concepts, such as the separation of traffic and residential zones, the penetration of sun in every dwelling and large green spaces – all for medical reasons.

After WWII focus shifted towards social-cultural aspects of architecture and urban design. Plans were needed for large urban areas and for the county as a whole; for reconstruction purposes, but also because of an increase in population and prosperity. The Dutch government directed spatial planning and urban design on all levels of scale. Society was to be healthier in the sense of improved morality and order. The neighbourhood became the corner stone of urban planning and design; it was to be the social-spatial unit of the city containing all functions related to its residential function. New neighbourhoods were made up out of 'stamps': a spacious pattern of open blocks in a green environment repeated throughout the whole neighbourhood. It was the time of the 'makeable society'; the idea that societal developments can be directed and controlled by government action (Van der Cammen & De Klerk, 2003).

The indoor climate also became makeable; the progress of technology brought the introduction of technical indoor climate control systems, decreasing the necessity of climate pre-conditioning by means of climate-sensitive urban design and architecture considerably.

The subject of health regained attention in the nineties, when the United Nations Conference on Environment and Development, also known as the earth summit, stated that " Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature" (UN, 1992). During this conference, sustainable development was defined as a harmonious combination of the three P's: "People", "Planet" and "Profit" (later replaced by "Prosperity" (UN, 2002)), three terms that stand for social, ecological and economical sustainability.

§ 1.2 Sustainability

In the western world, most attention has gone out to sustainability issues regarding "Planet" and in particular questions regarding energy consumption. In 1989, The Dutch government published its first National Environmental Policy Plan (VROM, 1989), which was immediately updated in 1990, addressing issues such as climate change, acidification, eutrophication due to fertilizers and waste. The main aim was to improve the living environment. "People" and "Prosperity" are largely non-western issues and have been, and still are, largely overlooked in developed countries, probably because of the advanced medical care and –until recently- stable economic situation. On the subject of "People" and microclimate more specifically, attention has been paid to the effects of air quality and (traffic) noise on health, resulting in standards and regulations. Other microclimate-related topics, however, have not received as much consideration. This is probably (partly) caused by the before mentioned development of technical indoor climate control systems; as they improve the indoor climate and therewith the physical well-being of people, the incentive for climate pre-conditioning by means of climate-sensitive design has been largely lost. However, this lack of climate-sensitive design frequently leads to unwanted microclimate situations outdoors: constantly shaded public spaces due to poor orientation and/or high buildings, the obstruction of air movement in high-dense environments, leading to increased air pollution levels, etc. Furthermore, indoor climate control systems deteriorate the outdoor climate as they exhaust their waste heat, greenhouse gasses and other pollutants into the open air.

Not only the microclimate, but also the climate on the larger scales is affected by these anthropogenic exhausts; they are thought to be partly responsible for a global temperature rise between 1.1 and 6.4 degrees Celsius by the end of the century (IPCC, 2007). Based on the predictions by the IPCC and supplemented with its own climate models, The Royal Dutch Meteorological Institute (KNMI) has made predictions for the climate in the Netherlands in the year 2050. The KNMI predicts that the winters will be warmer and moister and that summers will be warmer and dryer. Further predictions are an increase in extreme precipitation events all year round, but a decrease in the number of days with precipitation in summer. The rise in temperature in the Netherlands is already higher than the mean global temperature rise, and this is thought to continue in the future. This higher warming rate is mainly due to the position of the Netherlands close to the landmass of Eurasia, which warms significantly more (almost twice as fast) than the global mean. As a result of this warming there will be stronger westerly winds in winter and more easterly winds in summer (KNMI, 2006, 2009).

These larger scale climate changes will in their turn modify urban microclimates. Combined with the urban heat island (UHI) effect - the phenomenon that the urban air temperature is higher than that of the surrounding (rural) environment-, the climate in cities is thus likely to become more unhealthy, especially in summer, when a large increase in temperatures and therewith heat stress can be expected. Furthermore, higher temperatures stimulate the formation of ground-level ozone in urban areas, which can lead to or aggravate cardio-respiratory diseases such as lung inflammation and decreased lung function. The last decade we've already had a foretaste of the consequences of climate change; the heat wave in the summer of 2006 caused about a thousand heat-related deaths in The Netherlands and was rated the fifth natural disaster of that year (Hoyois et al., 2007).

The (re-)introduction of climate-sensitive urban design can mitigate the combined effects of climate change and UHI's, and improve outdoor microclimates in general. It consequently contributes to the physical well-being of people in the urban environment. Furthermore, climate-sensitive urban design can create conditions for a favourable indoor climate, which reduces the need for utilization of HVAC systems, leading to decreased energy consumption and related costs and environmental impacts. Hence, climate-sensitive urban design does not only contribute to the sustainability pillar of "People", as well as to the pillars of "Planet" and "Profit".

§ 1.3 Objective and approach

Careful design of the urban environment can contribute significantly to the physical well-being of people in the city. The World Health Organization claims that a significant part of the global disease burden can be prevented by healthier environments (WHO, 2006). They further state that urban design is an important contributor to healthy cities (WHO, 2014). The urban microclimate is one of the environmental factors affecting physical well-being and should therefore be in the focus of the urban designer. However, urban design and urban microclimatology have developed more or less separately over the last decades and therefore the application of climate-sensitive urban design in practice often proves to be difficult or neglected. The objective of this research is therefore:

Finding the best way to disseminate expert knowledge on urban microclimates to the urban design process, in order to support the urban designer in decision-making regarding microclimate-sensitive urban design measures that benefit the physical well-being of people.

In order to achieve the integration of knowledge from the specific field of urban microclimatology into the generic field of urban design, this dissertation will approach the subject from both points of view.

Following the theory of Müller et al. (2005) on learning processes, urban design and the development of expert microclimate knowledge can be seen as processes that follow the same sequence of creative, descriptive and normative steps, as depicted in Figure 1.1. In the creative step, ideas or concepts that exist in the mind are translated into physical form. These physical products can be examined and described in the descriptive step. In the normative step, the information gained in the descriptive step is interpreted and translated into ideas and concepts, which in turn can be input for the (next) creative step. This generic learning cycle applies to design processes, as well as scientific and deliberation processes. However, the processes differ in focus and aim. Design focuses on the creative step, aiming at developing design solutions to problems. Science focuses on the descriptive step, explaining certain effects, and deliberation focuses on the normative step. Müller et al. suggest that the focuses of the different processes complement each other at the larger scale of the whole planning cycle (Figure 1.2). Instead of being exclusive fields, design – in this case urban design, science – in this case microclimate knowledge - and deliberation can learn from each other and provide input for each other.

Focussing on the topic of climate-sensitive urban design, it would thus be important for urban designers to learn from urban microclimatology what the effects of common design decisions on urban microclimates are and where possible conflicts or win-win situations exist. From the point of view of microclimate experts it would be relevant to learn what the ingredients of urban design are – in order to study their effects -, and what kind of information benefits the synthesis-oriented designer. In order to place matters in context, it is also important to have normative information; what are desirable microclimate conditions with regard to the physical well-being of people?

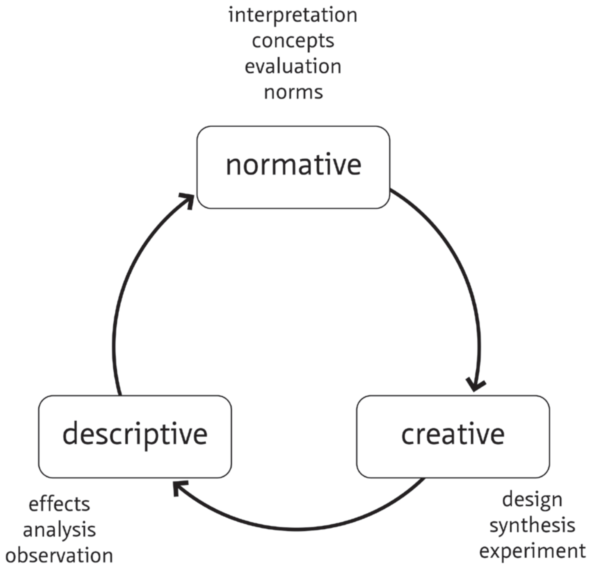

Figure 1.1
The generic learning cycle after Müller et al. (2005).

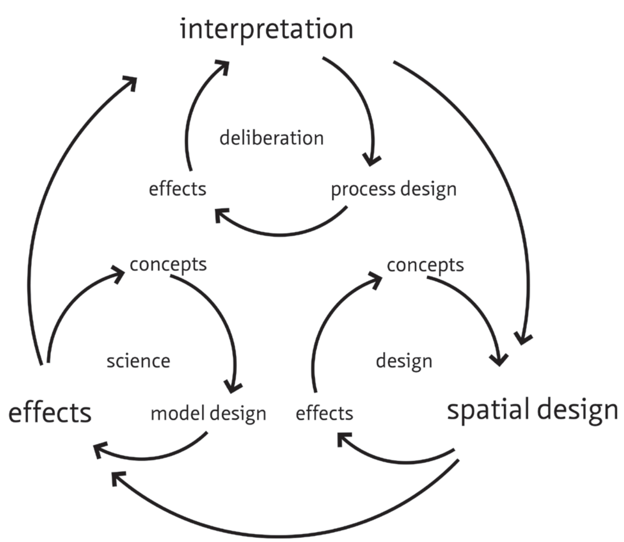

Figure 1.2
The indisciplinary cycle after Müller et al. (2005).

§ 1.4 Used definitions and limitations

§ 1.4.1 Physical well-being

The World Health Organization defines health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'. This definition includes aspects of well-being that are universal and quantifiable (the absence of disease) as well as aspects that are very diffuse and different for everyone, such as happiness.

Manchanda & Steemers (2012) capture this wide range of well-being aspects by defining a spectrum extending from the directly measurable (e.g., symptoms including body temperature, blood chemistry, etc.) to the immeasurable (e.g., quality, delight, pleasure, etc.). On one end of their spectrum lies "health", defined as the absence of disease, on the other end lies "happiness" (Figure 1.3). "Comfort" lies at the intersection of the two, and thus between quantifiable parameters (e.g., temperature, luminance, etc.) and qualitative concerns (e.g., perception, beauty, etc.). Manchanda and Steemers further point out that the parameters of comfort, health, and happiness are also further interrelated in that unhappiness and discomfort can lead to poor health, psychological or physical.

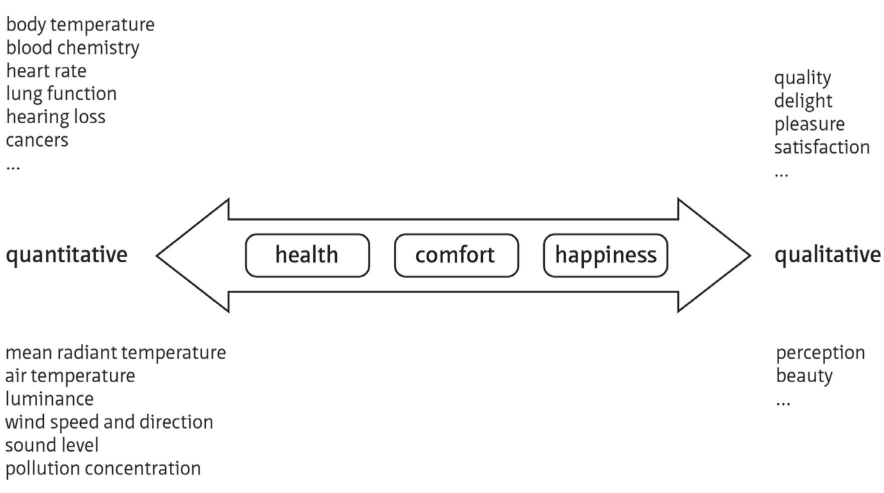

Figure 1.3
Spectrum of well-being, adapted from Machanda & Steemers (2012).

This research focusses on the aspects of well-being that are universal, looking for general criteria that apply to as many people as possible, as this is most useful for urban design. It consequently approaches Machanda and Steemers' spectrum from the quantitative side, focussing on physical well-being. Quantifiable health effects of the urban microclimate and its separate constituents will form the context for the search for desirable urban designs. When strictly quantitative well-being criteria do not provide enough starting points for design, the focus will move towards the right on the spectrum and the 'softer' indicators for comfort will be considered[1].

§ 1.4.2 Spatial limitations

Regarding urban climate, two scales are important (Oke, 1982, 1987). The city as a whole modifies the regional climate conditions, which results in differences in climate between the city and its surrounding (rural) area. This modified climate is prevalent in the Urban Boundary Layer (UBL) - above the city's roofs - and is rather homogeneous over the urban area. In contrast, the climate in the Urban Canopy Layer (UCL), below the roofs in the spaces between the buildings, can vary significantly within a distance of even a few metres (Figure 1.4). These microclimates form the immediate surroundings of people in the city and directly influence their physical well-being. The UCL is therefore the focus of this research.

1 Recent research into the influence of urban design measures on the Dutch urban microclimate, and in particular thermal comfort, that takes into account psychological factors – and thus is positioned more in the centre of Machanda and Steemers' spectrum – was carried out by Lenzholzer (2010, 2013).

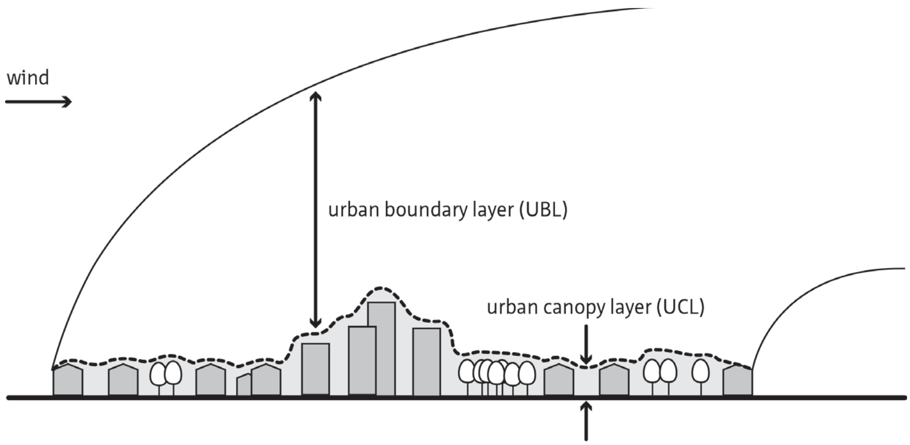

Figure 1.4
The Urban Boundary Layer and Urban Canopy Layer after Oke (1987).

This means that the starting point will be the small-scale level of the street (or other outdoor spaces bordered by buildings, such as squares, courtyards or gardens). In order to be able to present some useful urban design instruments and guidelines, connections to larger scale levels will be made, up to that of the neighbourhood (Table 1.1); up to this scale a certain homogeneity in the design of streets and buildings, but also densities and land use can be expected.

Name of area	Nominal radius [m]
Building part / urban part	1
Room / space	3
Building / plot	10
Building complex / block	30
Ensemble	100
Neighbourhood	300
Village / area	1000
Town / district	3000
Conurbation / sub-region	10000
Metropolis / region	30000
Sub national	100000
National	300000

Table 1.1
Levels of scale, adapted from De Jong & Rosemann (2002)

§ 1.4.3 Microclimate elements

Climate can be defined as the conditions of the atmosphere at a particular location over a long period of time; it is the long-term summation of the atmospheric elements (and their variations) that, over short time periods, constitute weather. These elements are solar radiation, temperature, humidity, precipitation (type, frequency, and amount), atmospheric pressure, and wind (speed and direction), (Encyclopaedia Britannica, retrieved 2014).

From the combined perspectives of urban design, i.e. the influence of the built environment on microclimates, and physical well-being, i.e. the influence of urban microclimates on health and comfort, not all of the elements of the large scale climate mentioned above are equally relevant when studying urban microclimates. This research includes solar radiation (including daylight), temperature and wind, and additionally air quality and noise, as these elements can have a significant impact on physical well-being in the urban environment, and are influenced by the built environment on the small scale of the urban canopy. Humidity will be touched upon in relation to the subject of thermal comfort.

In order to keep the amount of parameters manageable, the research is confined to the Dutch climate. Results and conclusions can however be seen as a rough guide for other temperate (European) climates.

§ 1.5 Research outline

Resulting from the objective and approach of this research, the main question is the following:

How can the design of urban neighbourhoods contribute to microclimates that support physical well-being and what kind of information and form of presentation does the urban designer need in order to make design decisions regarding such urban microclimates?

In relation to this main question, the following sub-questions can be formulated:

1 ***What aspects of urban design are relevant with regard to the dissemination of expert knowledge on urban microclimates to the urban designer?***
For the purpose of the integration of expert knowledge on microclimates into the field of urban design, it is important to know some things about urban design. An analyses of the ingredients of urban design is necessary; different plan elements are important on different scales and each of these plan elements can have a different effect on the urban microclimate. An urban designer does not make decisions regarding these plan elements on his/her own; every urban design process/project knows many stakeholders and thus many interests that need to be taken into account and weighed against each other. It is valuable to know who these stakeholders are and what the position and role of the urban designer in this multi—actor environment is. Furthermore, insight into the process of designing itself and different design frames is important, in order to be able to attune the offered expert information to the needs of the designer.

This sub-question will be treated in Chapter 2 by means of a literature review.

2 ***How do urban designers collect information and which forms of information presentation do they prefer?***
Urban design deals with wicked problems and is highly context-dependent. Urban designers have to select, filter and combine information on many different topics. Chapter 3 focuses on how urban designers use knowledge in the design process. As the amount of empirically based knowledge is limited in this field, a field research among Dutch urban designers was carried out, consisting of a series of interviews with urban designers as well as an online questionnaire consisting of questions on the same themes that were discussed in the interviews.

3 ***What is the impact of the urban microclimate and its constituents on physical well-being and what are related regulations and standards?***
The various climate elements all act directly upon the human body, which may accept or counteract their effects with physical and physiological reactions, such as sweating,

shivering, and the dilation or narrowing of blood vessels. This can lead to significant stresses on the body, with discomfort or even health danger as a result. Chapter 4 presents an overview of the most important effects of the urban microclimate and its elements on physical well-being, based on a literature review. Furthermore, standards and regulations with regard to these effects will be discussed. This information indicates what desirable microclimate conditions are and therewith serves as a normative context.

4 ***What is the influence of the built environment on the urban microclimate?***
Chapter 5 presents a literature review on the effects of different physical parameters of the urban environment on each of the microclimate elements. The most commonly used concepts in urban microclimatology are the single building or building block, the urban canyon and two or more interlinked canyons. Most of the literature is confined to this spatial concept. As we are interested in the urban canopy up to the scale of the neighbourhood, a translation of the available information to guidelines regarding common urban design plan elements will be made. Furthermore, the influence of materialization, vegetation and water will be discussed.

5 ***How can expert information on urban microclimates best be presented to the urban designer?***
In Chapter 6 the fields of urban design and urban microclimatology come together in a framework for a design-decision support tool, aiming at the dissemination of expert microclimate knowledge to the urban design process. This framework is based on the knowledge acquired in the previous chapters and combines information on common (spatial) urban design choices and information on the microclimate elements. It proposes a tool that has different layers of complexity in its information presentation, and provides the possibility to approach the information from different directions.

6 ***How can expert tools be employed to support the first phases of the urban design process?***
In Chapter 7 numerical tools will be employed to calculate the effects of two urban density parameters and street orientation on solar irradiation and wind shelter. The results of the calculations are compared to see where possible conflicts and promising combinations occur with regard to the spatial characteristics that create favourable conditions for each climate element. Such an integrative approach is essential for urban design.

The chapter further highlights the differences between expert tools and the design-decision support tool as proposed in Chapter 6 and discusses how they can complement each other.

Figure 1.5 summarises the research outline.

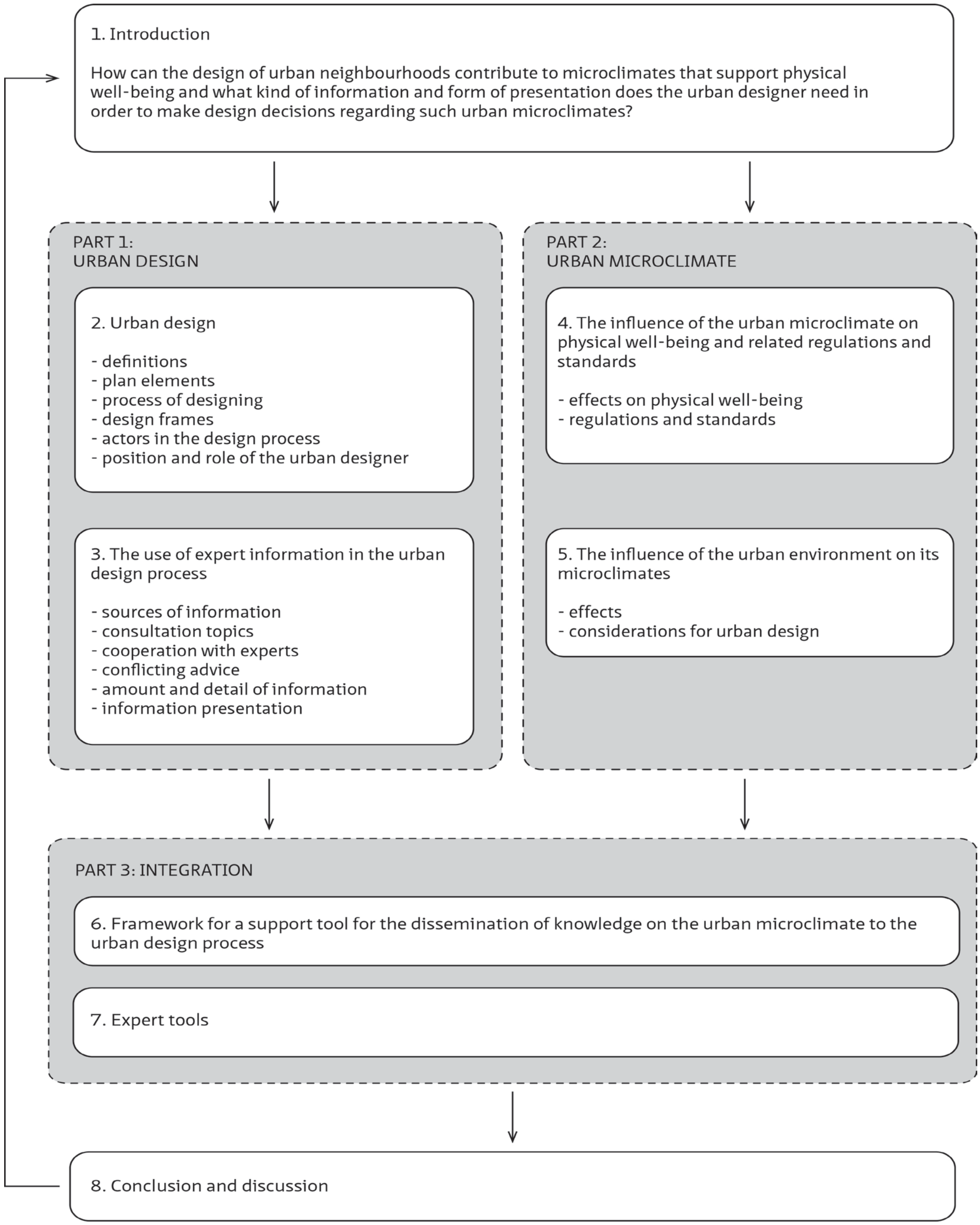

Figure 1.5
Research outline.

Common to both the design process and sustainable development is the need to emphasize the relation between different possible design decisions. A design tool developed by the proposed framework can help to bring these relations to light and support decision-making with regard to climate-sensitive design. This tool will enable designers and planners to estimate the influence of their spatial design choices on the (future) microclimate, helping them create conditions for urban microclimates that favour physical well-being.

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PART 1 Urban Design

2 Urban Design

§ 2.1 Introduction

In order to achieve the integration of knowledge from the field of urban microclimatology into the field of urban design, a successful transfer of information from the expert to the urban designer is paramount. In order to attune the information to the receiver, it is important to consider the relevant content-, process- and context-related aspects of urban design first. To start, it is important to know *what* is actually being designed in the field of urban design, because this information gives insight into the tools an urban designer has to influence the urban microclimate. This will be discussed by means of definitions of urban design from literature (Section 2.2) and by describing the various ingredients of urban design – the plan elements (Section 2.3). Second, it is important to know *how* it is being designed. Insight in the mental process of designing (Section 2.4) and the different design frames of individual designers (Section 2.5) helps to attune the microclimate information to the needs of the urban designer. Finally, it is important to consider the context of urban design; who are the other actors in the design process (Section 2.6) and what is the position and role of the designer (Section 2.7)?

§ 2.2 Definitions from literature

Many people, scholars as well as practitioners, have provided definitions of urban design. The focus of these definitions varies from the activities of the urban designers and their tasks, to matters of scale, related fields and professions, and the process and products of urban design. Below, a short overview of these definitions is given. Combined, the different definitions give a comprehensive image of the object of design in urban design.

Barnett (1982) gives a general definition of urban design: "Urban design is the generally accepted name for the process of giving physical design direction to urban growth, conservation, and change. It is understood to include landscape as well as buildings, both preservation and new construction, and rural areas as well as cities." He further describes urban design as "the designing of cities without designing buildings".

According to Portugali (2009), urban design deals with the interrelations between social structure, culture, economy, politics, architecture and other topics associated with life in the cities. The physical-spatial construct of the urban environment is a product of its users and in its turn exerts an influence on, and sets the conditions for the processes that take place within its spaces, such as the flows of people, products, services and waste, the use of public transport, the intensity of use of public space, energy consumption and other environmental impacts, and health and safety. Physical-spatial constructs furthermore influence (the development of) spatial cognition and therewith the identity of an urban environment. This identity in turn influences a city's appeal to people for living, recreation or otherwise as well as its business climate.

Lai (1988) describes urban design by comparing it to architecture: "Simply defined, urban design is the composition of architectural form and open space in a community context. The elements of a city's architecture are its buildings, urban landscape, and service infrastructure just as form, structure and internal space are elements of a building. Whether public or private in actual ownership, urban design comprises the architecture of an entire community that all citizens can enjoy and identify as their own. Like architecture, urban design reflects considerations of function, economics, and efficiency as well as aesthetic and cultural qualities."

The profession of urban design is traditionally most closely related to architecture and spatial planning. Generally speaking, the scale of urban design plans can be placed between spatial planning and architecture (Ryu, 2009). Where the fields meet, there is a significant overlap, and both professions can be engaged in making plans for the same scale[2]. Schurch (1999) defines several 'thresholds of scale' in urban design: the site-specific scale of an individual land parcel, the neighbourhood or district, an entire city, the region in which a city lies and corridors, which can be streets, freeways, rivers, canyons, etc. He states that a design intervention at one scale requires consideration of the context of the other scales. De Jong & Van der Voordt (2002) make a more elaborate distinction between levels of scale in the urban environment, based on their nominal radius (see Table 1.1).

2 In the Netherlands urban design is an autonomous accredited profession. Its relation to allied professions is therefore more distinct than it is in most other countries, although there are many similarities to be found.

Heeling (2001) emphasises the spatial tasks of the urban designer (translated from Dutch): "An urban designer gives objects and function a place in urban space. He distinguishes between public and private spaces, and determines where to build. He/she does this based on a chosen coherence, of which it may be expected to make the whole function properly." Heeling further specifies four aspects of urban design: the spatial-functional organization of territory – which is related to the profession of planning, the design and composition of the city plan, public space design and the drawing up of building rules or design guidelines, which set the frame for architectural elaboration.

Hajer & Sijmons (2006) relate the task of spatial planning - among which they also consider urban design - to the public interest. They stress the importance of "spatial propositions that match the interests of different stakeholders where possible and prevent conflicts". Other authors have also pointed out the public task of urban design.

Lang (1994) distinguishes four public interest concerns: "the welfare of the public, the health of the biogenic environment, the preservation of environmental elements that are likely to be of importance in the future and the concern for those who are not represented or underrepresented in the decision-making process; specific minority groups, children, the poor." As climate-sensitive urban design promotes physical well-being, it directly contributes to the welfare of the public. Designing beneficial urban microclimates should as such be considered an important design task.

In line with the definitions mentioned above, this research uses the following definition for urban design:
Urban design is concerned with shaping the physical environment to facilitate urban life and all the processes associated with it. Urban design combines and translates the interests of different stakeholders into spatial requirements and formulates a proposition for the realization of physical-spatial constructs in the urban environment. The next section will discuss what such a proposition – an urban design plan – consists of.

§ 2.3 Plan elements

An urban design plan contains different physical and spatial elements. These can be placed into different categories or layers according to their characteristics. There are different examples of such 'layer approaches' that in the Netherlands are used both as an analysis and design instrument. The former Ministry of Housing, Spatial Planning and the Environment[3] has developed the 'layer approach' for planning purposes, in which three layers of space can be distinguished: the primary layer, which consists of the soil and water system, the infrastructure networks, and the occupational patterns of living and working (Rijksplanologische Dienst, 2001). According to this approach, each layer sets the conditions for the layer above it (Figure 2.1). Choices regarding location and/or the design of functions in one layer should therefore be based on the layer underneath it.

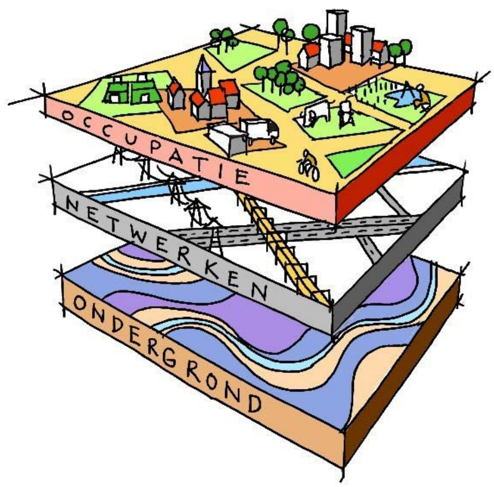

Figure 2.1
The layer approach by the former Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) distinguishes three layers of spatial planning tasks: substratum, networks and occupation.
Reprinted from Rijksplanologische Dienst (2001). Ruimtelijke verkenningen 2000: Het belang van een goede ondergrond, Den Haag, Ministerie van VROM.

A few Dutch scholars/designers have also developed layer approaches. That of Heeling et al. (2002) consists of five layers – territory, city plan, public space, buildings and use (Figure 2.2) - and can be considered as an elaborate variant on the layer approach of the former Ministry of Housing, Spatial Planning and the Environment. It is more focussed on urban design, but like the ministry's layer approach it is also based on the

3 Currently the Ministry of Transport and the Environment

idea of conditionality of one layer for the layer(s) above it. The design of the city plan takes up a central role in this approach; it is the mediator between a territory and its possible uses, and it regulates the boundaries between private and public space.

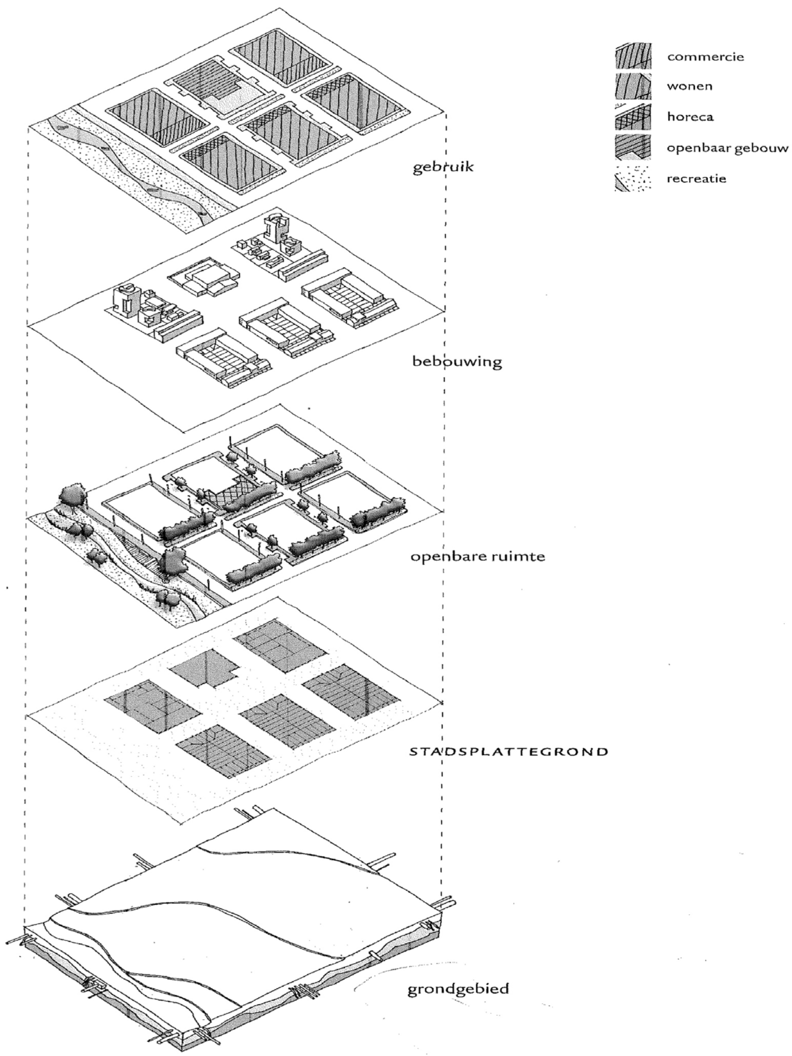

Figure 2.2
Layer approach by Heeling Meyer & Westrik.
Reprinted from Heeling et al. (2002). De kern van de stedebouw in het perspectief van de eenentwintigste eeuw. Dl. 1. Het ontwerp van de stadsplattegrond door Jan Heeling, Han Meyer en John Westrik. Amsterdam, SUN

The layer approach that is adopted in this research is that of Kristinsson et al. (1997). It consists of four layers: the layer of abiotic components such as water, earth, metals and other (raw) materials, the layer of biotic components which contains all living organisms, the layer of technical components which contains everything man-made, such as buildings, roads, transport systems, infrastructure, canals, and the layer of physical components; air, light, heat, radiation, evaporation, etc. (Figure 2.3). This model is the only of the three including the (micro)climate and as such is the most complete layer approach. The model furthermore includes exchanges between the man-made environment (the layer of technical components) and the other layers, thereby outlining not only the broader context of urban design, but also the influence– either positive or negative – man-made constructs exert on their environment by using from and adding to the other layers.

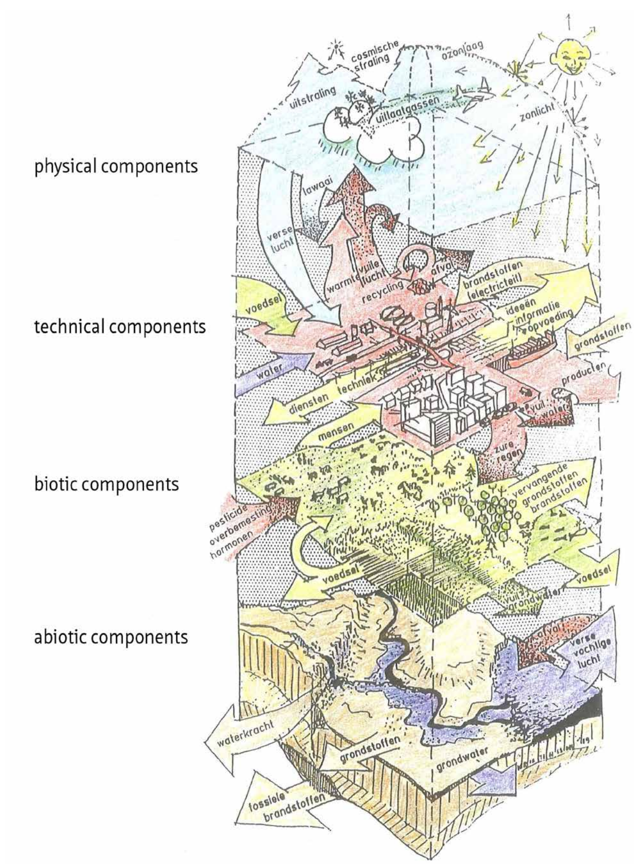

Figure 2.3
Layer approach by Kristinsson.
Reprinted from Kristinsson et al. (1997). Inleiding Integraal Ontwerpen. Delft, Faculteit der Bouwkunde, Technische Universiteit Delft.

An urban design plan can be made for different scales. On each scale different things need to be considered and different plan elements play a role. This research defines the following plan elements (Figure 2.4), based on Heeling (2001) and Heeling et al. (2002):

Spatial-functional organization

On the scale of the city or district the positioning of functions - working, living, commerce, industry, public and cultural facilities and green areas – in relation to each other, the existing environment and infrastructure is an important subject of design. Infrastructure itself is also a plan element; the main road and rail networks, water networks, and underground infrastructures of cables and wires[4], as well as the positioning of parking facilities, ports and stations. On this large scale also decisions are made concerning densities, concentration and dispersion.

City plan

On a smaller scale, corresponding to that of the neighbourhood, the abovementioned design concepts are elaborated. Design choices with regard to pattern, mesh, sections and junctions of the network of streets and other public spaces, such as avenues, boulevards, canals and squares are made. The islands enclosed by this network are divided into plots to be built upon. The dimensioning and orientation of these plots set the conditions for the type of buildings that can be developed and their relation to the surrounding public space.

Public space design

On the scale of individual public spaces designs are made for street profiles – symmetric or asymmetric, mixing or separation of modes of transport, sidewalks, parking – junctions and interchanges, and the layout of enclosed spaces such as squares and parks. Paving materials, vegetation and street furniture, such as benches and lampposts, are also decided upon.

Rules for architecture

To have some say in the expression of the vertical boundaries of public spaces, the urban designer can set up rules or guidelines for the architect concerning building lines, the proportioning of the building on the plot, building heights and architectural articulation of the façade(s) facing public space.

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4 Underground infrastructures are usually designed by the civil engineer.

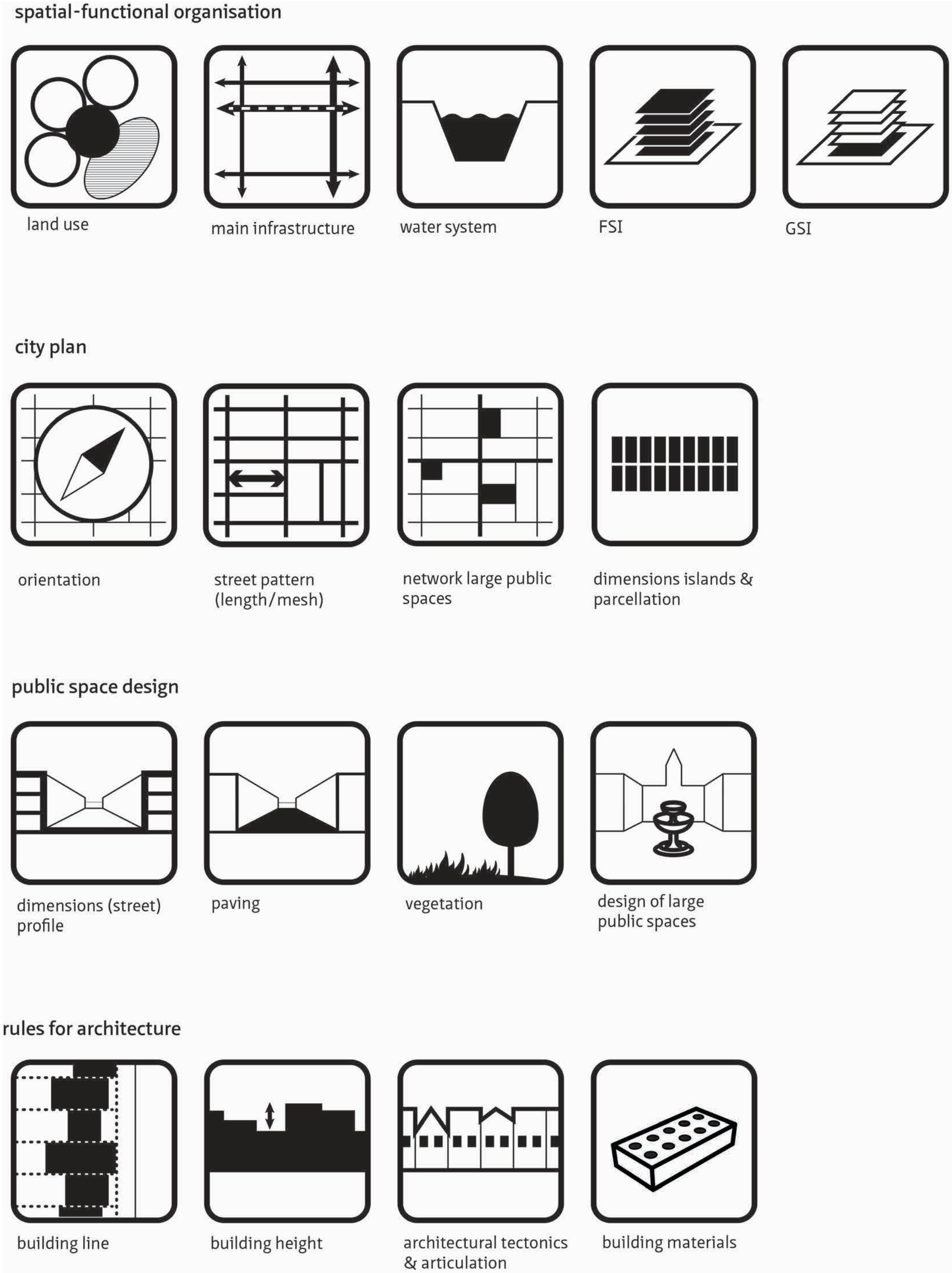

Figure 2.4

Plan elements in urban design.

The great majority of these plan elements belong to the layer of technical components in the layer approach by Kristinsson (Figure 2.3), only the water system and vegetation belong to the layers of abiotic components and biotic components, respectively.

This section elaborated on urban design plans and their ingredients, the next section will describe how an urban design plan is conceived, focussing on the cognitive process of the designer.

§ 2.4 The process of designing

The previous sections show that there are many physical, social and economical issues that place constraints and quality demands on the design of the urban environment, such as infrastructure and mobility, soil conditions, water management, the environment, the housing market, land prices, employment, culture, safety, health and many more. Urban designers thus have to deal with many types of knowledge. Furthermore, the diversity of design solutions, as well as the diversity of contexts or perspectives to function in, is very large. Consequently, the diversity of rational reasons (determined by context) to opt for a final alternative is even larger (De Jong & Van der Voordt, 2002).

Such complex problems are commonly referred to as wicked problems (Rittel & Webber, 1973): – ill-defined, ambiguous problems that are hard or impossible to solve because of incomplete, contradictory and changing requirements, which are often strongly stakeholder-dependent. In order to be able to deal with these wicked problems, designers initially focus attention on a limited selection of constraints (Lawson, 2006). This restricts the range of possibilities to a small class of solutions that is cognitively manageable (Darke, 1979). Based on this first selection of constraints a conjecture is made and consequently tested against the problem as understood so far. The initial solution is adjusted to improve its fitness. This process is repeated – often for different sub-problems, and including more and more constraints - until a satisfactory solution is found.

The process described above does not follow a pre-established strategy. The global process can be described as top-down, but many deviations are made through decomposition in partial problem-structures (Visser, 1992). Wide-scope and in-depth approaches are used alternately. In-depth strategies are used to explore solution concepts for smaller sub-problems, and through synthesis these solution components are compared and combined in the larger picture (Cross, 1982). Through this process of coming up with possible solutions a designer learns about the problem. Lawson states that 'both objectives and priorities are quite likely to change during the design process as the solution implications begin to emerge.' The design problem is thus reframed several times as insight increases through the making of designs; problem space and solution space evolve simultaneously.

Drawing or sketching is a key activity in designing. A sketch or drawing is not only a result; it has several other, important functions during the design process. Firstly, a sketch functions as an external memory aid. As the cyclic process of problem-framing and making and testing solutions is too complex to perform completely in the mind, sketches externalize the visual ideas in the mind, which can subsequently be used to access other information from the mind (or elsewhere) at any desired moment. Furthermore, sketches and other visualizations are often reinterpreted when reviewed. Designers can associate their own depictions with a new concept, function or meaning. This new way of seeing may apply to separate elements of the drawing as well as (spatial) relations between these elements. Designers thus cognitively interact with their own sketches at higher levels than just the physical. Sketching helps them to decide when to think of functional and perceptual issues and how (Ferguson, 1978; Suwa et al., 1998; Purcell & Gero, 1998).

In this section designing was described as an iterative process consisting of a variety of (mental) activities: problem-framing, formulating possible solutions and testing these solutions. The framing of the design problem – and consequently the formulation of solutions - is usually not objectively based on the design brief, but is different for each designer, as will be described in the next section.

§ 2.5 Design frames

The concept of problem-framing in which designers are focussing on a selection of constraints and solutions is widely acknowledged in the study of design problems, but the particular processes have a domain-dependent character. At this point there is a wide range of empirical studies on software design, mechanical design, industrial design and architectural design (De Vries, 1994), but not on urban design. Available knowledge on problem-framing in architecture and design in general, however, give an indication on the possible types of problem-framing by urban designers.

Lawson (2006) distinguishes four types of constraints that arise in design problems: radical constraints, which are constraints regarding the primary purpose or function of the object to be designed, practical constraints, which can be about materials, structures or systems, formal or geometrical constraints, and symbolic constraints.

The choice of constraints at different moments in the design process relates to the designers experience, expertise, resources and frame of reference. The designer is aware of this individual framing of the design problem (Dorst & Cross, 2001).

As Van Bakel (1995) describes for architects, designers can have different starting points[5]. Some prefer to start from the program, others start from a concept, and yet others prefer to begin from the site or existing situation.

A program-oriented designer uses the design brief as a starting-point as well as evaluation instrument. The program-oriented designer is likely to start searching for the key problems to be solved. He may formulate a set of rules based on the design brief to facilitate decision-making. This kind of designer will most likely start with constraints which Lawson would call 'radical' constraints; constraints regarding the functions and purposes of the design.

A concept-based designer starts forming a mental image of the design; this image can be formal, functional or other. Shape concepts – an initial set of formal or geometrical constraints - are less common in urban design then they are in architecture. Functional or symbolic concepts, such as 'a child friendly neighbourhood', or 'the green city' are more common amongst urban designers.

A site-oriented designer tends to be rather pragmatic (choosing practical constraint as defined by Lawson), using what the site and its surroundings provide, such as features of the underlying landscape, or other existing structures, elements or program. The characteristics of the plan area are guiding for the application of the program. This design style is probably the most common in urban design, as this is the most context-sensitive design field.

The previous two sections described the design process as it takes place in the mind of the (urban) designer. The urban designer, however, is not the only person involved in the urban design process. Many actors factor into the process and influence its outcome. The next section will address the different types of actors that can be involved as well as their possible roles.

5 Van Bakel calls these starting-points 'design styles', but as this term is commonly used in relation to the characteristics of appearance the design object, the term 'design frames' is used in the context of this dissertation.

§ 2.6 Actors in the urban design process

One actor that is always involved in the urban design process is the government, either local, provincial or national or all three. They are often clients – although increasingly stepping back as direct principals - and furthermore they are responsible for the policy regulations urban design plans have to comply with. Project developers and (housing) corporations have also become important clients over the last decade; they commissioned 33% of the work done by Dutch urban designers in 2009 (Van Rossum et al., 2010).

Societal organizations, interest and pressure groups as well as individual citizens are often stakeholders in the design process. They are usually given the opportunity to ask questions and give feedback on one or more occasions, but are more and more often also actively participating in the design process.

Other actors involved in the urban design process are experts, commissioned either by the client or the designer himself/herself. These experts can come from the public as well as the private sector - consultancy firms, law firms, knowledge and research institutions, municipalities, etc. They inform the process by providing information on (desirable) possibilities as well as restrictions. The amount of experts/fields of expertise involved has increased over the last decades. One reason for this is that the sectors traditionally incorporated in urban design, such as road infrastructure planning, housing development, leisure area development, and water management have increasingly specialized and have become separated disciplines. Another reason is that urban design has become increasingly integrative, trying to include as many fields of importance as possible. More topics have emerged, such as environmental impacts of urban areas, reuse, the conservation of historical cityscapes, monuments, nature and landscapes, area development, mixed use, the network city, globalization, the design of identities, etc. In order to achieve successful integration of all fields into one design, a good exchange of information between expert and designer is crucial.

The inclusion of more topics and the democratization of the decision-making process have resulted in an increase in the number and type of actors that influence the process and its outcome. As a consequence, designing for the urban environment has become increasingly complex.

§ 2.7 Position and role of the urban designer

Traditionally, the majority of the urban design professionals were in the employ of municipalities. As municipalities increasingly outsourced their urban design activities (like many other activities), a professional market sector emerged. These urban design firms and freelance advisors would mainly be responsible for the practical urban design work commissioned by their colleagues from municipalities, who would be responsible for supervision of the plans and testing them against policy. The current picture is quite different; municipalities are no longer the primary employer and their role as client is also diminishing. In 2009, 32% of the Dutch urban design professionals worked for the government (largely municipalities) or universities and 68% worked in the market sector (Van Rossum et al., 2010). In 2013, this number had risen to 71% (Pijpers-van Esch et al., 2013)

With the government stepping back as a client, other parties take up this role. More and more often there is not one client for a commission, but different actors from public and private parties form increasingly complex partnerships for the development of spatial plans. This is also stimulated by the national government, as stated in the Fifth Policy Document on Spatial Planning by the Ministry of Housing, Spatial Planning and the Environment (Ministries of VROM, LNV, V&W & EZ, 2004). A lot of effort and time goes into establishing consensus between all participants (Hajer & Sijmons, 2006), which results in more emphasis being placed on the process than the outcome: the design. Because of the complexity of the process and the multitude of actors involved, the urban designer more often sits in only on a part of the planning process, which reduces the influence of the designer on the outcome (Van Rossum et al., 2010).

The type of commissions for urban designers is also changing; there is less need for urban expansions, but more for urban transformation and renewal plans, which are often more complex. Related to this is the changing scale of the assignments; small-scale interventions in the existing urban environment, often to achieve changes in the system at the larger scale, rather than large-scale projects. The generation of value other than just economical is also increasingly part of the assignment (Pijpers-van Esch et al., 2013; Van Rossum et al., 2010)

In order to approach the increasingly complex design problems in an integral way, urban designers more often work together with professionals from related design fields: urban planners, landscape architects, architects and interior designers. Furthermore, urban designers need to acquire knowledge and skills from these design fields, making the distinction between the different design fields less clear.

This changing plan context combined with the extensive partnerships between public and private parties is causing a shift in the role of the urban designer. As the number of participants with different interests increases, the urban designer becomes more of a communicator, trying to establish consensus and acquiring public support. As a consequence, the urban designer spends a lot of time in meetings and consultation, and especially urban designers from municipalities are often more involved in management and assessment.

Along with the role of the designer, the role of the design is also changing. It functions more as a medium for deliberation and decision-making – bringing people together - as well as a guideline for the exploration of the legal possibilities and consequences of a plan rather than a result of a fixed process. The design has a political role in this sense (Hajer & Sijmons, 2006). There is often more focus on the design as a vision, than on the elaboration of the design than before. Research by design is replacing the traditional survey research.

§ 2.8 Conclusion

Urban design is a field of design that is concerned with making plans for physical-spatial changes in the urban environment in order to facilitate and give direction to life in the city and the different processes related to it. Such plans can be made for different levels of scale, focussing on different physical-spatial elements. These plan elements are:

- Spatial-functional organization
  - Land use
  - Main infrastructure
  - Water system
  - Gross floor space (FSI)
  - Compactness (GSI)
- City plan
  - Street pattern
  - Orientation
  - Network of larger public spaces
  - Dimensions islands and parcellation
- Public space design
  - Dimensions (street) profile
  - Paving
  - Vegetation
  - Design of enclosed spaces

- Rules for architecture
  - Building line
  - Building height
  - Architectural tectonics and articulation
  - Building materials

The urban design task is a complex one as there are many actors and interests involved that place different – incomplete, contradictory and/or changing - constraints and quality demands on the design and the design process. Furthermore, the amount of possible scenario's and design solutions is very large, rendering it virtually impossible to come to a single optimal solution.

To handle this complexity, the urban designer starts with a small selection of constraints, iteratively working to a design solution, incorporating more and more constraints. In this process focus shifts between sub-problems and solutions and both divergence and convergence strategies are used. The selection of constraints, also called 'problem-framing', happens subjectively. Three types of design frames can be distinguished: program-oriented – starting from radical (functional) constraints, concept-oriented – starting from formal or symbolic constraints and site-oriented – starting from practical constraints.

From the above it can be concluded that in order to make design decisions, the urban designer needs information on many different topics. How he/she collects information is the topic of the next chapter.

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3 The use of expert information in the urban design process

§ 3.1 Introduction

The previous chapter discussed the complex nature of urban design; dealing with a large amount of constraints and uncertainties. Urban designers have to select, filter and combine information on many different – sometimes very specific - topics. How they do this is the focus of this chapter. The research question is the following: How do urban designers collect information and which forms of information presentation do they prefer? First, a theoretical approach to the subject will be presented (Section 3.2); what is known on how urban designers use information in the design process? As the amount of empirically based knowledge is limited in this field, a field research among Dutch urban designers was carried out. Before describing the results of this field research (Section 3.4), the methodology of the research will be explained (Section 3.3). Based on the results, conclusions will be drawn and suggestions for the presentation of expert information will be presented (Section 3.5).

§ 3.2 Theory on designers using information

A clear and straightforward transfer of expert information from the different fields of knowledge involved to the design process is a challenge. This knowledge transfer is frequently found to present problems in practice, often attributed to a difference in 'language' spoken by experts and designers. This difference in languages is a consequence of differences in focus, method and values between the fields of research and design (Cross, 1982; Müller et al., 2005); where science is problem-focused, design is solution-focused. Science is descriptive, using analysis, measurement and observation; design is creative, using synthesis, pattern-formation and sketches. Science looks for 'the truth', design for appropriateness.

The cognitive process of the urban designer as described in Section 2.4. asks for information that helps selecting constraints and generating appropriate (partial) design solutions. Such information should thus focus as the designer as the receiver of information. In addition, the urban designer also needs information to communicate with the other actors within the design process; the urban designer acts in a multi actor environment employing participative design strategies (Tjallingii, 1995, Conte & Monno, 2001). The same information may serve both purposes, but that is not always the case.

As the aims of the second perspective are shared ambition, perception, comprehension and responsibility (Checkland, 1999), the level and form of communication will direct the information that is used. In this case the form of information will also be determined by the usefulness of information in a multi actor process, depending on the phase in the process and the actors one has to address (Zlatanova et al., 2010).

In an effort to structure the design process from a functional perspective Chermayeff & Alexander (1965) found that the complexity of design makes it impossible for the designer to research the relation between all variables involved. They placed their hope in the use of computers to process the huge amount of information to facilitate the designer. The studies that followed this path have resulted in ways to structure data from a problem-orientated perception (Sisjanin, 2001). The presumption with such computer aids is the clarity of all data involved, which is usually not the case with wicked problems.

Another way in which the computer is employed in an effort to assist the designer is the creation of simplified versions of expert computer programmes by the experts themselves. These 'design tools' are usually still tools for analysis – usually some sort of design is requested as input - and therefore do not sufficiently support the way in which designers work. Furthermore, such simplified analytic programmes bring the risk of modelling errors and misinterpretation, as the designer often lacks the theoretical knowledge necessary to interpret the results (Yannas, 1989). Moreover, the amount of computer programmes the designer should employ to cover all knowledge fields involved is too extensive for practical purposes.

Analytical (computer) programmes thus do not help the urban designer. What is more, from the viewpoint of the designer, a focus on information systems for structuring the design process leads to an increase in the amount of solutions (De Vries, 1994), complicating the design process Therefore, other ways of transferring information should be employed. To investigate which are the most promising, a field research was carried out among Dutch urban designers. The perspective of the urban designer as the receiver of information was the focus of the research. Emphasis lay on the intersubjectively perceived necessity of information; the necessity of information for the quality of the design or design process was not part of the research.

§ 3.3 Methodology of the field research

Since little information is available on information collection by urban designers[1] explorative interviewing was chosen as the method of study. The interviews were carried out in the period of December 2009 to July 2010. To cover as much of the diversified field of urban design as possible, the interviews were held with practicing designers of urban design firms of different sizes as well as urban designers from municipalities, and a landscape design firm with affinity for urban design. In total, sixteen designers from six different firms and two large municipalities were interviewed. Eight interviews were held; five with individual designers and three with small groups of designers. In this setup, individual interviews have the function of showing the diversity and scatter of answers, and group interviews have the function of revealing intersubjective values and to see whether a debate is taking place within the profession.

The interviews were semi-structured; there was a list of themes to be covered, but the order in which they were discussed was flexible and depended on the direction in which the interview was leading. The themes to be discussed regarded different parts of the main research question: sources of information, actions in case of specific questions beyond the scope of the designers own knowledge, the consultation of experts or advisers, actions in case of expert advice conflicting with design ideas, and preferences with respect to amount, detail and representation of information. Questions were open ended in order to allow for the interviewees to talk relatively freely and to avoid pre-defined responses as much as possible. The interviews were held in the participants' offices and each took about one hour to an hour and a half.

In addition, a questionnaire was distributed online from January to June 2012. Designers were invited to complete the questionnaire via the website of the professional association of Dutch urban designers and planners (BNSP). Furthermore, a selection of designers was invited personally to fill out the questionnaire by email. In total, fifty-eight people completed the questionnaire, of which thirty-three were schooled as urban designer, eighteen as architect, three who received both educations, one landscape architect, one architect/landscape architect and one other.

The questionnaire consisted of questions on the same themes that were discussed in the interview. The questions were posed in the form of a list of items (e.g. information sources or representations of information) accompanied by a bipolar 7-point rating scale, either relating to the frequency of use (never - always) or assigned importance (not important – very important). The answers were weighed to provide an insightful rating scale of all aspects; an answer of 1 ('never' or 'not important') was given a score of minus three, an answer of two was given a score of minus two, and so forth. An aspect could thus receive a maximum score of minus or plus 174 (58 * (-)3).

The interviewees and respondents of the questionnaire were not informed about the topic of this dissertation, to minimize bias in their answers. The only question about the urban microclimate was therefore stated at the very end of the questionnaire[6].

The interviews and questionnaires were in Dutch; for this dissertation questions and answers are translated in English as accurately as possible. The outline of the interviews and the questionnaire can be found in Appendices I and II.

§ 3.4 Results

§ 3.4.1 Sources of information

In three of the eight interviews, the first given answer on the question which sources of information the interviewees usually use in their design process was 'talking to other people'. In another three interviews 'talking to other people' was also mentioned, but as a later answer. Categories of 'other people' mentioned were: the client, users, residents, aldermen, experts, and colleague-designers from their own firm or other firms. An almost equally popular information source is the internet; it was mentioned in six of the interviews, although only in one interview as the first answer. Search engines are frequently used for a first scan, but for reliable information websites of knowledge and research institutions, profession-related websites, websites of municipalities and project websites are consulted. The internet also functions as a portal to find experts. In five interviews other plans or designs were said to be an important source of information; these plans or designs can either their be previous own work or work from other firms. The function of such 'example plans' can be rather concrete, for example in the case of earlier (stranded) plans for the same plan area, but other plans can also be inspirational. The interviewees often mentioned the use of other plans as reference images for their clients. Furthermore, maps – topographical, historical and soil maps - were mentioned to be an indispensable source of information.

6 This chapter discusses the questions in a different order than stated in the interviews and questionnaire.

Other sources that were brought up by the interviewees were (in order of times mentioned): books, experts, articles, workshops/symposia (sometimes organized by the design firms themselves), policy documents, reports, excursions to the site, photographs and paintings.

To further explore possible information sources of importance the interviewees were asked what they do when they have a specific question on which information is not directly available to them. The answers overlapped with those of the previous question; this time almost all of the answers involved consulting other people. The consultation of experts, either internal or external, was mentioned in four interviews, consultation rounds with different actors involved were mentioned in three. Again also the internet, books, the site, other plans and articles were brought up. One interviewee answered that he would first make an assumption based on experience or handbooks, report this to the principal and look for the exact information later.

The questionnaire presented the respondents with a list of possible information sources. The respondents were asked individually to rate how often they use these sources on a scale of 1 (never) to 7 (always). Figure 3.1 shows the response to this question. It can be seen that the answers from the questionnaire agree well with the answers to the open question in the interviews; 'other people' represented in the questionnaire by 'meetings', 'experts', 'client' and 'official bodies' receive high scores on the rating scale. Example projects also score high, as does the Internet. Notable is the negative value for scientific journals. This may partly be due to their difficult accessibility, as indicated by some of the interviewees. Laws and standards are also scarcely used. A possible explanation could be that the designers consult advisers or experts on the usually specific topics that laws and standards deal with.

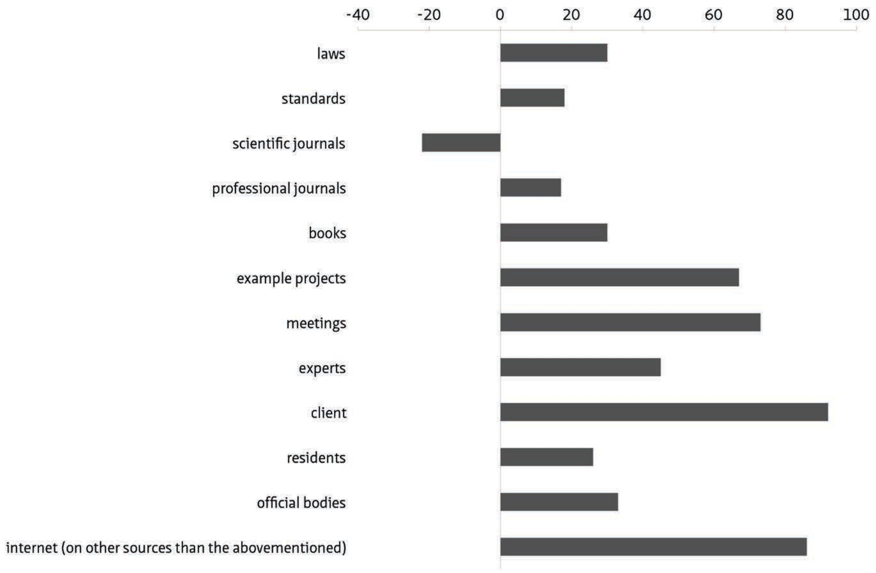

Figure 3.1
The weighed frequency of the consultation of information sources (minimum/maximum score -/+ 174).

§ 3.4.2 Consultation topics

All interviewees acknowledged seeking advice from experts on a regular basis; experts from knowledge institutions, legal advisers, urban planning economists, district water boards, and all kinds of engineers and related professionals; traffic experts, civil engineers, building services experts, structural engineers, soil experts, hydrologists and ecologists were all mentioned frequently. Furthermore, some of the interviewees also indicated to consult other designers, such as architects, landscape architects or designers from specialized design firms, and even artists. Culture historians were also mentioned as valuable advisers.

The different fields of expertise mentioned in the interviews can also be found in the questionnaire; the respondents were asked to indicate – again on a 7-point rating scale - how often they would seek information on specific topics and how important they consider it to take these specific topics into account when designing (Figure 3.2). Although 'seeking information' is much broader than consulting an expert, the combined results of the interviews and questionnaires still indicate which topics play a role in current Dutch urban design practice.

For almost all topics the considered importance agrees well with the frequency of inquiry on these topics. Water management, users, soil, and vegetation are thought to be almost equally important, closely followed by infrastructure, environment, societal developments and history. History is the topic most often consulted on, followed by infrastructure, soil and vegetation.

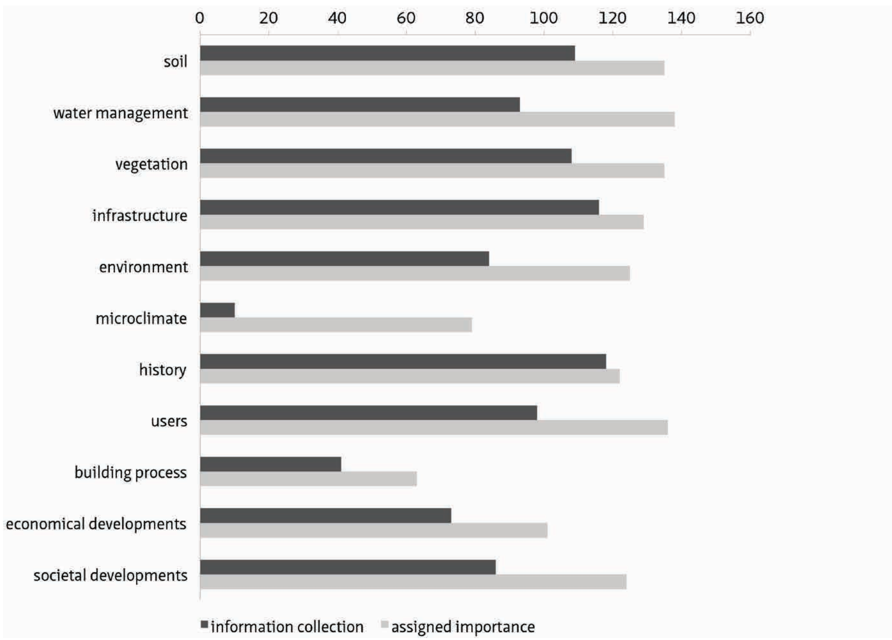

Figure 3.2
Comparison of the weighed frequency of the inquiry into information topics and the weighed assigned importance of these topics (minimum/maximum score of -/+ 174).

Most striking are the results for the topic of microclimate; almost all interviewees and respondents find it important, but the majority of them seldom collect information on it. Furthermore, considerable differences exist between the various elements of the microclimate – both in frequency of inquiry into these topics as well as in assigned importance (Figure 3.3). It seems that climate elements for which regulations or standards exist are more in the focus of the designers than those without regulation. Sound and solar irradiation receive the highest scores, followed by daylight access and air quality. Little information is collected on wind comfort, although its assigned importance is significant. This discrepancy is even greater for air movement and temperature.

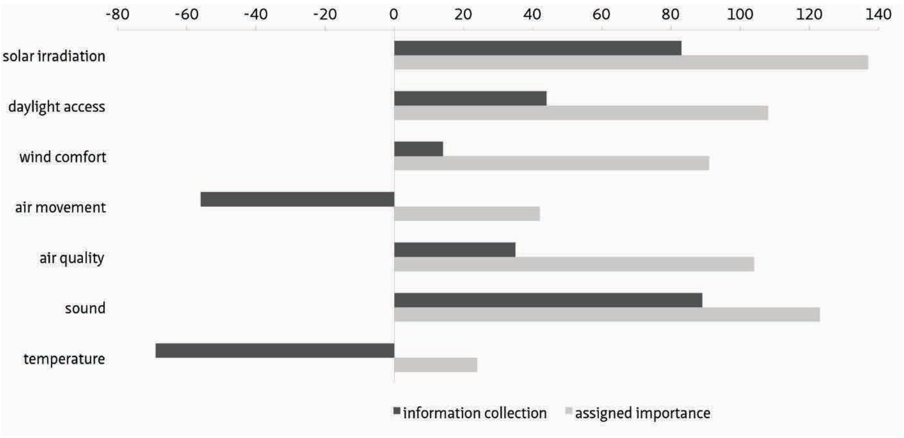

Figure 3.3
Comparison of the weighed frequency of the inquiry into information on the various microclimate elements and the weighed assigned importance of these elements (minimum/maximum score of -/+ 174).

§ 3.4.3 Cooperation with experts

All of the interviewees strive to involve the necessary experts in an early stage of the design process. The results from the questionnaire presented in Figure 3.4 show that the same is true for the consultation of information in general. The figure conveys a clear trend; most information is collected in the orientation phase, decreasing through the sketching and elaboration phases. Relatively little information is collected in the evaluation phase.

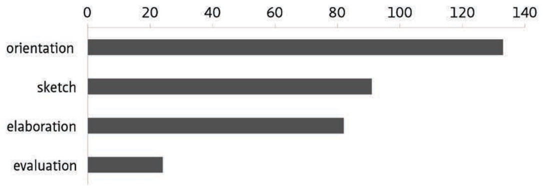

Figure 3.4
The weighed frequency of information collection in the different phases of the design process (minimum/ maximum score of -/+ 174).

During the interviews the question was posed how many meetings the designers would have with an expert during a project. All answered that multiple meetings would be arranged, and that working with experts in a cyclical process is important for the quality of the outcome. One of the larger firms explained how they form project teams for sub commissions within a project. Such project teams consist of the firm's own people as well as external experts and often get their own space within the firm's office building to promote interdisciplinary cooperation.

In four of the eight interviews the value of the expert that can think along with the designer was expressed. It is highly appreciated when the expert has an integral outlook and that he/she is able to (temporarily) let go of his/her assaying attitude in order to come to practical solutions, at least in the first stages of the design process. In two interviews a preference was expressed for experts that can filter the information for main issues and side issues – in relation to the design issues at hand - and communicate these clearly to the designer. One of the interviewees explicitly mentioned that filtering information also means leaving things out. Some interviewees said to be looking for the bandwidth of possibilities in the experts' advice. Another interviewee expressed the need for guidelines and different options.

In the designers' view, experts are often too accurate for practical purposes and seem afraid to make rough estimates or assumptions, which are needed in the first stages of the design process, and wait with the supply of information until they are absolutely certain of their advice.

Academics are not often consulted. One of the interviewees made a very conscious distinction between advisers that provide inspiration and advisers that provide boundaries.

§ 3.4.4 Conflicting advice

The designers were asked what they do when they get expert advice that conflicts with their design (concepts). Most interviewees said they try to avoid conflicting advice by involving experts in an early stage and by making them part of the process. This also benefits the quality of the design. If conflicting interests arise nevertheless, some interviewees first try to find out whether there is no misunderstanding between the designer and the expert, others may ask for a second opinion or find another expert; 'one that is more flexible or practical', depending on the seriousness of the conflict, risks involved, feasibility and plan phase. Weighing one interest against the other can be quite difficult because of the great variety of aspects involved. In one of the group interviews it was mentioned how they would deliberate on possible (design) solutions and their consequences and leave the final decision up to the principle, after informing him/her on the possibilities and their viewpoint on these possibilities.

All interviewees indicate they change their design if proven necessary. One of the interviewees explained this to be natural and essential to the design process; “the design can be seen as a hypothesis that is being tested over and over throughout the design process, and subsequently adjusted to improve its fitness”.

§ 3.4.5 Amount and detail of information

The question on preference of amount and detail of information to receive yielded quite different responses. In four of the eight interviews the designers answered that they wanted as much information as possible, with as many detail as possible, so that they can select the information that is important to them themselves; “people often don’t know what they have” or “cannot assess its (the information’s) value”. An overview of all information available can also provide insight in “what are the controls to solve a problem”. In addition to this, a few interviewees remarked they prefer the original information documents instead of edited or abstracted information for this same reason of having the possibility of making their own interpretation of the information. The other half on the contrary, reported to prefer global information first and more detailed information if needed later on.

§ 3.4.6 Representation of information

In six of the interviews visual information was indicated to be the preferred form of information, which was specified by some as information presented in maps or drawings. In five interviews it was mentioned that visual information in abstract form such as diagrams and tables is appreciated. In four interviews it was emphasized that information should be spatial. It was mentioned by some that although they preferred visual information, a combination with other forms of information is important for completeness and deepening. Verbal information was mentioned in half of the interviews, which is in agreement with ‘talking to other people’ being mentioned as an important source of information.

The questionnaire also inquired after the frequency of use of several forms of information representation, for the purpose of collecting information as well as a means of communication about their own work. Figure 3.5 shows the responses to these questions. It can be seen that photographs, drawings, verbal and written information are very important forms of information exchange, both for consultation and communication. Photographs are more often used for the collection of information than for the communication about own work, while for verbal information it is the other way around. Numerical information, scale models and computer programmes seem to be the least popular among the designers; most respondents hardly use them.

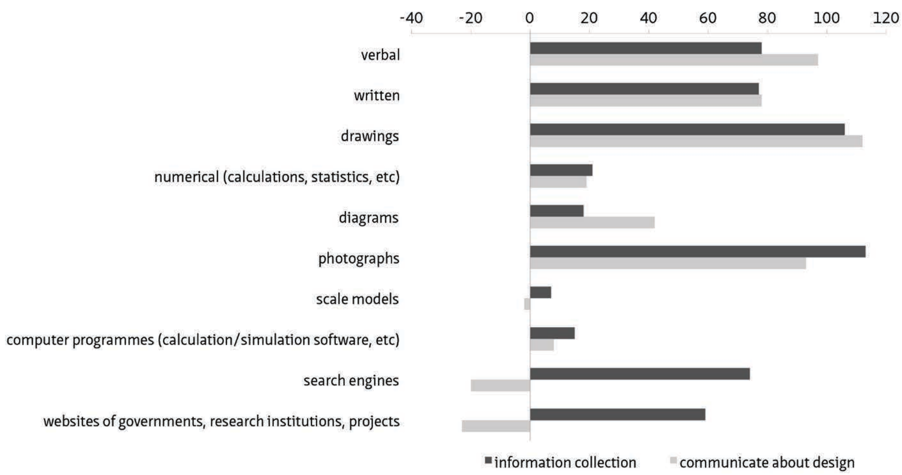

Figure 3.5
Comparison of the weighed frequency of the use of different forms of information for the purposes of collecting information and communicating about own designs (minimum/maximum score of -/+ 174).

§ 3.5 Conclusions and discussion

The objective of this Chapter has been to expand our understanding of how urban designers collect information and which forms of information presentation they prefer. A series of interviews with urban designers has been carried out, followed up by a questionnaire. The results of the interviews and questionnaire point in the same direction: visual information in the form of photographs, drawings and maps are of great importance, just as verbal information from other actors and fellow designers. The verbal and visual information mentioned may be more practical and specific for the design task at hand, giving direct input for the design process. As urban design is context specific, this may explain the primary need for specific information and not for generic information; information from scientific journals, books, standards and laws is less important to the urban designers. Written (textual and numerical) specialist information may be more objective and precise but needs a translation within the given context of the design. Especially numerical information is unpopular. Numerical information appeals to people in search of measurable objective information, whereas this occupational group seems to be looking more for normative information.

Within the category of verbal information sources clients and meetings are more popular than experts. This again may have to do with the type of (generic) information that experts bring in, and – related to this - the difference in approach between designers and experts as mentioned several times in the interviews; in the designers' view, experts are often too accurate for practical and wait with the supply of information until they are absolutely certain of their advice. This approach differs from that of the designer; he or she first makes an assumption based on experience or handbooks and looks for the exact information later, as one of the interviews answered when he was asked what he would do when information is not directly available.

It is interesting to see that residents are not of great importance as a source of information, but that urban designers use experts or other sources to get knowledge about the users of their plans. Furthermore, the designers take themselves as a reference; according to them, if they like the design so will the user. All interviewees seek knowledge from experts and here the physical environment is of more importance than the non-physical; information is collected much more frequently on topics such as soil, water management, vegetation and infrastructure, than on microclimate, building process and economical developments – although the interviewees do attribute some importance to these topics. The focus of Dutch practice seems to lie on urban design as a thing rather than urban design as an ongoing process and an experience.

The results show that very little information is collected in the evaluation phase. This raises the question whether little information is necessary when evaluating or if actually little evaluation is being carried out. It is however clear that information presentation should focus at the first stages of the design process.

With the gained knowledge suggestions on how expert information should be presented in order to facilitate its use in the urban design process can be made. It is not the aim of the research to prescribe one single manner of presenting information, but rather to suggest various approaches, that may be combined in different ways.

As designing is a creative rather than an analytic activity, knowledge transfer should focus on filling the designers' cognitive gaps and intuition in the field of interest. This can be done by providing the designer with basic principles and guidelines, preferably in photographs, drawings or other visual form, accompanied by short and simple explanations in writing. These basics could be supplemented with elaborated information, but presented in a manner that it can be consulted separately –some of the interviewees indicated to prefer all possible information from the start, while others reported to prefer global information first and more detailed information if needed later on -, but without compromising the interrelation between basics and details.

Furthermore, images of examples or applications in other projects can be helpful in different ways; they can indicate the range of possibilities, give insight into the context of application, but also inspire the designer to come up with variants or even new solutions. If more options are available, these options should be made comparable, for example by listing their advantages and disadvantages and/or by indicating their (spatial) consequences. In this way the options could be weighed against each other, but also against other design decisions to be made.

The internet would be a suitable medium; not only because it scored high in the interviews and questionnaire, but also because it has the advantage of the possibility of providing information in different layers of complexity and of arranging the information in multiple ways (for example by topic, principle, site, designer or in any other way that is relevant). Pieces of information may be interlinked and also hyperlinks to other websites are possible. Such a website is preferably managed by an official organization (e.g. a knowledge institution) that can keep the information up to date and recommend experts available for consult.

Books or information sheets/cards may also be valuable media, since they can easily be brought to meetings with the expert, but also the principal or colleagues. Like on an internet page, abundant images should be included as well as a clear structure distinguishing main and side issues.

The employment of computer programmes is a difficult case; computer programmes are the least popular form of information among the interviewees, probably because most of these programmes – especially simplified expert tools – are tools for analysis and do not easily match the design process. Moreover, as computer programmes usually deal with one specific field of expertise, the designer would need to obtain and learn to work with a rather substantial amount of computer programmes, which could be rather expensive and time-consuming. This does not mean that such expert tools are not valuable; they can be employed – by the expert – if in a later stage doubts arise about the appropriateness of the proposed solution.

Providing expert information according to the guidelines proposed above can be expected to fill designers' cognitive gaps and enhance designer intuition - for any field of expertise - as well as support the way designers work. It also facilitates integration of different fields of knowledge into urban design and thus enriches it.

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PART 2 Urban Microclimate

4 The influence of the urban microclimate on physical well-being and related regulations and standards

§ 4.1 Introduction

This chapter describes the influence of the different urban microclimate components on the physical well-being of people. Some components have both positive and negative effects, while others only have negative effects. Each of the urban microclimate components - solar radiation (Section 4.2), daylight (Section 4.3), wind (Section 4.4), air quality (Section 4.5) and sound (Section 4.6) - will be discussed in a separate section. Additionally, there will be a section on the concept of thermal comfort (Section 4.7), where solar radiation, air temperature, wind and relative humidity have a combined effect on physical well-being.

Furthermore, this chapter will discuss regulations and standards that were set up to either promote the positive effects of the urban microclimate components or minimize the negative effects, aiming to optimize the conditions for physical well-being. In addition to Dutch regulations and standards, some regulations and standards from neighbouring countries (Germany, The UK and Belgium) are discussed, as these countries have a climate similar to the Dutch. Regulations and standards from other countries are only mentioned if these are relevant for urban design. Regulations and standards for both the outdoor and indoor environment are given. For the indoor environment, only those (quantifiable) regulations and standards are considered that refer to the building envelope as the measurement location, or those dependent on interventions in the building envelope. The building envelope is the physical boundary between the outdoor and indoor environment, and therewith the boundary to where the influence of the urban designer on the building and its interior reaches. It sets the conditions for the indoor climate and gives the possibility for exchange between the outdoor environment and the indoor environment.

§ 4.2 Solar radiation

The sun emits radiation of different wavelengths. The radiation reaches the earth as daylight, ultraviolet (UV) radiation, and infrared radiation (heat), the latter two being invisible to the human eye. About 50% of the solar radiation on earth is in the visible part of the spectrum (daylight), another 10% is in the UV spectrum and about 40% in the infrared spectrum.

These various types of radiation have different effects on our well-being. This section will describe the health effects of the invisible parts of the solar radiation spectrum: UV radiation and heat. The effects of daylight will be described in Section 4.3.

§ 4.2.1 UV radiation

A Effects on physical well-being

UV radiation has both beneficial and adverse affects on well-being, as discussed in several review papers and reports (Juzeniene et al., 2011; WHO, 2006a; De Gruijl, 1997).

Overexposure to UV radiation causes adverse health effects, which include sunburn, accelerated skin ageing and different types of skin cancer[7]. Other effects are a loss of skin tightness and the development of solar keratoses[8]. UV radiation can also have some adverse effects on the eyes: cortical cataract, pterygium[9] and squamous cell carcinoma of the cornea or conjunctiva[10].

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7 The types of skin cancer that are caused primarily by overexposure to UV radiation are the following: cutaneous malignant melanoma, which is a life-threatening malignant skin cancer, squamous cell carcinoma of the skin, which is malignant, but progresses less rapid than melanoma and is less likely to cause death, and basal cell carcinoma of the skin, a slow-growing skin cancer appearing predominantly in older people.

8 Thick, scaly, or crusty patches of skin

9 A fleshy growth on the surface of the eye

10 A rare tumour of the surface of the eye

UV radiation also has beneficial effects. Small amounts of UV radiation are necessary for the production of vitamin D. Vitamin D deficiency can lead to rickets[11], osteoporosis[12] in older adults, and osteomalacia[13]. There is evidence that exposure to UV radiation and the related vitamin D production – especially vitamin D3 – reduces the risk of certain types of cancer, among which breast cancer, colon cancer, non-Hodgkin's lymphoma, ovarian cancer, and prostate cancer (Grant, 2007). Furthermore, UV radiation and vitamin D reduce the risk of infectious diseases and appear to affect MS and several other autoimmune diseases (Juzeniene et al., 2011; Grant, 2007).

The UV dose necessary for the adverse effects on skin and eye is much higher than the dose needed for vitamin D production, which can also be maintained by the intake of food. However, it is estimated that approximately 80-100% of vitamin D is derived from sunlight on the skin. This shows there is an optimum UV dose(-range) for physical well-being.

The ambient UV radiation is determined by stratospheric ozone levels (depletion of ozone leads to an increase in certain types of UV radiation reaching the earth's surface), cloud cover (clearer skies on average yield higher levels of UV radiation), latitude (the higher the latitude, the lower the UV radiation level), season/sun elevation (the higher the sun in the sky, the higher the UV radiation level), and atmospheric pollution (De Gruijl, 1997).

Personal factors that significantly influence the effects of UV radiation are behaviour and culture, such as sun-seeking or sun-protective behaviour and dress. Other personal factors are genetics and immune competence (WHO, 2006a). Such personal factors may (partly) explain why variations in the relationship between UV exposure and mortality occur on a national scale rather than on a regional scale or latitude (Langford et al., 1998).

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11 A softening of the bones in children potentially leading to fractures and deformity

12 Disease of the bones that leads to an increased risk of fractures

13 Softening of the bones in adults

B Regulations & standards

There are no regulations or standards concerning UV radiation. The World Health Organization (WHO, 2009) recommends measures focusing on the behaviour of people to avoid overexposure to UV radiation, such as seeking shade, applying sunscreen and wearing sunglasses. Concerning underexposure to UV radiation, the WHO (2006a) states that a ‘daily exposure of 6-10% of the body surface (one arm, one lower leg, or face and hands) to 1 MED (Minimal Erythemal Dosis) should be sufficient to maintain vitamin D sufficiency’. 1 MED equals 200 j/m^2 of biologically effective UV radiation, which is the dose of UV radiation required to produce a barely perceptible redness of the skin in people with the lightest skin type. For reference: the total hourly solar radiation (direct + diffuse) on a horizontal surface at the 21st of December around noon is around 375.000 j/m^2 in the Netherlands.

In order to facilitate sensible behaviour with regard to overexposure to UV radiation, outdoor spaces should provide enough shading in summer. Guidelines for urban design could be formulated in the form of a minimum percentage of shaded area in every outdoor space in summer, with an absolute minimum of square meters – enough for a person to stand or sit in.

In order to prevent underexposure to UV radiation, a similar guideline could be formulated for direct irradiation of outdoor spaces in winter. As underexposure to UV radiation is less likely and can be largely made up for by the intake of vitamin D (in food), such a guideline may be less strict.

Irradiation and shading do not only influence exposure to UV radiation, they also influence a person’s thermal balance, as will be describe in section 4.7. Guidelines concerning (direct) irradiation and shading should therefore ideally consider the effects of both UV radiation and heat.

§ 4.2.2 Heat

Our thermal environment is created by the interplay of radiation coming from the sun and the reflection, absorption and re-emission of this radiation by the earth and its atmosphere. The incoming solar radiation is short wave, the radiation emitted by earth and atmosphere is long wave (Figure 4.1). Short wave radiation contains more energy than long wave radiation.

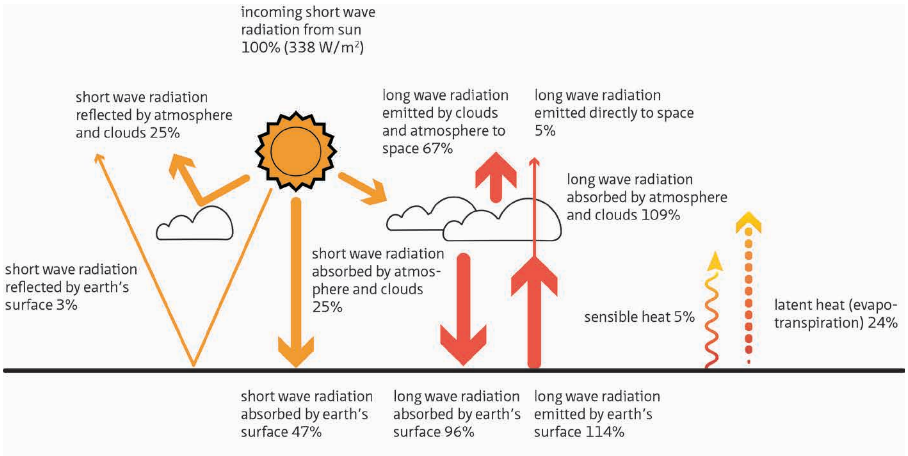


Figure 4.1
The earth's energy balance.

The net radiation exchange Q* between the human body and its environment (Figure 4.2) can be noted as (Eq. 1)

$$Q^* = (K_{dir} + K_{dif} + K_{ref})(1-R_s) + L_{sky} + L_{ter} - L_s \qquad (1)$$

where:

K_{dir} = direct short-wave radiation incident on the body (direct sun beam)
K_{dif} = diffuse short-wave radiation incident on the body (scattered by the atmosphere)
K_{ref} = indirect short-wave radiation incident on the body, reflected from surfaces
L_{sky} = long-wave radiation incident on the body, emitted from the sky
L_{ter} = long-wave radiation incident on the body, emitted from (terrestrial) surfaces
L_s = long-wave radiation emitted by the body to the environment
R_s = albedo of skin/clothing

The perceived result of this radiation exchange can be expressed as the Mean Radiant Temperature (MRT). MRT is defined as the uniform temperature of an imaginary enclosure in which radiant energy exchange with the body equals the radiant energy exchange in the actual non-uniform environment; an area weighted mean temperature of all surfaces surrounding a space, including the sky.

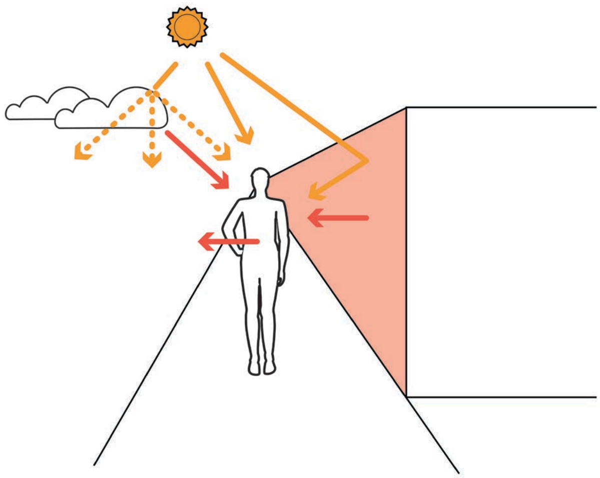


Figure 4.2
Radiation exchange between the human body and its environment.

Together with air temperature, which is also determined by solar radiation, MRT exerts a strong influence on the human body's thermoregulatory system. The thermoregulatory system consists of various mechanisms to deal with an imbalance between heat gains and losses. When heat gains are greater than heat losses, the body will initially respond by vasodilation, increasing blood flow to the skin, therewith increasing skin temperature and thus heat dissipation. If this is not sufficient, the production of sweat starts which supplies the body with evaporative cooling. These processes may cause discomfort, but are not yet threatening to health. However, if heating continues, hyperthermia might occur, which is damaging to the body. When it is too cold, the blood flow will drop through vasoconstriction, and skin temperature and heat dissipation will reduce. If this mechanism is not sufficient, the body starts to shiver; a non-controllable muscle activity that increases the heat production drastically. Ultimately, hypothermia will occur with a chance of serious harm to the human body.

Radiation and air temperature are two of the four climate elements influencing the human thermal balance, the other two being wind and relative humidity. Their separate influences on the human thermoregulatory system cannot be clearly distinguished, as the human body does not have selective sensors for the perception of the individual climate parameters, but rather senses their combined thermal effect as a 'felt temperature' (Höppe, 1999).

Most research on the effects of the thermal environment on human health has been epidemiological and has mainly focussed on the relation between ambient air temperature and mortality and/or morbidity. Morbidity and mortality due to (too little or excess of) solar irradiation are very likely to be included in these studies; ambient air temperature can be regarded as a marker for the health effects of the thermal environment as a whole. This section will discuss the results of epidemiological research, which are well documented in several reviews, as well as existing regulations and standards concerning solar irradiation. Section 4.4 will discuss the thermal effects of wind and section 4.7 will discuss thermal comfort, which besides purely physiological aspects also includes psychological aspects.

A Effects on physical well-being

Many studies have shown a significant effect of ambient air temperature on mortality (Analitis et al., 2008; Ballester et al., 2011; Basu & Samet, 2002; Curriero et al., 2002; Keatinge et al., 2000). Most studies have found a V-like relationship between temperature and mortality, with an optimum temperature value for the lowest mortality rate. Above and below this optimum temperature mortality rates rise (Figure 4.3). The value of the optimum temperature varies with location; higher latitudes show a lower optimum than lower latitudes (Curriero et al., 2002; Keatinge et al., 2000), which may be due to acclimatization and/or better protection from cold respectively heat stress. Elderly people, people with pre-existing diseases and low fitness are more vulnerable to heat-related illnesses and mortality (Analitis et al., 2008; Basu & Samet, 2002; Curriero et al., 2002; WHO, 2004).

Research has shown that low ambient temperatures can be associated with increased mortality due to cerebrovascular[14], cardiovascular[15] and respiratory[16] disease (Analitis et al., 2008, Carder et al., 2005). The effects of cold are greater in warmer climates (Analitis et al., 2008, Bhaskaran et al., 2009). Research among the Dutch population has shown that in particular mortality due to cardiovascular disease increases during cold spells, and that respiratory mortality increases sometime after cold spells, as cold has a more lagged effect on this kind of mortality (Huynen et al., 2001). The increase of respiratory mortality is thought to be related to the increase in occurrence of influenza and influenza-like conditions, which are also strongly correlated with low temperatures in the Netherlands, also with a lagged effect (Kunst et al., 1993).

14 Disorders of the blood vessels supplying the brain

15 Disorders of the heart and blood vessels

16 Disorders of the airways, lungs and muscles of respiration

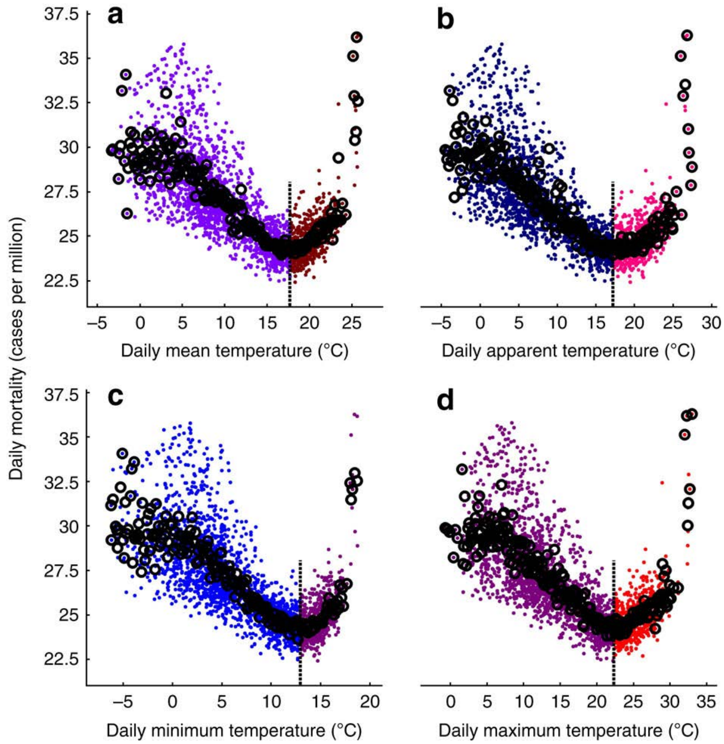


Figure 4.3

Observed relationship between daily temperatures and number of deaths in Europe in the period 1998-2003. Reprinted by permission from Macmillan Publishers Ltd: Nature Communications 2(1), Ballester et al., copyright 2011.

Low temperatures can lead to a (temporary) increase in blood pressure due to vasoconstriction (Gavhed et al., 2000) and elevated blood viscosity, which in turn may be related to a greater incidence of certain types of cerebrovascular disease in the winter season[17] (Gill et al., 1988).

Low temperatures also cause cooling of the skin, which has been reported to give pain sensation (Gavhed et al., 2000). This is presumed to be a warning for the onset of frostbite.

17 The types of cerebrovascular disease that show a relation to cold are: subarachnoid haemorrhage (bleeding in the area between the brain and the thin tissues that cover the brain), cerebral infarction (stroke) and ill-defined cerebrovascular disease.

Exposure to high temperatures for a period over 6 hours leads to changes in blood composition and a fall in arterial pressure, promoting arterial and cerebral thrombosis (Keatinge et al., 1986). Hospitalization and mortality rates from thrombosis and other cardiovascular diseases, such as myocardial infarction[18], as well as from respiratory and cerebrovascular diseases have been reported to rise during and shortly after a heat wave (Basu & Samet, 2002; Morabito et al., 2005). Research among the Dutch population has shown that especially mortality from respiratory disease increases during and shortly after a heat wave (Kunst et al., 1993; Huynen et al., 2001).

Considering the climate predictions for the Netherlands, an increase in heat stress and related morbidity and mortality can be expected (Ballester et al., 2011). Heat stress can cause a spectrum of illnesses, with less severe conditions such as heat rash, heat cramps, and heat syncope, the latter caused by a failure of the circulation to maintain blood pressure and supply oxygen to the brain. Heat syncope may progress into thermal exhaustion, when sweating cannot dissipate the heat generated within the body, and finally into heat stroke, when the body's thermoregulatory system fails. A heat stroke is a medical emergency and its complications include respiratory distress syndrome[19], kidney failure, liver failure and disseminated intravascular coagulation[20] (Donoghue et al., 1997).

B Regulations & standards

There are no regulations or standards concerning heat (or cold), outdoor air temperature or the outdoor thermal environment in general, probably because we regard the extremely variable outdoor thermal environment as a given, mainly governed by the regional climate conditions. The built environment can, however, modify the thermal environment at the micro level by allowing or preventing access to the sun – and therewith to direct short-wave radiation incident on the body, but also indirect short-wave radiation reflected from the surroundings and less directly also long-wave radiation emitted from surrounding surfaces.

18 Heart attack

19 A lung condition that leads to low oxygen levels in the blood

20 A condition that prevents blood from clotting normally, leading to the formation of small blood clots inside the blood vessels throughout the body

Regulations or standards concerning solar access in temperate climates are limited to a certain minimum of solar access to the indoor environment, in order to allow for enough solar warmth and light indoors in winter (historically also for hygienic reasons). Indoor overheating and the outdoor situation are neglected so far.

The Dutch standard NEN 2057 (2011) recommends 2 hours of direct sunlight in the middle of the window at the height of the windowsill in at least 25% of the occupancy spaces of a building during the period between March 1st and September 1st. The solar altitude should be at least 10 degrees. The standard further recommends adequate solar shading and/or brightness prevention.

Before the NEN 2057, the Dutch standard originated from the 'woonwaarderingsstelsel' (the Dutch residential appraisal system) from 1962. It was formulated by the Netherlands Organization for Applied Scientific Research (TNO) (Hanssen, 1975), and it is still frequently used. It has two variants; a 'light' and a 'strict' variant. The 'light' variant states that for sufficient irradiation of the living room 'at least 2 possible sunlight hours per day in the period from February 19th to October 21st (during eight months) at the middle of the windowsill on the inside of the window' is required. The 'strict' variant states that for good irradiation 'at least 3 possible sunlight hours per day in the period from January 21st to November 22nd (during ten months) at the middle of the windowsill on the inside of the window' is required. The municipality of Rotterdam uses the 'light' standard, as does the municipality of The Hague, with the addition of a minimum solar altitude of ten degrees, which is taken from the British standard (described below). Furthermore, The Hague not only applies this standard to indoor spaces, but also to outdoor spaces (Berg, v.d. et al., 1995; Norder, 2010).

The German Industrial Standard originally recommended '4 possible sunlight hours at the window centre on March 20th', but recently changed it to '1 possible sunlight hour on January 17th' to include some sunlight in winter (DIN 5034-1, 2011) .

The British Research Establishment (Littlefair, 1991) and the British Standard BS 8206-2 (2008) recommend 25% of annual probable sunlight hours at the centre of the window. To include some winter sun, 5% of annual probable sunlight hours should be received between September 21st and March 21st.

For the outdoor environment, the BRE recommends that preferably no more than 25% of a garden or other outdoor space should be in shadow on March 21st. Sunlight at an altitude of 10 degrees or less does not count. The BRE further states that the loss of sunlight is likely to be noticeable if, as a result of any new development, any existing outdoor space does not meet these guidelines, and the area which can receive some sun on 21 March is less than 0.8 times its former value.

Most of these guidelines concern the indoor environment; only the BRE and the Municipality of The Hague make statements concerning the outdoor environment. Of these two, the BRE guidelines are the most practical for urban design purposes since they have a clear spatial aspect.

The different standards and guidelines concerning solar irradiation emphasize solar access in winter, in order to allow for enough solar warmth and light in the indoor environment. Up until now little attention is paid to the minimization of solar access in summer to prevent the (over)heating of building materials and heat stress in humans. For this purpose, the existing guidelines – already stating a minimum of either sunlight hours or irradiated surface – could be extended with a maximum value of solar access. Alternatively, explicit recommendation of a minimum percentage of shaded area would emphasize the importance of shade as a means to prevent excessive solar gain and heat stress.

§ 4.3 Daylight

A Effects on physical well-being

The human eye is sensitive to radiation with wavelengths from about 380 to 750 nm. These wavelengths correspond to the radiation peak of the solar spectrum on earth, the daylight spectrum. The eye is attuned to this daylight spectrum through evolution. The daylight spectrum provides the highest levels of light needed for biological functions. The biological function that is most clearly affected by daylight is the circadian system. Four main circadian biological rhythms - cycles of approximately 24 hours - can be distinguished: secretion of melatonin and cortisol (both hormones), alertness and body temperature (Veitch et al., 2004).

Melatonin regulates the circadian rhythms of wake and sleep and core body temperature (Veitch et al., 2004; Edwards & Torcellini, 2002). It also shows a strong link with alertness. Daylight suppresses melatonin production during the day and in this way controls the circadian system. Without daylight stimulus at the right time, the system will run free (slightly longer than 24 hours) and eventually becomes desynchronised from the day/night cycle. Disruption of the circadian melatonin cycle can have several negative effects: poor sleep quality, lack of alertness, feeling down, seasonal depression, immune deficiencies and possibly tumour growth (Figueiro et al., 2002). Seasonal changes in melatonin cycles have been attributed to the seasonal changes in daylight levels. This is thought to be a cause of Seasonal Affective Disorder

(SAD), also known as winter depression. SAD patients have a delay in their onset of nighttime melatonin secretion, which leads to the hypothesis that the depression may be caused by a shift in their circadian rhythm (Webb, 2006; Boyce, 1997).

Cortisol regulates the production of glucose from protein and facilitates fat metabolism, thus supplying energy. Its secretion peaks close to habitual wake time and decreases to its minimum close to habitual bedtime. Superimposed on this circadian rhythm, cortisol is secreted in an ultradian rhythm of pulses over the day. It is also acutely secreted in response to strong external stimulation such as stressful events.

Melatonin and cortisol form important constituents of the neuroendocrine system[21]. Daylight falling on the eye has positive effects on the neuroendocrine system, which is manifested through: improved mood, enhanced morale, lower fatigue, reduced eyestrain, reduced stress levels, decrease of anxiety and improved concentration (Edwards & Torcellini, 2002).

Light intensity is of great importance for the effect of light exposure; the brighter the light, the larger the effect. People that don't receive enough light in indoor spaces might therefore 'self medicate' themselves by spending more time outdoors. (Figueiro et al. 2002)[22].

The wavelength of light is also an important factor. The spectral quality of daylight is very difficult to imitate artificially and it is therefore that electrical light sources have a different spectral distribution than natural light. Electrical light usually lacks the blue portion of the daylight spectrum and it is particularly this portion that is thought to be most important for the biological functioning of the human body (Brainard, 1994).

B Regulations & standards

As high daylight levels are readily available outdoors, no regulation or standards exist with regard to the outdoor daylight conditions. As daylight levels are much lower indoors, in most countries regulations or standards concern indoor lighting. These

21 The neuroendocrine system is made up out of the nervous system, responsible for the control of the body and communication between its parts, and the endocrine system, the collection of glands in the body that secrete hormones.

22 Exposure to daylight of high intensity may lead to discomfort (glare), but accept headache has no adverse health effects and is therefore out of the scope of this research.

rules can be divided in four categories: rules concerning illuminances[23], [24], rules concerning daylight factors,[25] rules concerning (relative) window size and rules for building dimensions and distances (obstruction angles). The purpose of most of these rules is to guarantee enough light for visual tasks. These light levels may partly be provided by artificial lighting and are lower than those needed for the regulation of the human circadian system.

In The Netherlands, indoor daylight access is regulated through the national Buildings Decree (Bouwbesluit, 2012), which prescribes a minimum 'equivalent daylight area' (Table 4.1)

function	threshold value daylight area [%]	absolute minimum [m^2]
dwelling	10	0.5
gathering		
- nursery	5	0.5
- other gathering spaces	-	-
cell	3	0,15
health care	5	0,5
industry	-	-
office	2,5	0,5
lodging	-	-
education	5	0,5
sports	-	-
shopping	-	-
other functions	-	-
structures not being buildings	-	-

Table 4.1
Dutch building legislation concerning daylight access

23 Illuminance is the total luminous flux incident on a surface per unit area (lm/m^2). It is a measure for the received light.

24 Rules concerning illuminances will not be discussed, as they are highly related to artificial lighting.

25 The daylight factor is a percentage ratio of the illuminance at a point (indoors or outdoors) to the outdoor illumination level occurring simultaneously on a horizontal plane under an unobstructed hemisphere of overcast sky

This equivalent daylight area can be considered as the effective window area, corrected for obstructions. The threshold value of this equivalent daylight area depends on the function of the building. For a habitable area, consisting of two or more adjoining habitable spaces, the building regulations prescribe a minimum equivalent daylight area (threshold value) equal to a certain percentage of the floor area. This rule only applies to new buildings. For habitable spaces, the absolute minimum equivalent daylight area is prescribed in square meters. This rule applies to both new and existing buildings.

The United Kingdom and Germany also prescribe a minimum equivalent daylight area. The British Standard BS 8206-2 (2008) recommends a minimum window area of 20% of the external wall for rooms measuring less than 8 meters in depth and 35% of the external wall for rooms more than 14 meters in depth.

The German Standard DIN 5034-1 (2011) states that the total width of the transparent window parts should be at least 55% of the wall containing the window. Furthermore, the standard states that the height of the windowsill should be no higher than 0.9 meter, the lower edge of the transparent parts no higher than 0.95 meter, and the upper window edge at least 2.2 meter above floor level.

In addition to minimum equivalent daylight areas, the British and German standards recommend average daylight factors for specific spaces. The daylight factor is a percentage ratio of the illuminance at a point to the outdoor illuminance occurring simultaneously on a horizontal plane under an unobstructed hemisphere of overcast sky. A daylight factor is of more practical use than specific illuminances because of the variable nature of daylight.

The British Standard BS 8206-2 (2008) recommends an average daylight factor of 2% in kitchens, 1,5% in living rooms and 1% in bedrooms. The Chartered Institution of Building Services Engineers (CIBSE), based in the UK, recommends an average daylight factor of 5% for interior spaces that are fully daylit (Tregenza & Loe, 1998). The German Standard DIN 5034-1 (2011) recommends an average daylight factor of 4% on the working plane (0,85 m) for workspaces.

The regulations and standards described above place the responsibility for daylight availability with the architect mainly, as they set requirements for the design of the (transparent parts of the) façade and indoor spaces. The urban environment, however, also has a significant influence on the indoor daylight availability. Guidelines that are more directed towards the urban designer are therefore also important. Guidelines that concern daylight factors on the façade address the design of the street profile. The British Standard 8206-2 (2008), for example, recommends a vertical sky component (daylight factor without reflections) of 27% on the windowpane.

More practical for urban design are recommendations for building height and spacing or obstruction angles. One of the first regulations of this kind was the New York City 1916 Zoning Ordinance, which prescribes a maximum 'street wall' height and 'sky exposure plane' in relation to street width (Bryan & Stuebing, 1986; Figure 4.4). Later changes to these regulations - a 1961 amendment prescribed a maximum floor area ratio for a plot and included incentives to developers to create plazas for the access of daylight and air to outdoor public space on their sites in return for extra floor space – were not as effective protecting natural light access to the street. Therefore, Midtown Manhattan revised its zoning ordinance in 1981, prescribing (again) street wall height and length, as well as the amount of sky that a building could obstruct.

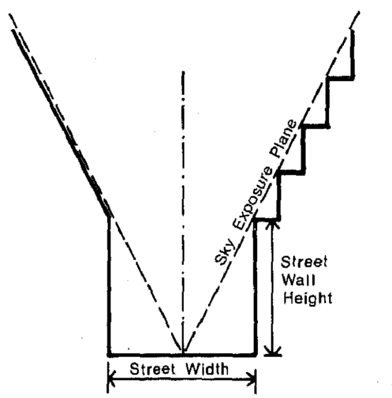


Figure 4.4
New York City 1916 Zoning Ordinance prescribing street wall height and sky exposure plan to allow enough daylight into the street and its aligning buildings.
Reprinted from Lighting Design and Application: LD and A. 16(6), Bryan, H. & Stuebing, S., Natural light as an urban amenity, 44-48, copyright 1986.

Although these regulations only concern the section of a street – a three dimensional situation also presents non-continuous obstructions and differences in building heights, allowing light around the sides of buildings – they provide practical and manageable guidelines for urban design.

§ 4.4 Wind

A Effects on physical well-being

Thermal effects
Wind chill is the phenomenon that the convective heat transfer of an object increases with increasing wind speeds. Wind causes the (skin) surface to cool down to the ambient temperature more quickly, increasing the sensation of cold or even pain at (near) freezing temperatures and higher wind speeds (Gavhed et al., 2000). Increased convective heat transfer also affects the body's thermal balance. In summer the cooling effect of wind may be desirable, in winter however, cooling may cause discomfort or even health problems, as described in Section 4.2.

The effect that wind has on perceived air temperature is expressed by the Wind Chill Temperature (WCT); it is the equivalent air temperature equal to the air temperature needed to produce the same cooling effect under calm conditions (OFCMSSR, 2003).

The wind chill concept was first studied and quantified by Siple & Passel (1945), and the most recent approach to determining WCT was developed and implemented in 2001 by the National Weather Service USA and Environment Canada (Oscevski & Bluestein, 2005). The wind chill concept was first studied and quantified by Siple & Passel (1945), and the most recent approach to determining WCT was developed and implemented in 2001 by the National Weather Service USA and Environment Canada (Oscevski & Bluestein, 2005). Table 4.2 shows the new Wind Chill Temperature index chart, with wind speed measured at 10 metres elevation, and air temperature at 1,50 metres elevation. shows the new Wind Chill Temperature index chart, with wind speed measured at 10 metres elevation, and air temperature at 1,50 metres elevation.

Wind speed		Temperature (°C)								
m/s	Km/h	10	5	0	-5	-10	-15	-20	-25	-30
1.4	5	9,8	4,1	-1,6	-7,3	-12,9	-18,6	-24,3	-30,0	-35,6
2.8	10	8,6	2,7	-3,3	-9,3	-15,3	-21,2	-27,2	-33,2	-39,2
4.2	15	7,9	1,7	-4,4	-10,6	-16,7	-22,9	-29,1	-35,2	-41,4
5.6	20	7,4	1,1	-5,2	-11,6	-17,9	-24,2	-30,5	-36,8	-43,1
7.0	25	6,9	0,5	-5,9	-12,3	-18,8	-25,2	-31,6	-38,0	-44,5
8.3	30	6,6	0,1	-6,5	-13,0	-19,5	-26,0	-32,6	-39,1	-45,6
9.7	35	6,3	-0,4	-7,0	-13,6	-20,2	-26,8	-33,4	-40,0	-46,6
11	40	6,0	-0,7	-7,4	-14,1	-20,8	-27,4	-34,1	-40,8	-47,5
13	45	5,7	-1,0	-7,8	-14,5	-21,3	-28,0	-34,8	-41,5	-48,3
14	50	5,5	-1,3	-8,1	-15,0	-21,8	-28,6	-35,4	-42,2	-49,0
15	55	5,3	-1,6	-8,5	-15,3	-22,2	-29,1	-36,0	-42,8	-49,7
17	60	5,1	-1,8	-8,8	-15,7	-22,6	-29,5	-36,5	-43,4	-50,3

Table 4.2
Wind chill temperature index chart (based on KNMI, 2009 and OFCM, 2003)
Frostbite may occur in less than 30 minutes (light orange) or less than 60 minutes (dark orange)

Mechanical effects
In addition to the effects of wind on thermal comfort, wind also has some mechanical effects on the human body that can be perceived as uncomfortable or even dangerous. These effects are the result of the force that is being exercised on the body by the wind. This wind force is proportional to the square of the wind speed. The body takes this force by leaning over. When this skewed position exceeds an angle with the vertical of 8° degrees - which corresponds to an average wind speed of 15 m/s - problems with balance are likely to arise. Wind gusts can also affect balance significantly, as they have a surprise effect. Apart from balance problems, wind can have other – less dangerous - uncomfortable effects. These occur at wind speeds below the aforementioned 15 m/s and are categorized under the denominator 'wind discomfort'. One might think of the flapping of clothes, entangled hair, the raising of papers and difficulties in using an umbrella.

Whether someone will experience discomfort from the wind depends on some personal factors: physical condition (health, age, sex), psychological condition (happy or unhappy), activity (sitting, walking, exercising), thermal comfort and habituation to the climate (Beranek & Van Koten, 1979). Nevertheless, some general trends of wind effects can be given.

The effects of steady winds (Murakami et al., 1980) are shown in Table 4.3. Wind effects of non-uniform winds, varying in direction and speed, are comparable to the effects of steady winds with two times the maximum wind speed of the non-uniform wind. The effects of wind gusts are larger than the effects of steady winds of the same wind speed because of their surprise effect (Table 4.4).

Average wind speed [m/s]	Effects
5	Minor disturbance of hair and clothes, wind felt on face
10	Walking not easy, hair disturbed, fluttering of clothes, difficult to hold umbrella, frequent blinking of the eyes
15	Walking difficult to control, upper body bends windward, hair violently disturbed, impossible to hold umbrella, tears falling from the eyes
20	Walking very difficult, whole body bends windward, facial pain, ear-ache, heada-che, breathing difficult

Table 4.3
Effects of steady wind according to Murakami et al., 1980

Wind speed [m/s]	Duration [sec]	Effects
4	5	Movements of hair and flapping of clothes
7	5	Entanglement of hair
15	2	Balance problems, dangerous for elderly people
20	-	Danger
23	-	People blown over

Table 4.4
Effects of wind gusts according to Bottema, 1993

B Regulations & standards

For the thermal effects of wind no regulations, standards or recommendations exist. For the mechanical effects of wind, however, there are several recommendations. The majority of those recommendations are based on the researches and criteria of Davenport (1972), Penwarden & Wise (1975), Isumov & Davenport (1975), Lawson & Penwarden (1975) and Hunt et al. (1976). These criteria distinguish between different activities, such as walking, strolling and sitting, or wind environment quality classes, and often combine these two. The criteria are composed of a threshold wind speed – either an average wind speed or a gust wind speed at pedestrian height (1,75 m) – above which discomfort or danger may occur, and a limit for the probability of exceeding this threshold wind speed within a certain period of time. An overview of existing criteria is given by Holger Koss (2006).

The NEN 8100 (2006) is the Dutch standard for wind comfort and danger (Table 4.5 and Table 4.6). This standard is adopted by the larger Dutch municipalities such as Rotterdam, The Hague and Utrecht. In these cities, an expert assessment of designs – especially plans including high-rise – is compulsory.

Quality class	Probability of exceeding of hourly mean wind speed P(U-loc>Uthr) in percentages of total annual hours	Activity		
		Walking (fast)	Strolling	Sitting (long time)
A	P(U > 5,0 m/s) < 2,5%	Good	Good	Good
B	P(U > 5,0 m/s) < 5%	Good	Good	Acceptable
C	P(U > 5,0 m/s) < 10%	Good	Acceptable	Bad
D	P(U > 5,0 m/s) < 20%	Acceptable	Bad	Bad
E	P(U > 5,0 m/s) > 20%	Bad	Bad	Bad

Table 4.5
Wind comfort

Probability of exceeding of hourly mean wind speed P(Uloc>Uthr) in percentages of total annual hours	Qualification
P(U > 15,0 m/s) < 0,0%	No danger
P(U > 15,0 m/s) < 0,3%	Limited risk, only acceptable for activities that are not sensitive to wind discomfort
P(U > 15,0 m/s) > 0,3%	Dangerous for the elderly, walking uncontrollable

Table 4.6
Wind danger

The NEN 8100 (2006) does not contain specific spatial information, but the activities stated in the criteria can be coupled to urban outdoor spaces; the activity of sitting fits to squares, parks, terraces and private gardens, the activity of strolling could be assigned to pedestrian and residential streets, and the activity of walking to main streets.

In order to assess whether the requirements for a certain quality class are met, expert calculations or measurements have to be carried out. This can be done only after a design is made. For design purposes, rules of thumb or guidelines concerning maximum dimensions and orientation of outdoor spaces relating to the quality classes could be useful to ensure a good wind climate, and to decrease the chances of major changes in the design being necessary after expert assessment.

§ 4.5 Air quality

Air pollution is one of the most serious health hazards. It is estimated that more than two million people die prematurely each year as a consequence of air pollution related diseases (WHO, 2006b). The most important pollutants are: particulate matter, ground-level ozone, nitrogen dioxide and sulphur dioxide. These pollutants are present in a vast majority of urban areas and have serious health effects.

A Effects on physical well-being

Particulate matter (PM) is a mixture of extremely small solid and liquid particles suspended in the atmosphere. PM is usually divided in two components: a coarse component of parts smaller than 10µm but larger than 2,5µm (PM_{10}) and a finer component of parts smaller than 2,5µm ($PM_{2,5}$). Mechanical processes, such as building activities, as well as re-suspension of dust and sea salt by wind are the main sources of the coarse component of PM_{10}. The fine fraction consists mainly of products of combustion processes, such as the combustion of fossil fuels and biomass and secondary particles, transported over long ranges (Vallius et al., 2005). This fine fraction is thought to be the most hazardous to human health as it can penetrate deeper into the lungs and veins.

Exposure to particulate matter contributes to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer (WHO, 2011). The effects aggravate with exposure duration because of accumulation, and therefore the long-term health effects are of most concern. Especially PM from diesel exhaust seems to be hazardous to health (Bernstein et al., 2004). In the EU, average life expectancy is over eight months lower due to exposure to $PM_{2.5}$ produced by human activities (WHO, 2011). Research has shown that all day mortality increases with increase in PM_{10}, as well as hospital admissions for asthma and chronic obstructive pulmonary disease[26] among elderly people and admissions for cardiovascular disease (Brunekreef & Holgate, 2002).

Ozone (O_3) on ground level can cause lung inflammation and decreased lung function, which may lead to premature death. The health effects of ozone arise within a very short term of a few hours. The effects are worse for asthma patients (Bernstein et al., 2004; WHO, 2003). Ozone is produced by human sources as well

26 Disorders of the long causing shortness of breath, persistent coughing and frequent chest infections

as natural sources (mainly volatile organic compounds from plants) and therefore threshold concentrations can be exceeded by natural production. Ground-level ozone concentrations are expected to increase in the future as a result of higher temperatures (Kinney, 2008).

Nitrogen dioxide (NO_2) is a poisonous gas that in high concentrations has harmful effects on a short term. These high concentrations, however, are not found in the outdoor environment. Through a photochemical reaction NO_2 reacts with carbohydrates to ground-level ozone, which is a main constituent of smog. Photochemical reactions with NO_2 also leave nitrate particles, which form a large fraction of $PM_{2,5}$. The most important function of NO_2 is its use as a marker for traffic related pollutants, such as particulate matter, nitrogen oxides and benzene. This mixture of pollutants is thought to have significant health impacts. Bronchitic symptoms of children increase with elevated concentrations of NO_2. Long-term elevated NO_2 concentrations are also linked with reduced lung function growth in children (WHO, 2011, 2003).

Sulphur dioxide (SO_2) is a product of the combustion of fossil fuels such as coal and oil. It is also released into the atmosphere in large quantities during volcanic eruptions. Health effects of SO_2 are decreased functioning of the pulmonary system and respiratory system, which may lead to premature death. As with ozone, the effects are worse for asthma patients. It is still uncertain whether these effects can be attributed to SO_2 alone or that it is a marker for a mixture of pollutants containing SO_2 (WHO, 2003).

B Regulations & standards

Maximum allowable concentrations of pollutants in the outdoor environment are regulated on European level. The Directive 2008/50/EC (2008) prescribes threshold values of concentrations that can be exceeded for a limited number of times. An overview of the EU regulations for the aforementioned pollutants is given in Table 4.7. These values are higher than the air quality guideline values proposed by the World Health Organization (Table 4.8), but most values comply with the WHO interim target values proposed as incremental steps in a progressive reduction of air pollution.

Pollutant	Concentration	Averaging period	Permitted events of exceeding each year
$PM_{2.5}$	25 µg/m³	1 year	
PM_{10}	50 µg/m³	24 hours	35
	40 µg/m³	1 year	
SO_2	350 µg/m³	1 hour	24
	125 µg/m³	24 hours	3
NO_2	200 µg/m³	1 hour	18
	40 µg/m³	1 year	
O_3	120 µg/m³	Maximum daily 8 hour mean	25 days averaged over 3 years

Table 4.7
Directive 2008/50/EC maximum allowable values for different pollutants

Pollutant	Concentration	Averaging period
PM2.5	10 mg/m³	1 year
	25 mg/m³	24 hours
PM10	20 mg/m³	1 year
	50 mg/m³	24 hours
Sulphur dioxide	20 mg/m³	24 hours
	500 mg/m³	10 minutes
Nitrogen dioxide	40 mg/m³	1 year
	200 mg/m³	1 hour
Ozone	100 mg/m³	8 hours

Table 4.8
WHO guidelines for air quality

Outdoor pollutants enter the building through ventilation and infiltration. Outdoor air quality thus influences indoor air quality. In the Netherlands, air quality in the indoor environment is regulated in the Dutch Buildings Decree (Bouwbesluit, 2012) by a required level of ventilation. The decree prescribes an air change rate related to the function and occupancy of the building (Table 4.9). Habitable spaces of dwellings are prescribed an air exchange rate of 0.9 l/s per m² floor space.

On European level, the European standard organization proposes design criteria for ventilation in buildings in the technical report CR 1752 (CEN, 1998) (Table 4.10). These criteria apply as a guideline in the Netherlands. For most functions, the guideline proposes higher air changes rates than the Buildings Decree; the values prescribed by the Buildings Decree can be regarded as an absolute minimum.

Function	B1	B2	B3	B4	B5
Gathering	4.8	1.9	0.8	-	-
Cell	1.0	1.0	1.0	1.0	1.0
Health care	1.3	1.3	1.3	1.3	1.3
Catering industry	4.8	1.9	0.8	-	-
Education	8.8	3.5	1.4	-	-
Sports					
areas used for sports	8.0	3.2	1.3	0.5	0.5
other	4.8	1.9	0.8	0.5	0.5
Shopping	-	1.9	0.8	0.5	-
Office	1.3	1.3	1.3	1.3	1.3
Lodging	1.0	1.0	1.0	1.0	1.0

Table 4.9
Air change rate for habitable areas in l/s per m^2 floor space as prescribed by the Dutch Buildings Decree
Occupancy in floor surface:
B1 <1.3 m^2 per person
B2 1.4-3.3 m^2 per person
B3 3.4-6.6 m^2 per person
B4 6.7-20.0 m^2 per person
B5 > 20.0 m^2 per person

Type of building/space	Occupancy [m² / person]	Category	Ventilation rate [l/s per m²]
Single office (cellular)	10.0	A	2.0
		B	1.4
		C	0.8
Landscaped office	14.3	A	1.7
		B	1.2
		C	0.7
Conference room	2.0	A	6.0
		B	4.2
		C	2.4
Auditorium	0.7	A	16
		B	11.2
		C	6.4
Cafeteria or restaurant	1.4	A	8.0
		B	5.6
		C	3.2
Classroom	2.0	A	6.0
		B	4.2
		C	2.4
Kindergarten	2.0	A	7.1
		B	4.9
		C	2.8
Department store	6.7	A	4.2
		B	3.0
		C	1.6

Table 4.10
Air change rates advised by CR 1752 (CEN 1998). Classes A, B and C refer to a high, medium and moderate level of expectation with regard to environmental quality.

The regulations and guidelines mentioned above are difficult to use for design purposes since no spatial information whatsoever is included. Because the dispersion of pollutants is closely related to wind flow, the guidelines for wind comfort and danger (see Section 4.4) could be complemented with information on spatial configurations that support the removal of polluted air from (different types of) outdoor spaces.

In addition, guidelines could be given to promote natural ventilation of buildings. Such guidelines might address the influence of the orientation and spacing of buildings on air pressure differences between inlets and outlets, as well as the location of inlets and outlets in relation to outdoor air quality.

§ 4.6 Sound

The human ear is not equally sensitive to all tones. Sounds with a frequency of 2000 Hz are more easily perceived than sounds with a frequency of 100 Hz for example. There are limits to what the (average) human ear can hear, as depicted in Figure 4.5. There is also a threshold of pain. Adverse health effects already occur, however, at much lower sound intensities and frequencies, as will be discussed below.

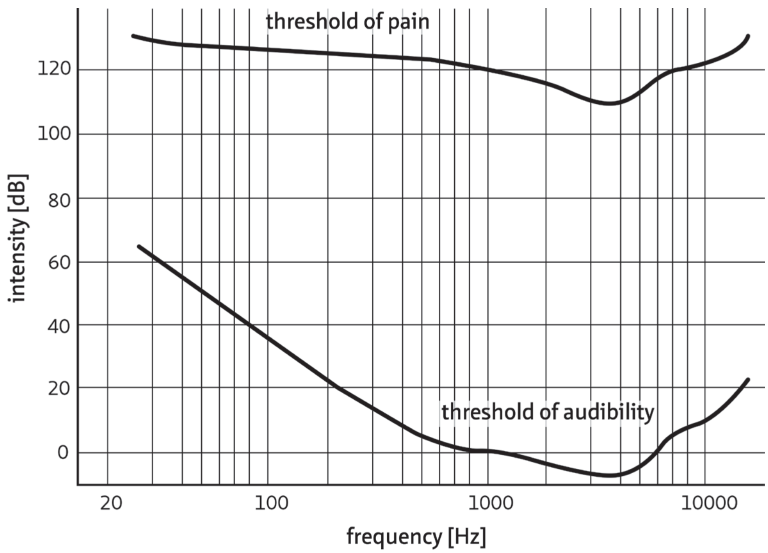


Figure 4.5
Thresholds of hearing.

Sound has auditory as well as extra-auditory effects on well-being (Passchier-Vermeer & Passchier, 2000; Stansfeld et al., 2000; Ising & Kruppa, 2004). Auditory effects, such as acoustic trauma[27], tinnitus[28] and hearing loss, are most likely to occur from occupational[29] and social noise exposure[30]. In the outdoor urban environment, extra-auditory effects of sound on well being are the main focus of concern. These extra-auditory are highly related to the occurrence of annoyance and related stress, causing significant health-effects for a possibly a considerable part of the population; according to the WHO about half of the people living in EU countries are exposed to traffic sound levels that can cause annoyance (WHO, 1999). The Dutch National Institute for Public Health and the Environment states that almost 20 million adults in Europe are indeed annoyed by noise from traffic and industry, of which over 9 million are highly annoyed (RIVM, 2014). This section will discuss the extra-auditory effects due to sound annoyance as well as the perception of different sounds as noise.

A Effects on physical well-being

Sound can cause annoyance due to disturbed activities, communication, concentration and sleep, and psychological reactions to noise (Miedema, 2007; Öhrström, 2004). The effects of sleep disturbance have been well described (Carter, 1996; Miedema & Vos, 2007; Muzet, 2007). Immediate effects of sleep disturbance are difficulty of falling asleep, increased body movements, awakenings and alterations of sleep stages or depth, vasoconstriction and changes in heart rate. These responses to noise do not seem to habituate. Secondary effects (during the day) are: reduced perceived sleep quality, increased fatigue, depressed mood or well-being and decreased cognitive performance.

Annoyance may lead to stress, associated with an increase in stress hormone levels and blood pressure (Ising et al., 1980), and it seems that especially prolonged exposure to occupational noise and air traffic noise lead to hypertension (Van Kempen et al., 2002; WHO, 1999), whereas exposure to road traffic noise may increase the risk of myocardial infarction and total ischemic heart disease (Van Kempen et al., 2002).

27 Acute hearing damage caused by a sudden and extremely loud sound, e.g. an explosion, gunshot, etc.

28 Ringing of the ears

29 The industrial workplace, the military and musical professions are high-risk occupations.

30 Head phones, concerts

The type of noise source is thus important for the experience of annoyance. With a given sound level, people have different perceptions of sounds from different sources.

In general, sounds from nature are experienced as positive, whereas traffic sound is found most annoying. There are however differences for different modes of traffic; annoyance from air traffic noise is highest compared to noise from other modes of transportation, followed by noise from road traffic. Railway noise is considered the least annoying, and annoyance from railway noise also increases the least rapidly with increasing noise level (Miedema & Vos, 1998; Fields & Walker, 1982). At a sound level of 60 dB (Lden), about 20% of the people is highly annoyed for air traffic, about 10% for road traffic and about 7% for rail traffic. At 70 dB (Lden), these percentages rise to 40, 30 and 15, respectively (Miedema & Vos, 1998).

An extensive survey in urban open public spaces in Europe and China (Zhang & Kang, 2007) shows that water sounds and birdsong are highly appreciated (more than 75% of the interviewees), whereas mechanical sounds, such as construction sounds, music from cars and vehicle sounds are least favoured and are even found annoying. Culturally approved sounds like church bells and live music are usually well-approved. Human sounds, such as speech and children's shouting are neither favourite nor annoying. Similar results in different settings were found by Anderson et al. (1983), Berglund & Nilsson (2006) and Nilsson & Berglund (2006).

For residential areas it has been shown that access to quiet indoor and outdoor spaces of the dwelling results in a lower degree and extent of annoyance and less health complaints (Öhrström et al., 2006). Furthermore, soundscapes at the shielded side of the dwelling, outdoors as well as indoors, are perceived as less unfavourable, compared to the corresponding soundscape at the exposed side (Berglund & Nilsson, 2006).

B Regulations & standards

As traffic is the main cause of sound annoyance, and it is the noise source that by far most people are exposed to in the urban environment, this section will focus on regulations and standards concerning traffic noise.

The Dutch Noise Abatement Act (Wet Geluidhinder, 2012) defines a zone on both sides of a road in which traffic noise cannot exceed an equivalent sound level of 48 dB(A), measured at the façade of the dwellings. The width of this zone depends on the number of road lanes and whether the road is inside or outside the urban area (Table 4.11). 30 km/h roads are excluded from these rules. In urban areas this limit for noise exposure from new roads can be extended to 58 dB(A) for planned dwellings and 63 dB(A) for existing dwellings. For new dwellings along an existing road in urban areas the limit can be extended to 63 dB(A) and 68 dB(A) for new dwellings that replace existing ones.

Type of area	Number of lanes	Zone width (extending from road axis to both sides of the road)
Urban area	≥ 3	350 m
	1 or 2	200 m
Rural area	≥ 5	600 m
	3 or 4	400 m
	1 or 2	250 m

Table 4.11
Width of zone with sound regulations for road traffic according to the Dutch Noise Abatement Act (Wet Geluidhinder, 2012).

In a similar way, railway traffic noise is limited to a sound level 55 dB(A), measured at the façade of the dwelling, in a zone extending from 100 meters to 1200 meters from both sides of the rail, depending on the maximum allowed sound production of the railway (Table 4.12). This limit can be extended to 68 dB(A).

Maximum allowed sound production	Zone width (extending from railway axis to both sides of the railway)
< 56 dB(A)	100 m
56 – 60 dB(A)	200 m
61 – 65 dB(A)	300 m
66 – 70 dB(A)	600 m
71 – 73 dB(A)	900 m
>74 dB	1200 m

Table 4.12
Width of zone with noise regulations for railway traffic according to the Dutch Noise Abatement Act (Wet Geluidhinder, 2012)

The same law states that industrial areas may not cause equivalent sound levels over 50 dB(A) on the façades of dwellings and other buildings bordering the area. Inside the industrial zone the limit is also set to 50 dB(A), but it can be extended to 55 dB(A) for planned dwellings, 60 dB(A) for existing dwellings and 65 dB(A) for new dwellings that replace existing ones.

The law further states that indoor sound levels due to traffic or industrial activities should be no higher than 35 dB(A) when the maximum outdoor level is set under 55 dB(A) or 40 dB(A) when outdoor levels are allowed to exceed 55 dB(A).

Both the United Kindom and Germany do not regulate traffic noise by Federal law[31], but delegate this to local authorities. Belgium, however, has quite extensive regulations for environmental noise.

Belgian law defines maximum outdoor sound levels for different areas during the day, the evening and the night (Table 4.13) and gives guidelines for indoor levels (Table 4.14).

Type of area	Environmental quality standard [dB(A) in open air*]		
	day	evening	night
Rural areas and areas with recreational accommodations	40	35	30
Areas or parts of areas situated within 500 m from industrial areas, community facility areas or public utility areas	50	45	45
Areas or parts of areas situated within 500 m from business areas or areas under development	50	45	40
Residential areas	45	40	35
Industrial areas, community facility areas, public utility areas, business areas and areas under development	60	55	55
Agrarian areas	45	40	35
Recreational areas, areas with recreational accommodations excluded	50	45	40
All other areas, excluding: buffer zones, military areas and exceptions	45	40	35
Buffer zones	55	50	50
Areas or parts of areas situated within 500 m from gravel extraction areas	55	50	45

Table 4.13
*Maximum allowed outdoor sound levels according to Belgian law (VLAREM II). *Sound levels are to be measured 4,0 ± 0,2m in front of the most exposed facade (in agreement with European Directive 2002/49/EG).*

31 The UK and Germany endorse the method to assess sound levels in the urban environment as prescribed by the EU Directive 2002/49/EC.

Type of area	Guideline [dB(A)]		
	day	evening	night
Rural areas and areas with recreational accommodations	30	25	25
Industrial areas, community facility areas, public utility areas, business areas and areas under development	36	31	31
Residential areas and all other areas	33	28	28

Table 4.14
Guidelines for indoor sound levels according to Belgian law (VLAREM II).

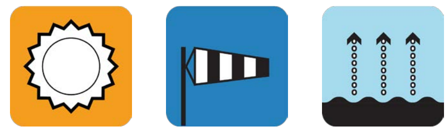
Both the Dutch and Belgian law are within the limits recommended by the WHO (1999) for the avoidance of several critical health effects (Table 4.15). According to the WHO about 40% of the EU population are exposed to road traffic noise exceeding 55 dB(A), and more than 30% are exposed at night to sound levels exceeding 55 dBA, despite the regulations in different EU countries.

Environment	Health effects	Equivalent sound level (LAeq)	Averaging period	Maximum sound level (incident)
Outdoor living area	Serious annoyance, day-time and evening	55 dB(A)	16 hours	
	Moderate annoyance, daytime and evening	50 dB(A)	16 hours	
Dwelling, indoors	Speech intelligibility, moderate annoyance	35 dB(A)	16 hours	
	Sleep disturbance, nighttime	30 dB(A)	8 hours	45 dB
Outside bedrooms	Sleep disturbance, window open	45 dB(A)	8 hours	60 dB
Industrial, shopping and traffic areas, indoors and outdoors	Hearing impairment	70 dB(A)	24 hours	110 dB

Table 4.15
WHO recommendations on sound levels.

The Belgian law gives more starting points for urban design than the Dutch law, in the sense that it defines different types of land use. The WHO recommendations distinguish some functions that can be related to space. The idea of different sound level limits for different types of land use or function agrees with the given that the setting in which a sound is heard influences the perception of noise. As annoyance from noise is influenced by such psychological factors, it can occur even if sound levels are beneath the legal threshold, with consequential effects on well-being. In addition to the legislation that focuses on quantitative noise reduction, standards or guidelines could be developed for qualitative noise reduction (e.g. the masking of unpleasant sounds with pleasant sounds).

§ 4.7 Outdoor thermal comfort



A Effects on physical well-being

Air temperature, radiation, wind and relative humidity are the main climate elements influencing the human thermal balance, as stated in Section 4.2.2. The human thermal balance equation can be written as Eq. 2:

$M \pm R \pm C_v \pm C_d - E = \Delta_S$ (after Auliciems & Szokolay, 2007) (2)

where:

M = metabolic rate
R = net radiation
C_v = convective heat flow
C_d = conductive heat flow
E = evaporative heat loss
Δ_S = change in heat stored

The metabolic rate is the rate of a person's internal energy production for basal processes, such as breathing and blood circulation, and for muscular work. The metabolic rate can range from 70 W for a body asleep to 700 W at intense exercise. The heat produced needs to be dissipated to the environment in order to maintain a steady core temperature.

Net radiation is the balance between radiation gained and radiation emitted by the body, as described in Section 4.2.2. In the sun this balance may be positive, while on a cold cloudy day it may be negative. The radiant field can be described by the Mean Radiant Temperature (MRT), which is the area weighted average of the various radiation influences on the body.

Convection is the process of heat transport through the movement of a fluid – in this case air - from an object to the surrounding environment. Wind can significantly enhance convection; the higher the wind speed, the higher the convective rate. In warm weather with air temperatures above skin temperature, the body may gain heat from convection, but most of the time the body will lose heat through convection.

Conduction is the process of heat transfer between materials that are in direct contact with each other. The heat transfer takes place through molecular vibration, without motion of the substance as a whole, as opposed to convective heat transfer. As often the only contact of a person with materials in the outdoor environment is through his or her shoes while standing or walking, the contribution of conductive heat transfer to the human thermal balance is usually negligible. Conductive gains or losses from air are also very small, as air is a poor conductor.

A person further loses heat through the evaporation of sweat and respiration (exhaled air is usually warmer and more moist than inhaled air). A high relative humidity (>65%) hampers evaporation of sweat, while a low humidity (<30%) leads to drying out of the skin, mouth and throat, both leading to discomfort.

The relative contribution of the different climate elements on the thermal balance depends on the weather conditions. When there is little wind, the MRT roughly has the same importance as the air temperature. However, at high wind speeds air temperature is far more important as it dominates the increased convective heat exchange (Höppe, 1999). MRT has a great influence on the thermal balance in warm conditions (Matzarakis et al., 1999; Mayer, 1993), while wind speed has a greater influence in cold conditions (Bröde et al., 2010).

If heat gains and losses are in equilibrium ($\Delta_S = 0$ in Eq. 2), a minimum of energy is needed to maintain a steady core temperature and there is no thermal stress physiologically.

One of the first and most frequently used thermal indices for indoor thermal comfort, the Predicted Mean Vote (PMV), originally developed by Fanger (1972), is based on the assumption that comfort is only reached and maintained at thermal equilibrium; any physiological stress is absent. It is based on a steady-state heat balance model, empirically fitted to the sensation vote on a seven-point scale of a group of human test subjects exposed to static conditions in a controlled indoor environment. The seven-point scale ranged from sensations hot, warm, slightly warm, neutral, slightly cool, cool, to cold, with neutral being assigned a value of 0 and the extremes of the scale values of 3 and -3, indicating the perception of comfort. As a result of the purely physiological approach, comfort standards based on PMV have rather strict ranges of indoor climate conditions.

An index for outdoor thermal comfort, also based on a steady-state human thermal balance model (MEMI), is the Physiological Equivalent Temperature (PET). It was introduced by Mayer and Höppe (1987) and compares complex outdoor conditions to a typical steady-state indoor setting (MRT=T_a, v=0.1 m/s, VP=12 hPa or RH=50% at Ta=20°C). Its unit is degrees Celsius, which makes it comprehensible for everyone. Höppe (1999) gives some examples of PET values for different climate conditions (Table 4.16).

Scenario	T_a [°C]	MRT [°C]	U [m/s]	VP [hPa]	PET [°C]
Typical room	21	21	0.1	12	21
Winter, sunny	-5	40	0.5	2	10
Winter, shade	-5	-5	5.0	2	-13
Summer, sunny	30	60	1.0	21	43
Summer, shade	30	30	1.0	21	29

Table 4.16
Examples of PET values for different climate conditions. Source: Hoppe (1999).

PET is sometimes related to PMV to predict whether an outdoor space will be perceived as thermally comfortable or not (see Table 4.17). This is plausible as both indices are based on steady-state thermal balance models taking a fixed indoor situation as a reference. However, the coupling of PET and PMV may not give a correct image of outdoor thermal comfort as there are some differences between outdoor and indoor climate that make direct comparison of comfort difficult; outdoor climate varies much more, temporally as well as spatially, values of the climate elements are usually very different from indoor values, and their relative influence can also be very different. Furthermore, physiological adaptation of a person entering a climatically different environment takes some time (Höppe, 2002; Fiala et al., 2001). Therefore, steady-state models do not predict outdoor comfort properly.

The Universal Thermal Climate Index (UTCI) is based on a dynamic physiological response model (Bröde et al., 2010). Like PET it is an equivalent temperature. The reference situation for UTCI is an outdoor climatic environment with a relative humidity of 50%, still air and MRT equalling air temperature. The person is assumed to have a metabolic rate of 135 W/m^2, walking with a speed of 4 km/h, and wearing temperature-dependent clothing. Values of PMV, PET and UTCI are shown in Table 4.17, for comparison.

PMV (indoor)	PET (Germany)	UTCI	Sensation vote
	<4	<-40	Very cold
		-40--27	
-3	4-8	-27--13	Cold
-2	8-13	-13-0	Cool
-1	13-18	0-9	Slightly cool
0	18-23 (temp range for indoor comfort)	9-26	Comfortable/ neutral
1	23-29	26-32	Slightly warm
2	29-35	32-38	Warm
3	35-41	38-46	Hot
		>46	
	>41		Very hot

Table 4.17
Comparison of thermal indices PMV, PET and UTCI.

More and more studies point towards an adaptive approach towards thermal comfort - especially for outdoor environments -, in which not only physiological but also psychological factors play an important role. When discomfort is not an immediate threat to health, psychological factors with regard to expectations, perceived control, environmental stimulation, experience, time of exposure and naturalness of a space influence the comfort zone and the acceptance of short-term discomfort (Nikolopoulou & Steemers, 2003).

Thermal comfort sensation outdoors is perceived very differently from indoor comfort and people tend to except a much wider range of thermal conditions outdoors than indoors. In the context of European project RUROS (Nikolopoulou, 2004) outdoor thermal comfort was studied through field surveys in 14 European cities. Only 11% of the interviewees were dissatisfied with the thermal environment averaged over the year, whereas the predicted percentage of dissatisfied people based on the theoretical calculation of PMV was 66% (Nikololoulou et al., 2001; Nikololoulou & Steemers, 2003). Based on the survey and measurements an index comparable to PMV has been developed for outdoor conditions: the Actual Sensation Vote (ASV). It consists of a 5 point-scale ranging from very cold to very hot and can be used for ambient air temperatures between 5 and 35°C (there were no interviews performed under colder and warmer conditions).

Equations have been developed to predict ASV for Europe as a whole, but also for the 14 cities separately. The extensive study shows that people in warmer climates perceive higher temperatures and wider variation as being comfortable opposed to people in colder climates. This can be appointed to long-term physiological adaptation, but also to expectations and past experiences with regard to the outdoor thermal environment. Neutral temperatures (not warm, not cold) vary widely throughout Europe (over 10°C), and also throughout the seasons; warmest temperatures are expected in summer, followed by autumn; in spring cooler temperatures are regarded as comfortable, as people 'remember' the colder conditions of winter (Nikolopoulou & Lykoudis, 2006).

The survey also brings another psychological aspect to light; people are more tolerant towards the thermal environment if it is their own choice to be in the space than when they are there 'compulsory' i.e. waiting, work-related or otherwise. In other words, the degree of control over the thermal environment also plays an important role in the experience of comfort. This pleads for a variety of microclimates in one space; providing a choice increases the degree of control and therewith the amount of people feeling comfortable.

Another tool for the assessment of outdoor thermal comfort is the bioclimatic chart by Olgyay (1963). The bioclimatic draws the zone of outdoor thermal comfort for a person dressed in indoor clothing, sitting and/or doing very light work, in a situation without wind and direct solar irradiation. For any combination of air temperature and relative humidity that falls inside the comfort zone no corrective measures are needed. For any point falling outside the zone, needed climate measures can be read from the chart. The further a point falls outside the comfort zone, the sooner negative effects on physical well-being will occur. Figure 4.6 and Figure 4.7 show the bioclimatic chart for temperate European climates (adapted from Reiter & De Herde, 2003.)

The advantage of the bioclimatic chart over the thermal indices described above is that it shows the relationship between the different climate elements and thermal comfort instead of a single mean vote or equivalent temperature. The urban designer can get a first idea of what the climatic needs of a site are by plotting the climate data on the chart (as will be shown in Chapter 7). Design decisions can then be made accordingly.

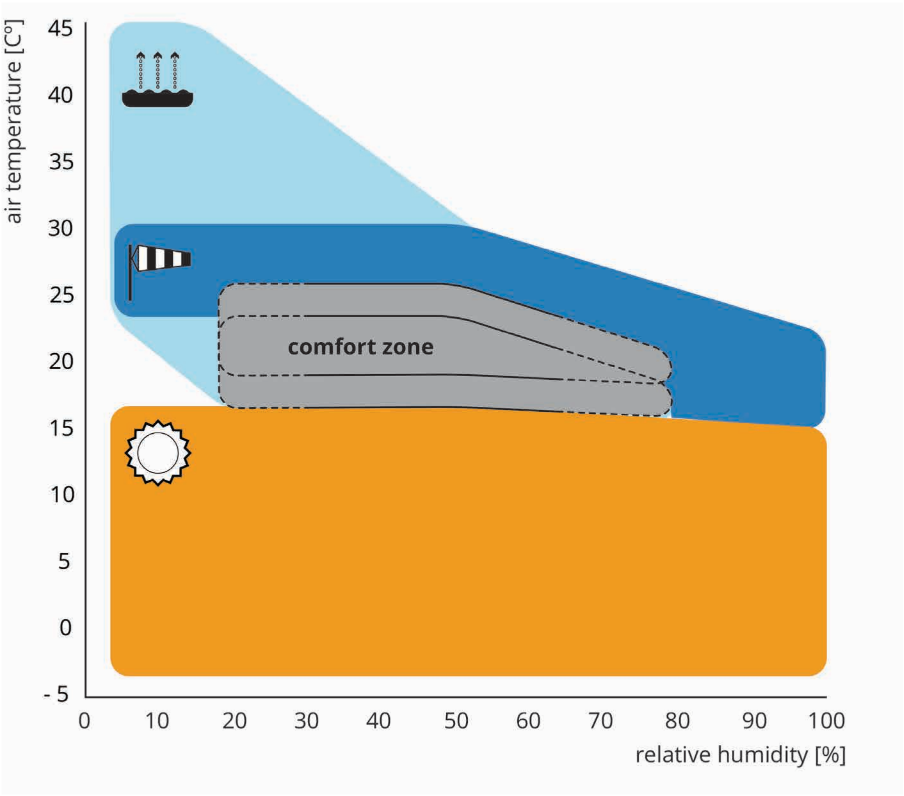


Figure 4.6
The bioclimatic chart for temperate European climates after Olgyay (1963) and Reiter & De Herde (2003).

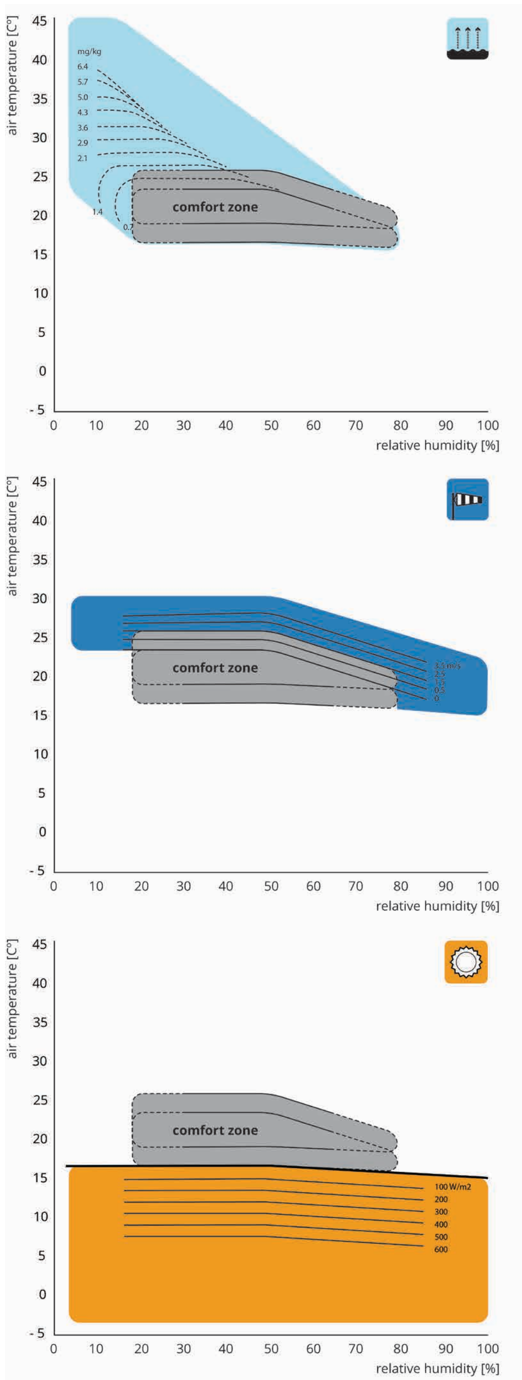


Figure 4.7

Amounts of added moisture, wind and radiation needed to restore comfort in relation to air temperature and relative humidity.

B Regulations & standards

No regulations or standards exist for outdoor thermal comfort; such rules would be virtually impossible to comply with. Guidelines for the separate climate elements contributing to thermal comfort would be more sensible. The two elements most easily influenced by the built environment are solar radiation, through limiting or allowing solar access, and convective heat exchange, through the creation of wake areas or areas with increased wind speeds. Existing standards and suggestions for guidelines regarding solar radiation and wind are given in Sections 4.2 and 4.4 respectively. Air temperature and relative humidity can only be modified by urban design to a limited extent on the small scale, as will described in Section 5.7. Regulations or standards would therefore be unproductive.

§ 4.8 Conclusion

§ 4.8.1 Overview of effects of the urban microclimate on physical well-being

This chapter discussed the influence of the different urban microclimate components on the physical well-being of people. Some of these effects are acute, others develop over a longer period of over/underexposure. Some cause discomfort – which can result in more serious health effects over a longer period of exposure - , others can be life threatening.

A short overview of the effects is given in Table 4.18.

	Too little UV: vitamin D deficiency (causing rickets, osteoporosis and osteomalacia) Too much UV: sunburn accelerated skin ageing solar keratoses (thick, scaly, or crusty patches of skin) skin cancer (cutaneous malignant melanoma, squamous cell carcinoma of the skin, basal cell carcinoma of the skin) cortical cataract pterygium (a fleshy growth on the surface of the eye) cancer of the eye (squamous cell carcinoma of the cornea or conjunctiva)

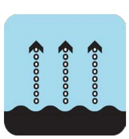
	disruption of the circadian melatonin and cortisol cycles (causing poor sleep quality, lack of alertness, feeling down, seasonal depression, immune deficiencies and possibly tumour growth)
	convective cooling of the skin (positive in summer, negative in winter) discomfort (disturbance of hair, flapping of clothes, difficulties holding umbrella) danger because of balance problems
	Particulate matter (PM10/PM2.5): cardiovascular diseases respiratory diseases lung cancer aggravation of asthma, chronic obstructive pulmonary disease and cardiovascular diseases Ozone (O3): lung inflammation decreased lung function Nitrogen dioxide (NO2): aggravation of bronchitic symptoms in children reduced lung function in children Sulphur dioxide (SO2): decreased pulmonary and respiratory functions
	sleep disturbance (and therewith increased fatigue, depressed mood or well-being and decreased cognitive performance) annoyance stress (leading to hypertension, myocardial infarction and total ischemic heart disease) hearing impairment
  	Too little heat (cold): hypothermia frost bite aggravation of cardiovascular, respiratory and cerebrovascular diseases Too much heat: heat stress (heat rash, heat cramps, heat syncope, thermal exhaustion, heat stroke) arterial and cerebral thrombosis aggravation of cardiovascular, respiratory and cerebrovascular diseases

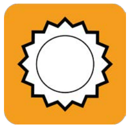
Table 4.18

Effects of the urban microclimate on physical well-being.

§ 4.8.2 Overview of regulations and standards

In this section an overview will be given of the Dutch regulations and standards concerning the different climate aspects as discussed in the previous sections. The reviewed regulations and standards of neighbouring countries are also given. A distinction is made between regulations and standards concerning the outdoor environment and those concerning the indoor environment. As stated in the introduction of this chapter, only those regulations and standards for the indoor environment are considered that refer to the building envelope as the measurement location, or those that are dependent on interventions in the building envelope .

Only those climate components that are highly influenced by human activity and having primarily negative influences on physical well-being are regulated by law: air quality and noise (Table 4.19). An exception to this rule is indoor daylight access, which is laid down in the Dutch Buildings Decree.

	outdoor	indoor
	BRE: no more than 25% of an outdoor space in shadow on March 21st (recommendation)	NEN 2057: At least 2 possible sunlight hours between March 1st and September 1st at window centre (windowsill height) DIN 5034-1: At least 1 possible sunlight hour on March 20th at window centre BS 8206-2: At least 25% of annual probable sunlight hours at window centre, 5% between September 21st and March 21st.
	-	Buildings Decree: Equivalent daylight area is at least 0,5 m^2 (for: dwellings, offices, schools and health care buildings) DIN 5034-1: Width of window is at least 55% of wall containing window Daylight factor of at least 4% on work plane for offices. BS 8206-2: Window area is at least 20%-35% of wall containing window (depending on room depth) Vertical daylight factor of 27% on window-pane Daylight factor of at least 2% in kitchens, 1,5% in living rooms and 1% in bedrooms.
	NEN 8100: Threshold wind speed for comfort is 5 m/s, Threshold wind speed for danger is 15 m/s + limits for the probability of exceeding this threshold wind speed within a certain period of time	-
	Directive 2008/50/EC: PM2.5 25 $\mu g/m^3$ (1 year) PM10 50 $\mu g/m^3$ (24 hours), 40 $\mu g/m^3$ (1 year) SO2 350 $\mu g/m^3$ (1 hour), 125 $\mu g/m^3$ (24 hours) NO2 200 $\mu g/m^3$ (1 hour), 40 $\mu g/m^3$ (1 year) O3 120 $\mu g/m^3$ (maximum daily 8 hour mean) + permitted events of exceeding these values each year	Buildings Decree: Air exchange rate of 0.9 l/s per m^2 floor space for habitable spaces of dwellings, 1.3 l/s per m^2 floor space for habitable areas of offices.

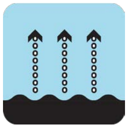
	-	Noise Abatement Act: No more than 48 dB(A) at façade due to traffic noise (with exceptions) No more than 50 dB(A) at façade due to industrial noise (with exceptions) No more than 55 dB(A) at façade due to rail traffic noise (with exceptions) Only valid for dwellings VLAREM II: No more than 45 dB(A) at façade during the day No more than 40 dB(A) during the evening No more than 35 dB(A) during the night Other values for other land uses
	-	-

Table 4.19
Regulations and standards regarding the components of the urban microclimate

§ 4.8.3 Discussion

The impact of the urban microclimate on physical well-being can be significant, as was shown in this chapter. Since the morphology, materialization and landscaping of the urban environment have a substantial influence on the urban microclimate, it is highly desirable that the urban microclimate is considered in the urban design process.

Legislation is a very effective way of guaranteeing that attention will be paid to the urban microclimate in the design process. The majority of current regulations and standards, however, are not formulated in a way that makes them practical for design purposes and in particular not for the first phases of the design process; they often lack spatial information and are focussed on assessment rather then giving design guidelines. As a result, attention given to the microclimate usually is limited to a test by an expert at the end of the design process, as was mentioned in chapter 3 of this dissertation.

A requirement made by the client or the existence of general awareness of the importance of the urban microclimate may be a better incentive, but also more difficult to bring about. Enhancing the intuition of the urban designer by offering some simple and basic knowledge on the microclimate in relation to built form is necessary to promote climate-sensitive design and related physical well-being. The next chapter will provide this basic knowledge and tries to translate this knowledge into guidelines for urban design.

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5 The influence of the urban environment on its microclimates

§ 5.1 Introduction

The previous chapter described how the urban microclimate affects the physical well-being of people. The urban microclimate is highly influenced by the morphology, materialization and landscaping of the urban environment. This chapter will discuss this influence of the urban environment on its microclimates by means of a literature review.

One of the best-known effects of the influence of the urban environment on its climate is the Urban Heat Island effect (UHI effect). The UHI effect is the phenomenon that the urban air temperature is higher than that of the surrounding (rural) environment. The extent of the temperature differences varies in time and place as a result of meteorological, locational and urban characteristics. The UHI effect can be found in both the Urban Boundary Layer (UBL) and the Urban Canopy Layer (UCL) and has the following causes (Oke, 1987; Santamouris, 2001) (Figure 5.1):

1. Absorption of short-wave radiation from the sun in low albedo materials and trapping by multiple reflections between buildings and street surface.
2. Decreased long-wave radiation heat loss from street canyons, caused by obstruction of the sky by buildings, trees and other objects. The heat is intercepted by the obstructing surfaces, and absorbed or radiated back to the urban tissue.
3. Absorption and re-emission of long-wave radiation by air pollution in the urban atmosphere.
4. The release of anthropogenic heat by combustion processes, such as traffic, space heating and industries.
5. Decreased turbulent heat transport from within streets caused by a reduction of wind speed.
6. Increased heat storage by building materials with large thermal admittance. Cities have a larger surface area compared to rural areas and therefore store more heat.
7. Decreased evaporation from urban areas because of 'waterproofed surfaces' – less permeable materials, and less vegetation compared to rural areas. As a consequence, more energy is put into sensible heat and less into latent heat.

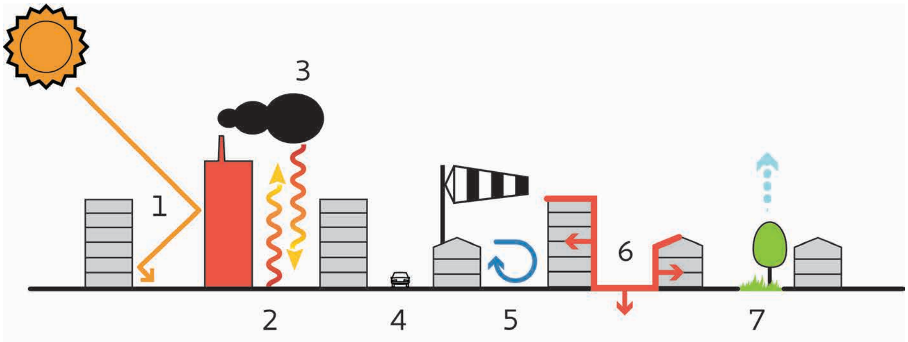

Figure 5.1
Causes Urban Heat Islands.

Not only the thermal components, but all components of climate are modified by the urban environment, with related effects on physical well-being (Chapter 4). This chapter will describe the influence of the urban environment on each of the urban microclimate elements separately- solar radiation (Section 5.2), daylight (Section5.3) wind (Section 5.4) air quality (Section 5.5) and sound (Section5.6) – on the basis of available literature. Each of these sections will describe the effects in the UCL on the scale of a single building, the urban canyon and systems of interlinked urban canyons, respectively[32]. These spatial concepts are commonly used in urban microclimatology. The urban canyon is defined as the (outdoor) space confined by facades, ground, roofs and the (imaginary) plain between the rooftops, and the air volume within this space (Figure 5.2). The urban tissue can be seen as a system of interlinked urban canyons. Street crossings, differences in building heights and special elements, such as squares and other enclosed spaces, cause phenomena additional to those in single urban canyons.

These spatial concepts from urban microclimatology are different from the plan elements used by the urban designer (Section 2.3). In order to make the information useful to the urban designer each section will therefore conclude with a 'translation' of the information from the literature review to urban design guidelines related to the urban design plan elements.

32 When relevant and if literature is available.

Sections 5.2 to 5.6 focus on the influence of morphological aspects - the carcase of the city - on each of the microclimate elements separately. The morphology of a city is fixed for the long term and changes in morphology are often difficult to bring about. Additionally, section 5.7 discusses the influence of materialization and landscaping – the finishing. These properties of the urban environment are easier to change and can be employed as mitigating measures, and are therefore treated separately.

Figure 5.2
Schematic representation of an urban canyon (cross-section); the space confined by facades, ground, rooftops and the (imaginary) plain between the roof tops, and the air volume within this space.

§ 5.2 Solar radiation

Before reaching the earth's surface, the solar radiation passes through the atmosphere. The atmosphere's constituents and clouds reflect part of the solar short-wave radiation back into space, and absorb another portion. The rest of the solar radiation is transmitted directly to the earth's surface. The earth in turn reflects part of this direct radiation (about 3%) and absorbs the rest. This absorbed radiation is emitted back into the atmosphere as long-wave radiation (heat), of which a small part is directly transmitted to space, but the largest part is absorbed and re-emitted to the earth by the atmosphere. The short-wave solar radiation that is absorbed by clouds and the atmosphere is also emitted as long-wave radiation, partly to the earth and partly to space. The balance between incoming and outgoing radiation (both short-wave and long-wave is not in equilibrium; there is a surplus of incoming radiation. This surplus is offset by a conversion of energy into sensible heat and latent heat. (This energy balance was also shortly discussed in Section 4.2.2 and depicted in Figure 4.1). In the urban environment, anthropogenic heat - heat released by human activities - can also be a significant term in the energy balance. The urban energy balance can be written as:

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A \text{(Oke, 1988a)} \qquad (3)$$

where:

Q^* = net all-wave radiation flux (difference between incoming and outgoing short-wave and long-wave radiation)
Q_F = anthropogenic heat flux
Q_H = sensible heat flux
Q_E = latent heat flux
ΔQ_S = change in storage heat flux
ΔQ_A = change in net advective heat flux.

Anthropogenic heat is heat released by human activities and mainly consists of heat from combustion processes, such as traffic, space heating and cooling, and industries. The magnitude of this term depends on the energy use per person, the population density, and the type of activity. The spatial variability of the anthropogenic heat flux in a city can be quite high. The highest values are found in business districts and industrial areas. The variability in magnitude is also quite high between different cities (Figure 5.3).

The sensible heat flux is the exchange of heat between different surfaces or surface and air, resulting in a change of temperature. The sensible heat flux is mainly determined by the temperature difference between surface (wall or ground) and air; the greater the temperature difference, the greater the flux. When a surface is directly irradiated by the sun it can become quite warm and the sensible heat flux is then at its maximum. An east-facing surface will thus have the largest sensible heat flux in the morning and a smaller peak in the afternoon, in case of an opposite surface reflecting solar radiation. A west-facing surface will have the largest sensible heat flux in the afternoon and the smaller peak in the morning. The sensible heat flux of a south-facing wall will be more or less symmetrical around noon and have the highest value of all (vertical) orientations (Nunez & Oke, 1977; Mills, 1993; Arnfield & Grimmond, 1998; Idczak et al., 2010). The sensible heat flux depends on the incoming and outgoing radiation, which we will be discussed in this section, and on the thermal properties of the surface materials, which will be discussed in Section 5.7.1.

Latent heat flux is the heat transfer needed for the evapo(transpi)ration of water from vegetation, soil, open water and materials containing moisture. The required heat for phase change of the water is extracted from the air or surface. The more water and the more heat available, the greater the latent heat flux. The latent heat flux is on average much smaller in urban areas compared to rural areas because of a smaller availability of water in urban areas as they have more 'waterproofed surfaces' – less permeable materials, and less vegetation than rural areas. The effects of evapotranspiration will be discussed in Section 5.7.2. Latent heat flux and sensible heat flux are related; the greater the latent heat flux, the smaller the sensible heat flux.

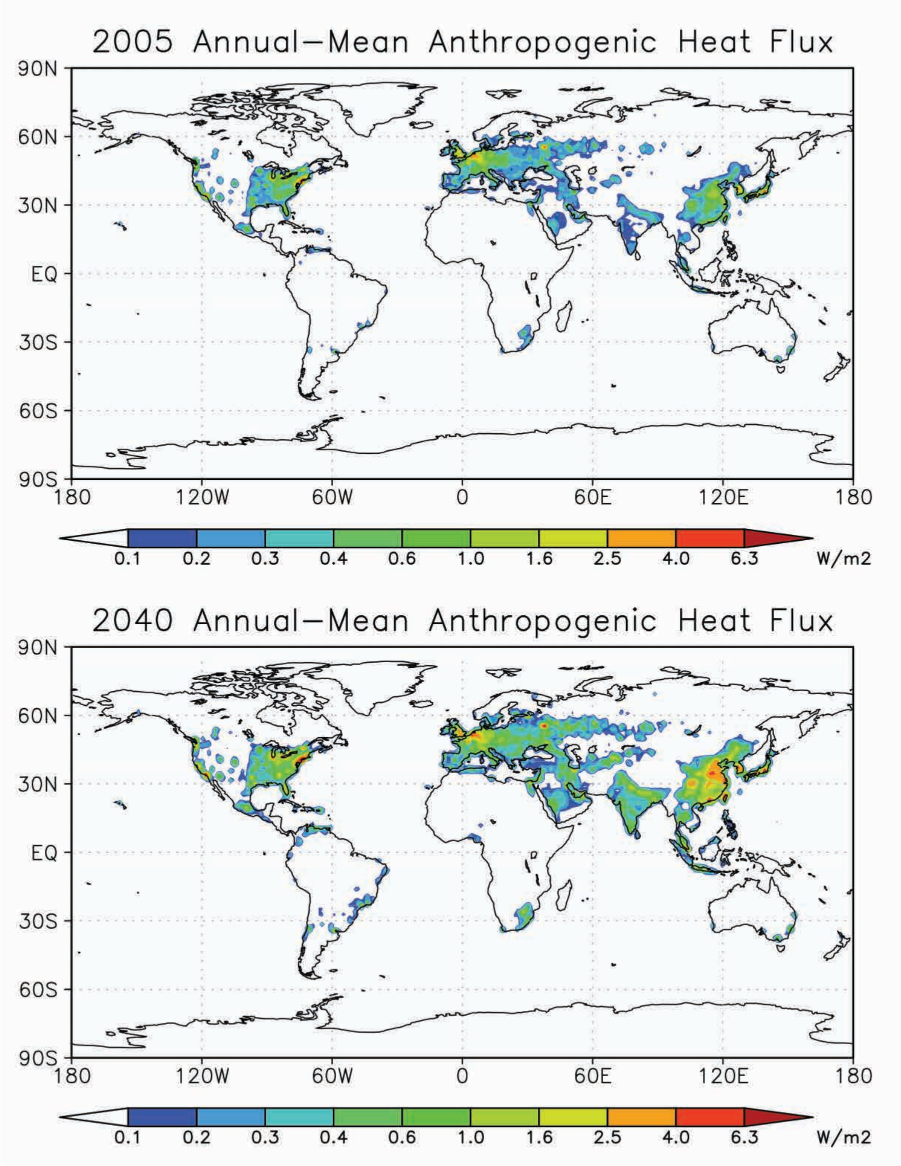

Figure 5.3

Estimated annual anthropogenic heat flux.

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The storage heat flux is the change in heat storage in the urban system. It consists mainly of the conductive heat fluxes in the paving and building materials; heat storage in the air is of a much smaller magnitude. As with the sensible heat flux, the conductive heat flux of a surface is largest when the sun directly irradiates it. It is usually negative at night due to long-wave radiative heat loss to the sky. The storage heat flux depends on the incoming and outgoing radiation, which we will be discussed in this section, and on the thermal properties of the surface materials, which will be discussed in Section 5.7.1.

The advective heat flux is the transport of heat by air movement. This component of the balance is usually small and therefore often neglected.

Figure 5.4 presents the general trends of the urban energy balance.

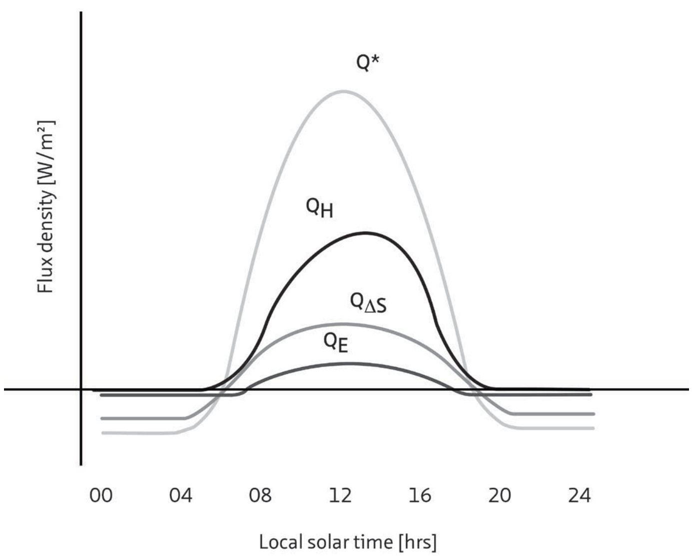


Figure 5.4
Urban energy balance - general trends.

The morphology of the urban canyon and tissue has a large influence on the net all-wave radiation by allowing the sun in or obstructing it and by promoting or hampering long-wave radiation loss to the sky, as will be elaborated in the next sections.

§ 5.2.1 Irradiation of a single building

A building with an unobstructed view to the sky will yield the highest possible global irradiation (direct + diffuse irradiation). The annual global solar irradiation for building surfaces with different orientations in The Netherlands is presented in Figure 5.5. Table 5.1 shows how much of the global irradiation is due to direct irradiation and how much due to diffuse irradiation. It can be seen that diffuse irradiation comprises the largest part of the total irradiation, for all orientations. Furthermore, it can be seen that direct irradiation varies greatly with orientation; the value for a surface facing south is more than twenty times higher than that of a surface facing north. Figure 5.6 shows how the global irradiation is distributed over the months of the year.

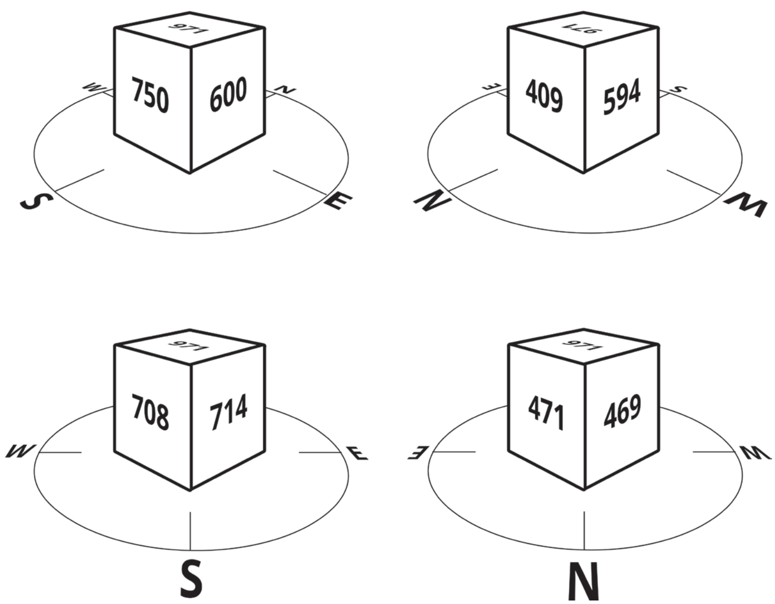


Figure 5.5

Annual incident global radiation [kWh/m²] for surfaces with different orientations. Data are for De Bilt, The Netherlands (52°06 N and 5°11 E) of the year 1995, a commonly used reference year (www.knmi.nl).

Direct [kWh/m²]		Diffuse [kWh/m²]	
Horizontal	382	Horizontal	589
S	358	Vertical	392
SW	316		
W	202		
NW	77		
N	17		
NE	80		
E	208		
SE	322		

Table 5.1
Annual incident direct and diffuse radiation for surfaces with different orientation

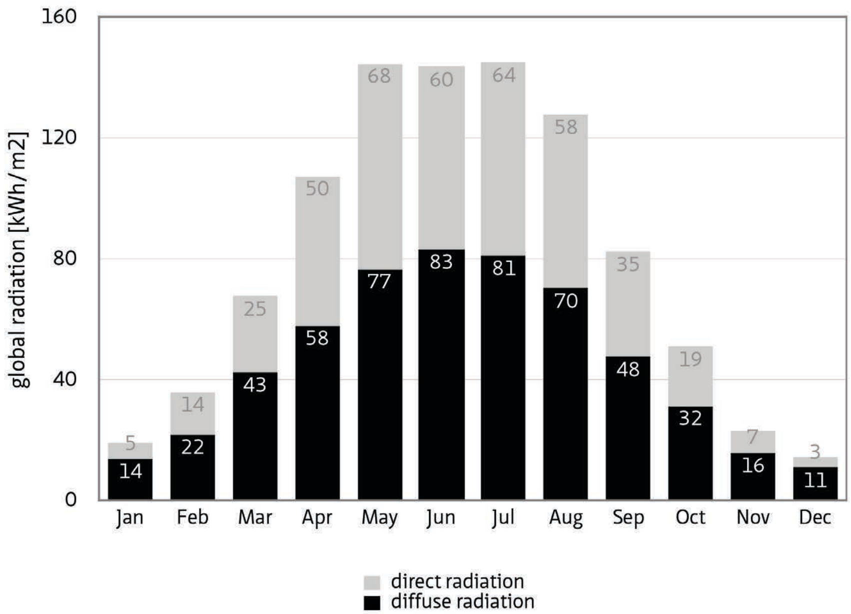


Figure 5.6
Monthly average global irradiation levels split into diffuse radiation and direct radiation. Data labels represent global irradiation values for horizontal surfaces.

The solar radiation incident on a building will be reflected and absorbed. The larger the amount of radiation that is reflected, the smaller the amount that is available for absorption.

The amount of reflected radiation depends on the albedo of the surface (also called reflection coefficient). Albedo is defined as the ratio of total-reflected to incident radiation and is a dimensionless measure for the diffuse reflectivity of a surface. It is determined by material surface properties (see Section 5.7.1). Generally speaking, light-coloured specular surfaces have the highest albedos.

The incident radiation on a surface that is not reflected will be absorbed and stored for a certain amount of time and re-emitted into the environment as long-wave radiation later.

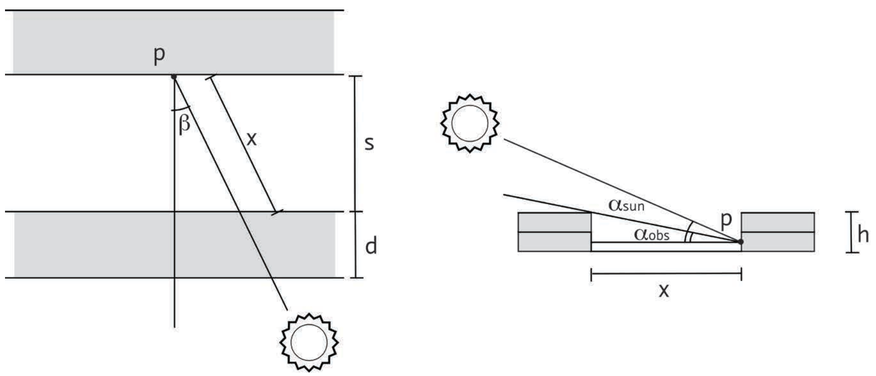
In the presence of other buildings or objects the incident radiation – both direct and diffuse - will go down as the view of the sun and sky are obstructed. This topic will be elaborated in the next sections.

§ 5.2.2 Radiation in the urban canyon

Direct irradiation

The sun directly irradiates a given point within the urban canyon if its rays can travel from the sun to this point without meeting obstructions in their path. The position of the sun in the sky varies from moment to moment – depending on time of day and season -, and as a consequence, the imaginary line between point and sun also changes with time.

This (apparent) movement of the sun through the sky is called the solar path. The position of the sun in the sky is defined by its vertical angle with the horizon, called solar altitude (α_{sun}), and its horizontal angle measured from due north, called solar azimuth (β). Solar altitude and azimuth depend on time of day and year, as well as latitude. The sun reaches the highest altitude at the equator and the lowest at the poles. At solar noon, when the sun is positioned due south, the highest solar altitude of the day is reached.

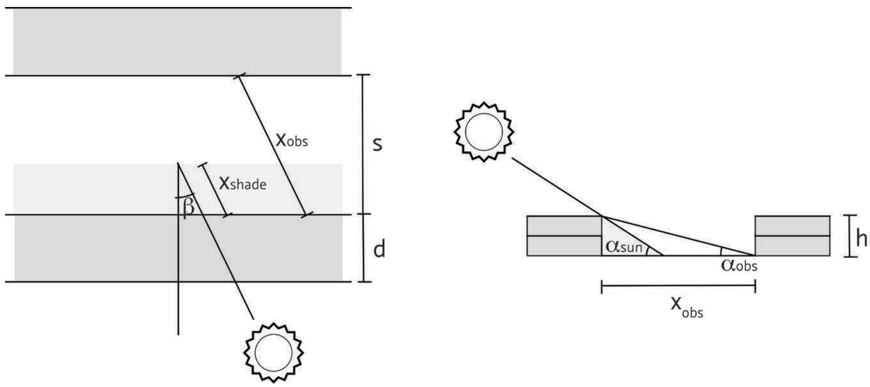


p	point under consideration
h	building height
α_{sun}	solar altitude
α_{obs}	obstruction angle
β	azimuth
x	street width in direction of azimuth
s	street width
d	building depth

Figure 5.7
Direct irradiation of a given point "p". Top view (left) and section parallel to the solar azimuth β (right).

A given point "p" will be irradiated when the solar altitude is greater than the obstruction angle in the direction of the solar azimuth, when smaller it will be in shade (Figure 5.7). The obstruction angle is defined as the angle between the horizontal and the line connecting the highest point of an obstruction and the point under consideration. Surrounding objects may intersect this line and thus intercept the sun's rays at one time, casting shades on the point of interest, but be no obstruction at another.

The fraction of directly irradiated canyon surface – ground or façade – can be determined in a way similar to that of a single point (Figure 5.8). When the street width and the dimensions of the aligning buildings are given, the corresponding obstruction angles can be determined for every combination of solar azimuth β and altitude α.



h	building height
α_{sun}	solar altitude
α_{obs}	obstruction angle
β	azimuth
x_{shade}	width non-irradiated street space in direction of azimuth
x_{obs}	street width for obstruction angle in direction of azimuth
s	street width
d	building depth

$x_{shade} = h/\tan\alpha_{sun}$
$x_{obs} = s/\cos\beta$
$\tan\alpha_{obs} = h/x_{obs}$

percentage of directly irradiated street surface = $((1-x_{shade}/x_{obs})*100\%$

Figure 5.8
Direct irradiation of the canyon floor. Top view (left) and section parallel to the solar azimuth β (right)

The height to width ratio (H/W) of the street strongly influences the fraction of the canyon surface irradiated, especially in winter when the sun is low. As can be expected, wider canyons yield larger percentages of irradiation. The impact of changes in H/W is largest for narrow canyons and decreases as canyons get wider. In general, higher building densities lead to less direct solar access in the urban canopy (Bourbia & Awbi, 2003; Van Esch et al., 2012).

Orientation of the canyon surfaces with regard to the solar path is of great influence on the moment and duration of their irradiation. North-south running canyons have the benefit of being directly irradiated in winter. Even on the shortest day of the year the ground surface is completely irradiated around noon, when the sun has unobstructed access to the street. North-south running canyons have building facades facing east and west, which will be irradiated in the morning and afternoon respectively. East-west running cantons yield large percentages of directly irradiated ground surfaces in the morning and afternoon in summer- leading to a prolonged period of warming of surfaces and air - but provide some shade for comfort around noon. East-west running canyons also have the benefit of constant direct irradiation (and shade) in spring and fall, but are heavily shaded in winter.

East-facing facades will be irradiated in the morning, their fraction of surface directly irradiated increasing until solar noon. West-facing facades will have the highest fraction of directly irradiated surface just after solar noon, decreasing during the afternoon. South-facing facades have the highest fraction of directly irradiated surface at noon in winter; in spring, summer and fall the highest fractions are found in the morning and evening. Highest surface temperatures correspond to the locations of maximum solar irradiation, which can be found at the top of the canyon walls, as the duration of irradiation is longest there. A secondary surface temperature peak can be found at the time of maximum solar irradiation of the opposite facade, as a consequence of long-wave radiation heat exchange between the canyon walls (Offerle et al., 2007).

Roof shape has a significant influence on the fraction of directly irradiated street surface. For canyons with an east–west street direction, single-pitched roofs give a significant higher yield than flat and gable roofs throughout the whole day in the cooler seasons, therewith providing the best outdoor conditions for pedestrians in these seasons. In summer, single-pitched roofs give the most shade in the early morning and late evening. During the day, flat roofs give somewhat more shade. For canyons with a north–south street direction, gable roofs yield the highest percentage of irradiated street surface in the morning, while single-pitched roofs give a better performance in the late afternoon (Van Esch et al., 2012).

Diffuse irradiation

The amount of diffuse radiation received depends on the fraction of the sky visible from the point/surface of interest. This is commonly indicated by the Sky View factor (SVF). The SVF is a measure of the degree to which the sky is obscured by the surroundings. A flat open terrain has a sky view factor of unity, a site where part of the sky hemisphere is obstructed by buildings or other objects will have a proportionally smaller SVF. Oke (1987) gives view factors for commonly occurring geometric arrangements, including the urban canyon (Figure 5.9).

A rough estimate of the diffuse radiation incident on an obstructed surface can be made by multiplying the diffuse irradiation for an unobstructed surface with the (average) SVF of that surface. This is an approximation of the actual diffuse irradiation because it assumes an isotropic sky. In reality the diffuse radiation is not distributed uniformly across the sky dome, but is higher near the sun.

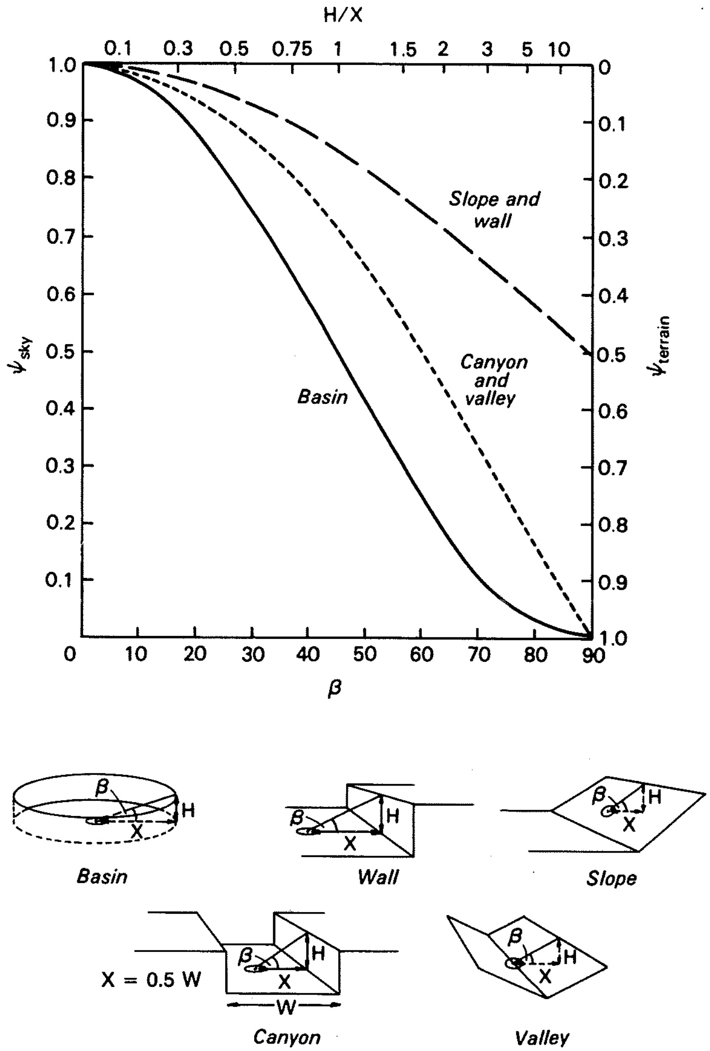


Figure 5.9
View factors for commonly occurring geometric arrangements.
Reprinted from Oke, T.R. (1987). Boundary layer climates. London, Methuen.

Global irradiation

Global irradiation is the sum of direct and diffuse irradiation and is thus dependent on the view of both the sun and the sky, as was discussed above. Important morphological factors are H/W and SVF, which are highly related, and orientation. Arnfield (1990) gives global irradiance values for north-south and east-west canyons with H/W ranging from 0.25 to 4.0, for all latitudes (Figure 5.10). It can be seen that for the Netherlands (at 52° NL), differences between canyons of different orientations are rather small.

Only in summer, wall irradiance values of canyons with H/W< 1 are much lower in east-west canyons than in north-south canyons.

H/W has a significantly larger influence on global irradiation of the canyon than orientation. As H/W increases, global irradiation decreases, due to a decrease in both direct and indirect radiation received. Long-wave radiation loss from the canyon during the night also decreases with increasing H/W. Together, this results in a damping of the diurnal temperature fluctuation (Swaid & Hoffman, 1990).

Roof shape has a minor impact on the total yearly global radiation yield of the canyon as a whole, its influence on the global radiation yield of the buildings is also small (presupposing the same building volume). Dwellings with single-pitched roofs are exposed to the most solar radiation when the street direction is east–west and flat roofs when the street direction is north–south (Van Esch et al., 2012).

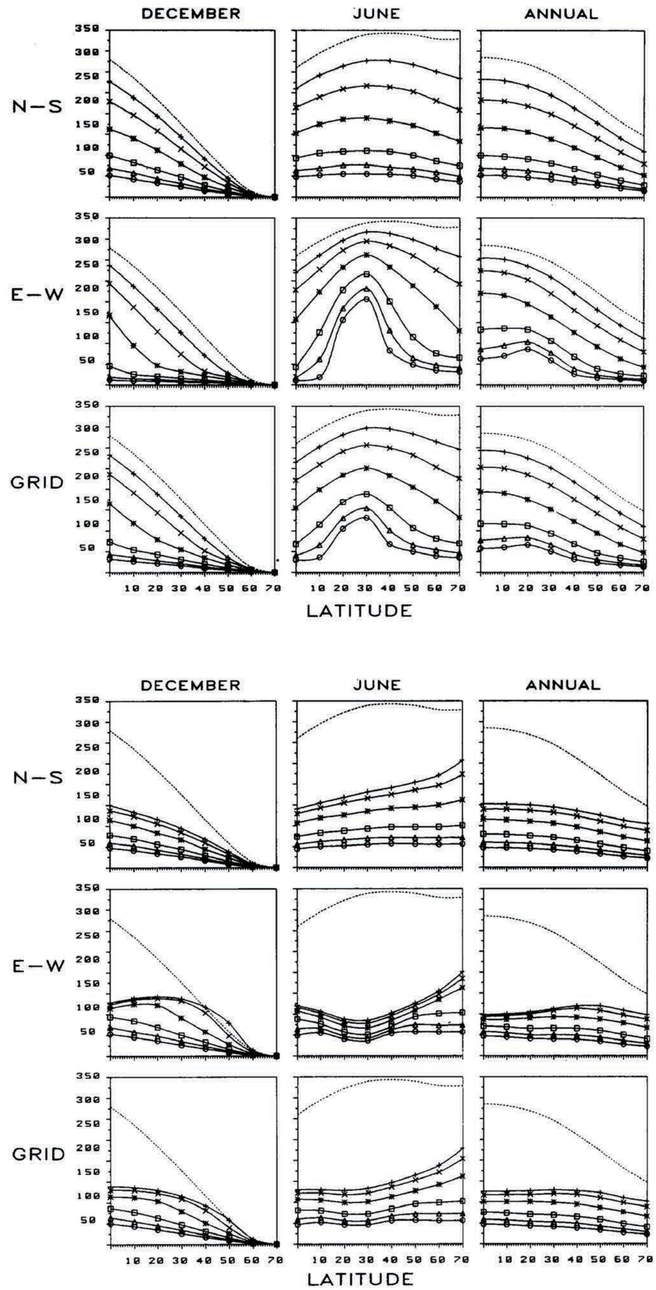


Figure 5.10

*Canyon floor (top) and wall (bottom) irradiances in W/m² by latitude (N), orientation, season and H/W. Line symbols denote H/W as follows: +-+ H/W = 0.25; x-x H/W = 0.5; *-* H/W = 1.0; []-[] H/W = 2.0; ^-^ H/W = 3.0; o-o H/W = 4.0.*

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Reflection, absorption and re-emission

The canyon surfaces will reflect part of the incident short-wave radiation back to the sky immediately, but also via each other. These inter-reflections result in an increase in the total amount of solar radiation that is absorbed. The greater the H/W of the canyon, the more inter-reflections occurring. A greater H/W (or smaller SVF) furthermore leads to a decrease in long-wave radiation heat loss from the canyon, as radiation exchange with the cooler sky is limited. Conversely, long-wave radiation (re-)emitted from one canyon surface is intercepted by another canyon surface and reflected and/or absorbed again. This process of multiple reflections of both short-wave and long-wave radiation leads to trapping of heat in the canyon (Figure 5.11).

Figure 5.11
Reflections of incident short-wave (left) and emitted long- wave radiation (right) lead to trapping of heat in the urban canyon.

The term albedo was already introduced in reference to the reflectivity of a single surface. It can also be used to express the reflectivity of a compound of urban surfaces –urban canyons or even a whole city. The canyon albedo has a close relation with the canyon energy balance; it expresses the ratio of radiation reflected back from the urban canyon to the sky to the total incoming radiation. The canyon albedo decreases with increasing H/W, so narrow streets trap more radiation than wide streets (Kondo et al., 2001), however, as less surface is irradiated directly, narrow streets are therefore cooler at the warmest time of the day than wider streets (Shashua-Bar et al., 2011).

The orientation of the canyon has a minor effect on its albedo; a north-south running canyon has a slightly lower albedo for high solar altitudes and a slightly higher albedo for low solar altitudes compared to an east-west running canyon. Their average albedo is the same (Aida, 1982). The solar altitude influences the canyon's albedo from an altitude of about 50 degrees and up; the albedo rises sharply from this point onwards (Aida, 1982). Materialization and finishing also have a significant impact on the albedo of the canyon. This will be discussed in Section 5.7.1.

§ 5.2.3 Radiation in urban tissues

The global radiation yield of buildings in tissues with low a GSI (tall and slender buildings at relatively large distances) is significantly more affected by H/W than in tissues with a high GSI (large, low buildings at small distances), especially in winter (Mills, 1997). This is due to the relatively large façade area that tissues with a low GSI have in comparison to tissues with a higher GSI. The facades are shaded more and more as H/W increases, decreasing the global radiation yield of the buildings. Tissues with a high GSI receive most radiation on the roof and are therefore less affected by variations in H/W of the streets. Mills (1997) furthermore shows that the average SVF of the buildings in a tissue with a low GSI - and therewith the potential of passive cooling by long-wave radiation loss - is more affected by changes in H/W of the streets than in tissues with a higher GSI.

For solar access to outdoor ground surfaces, tissues that have buildings facing south along east-west running streets are most efficient and tissues with buildings facing east/west along north-south running streets are least efficient, as shown by Kristl & Krainer (2001) for a mid-latitude site (46.03° N). Differences between orientations decrease with increasing H/W of the streets and with increasing building depth.

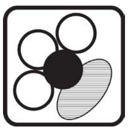
The influence of H/W is larger for squares and courtyards than for urban canyons, as they are enclosed from four sides instead of two. Yezioro et al. (2006) show that for a low-latitude site (32° N) it is already difficult to reach an average fraction of 50% of the square that is directly irradiated during the day in December, a fraction of 30% can be reached if H/W is below 1/3. For mid-latitude sites H/W should even be lower; if any sun is to reach the square in December, H/W should be smaller than ¼.

Enclosed spaces with a H/W smaller than 1/6 with unobstructed view to the sky have a significant long-wave radiation heat loss to the sky. At night this heat loss causes an air circulation, cooling the surroundings up to about one W extended from the enclosed space (Spronken-Smith & Oke, 1999).

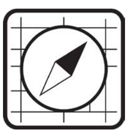
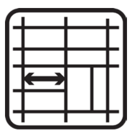
§ 5.2.4 Considerations for urban design

Guidelines

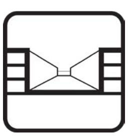
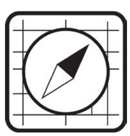
1 Minimizing FSI (or gross floor space) will maximize the potential for direct solar irradiation.



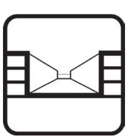
2 Functions with higher heating needs should be placed on top of functions with lower heating needs.

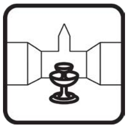
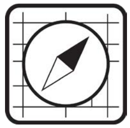

3 A tissue with buildings facing south along east-west running street are preferable, as this yields the largest solar gain in the heating season and the smallest in summer and is most beneficial for outdoor thermal comfort.

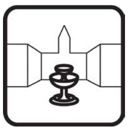
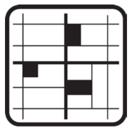
4 East-west streets are preferably wider than north-south streets; the impact of H/W on direct solar access to all canyon surfaces is largest for east-west streets and smallest for north-south streets.




5 In tissues with a low GSI, buildings are best spaced at considerable distances to allow direct irradiation of the facades. In tissues with a high GSI the roofs are the primary collectors of solar radiation, limiting the importance of street width for passive solar gain of the buildings.

6 Squares, courtyards, gardens and other enclosed outdoor spaces meant for sitting, waiting or recreation are best elongated in the north-south direction and should have a H/W of ¼ or smaller to allow direct solar access in winter. Solar shading should be provided in summer.

7 In dense urban environments, spaces with a high SVF, such as squares and parks with sparse tree cover, should be placed at regular intervals of about 2 diameters to promote nocturnal long-wave radiation loss in summer. To avoid overheating, (flexible) shading should be employed in these spaces during the day.

8 Buildings along east-west running streets preferably have single-pitched roofs (highest side facing south), as this benefits both outdoor and indoor solar access.

Discussion

Solar requirements in temperate climates depend on the season. In winter, solar access to indoor as well as outdoor environments is highly desirable. In spring and autumn both sun and shade is necessary. In summer, significant shading is more important. The spatial requirements for solar access to the outdoor environment may sometimes conflict with those for solar access to the indoors and vice versa. This is most evidently the case for orientation. Careful tuning of morphological parameters is therefore key.

An urban setup with streets running in an east–west direction aligned with single-pitched roofed buildings facing south, crossed by narrower streets running north–south provides indoor solar gain as well as outdoor thermal comfort for the largest part of the year. The only drawback is the limited direct irradiation of the street surface of the east-west streets in winter.

In practice, few examples of tissues where all buildings are facing south can be found. One of the reasons is the disadvantages the front-to-back orientation of this layout brings; private areas (gardens) along public roads being the most important disadvantage. Furthermore, the existing urban fabric might ask for a different orientation and layout, i.e. with regard to accessibility, readability, etc. In these cases, spacious (roof) gardens, courtyards or balconies will provide people the possibility to enjoy the sun. If density requirements do not allow large outdoor spaces at building or block level, public squares or parks at walking distance will fulfil the same function.

For the (passive) solar gain of buildings, the roof offers most possibilities, as it is usually the least obstructed building surface and has the most beneficial orientation. So, if for some reason a tissue with east-west streets and buildings facing south cannot be realized, a tissue with low and compact buildings is a good alternative; the relatively large roof area can provide passive heating to the buildings, while the sun can penetrate to street level because of the limited building height.

§ 5.3 Daylight

Daylight is solar radiation in the visible spectrum arriving from the sun and the sky hemisphere. It varies with time of day and season and is weather-dependent. For the assessment of daylight levels, a distinction is commonly made between three types of sky conditions: fully overcast, clear sky, and partly overcast or intermediate sky conditions. A fully overcast sky produces the lowest daylight levels and therefore this sky condition is most often used - it presents the 'worst case scenario'. The sky model for completely overcast skies defined by the International Commission on Illumination (CIE) is most widely adopted for daylight calculation purposes. In this sky model the luminance[33] distribution is as follows (Eq. 4):

$$L_\gamma=(L_z/3)*(1+2\sin\gamma) \qquad (4)$$

where:

L_γ = luminance of a sky element
L_z = zenith luminance
γ = elevation angle of the sky element above the horizon

33 Luminance is the luminous intensity per unit area, and is an indicator for the perceived brightness of a surface

This equation (4) states that the zenith luminance is three times that at the horizon, and that it increases from horizon to zenith gradually. In this model, the luminance is the same for all azimuth angles for a given altitude angle, so the daylight gain of a surface is orientation-independent.

The illumination at a point can be expressed by either illuminance, with unit lux, or by the daylight factor[34], which is dimensionless. While illuminance values may fluctuate widely because of the variable nature of daylight, the daylight factor remains constant. The daylight factor is therefore more often used for the assessment of building and urban designs.

The daylight factor consists of several components: the sky component, the externally reflected component and the internally reflected component (only for indoor points) (Figure 5.12).

The Sky Component (SC) is the portion of the total daylight factor received from the area of sky visible from the point considered. In addition to the area of the sky visible, the magnitude of the sky component depends on the position of the area at the sky dome; the closer to the zenith, the larger the luminance and thus the larger the sky component. This component is often the largest of the three because of the high luminance of the sky dome compared to those of reflecting objects.

The Externally Reflected Component (ERC) is the portion of the daylight factor that is received from reflection by external objects, such as buildings and the ground at the point considered. The contribution from buildings is usually (much) larger than that from the ground. The externally reflected component increases with decreasing building distances and thus higher building densities, at the expense of the sky component. Furthermore, the component increases with the albedo of the reflecting object(s).

34 The daylight factor is a percentage ratio of the illumination level on a point (indoors or outdoors) to the outdoor illumination level occurring simultaneously on a horizontal plane under an unobstructed hemisphere of fully overcast sky. Under sky conditions other than fully overcast the daylight factor is not always a reliable predictor; depending on the cloud cover the internal/external illuminance ratio can be as much as twice as high or as little as half as the predicted daylight factor (Tregenza, 1980).

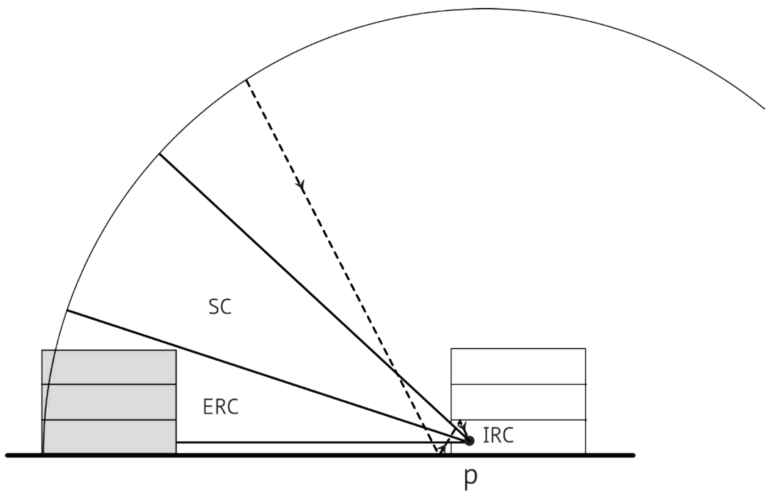


Figure 5.12
Components of the daylight factor: sky component, externally reflected component and internally reflected component, for an indoor point p.

For indoor situations, light from reflections by internal surfaces also forms a component: the Internally Reflected Component (IRC). Ceilings contribute significantly to this component.

The next sections will describe daylight access to the urban canyon and the urban tissue. Daylight factors as well as illuminances (or derivatives) will be used as indicators, as they both appear in the literature.

§ 5.3.1 Daylight in the urban canyon

Generally speaking, outdoor spaces can be expected to receive the majority of their daylight directly from the sky (exceptions can be caused by overhangs, large protrusions from buildings or other coverings). Indoor spaces, however, may have limited view of the sky.

The geometry of the urban canyon highly influences the amount of indoor floor space that receives direct skylight, as well as light reflected from external surfaces.

Van Esch & Haupt (2006) and Van Esch et al. (2007) studied the influence of a series of morphological parameters on the daylight performance of the urban canyon (Figure 5.14). In these studies the Daylight Performance Index (DPI_n) was defined as the percentage of the total indoor floor area that has a daylight factor higher than a chosen threshold n. Reflections were not considered; the daylight factor consists of SC only. The results for DPI_0 – the percentage of total floor area that had a SC higher than 0% – are shown in Figure 5.15. DPI_0 can be determined manually by drawing the no-sky-line; the line between the highest point of the obstruction and the top of the façade opening, extended to the floor[35] (Figure 5.13).

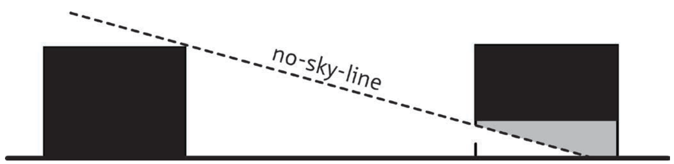


Figure 5.13
The no-sky-line is determined by the highest point of the obstruction and the top of the facade opening.

Figure 5.15 shows that increasing FSI (and therewith H/W) leads to less floor space being daylit. The speed of decrease is high when FSI (or H/W) is low and slows down when FSI (or H/W) becomes higher.

Comparing situations with the same program (FSI), but different ground cover (GSI), it can be seen that settings with high and slender buildings perform better than settings with low and compact buildings.

Varying the distance between buildings – increasing street width at the expense of garden depth or vice versa - appears to make no difference regarding the percentage of directly lit floor space. Also, when deep buildings, placed on great distance from each other, are compared to slender buildings on close distance, no difference in performance occurs. This, of course, presupposes the same amount of program and coverage in all cases.

35 DPI_0 can theoretically be greater than 100% in cases where the no-sky-lines of the opposing facades overlap.

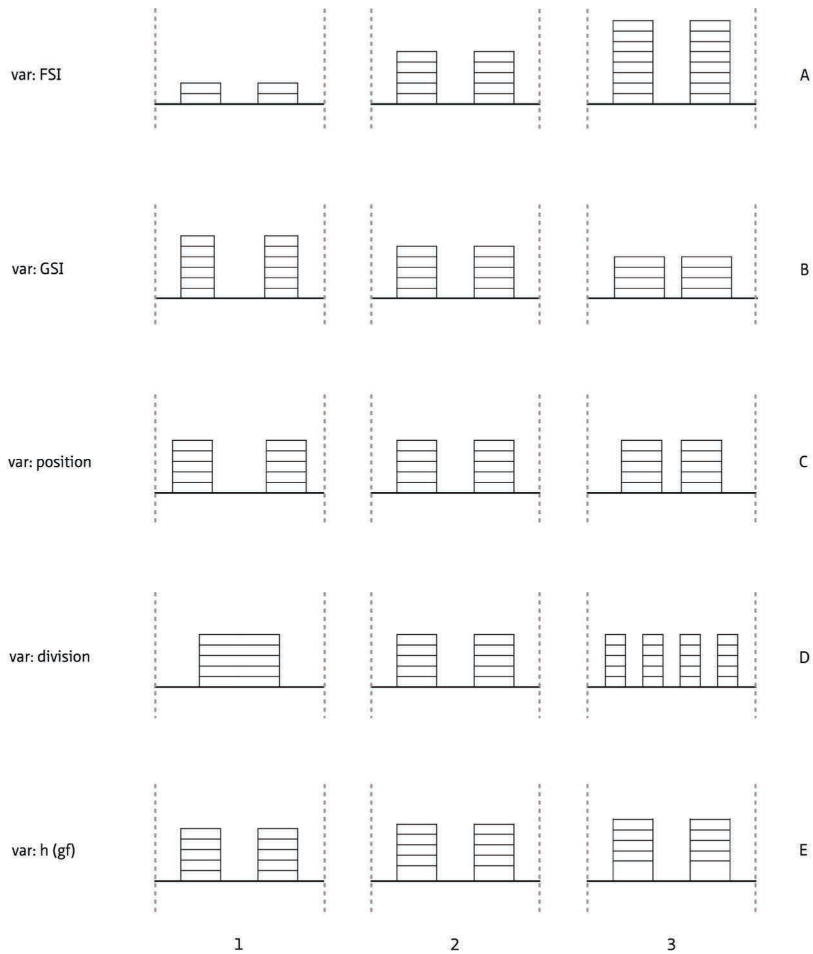


Figure 5.14
Studied morphological parameters by Van Esch & Haupt (2006).

Increasing the story height of the ground floor proportionally increases DPI_0.

The same behaviour was found for DPI_1 and DPI_3, only with lower values and less steep slopes (Van Esch et al., 2007).

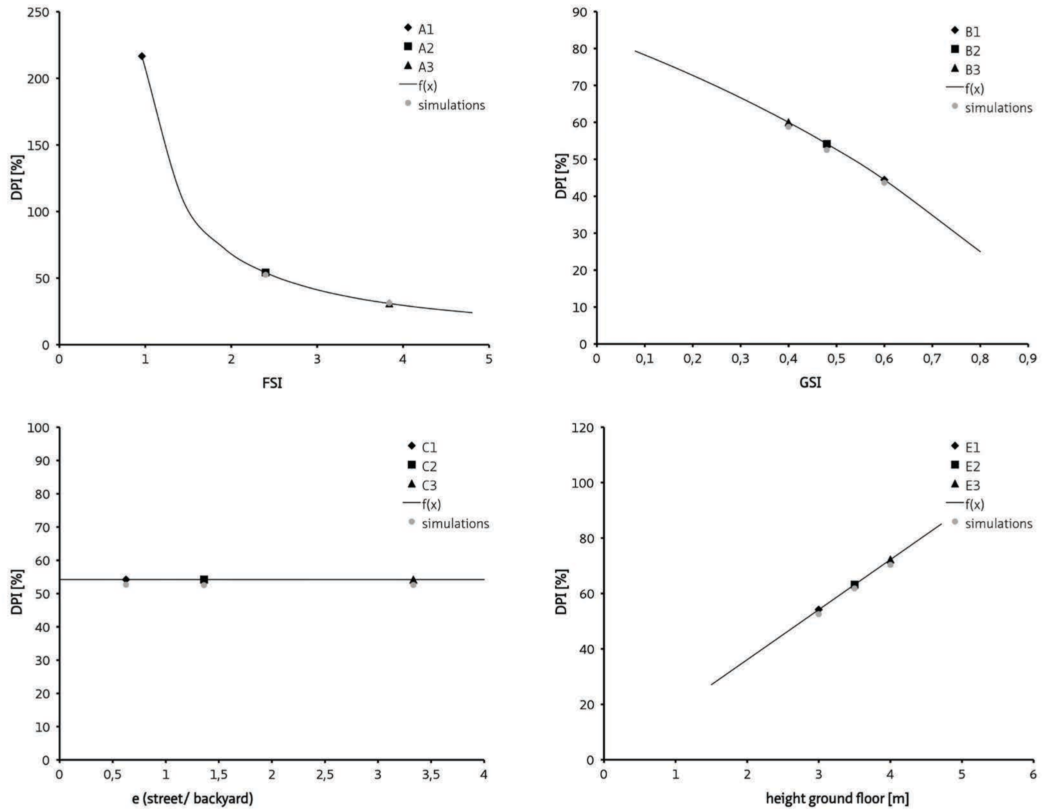


Figure 5.15
The Daylight Performance Index (DPIO) as a function of FSI (top left), GSI (top right), width-to-width ratio of street and backyard (lower left) and story height (lower right). Source: Van Esch & Haupt (2006).

When looking at the daylight factor in a specific point, a somewhat different behaviour can be observed (Figure 5.16). Increasing FSI leads to lower daylight factors, as can be expected. Increasing GSI, however, causes the daylight factor to increase to a certain maximum and then decrease again. This behaviour is due to the variation of H/W – which is smallest at GSI = 0,5 - when the fabric changes from high and slender to low and compact. The DPI doesn’t show a maximum at GSI = 0,5, because the building depth increases with GSI, leaving more space in relative darkness.

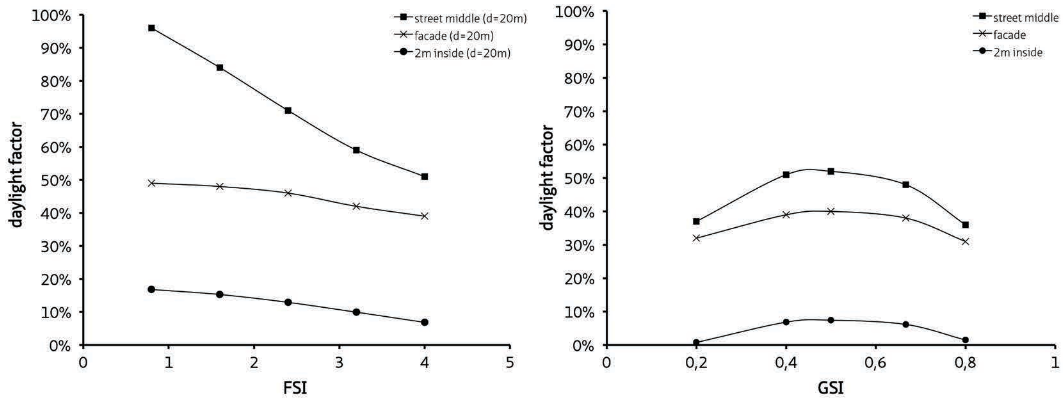


Figure 5.16
The daylight factor as a function of FSI (left) and GSI (right).

Tregenza (1995), Wa-Gichia (1998) and Strømann-Andersen & Sattrup (2011) show that the ERC can also contribute substantially to the daylight factor. In canyons with high H/W (>1,5) and high albedo (>0,75) it can be the highest fraction of the daylight factor on the lowest floors (Strømann-Andersen & Sattrup, 2011). In some cases it can even compensate for the loss of sky view caused by obstructions – Wa-Gichia (1998) found that when H/W is low (0,86) and reflectance is high (0,6), the reflection of sunlight by the opposing façade results in a mean interior illuminance which is higher than that observed without an obstruction, for all floors. The same effect can be experienced at the higher floors in canyons with high H/W ratios (H/W=3 in the study of Wa-Gichia). It must be noted that this phenomenon occurs when the opposing façade is directly irradiated by the sun, so in clear skies, not in fully overcast skies. In general, higher H/W results in lower mean indoor illuminances.

Reflectance of light from opposing facades leads to a more even distribution of illuminances throughout the canyon, also inside the buildings along the canyon. The rear of the interior seems to benefit most from external reflections.

When skies are not (fully) overcast, orientation plays a role in the daylight performance of urban canyons, especially in winter. East-west canyons (with buildings oriented north-south) are often overshadowed, as solar altitudes are low in winter. North-south canyons, however, allow direct access to the sun around noon, raising the daylight levels in the canyon through reflection (Strømann-Andersen & Sattrup, 2011).

This section discussed the influence of morphological aspects of the urban canyon and daylight performance. The situations sketched were (semi-) 2D and can be expected to give a good indication for the daylight performance of urban tissues. However, some additional daylight phenomena occur due to morphological aspects in 3D situations, which will be discussed in the next section.

§ 5.3.2 Daylight in urban tissues

The concept of an urban canyon presupposes a constant building height along the length of the canyon. Often, streets follow this principle (usually residential streets do), but significant differences in building height are also not uncommon (e.g. in business districts).

Ng (2005) studied the influence of building height differences by calculating the vertical daylight factors at the centre of the facades of the ground floors of 25 buildings (the middle 5x5 buildings of a 15x15 array). Sixteen scenarios of varying building heights were tested, maintaining the same building density (same FSI and GSI). The results show that the minimum daylight factor stays relatively constant, but the mean and maximum daylight factors increase significantly with increasing height differences.

Not only building height differences, but also crossings and lateral buildings/building wings have an influence on daylight access.

Ratti et al. (2003) studied the daylight performance of arrays of six archetypal urban forms: pavilions, slabs, terraces, terrace-courts, pavilion-courts and courts (Figure 5.17). The arrays have the same FSI and the same ratio of 'potentially passive' (i.e. the necessary illuminance is completely provided by daylight) to 'non-passive' floor area ('potentially passive' being the floor area within twice the floor to ceiling height from a façade). As a result, building height and width, as well as street and courtyard depth are different for each type.

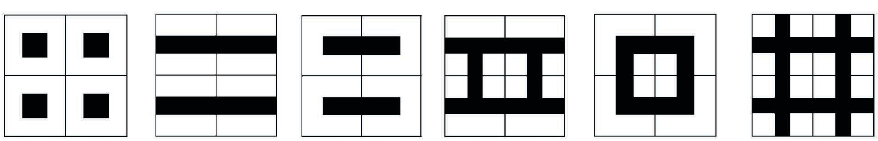


Figure 5.17
Urban forms studied by Ratti et al. (2003); pavilions, slabs, terraces, terrace-courts, pavilion-courts and courts. Reprinted from Energy and Buildings, 35(1), Ratti et al., Building form and environmental performance: Archetypes, analysis and an arid climate, 49-59, copyright 2003, with permission from Elsevier.

The arrays with pavilions and courts have the highest average SVF on the facades, indicating that these urban forms have the highest daylight potential. However, differences are small and Ratti et al. conclude that daylight distribution is relatively unaffected by urban form, when both built volume and passive to non-passive ratio are constant on a given site.

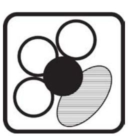
The same study by Ratti et al. also compares an array of courtyards to two arrays of different pavilions with the same built volume. In this case, the buildings in the the courtyard setting have the highest indoor daylighting potential, due to a high surface-to-volume ratio and a small building depth. Outdoor average daylight factors and sky view factors are however substantially lower than those of the pavilions.

§ 5.3.3 Considerations for urban design

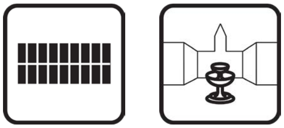
Guidelines

9 Minimizing FSI will maximize the potential for natural daylighting.

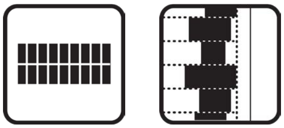
10 For a given FSI, tissues with a low GSI have a better daylight performance than tissues with a high GSI. In other words: high and slender buildings placed at large distances from each other perform better than low and deep buildings placed at short distances and are thus preferable. This effect increases with increasing FSI, as daylight access decreases with increasing density.



11 Functions with the highest daylight demands are best placed at locations with the highest daylight availability, e.g. on the highest floors of a building (and/or in the potentially passive zone near the façade (the floor area within twice the floor to ceiling height from a façade)).

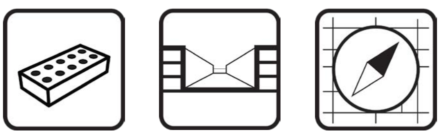


12 Large courtyards, squares or other enclosed spaces have a high potential for indoor daylighting.



13 Building depth should be minimized for indoor daylighting. .

14 Differences in building height increase average and maximum daylight factors.



15 In canyons with high H/W, materials or colours with a high albedo should be used to maximize reflection. This is most important for east-west canyons (with north/south facing buildings), as they are heavily overshadowed in wintertime.

Discussion

This section on daylight has focussed on the indoor environment, rather than the outdoor environment; high daylight levels are readily available outdoors as a view of the sky is almost always guaranteed. Daylight access to the indoor environment, however, needs to be well-designed. This is commonly thought to be the responsibility of the architect. Of course, the architect has a major influence on the daylight performance of buildings; it is usually the architect who determines the size and position of windows. Furthermore, he/she can employ patios, atria and skylights to improve daylight access. It is, however, the urban design that sets the basic conditions for daylight access to the interior by defining the geometry and other morphological aspects of the urban canyon and tissue, as was discussed above. If the urban design also establishes rules for the architectural articulation of buildings (i.e. concerning building materials, colours, façade openings), the influence of the urban design on the daylight performance of buildings even increases. It is therefore important that attention is given to daylight in urban design, already in the early stages, when decisions concerning density and building typology are being made.

The literature review above seems to suggest that - within a given density- (relatively) high and spacious urban tissues have the best daylight performance. Furthermore, building height differences contribute to the performance. Central business districts of larger cities and European post-war city extensions are often made up of such tissues. These tissues often have problems with the large scale of the buildings and public spaces, and related social problems, but also have problems with other climate elements, in particular wind. An urban tissue of mid-rise perimeter blocks, a common 19th century building type, may provide a good compromise. The often large (community) courtyards can provide enough daylight, while providing shelter to the wind, as will be treated in the following section.

§ 5.4 Wind

Wind is caused by differences in air pressure. Air pressure depends on air density, which is influenced by temperature. Heat causes air to expand and decreases its density. Warm air therefore has a lower pressure than cold air. Wind blows from areas with high air pressure to areas with low air pressure. The greater the pressure differences and the closer the areas with pressure differences are located to one another, the faster the wind will blow.

Wind speed increases with height above the earth, because the wind is slowed down by the earth's surface as it exerts friction. The rougher the terrain, the more friction is exerted. The vertical distribution of horizontal mean wind speeds is commonly described with a logarithmic wind profile, See Eq. 5:

$$U_z = U^*/\kappa \ln((z-z_d)/z_0) \qquad \text{(valid when } z>20*z_0 + z_d) \qquad (5)$$

where:

U_z = horizontal mean wind speed at height z
U^* = friction velocity
κ = Von Karman constant (0.4)
z_0 = aerodynamic roughness length
z_d = zero displacement length

Figure 5.18 shows the influence of terrain roughness on the wind profile.

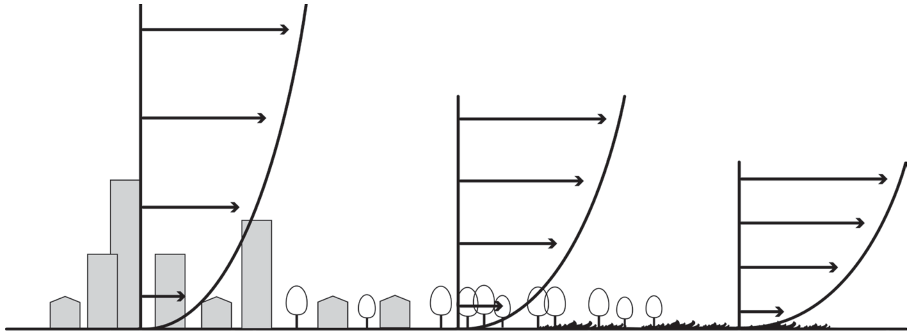


Figure 5.18
Schematic wind profiles for different terrain roughnesses.

Class	z_0 [m]	Landscape description
1 Sea	0.0002	Open sea or lake (irrespective of wave size), tidal flat, snow-covered flat plain, featureless desert, tarmac and concrete, with a free fetch of several kilometres.
2 Smooth	0.005	Featureless land surface without any noticeable obstacles and with negligible vegetation; e.g. beaches, pack ice without large ridges, marsh and snow-covered or fallow open country.
3 Open	0.03	Level country with low vegetation (e.g. grass) and isolated obstacles with separations of at least 50 obstacle heights; e.g. grazing land without windbreaks, heather, moor and tundra, runway area of airports. Ice with ridges across-wind.
4 Roughly open	0.10	Cultivated or natural area with low crops or plant covers, or moderately open country with occasional obstacles (e.g. low hedges, isolated low buildings or trees) at relative horizontal distances of at least 20 obstacle heights.
5 Rough	0.25	Cultivated or natural area with high crops or crops of varying height, and scattered obstacles at relative distances of 12 to 15 obstacle heights for porous objects (e.g. shelterbelts) or 8 to 12 obstacle heights for low solid objects (e.g. buildings).
6 Very Rough	0.5	Intensively cultivated landscape with many rather large obstacle groups (large farms, clumps of forest) separated by open spaces of about 8 obstacle heights. Low densely-planted major vegetation like bushland, orchards, young forest. Also, area moderately covered by low buildings with interspaces of 3 to 7 building heights and no high trees.
7 Skimming	1.0	Landscape regularly covered with similar-size obstacles, with open spaces of the same order of magnitude as obstacle heights; e.g. mature regular forests, densely built-up area without much building height variation.
8 Chaotic	≥ 2	City centres with mixture of low-rise and high-rise buildings, or large forests of irregular height with many clearings.

Table 5.2
Updated Davenport classification of effective terrain roughness, valid for fetches > 5 km (Wieringa. 1992)

The aerodynamic roughness length z_0 is a measure for the roughness of a terrain. Parameter z_0 does not indicate the actual object height, but can be regarded as an effective obstacle height as 'experienced' by the wind. Table 5.2 gives a classification of terrain roughness.

Parameter z_0 and the related logarithmic wind profile can only be used to predict mean wind speeds above the obstacles (e.g. trees, buildings). The airflow pattern in the vicinity of obstacles is highly dependent on the geometrical characteristics of these obstacles and is quite complex, as will be discussed in the following sections.

§ 5.4.1 Wind flow around a single building

The flow pattern around a single building is shaped by two pressure systems. The first pressure system is located at the windward façade of the building. As wind speed increases with height, so does air pressure as the wind is retarded by the building. The highest air pressure develops at about seventy to eighty percent of the height of the building in the middle of the façade and decreases outwards from there. This pressure gradient causes a downwash of air and a standing vortex at the foot of the building (Figure 5.19). The higher the building, the higher the wind speeds that will be directed downwards.

The second pressure system is made up out of the overpressure zone at the windward side and the underpressure zone at the leeward side of the building. This pressure system causes recirculation of air at low speed in the wake of the building and contributes to the high wind speeds in the corner streams that detach from the sides and top of the building. Between the layers with high winds speeds and the wake area, shear layers with large speed gradients and high turbulence intensity can be found.

It is also this second pressure system that causes pressure short-circuiting in passageways through or underneath a building, or between two buildings if their over- and underpressure zones connect. Pressure short-circuiting can cause serious discomfort. Most wind discomfort can be expected in the corner streams and frontal vortex, due to the higher wind speeds.

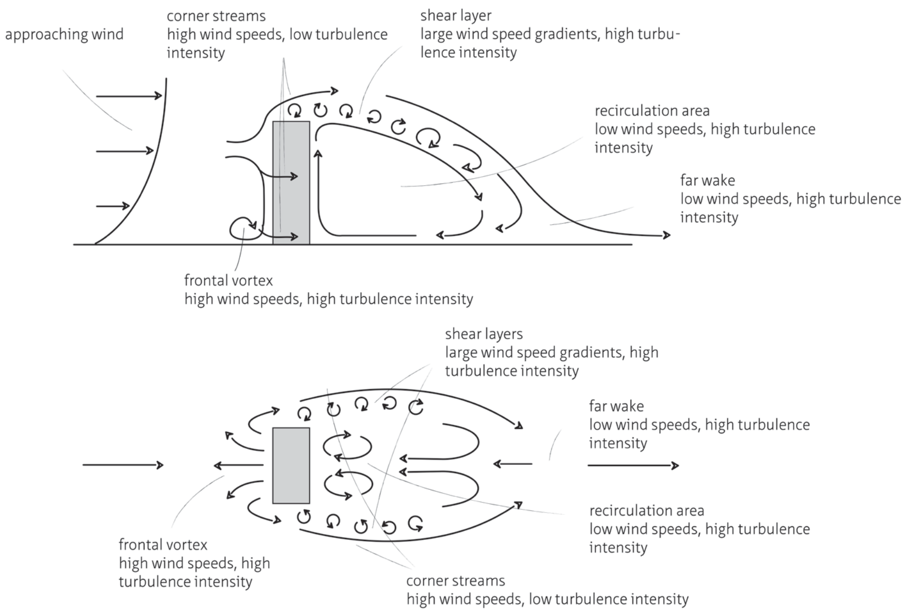


Figure 5.19
Flow pattern around a single building, side view (top) and top view (bottom).

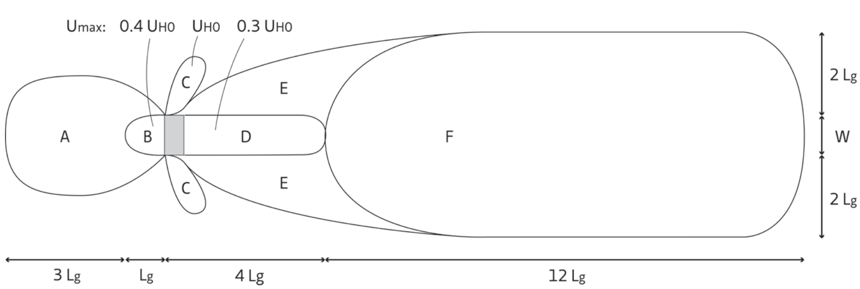


Figure 5.20
Influence area and flow zones around a building. Dimensions are given as a multiple of the geometrical influence scale Lg. Flow zones: upstream retarded zone (A), frontal vortex (B), corner streams (C), recirculation area (D), shear layers (E), far wake (F) (after Bottema, 1993).

The dimensions of the area in which the wind flow is directly influenced by the building can be expressed with a geometrical length scale L_g. This length scale is about the size of either the width of the building or two times the height of the building, whichever one is smallest (If $w<2h$: $L_g=w$, If $w>2h$: $L_g = 2h$). The area of influence stretches to about four length scales from the windward side of the building, sixteen length scales from the leeward side of the building and two length scales from the sides of the building (Bottema, 1993), as shown in Figure 5.20.

The geometry of the building affects the flow pattern in its influence area. When a building is high and slender, most of the air will pass the building sideways, when it is high and wide the downwash and frontal vortex will be large, as will be the recirculation area. A low and wide building will have the most air passing over the building (Figure 5.21).

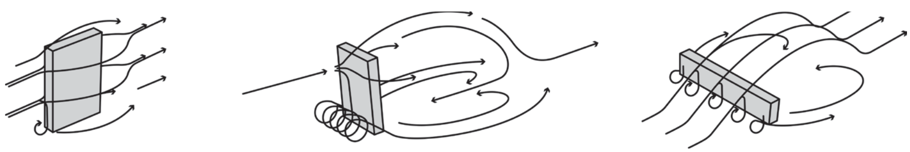


Figure 5.21
Airflow around a tall and slender building, a tall and wide building and a low and wide building.

Figure 5.21 also indicates the influence of orientation; a building that is placed with its longest façades parallel to the (prevailing) wind direction will yield the smallest discomfort areas, but also the smallest sheltered areas. A building placed with its longest façades perpendicular to the wind direction will yield both the largest discomfort and shielded areas. In case the building orientation is at an angle to the wind, the sizes of the discomfort areas and shielded area will lie between those of a perpendicular building and those of a parallel building. The experienced discomfort, however, may be larger, because the maximum wind speeds in the corner streams are higher than in the parallel and perpendicular cases, presumably because the wind can flow relatively easy along the windward façades.

This section has shown that the flow pattern around a single building is determined by its geometry and its orientation with regard to the wind direction. The same is true for the flow pattern in an urban canyon, as will be described in the next section.

§ 5.4.2 Wind flow in the urban canyon

Three flow patterns can be distinguished in urban canyons, correlated to the wind direction at roof height: parallel, perpendicular or at an angle to the canyon axis (Figure 5.22).

When the wind direction is parallel or nearly parallel to the canyon axis (within a deviation of fifteen degrees) the wind can blow right through the canyon. At the windward opening of the canyon, stream-wise as well as vertical velocity are sharply increased as air enters the canyon. Further into the canyon, the stream-wise velocity decreases due to air escaping the canyon vertically at roof level. At a distance of about 6H (for a canyon with H/W=1) into the canyon the stream-wise velocity becomes nearly constant and the vertical velocity nearly zero (Hang et al., 2009a; Hang & Li, 2010). The higher H/W, the further into the canyon this fully developed flow starts (Hang et al., 2010). At the leeward opening of the street, air enters the canyon from above roof level and a slight increase in stream-wise velocity can be observed as a consequence.

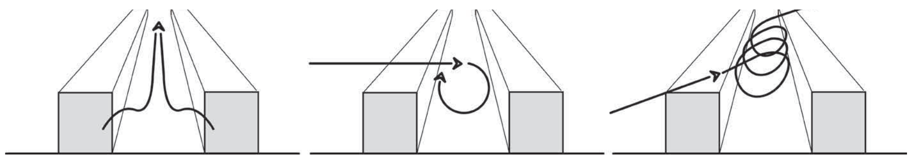


Figure 5.22
Flow patterns in the urban canyon, related to the wind direction at roof height; parallel, perpendicular or at an angle to the canyon axis.

If the wind direction is (more or less) perpendicular to the canyon axis, three sub flow regimes can be distinguished: isolated roughness flow, wake interference flow and skimming flow (Baik & Kim, 1999; Hussain & Lee, 1980; Oke, 1988b; Sini et al., 1996; Xiaomin et al., 2006), as listed in Table 5.3 and shown in Figure 5.23. All these flow regimes consist of a complex system of vortices, which are closely related to the height to width ratio (H/W) of the canyon.

In the case of isolated roughness flow (H/W > 0.1), the individual flow fields of the building strips are clearly identifiable (similar to a single building). There is very little interaction between the flows of the upwind and downwind area of the canyon. Only the far wake is affected.

When the canyon is less wide (0.1 < H/W < 0.7), the recirculation zone of the upwind building strip and the frontal vortex of the downwind building strip interact and amplify each other. This is called the wake interference flow regime. The wind speeds in this regime are higher than those in the isolated roughness flow regime.

In even narrower canyons (H/W > 0.7), most of the air passes over the canyon and interaction between the air layers in and above the canyon is very weak. The air skimming over the roofs is the driving force behind a vortex that rotates inside the canyon, with its downward motion along the windward façade and its upward motion along the leeward facade. As the downward movement is stronger than the upward movement, by mass conservation, the centre of the vortex is shifted slightly downwind (Baik & Kim, 2002). The wind speeds in this skimming flow regime are lower than those in the wake interference flow and can even be lower than the wind speeds in the isolated roughness flow – in case of very narrow canyons.

Very narrow canyons (H/W > 1.6) can have multiple co-rotating vortices stacked on top of each other. The vortex nearest to the ground has the lowest wind speeds.

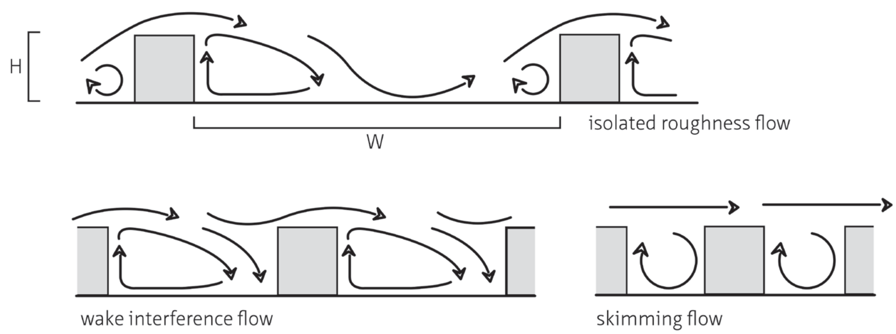


Figure 5.23
Flow patterns in an urban canyon with wind perpendicular to the canyon axis after Oke (1987).

Flow regime	H/W		Vortices characteristics
isolated roughness flow	< 0.1	< 0.2	2 co-rotative vortices
wake interference flow	0.1 – 0.7		
		0.2 – 1.6	1 main vortex
skimming flow	> 0.7		
		> 1.6	2 or more contra-rotative vortices

Table 5.3
Flow regimes and vortices characteristics in symmetrical canyons

Street canyons are not always symmetrical; one side of the street may have a higher building height than the other. When the downwind building height is higher (step-up notch), the centre of the main vortex is shifted upwards and downwind, and the top of the vortex is stretched diagonally between the roofs of the aligning buildings (Assimakopoulos et al., 2003; Xiaomin et al., 2006).

In the case of a step-down notch, the main vortex is weaker compared to a symmetrical-notch situation. The centre of the main vortex is shifted upwards and is located at roof level height of the lowest building, or even somewhat higher (Figure 5.24 and Figure 5.25).

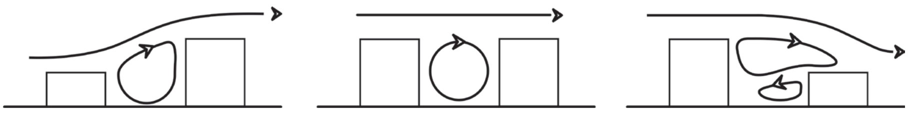


Figure 5.24
Schematic of vortex shape in a step-up notch, symmetrical-notch and step-down notch canyon. The wind direction is perpendicular to the canyon axis.

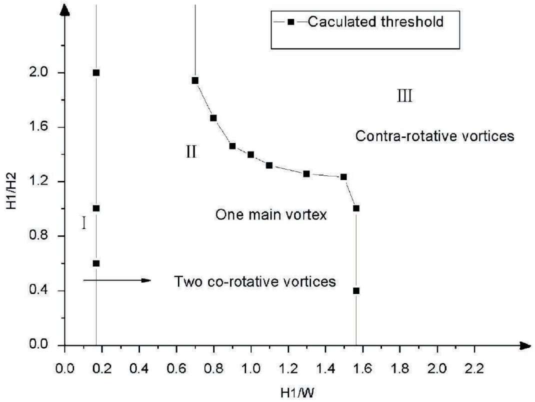


Figure 5.25
Vortices characteristics in the urban canyon according to the ratio H1/W and H1/H2. Wind direction is perpendicular to the canyon axis.
Reprinted from Building and Environment, 41(10), Xiaomin et al., The impact of urban street layout on local atmospheric environment, 1352-1363, copyright 2006, with permission from Elsevier.

Differential heating of the canyon surfaces by the sun influences the flow in the canyon. Ground and leeward wall heating intensify the flow in the canyon in case of a single vortex skimming flow regime (Sini et al., 1996; Kim & Baik, 1999; Cheng et al., 2009), as thermal buoyancy and flow direction act in unison. Windward wall heating may result in a change of the one vortex skimming flow regime into a two vortex skimming flow regime, as the thermal buoyancy counteracts the downward flow movement, causing a reversal in flow direction in the upper region of the canyon (Figure 5.26). Similarly, ground heating may cause a secondary counter-rotating vortex at the ground-level windward corner due to buoyancy (Cheng et al., 2009). Furthermore, ground heating causes a meandering of the vortex centre over time and in the canyon space (Baik et al., 2007).

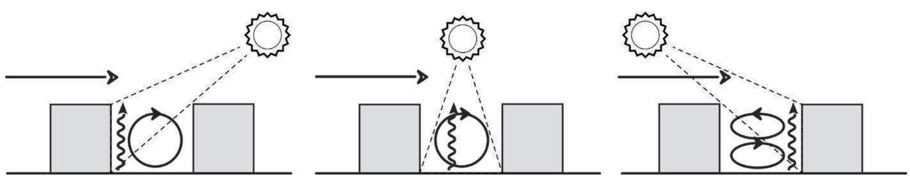


Figure 5.26
Influence of differential heating of the canyon surfaces on the occurring flow pattern.

Wind at oblique angles to the canyon axis will produce an along-canyon flow component added to the cross-canyon vortex structure, resulting in a cork screw-like airflow through the urban canyon. This flow pattern is basically a superposition of the cross-canyon (perpendicular) and along-canyon (parallel) flow components, as described above.

Average wind speeds will be highest in canyons parallel to the wind direction and lowest in canyons perpendicular to the wind direction (Figure 5.27).

Next to orientation and H/W, relative street length (L/H) is of influence on the wind speeds occurring in the canyon. Maximum wind speeds increase sharply from L/H = 4 to L/H = 12 and then level off (Bottema, 1993). This indicates that short streets are preferable in windy areas.

All flow patterns described above will occur when the wind speed at roof height is at least 1.5 m/s; at lower wind speeds the air in the canyon will be stale independent of wind direction.

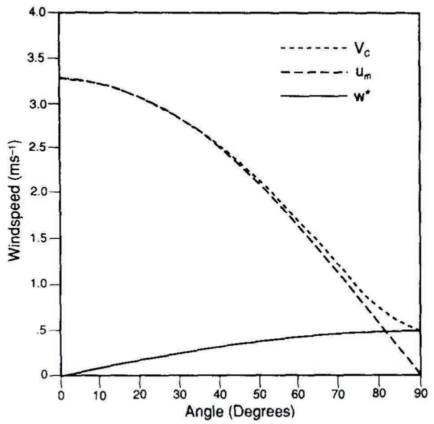


Figure 5.27

Wind speed in the urban canyon. V_c is the average canyon wind speed, u_m is the along-canyon wind speed and w is the cross-canyon wind speed (due to vortex).*

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§ 5.4.3 Airflows in urban tissues

A street grid can be seen as a series of interlinked urban canyons and the flow patterns as described above for single urban canyons can indeed be observed in various urban tissues (DePaul and Sheih, 1986). The crossing of streets, however, causes the occurrence of several additional phenomena.

Varying pressure in the streets (most) parallel to the wind direction causes alternating suction at the ends of the streets (most) perpendicular to the wind direction. This can cause the airflow in the street to change direction by 180 degrees. This effect of transverse flows is stronger as the street gets narrower (Beranek & Van Koten, 1982).

Transverse flows are not present when the wind is oblique to the street grid, but corner streams forming at the street corners will flow along the windward façade of the street. Together with the (along-canyon component of the) corkscrew flow, this may cause discomfort.

At street intersections, horizontal vortices are formed because of lateral recirculation from the building corners, producing along-canyon velocity components in the canyon perpendicular to the ambient wind direction for about 2-3 building heights canyon inward. In case of short canyons (L<6H) this prevents in-canyon vortices in the streets perpendicular to the wind from developing. The lateral recirculation zones converge in the canyon centre, which causes a strong vertical motion. For canyons that have aligning buildings with pitched roofs, the along-canyon flow caused by lateral recirculation is even more pronounced and has a greater length (Kastner-Klein et al., 2004). Pitched roofs furthermore cause a recirculation area with very high turbulence intensities (Rafailidis, 1997) spanning from the upwind notch across the canyon to the downwind notch (either pitched or flat), hampering an in-canyon vortex from developing (Kastner-Klein et al., 2004).

A study by Kim & Baik (2004) on wind flow in a regular grid of cube-shaped buildings and canyons shows that three flow patterns can be distinguished according to the ambient wind direction. The main characteristics of these flow patterns resemble those of free standing buildings and (infinite) canyons (Figure 5.28), as described above.

If one building is significantly higher than its direct surroundings in an urban setting - at least 15 metres higher or twice as high - this will change the flow pattern significantly. A frontal vortex forms at the windward side of the building, which may be amplified by the recirculation vortex of the lower building in front of it. The corner streams of the higher building cause changes in the direction and speed of the flow in the streets close to the upwind corners. The recirculation area of the higher building causes changes in flow direction in the streets downwind of the building (Hua & Wang, 2005). The area of influence of the high building is smaller in the urban context than it would be in the free field. Furthermore, the discomfort areas, especially in the corner steams, are smaller (Beranek & Van Koten, 1982).

Enclosed spaces, such as courtyards, in general give a relatively high degree of protection from the wind. Most shelter will be provided if the space is completely enclosed, width and depth of the space are (more or less) equal ($W \approx L$) and measure no more than two length scales ($W<2L_g$) (Bottema, 1993). If openings are necessary, they are best placed in line relative to the prevailing wind direction. Shifted openings can cause pressure short-circuiting and cross-courtyard flows. Oblique winds give the greatest discomfort in open corner compositions, as the corner streams can blow far into the space.

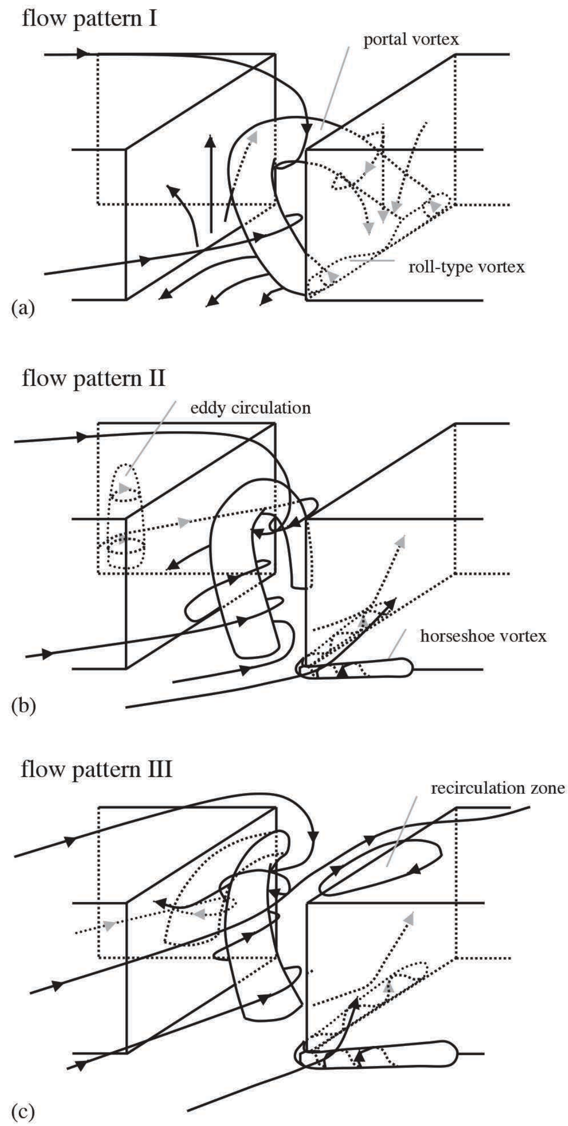
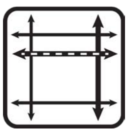
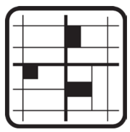
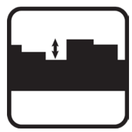


Figure 5.28
The schematic of the mean flow circulation according to different ambient wind directions.
Reprinted from Atmospheric Environment 38 (19), Kim, J.J. & Baik, J.J., A numerical study of the effects of ambient wind direction on flow and dispersion in urban street canyons using the rng k-e turbulence model, 3039-3048, copyright 2004, with permission from Elsevier.

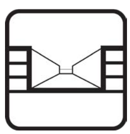
§ 5.4.4 Considerations for urban design

Guidelines

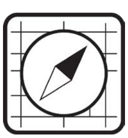
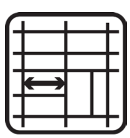
16 Buildings twice as high or more than fifteen meters higher than the buildings in its direct surroundings will cause discomfort, as downwash of high wind speeds will occur. Such differences in building height should therefore be avoided, or, if this is not possible, higher buildings should have their longest side placed parallel to the prevailing wind direction, so that the frontal vortex and corner streams are minimized.

17 Routes meant for pedestrians or cyclists should preferably not cross the frontal vortex and/or corner streams of tall buildings, nor should areas meant for stay (squares, parks, bus stops, etc.) be placed in these locations.

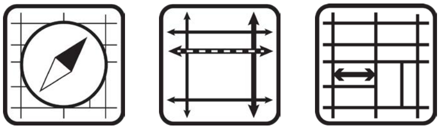
 

18 It is possible to design high-rise without (much) discomfort; if all buildings are more or less the same height and placed at distances less than 0.7 building heights from each other, the skimming flow regime will occur, preventing the downwash of high wind speeds.

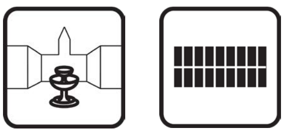
 

19 Street grids in line with the (prevailing) wind direction will have streets (and other outdoor spaces) with a high level of shelter (those perpendicular to the wind), but also streets with high wind speeds (those parallel to the wind). Furthermore, these grids have the possibility of transverse flows in streets perpendicular to the wind direction, which may cause discomfort. Grids oblique to the wind direction will have a more 'even' wind pattern.

20 Street crossings or other openings in canyons and buildings parallel to each other are best placed in line to the (prevailing) wind direction to prevent pressure short-circuiting.



21 Streets parallel to the prevailing wind direction should not be directly connected to open terrain, such as rural areas, lakes, rivers, etc. If this cannot be avoided, such streets are preferably short or have crossings at short intervals (L/H < 4).



22 Square, relatively small ($W<2L_g$) enclosed spaces (courtyards, squares) give the most shelter, as corner streams, frontal vortices and transverse flows are prevented.

Discussion

Designs which include high-rise buildings amidst low-rise buildings, or high-rise buildings placed at large distances from each other can be expected to give the most wind discomfort as downwash of high wind speeds can easily occur. It is exactly this kind of urban tissue that characterizes the European post-war developments; tall building slabs amidst urban green, sometimes combined with (perpendicular) low rise. The wind environment of these neighbourhoods might be improved by transforming the often uninhibited ground floor of the buildings into a podium – a larger low-rise base on which the high-rise is placed. Such a podium deflects the downwash, preventing high wind speeds to reach pedestrian level. The low-rise podium may accommodate public functions, removing one of the causes of the sometimes socially unfriendly living environments in the public space.

Dense high-rise environments in general have much less wind discomfort problems, as downwash and corner stream effects are greatly reduced due the skimming flow regime as a result of higher height to width ratios of the urban canyons. Such dense high-rise areas are uncommon in Europe, but can be found in the bigger cities of North-America and Asia.

An urban tissue of compact mid-rise perimeter blocks, a common 19^{th} century building type, provides sheltered semi-private or community courtyards combined with a street grid that, through its dimensions provides enough shelter. In general, the height to width ratio of these canyons is just within the skimming flow regime.

Another consideration concerns the natural ventilation of the indoor environment. Natural ventilation of buildings is driven by pressure differences between the different sides of the building. Airflow along the facades is therefore less suitable than airflow at an angle or perpendicular to the facades.

This section described the influence of the morphological properties of buildings and outdoor spaces on wind in the urban canopy, and described measures to minimize wind discomfort. Some wind, however, is beneficial for thermal comfort in summer, and is necessary all year round for the dispersion of air pollutants. This topic will be elaborated on in the next section.

§ 5.5 Air quality

The concentration distribution of pollutants in the urban canopy is highly related to the occurring wind flow pattern, as will be described below. Wind transports pollutants by advection and mixes them with cleaner air by turbulence. Both processes act to dilute the pollutants. In general, pollutants are trapped and/or deposited where wind speeds are low or where mixing with other air is limited: in the centre of vortices, in wake areas and spaces with stale air.

§ 5.5.1 Pollution dispersion in urban canyons

When the wind direction is parallel to the canyon axis, pollutants emitted inside the canyon (e.g. by traffic) will accumulate along the canyon; higher concentrations will be found downstream. Most pollutants escape the canyon through the leeward opening, but turbulence and the vertical motion at roof level also remove some pollutants from the canyon. Near the leeward opening, downward flow at roof level will cause some pollutants to re-enter the canyon, but in general, relatively cleaner air will decrease pollutant concentrations near the leeward opening (Hang et al., 2009b). Concentrations decrease almost exponentially with height and become close to zero at roof height (Di Sabatino et al., 2008; Hang et al., 2009b)

When the wind direction is perpendicular to the canyon axis, the lowest pollutant concentrations can be found along the windward facade, where relatively clean above-roof ambient air enters the street canyon by the downward vortex circulation on the downwind side of the canyon. The pollutant concentrations along the windward façade are almost constant with height. The highest concentrations can be found on the leeward side of the canyon, near the ground close to the upwind building, where a strong upward motion exists. On the leeward facade, the concentration decreases upward (Kastner-Klein & Plate, 1999; Chan et al., 2002). In case of multiple contra-rotative vortices stacked on top of each other in the skimming flow regime, and in complex multi-vortex systems in step-up or step-down canyons, the principle of higher concentrations at upward motions and lower concentration at downward motions holds true (Baik & Kim, 1999; Chan et al., 2001; Xia & Leung, 2001; Assimakopoulos et al., 2003; Xiaomin et al., 2006), (Figure 5.29).

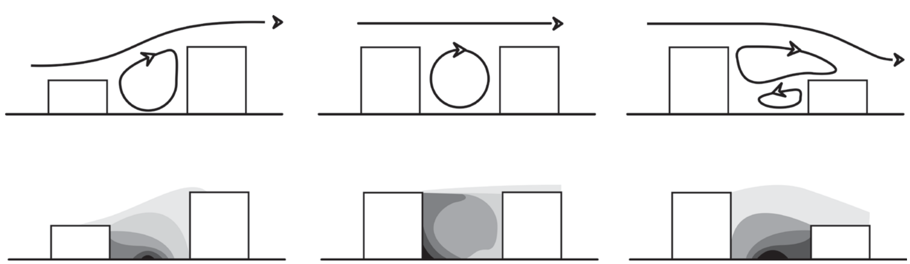


Figure 5.29
Schematic of pollutant concentrations in case of perpendicular flow. Based on Assimakopoulos et al. (2003) and Xiaomin et al. (2006)

Pollutants escape from the canyon by the upward motion near the upwind building and through the zone of high turbulence at roof level. The main vortex causes some escaped pollutants to re-enter the canyon (Baik & Kim, 2002). After emission has stopped, the highest concentration can be found at the centre of the vortex (or vortices), where they are trapped by the low wind speed, and concentrations decrease outwards from there (Baik & Kim, 1999). The wider the canyon the higher the pollutant decay rate, as exchange between street air and ambient air increases (Sini et al., 1996; Chan et al., 2002)

When pollutants from other sources are carried to the (symmetrical-notch) canyon from above roof level, the highest concentrations are found at the downwind side of the canyon, through advection at the downward motion of the vortex. (Sini et al., 1996; Baik & Kim, 1999). After the pollutant advection stops, pollutants trapped in the canyon escape through the upward motion, and concentration distributions are similar to those in the street-level source case; the highest concentrations can be found in the vortex centre, where there is little air movement.

Generally, concentrations in step-up canyons are a factor two lower compared to step-down and even-notch canyons (Hoydysh & Dabberdt, 1988; Assimakopoulos et al., 2003; Xiaomin et al., 2006).

The influence of ambient wind direction on pollutant concentrations at the canyon facades was studied by Hoydysh & Dabberdt (1988) and Berkowicz et al. (1997). They show that concentrations at the leeward façade are always higher than those at the windward façade, except when the wind direction is parallel to the canyon axis; then the concentrations on both facades are the same. Concentrations are highest when the wind direction is parallel and lowest when the wind direction is about 45° relative to the canyon axis. A secondary maximum appears when the wind direction is exactly perpendicular to the canyon axis (Figure 5.30).

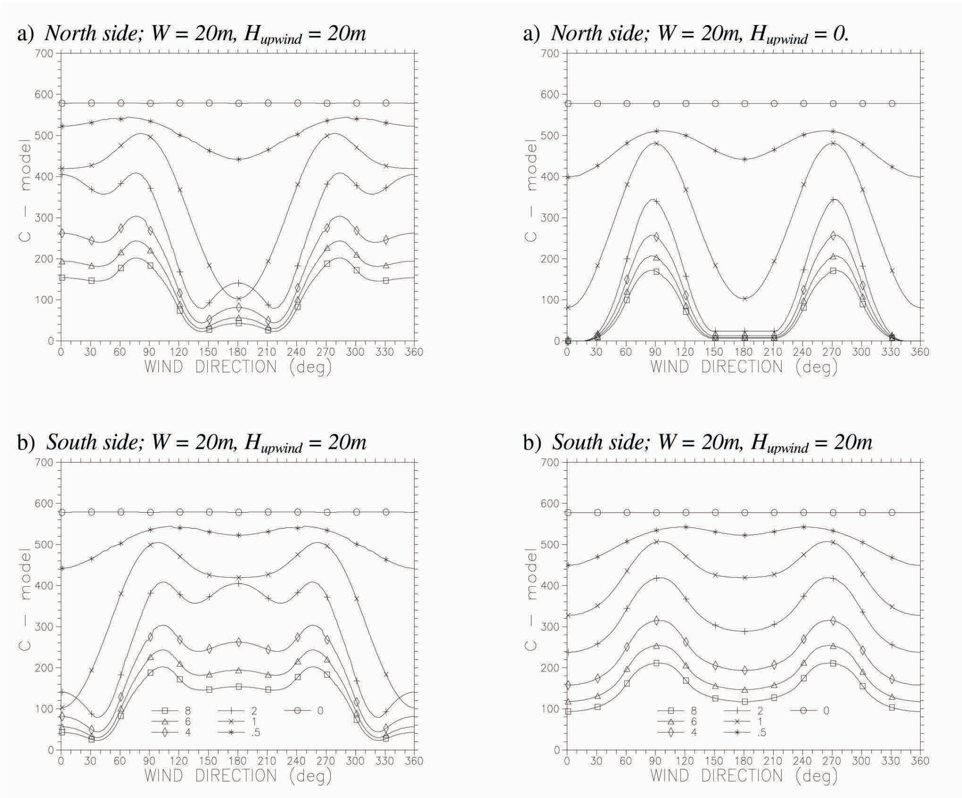


Figure 5.30

Modelled concentrations as function of wind direction (0° is North) and wind speed for an East-West street canyon with 20m high buildings on both sides. Pollutants are emitted with 1000 units m-1s-1. Wind speed (in m/s) is given in the legend.

Reprinted from Berkowicz, R. (1997). Modelling traffic pollution in streets. Commissioned by the Ministry of Environment and Energy and the National Environmental Research Institute, Denmark.

§ 5.5.2 Pollution dispersion in urban tissues

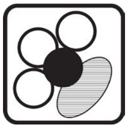
In case of a single source emitting at ground level a street parallel to the ambient wind direction, the pollution is confined to that street; dispersion to any side streets is limited. As the wind angle increases, more pollutants are blown into the side street, where some pollutants are trapped in the lateral recirculation vortex from the building corner (Hoydysh & Dabberdt, 1994; Wang & McNamara, 2007). When the ambient wind direction is perpendicular to the street containing the source, some of the pollutants spill into the side street(s), especially if the source is close to the crossing. Furthermore, pollutants escape the street at roof level and are carried over the buildings into the streets downwind.

When the ambient wind direction is normal to a regular street grid with ground-level emissions in al streets, the highest pollutant concentrations will be found near the walls of the streets parallel to the ambient wind direction, as the pollutants from the streets perpendicular to the ambient wind direction escape the streets by the outward flow dominant near the street bottom and accumulate in the street canyons parallel to the ambient wind directions - together with the pollutants emitted there (Kim & Baik, 2004; Santiago et al., 2007). As the incident wind angle becomes more oblique, pollutants are trapped in the lateral recirculation vortices from the building corners, which can lead to decreased pollutant removal compared to the normal case (Kim & Baik, 2004; Hang et al., 2009b).

Street grids with small meshes and thus short streets (L<6H) are likely to have low pollutant concentrations as they are well ventilated through upward flow in the streets parallel to the ambient wind direction and along-canyon flow in the perpendicular streets caused by recirculation areas from the building corners, combined with strong upward flow in the centre of the street where the recirculation areas meet (Kastner-Klein et al., 2004). As pitched roofs hamper ventilation at pedestrian level, they are best applied in shorter streets only.

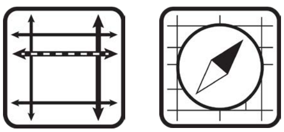
§ 5.5.3 Considerations for urban design

Guidelines

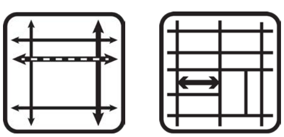


23 Areas that generate a lot of air pollution, such as industrial areas, harbours, etc., should be placed downwind (of prevailing wind directions) from residential areas.

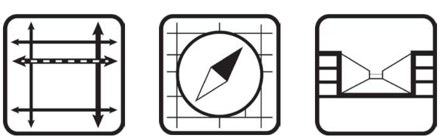
24 Areas meant for stay, such as squares, bus stops, etc., should not be placed in wake areas near busy roads or other pollution-emitting sources, as particles are accumulated and trapped in these locations for a long time.



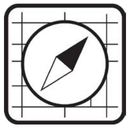
25 Foot and cycle paths along busy roads are preferably placed on the downwind side of the street, where relatively cleaner air enters the canyon from above and pollutant concentrations are thus the lowest. Streets with two contra-rotating vortices stacked on top of each other form an exception to this rule; in these canyons concentrations are the lowest near the upwind side. (For vortex characteristics see Figure 5.25)



26 Busy roads preferably have intersections or side streets at short intervals (L<6H) as this promotes ventilation; through strong vertical flow in streets parallel to the wind direction and through a combination of along-canyon and upward flow in streets perpendicular to the wind direction.



27 Busy roads should be executed as step-up canyons (in case of perpendicular flow), as this configuration yields the lowest pollutant concentrations.



28 For natural ventilation of buildings, street grids should be placed at an angle (of at least 15 degrees) to the governing wind direction.

29 Pitched roofs (as the only roof shape) should be avoided in roads with high pollutant concentrations, because they decrease ventilation.

Discussion

Many of the recommendations for air quality are in conflict with the recommendations for wind comfort. This is because wind comfort requires low wind speeds and the dispersion of pollutants requires high wind speeds. For each case, it is therefore important to make an estimation of the (relative) importance of the two aspects and balance negative and positive effects. In cases where air quality is less of an issue, i.e. where pollutant concentrations are expected to be low at all times, wind comfort can be optimized. In areas with low air quality – along busy roads, in and near industrial areas, etc., more consideration should be given to the ventilation of outdoor spaces and buildings.

The literature review above discussed how dispersion takes place in the urban environment. Whether dispersion or instead containment of pollutants is desirable is a question that should be answered case-specifically. Dispersion may be beneficial for the source area, but the pollutants might do more harm at the location(s) they are dispersed to than in the source area. When containment is desirable, vegetation may be employed to intercept particles and filter the air (see 5.7.2).

This section discussed air quality in the urban environment. In many cases the sources of air pollution are the same sources that also cause noise; traffic and industry being the most important ones. The next section will discuss the influence of the urban environment on the propagation of sound, and gives guidelines to minimize sound levels from unwanted sounds.

§ 5.6 Sound

Sound is an audible vibration transmitted through air or another medium as waves. Sound waves cause differences in (air) pressure. The magnitude of the pressure difference determines the loudness of the sound. Sound pressure level (or sound level) is measured in decibels (dB).

Sound waves are produced by a sound source. Commonly, a distinction is made between three idealised types of sound sources: point, line and area sources (Figure 5.31).

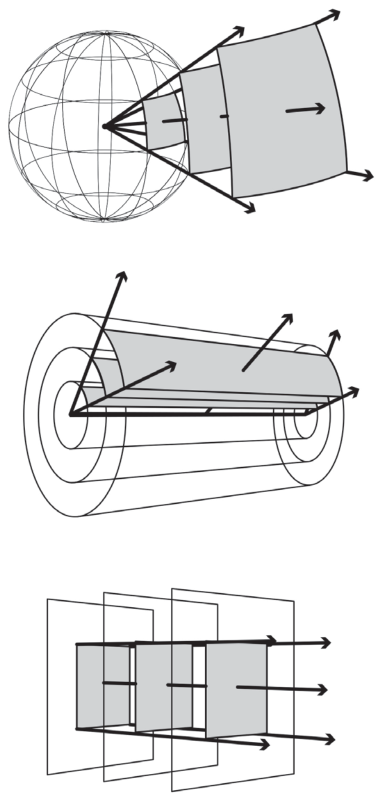


Figure 5.31
Idealised sound sources; point, line and area .

A source is considered to be a point source when it is small compared to the propagation distances being considered. Sound waves from a point source spread in three dimensions like a sphere. With a doubling of the distance to the source, the surface area of the wave front is four times greater, but has the same amount of power flowing through. This leads to a decrease of sound level of 6dB (VROM, 2006; Embleton, 1996). Single sources, such as speech from a person or a car in a street can be regarded as point sources.

A line source produces a cylindrical wave front. Because the wave front spreads in two dimensions the area of the wave front is proportional to distance, and therefore the sound level decreases by 3 dB per distance doubling. A road with traffic can be regarded as a line source, with the equivalent sound level decreasing by 3 dB per double distance from the road.

An area source produces a plane wave; a wave whose wave fronts are infinite parallel planes normal to the direction of propagation. Plane waves are one-directional and therefore have no geometrical spreading loss. Background noise may be regarded as an area source (Shaw & Olson, 1972) with a steady state sound pressure level. Sound level losses from geometrical spreading are frequency-independent. Figure 5.32 presents frequency ranges of some common sound sources.

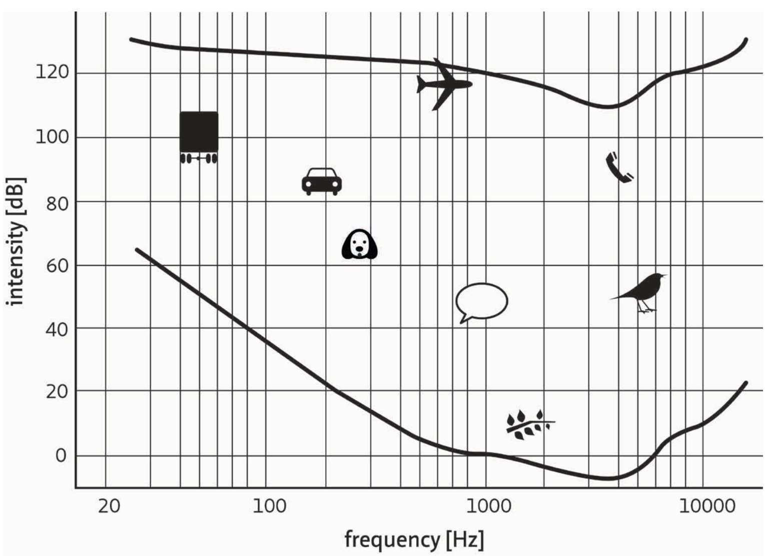


Figure 5.32
Frequency ranges of common sound sources.

Atmospheric influences

As a sound wave passes through the air, a part of its energy is absorbed. This is called atmospheric absorption. The level of atmospheric absorption increases with frequency and air temperature, and decreases with humidity (Piercy et al., 1977; Embleton, 1996). Saurenman et al. (2005) give an order of magnitude of atmospheric absorption depending on these three parameters at 500m from a point source (Table 5.4).

Frequency [Hz]	RH [%]	Temp [°C]	Sound loss [dB]
1000	75	10	2
1000	20	30	3
4000	75	10	16
4000	20	30	24

Table 5.4
Atmospheric absorption, from Saurenman et al., 2005

Another atmospheric effect on sound is diffraction. Diffraction is the apparent bending of waves around edges or small obstacles and the spreading out of waves past small openings, and is thus also present without atmospheric influences. Vertical temperature and wind speed gradients, however, will cause sound waves to diffract in the absence of obstacles or openings. Such gradients tend to be strong in the first few meters above ground. A temperature lapse, which is normal during daytime, or a wind speed gradient in the opposite direction of the sound propagation path (upwind sound propagation) causes sound rays to bend upwards, creating a shadow zone near the ground where little sound enters (Figure 5.33). A temperature inversion or downwind propagation causes sound rays to bend downwards, leading to higher sound levels near the ground than under neutral atmospheric conditions (Piercy et al., 1977; Daigle et al., 1985; Embleton, 1996). Because temperature is a scalar quantity the refraction of sound because of vertical temperature gradients is the same in all horizontal conditions. The effect of wind depends on the vector component in the direction of sound propagation; there is no effect if the sound propagates crosswind and the effect is the greatest if it propagates exactly downwind or upwind. The diffraction effects of temperature and wind gradients can be added; they can thus strengthen each other or (partly) cancel each other.

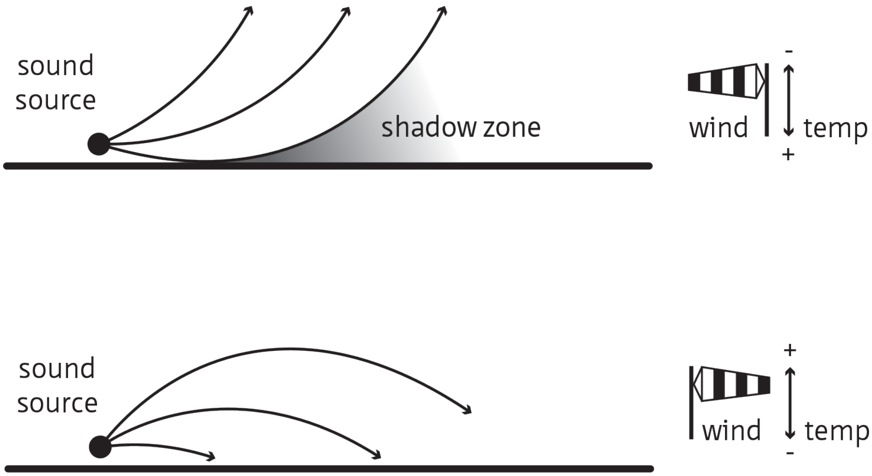


Figure 5.33
Atmospheric caused diffraction of sound.

Absorption and reflection
When a sound wave meets a surface, part of it will be reflected and another part absorbed. The acoustic properties of a material (or object) are usually expressed by the absorption coefficient (α), which is the ratio of non-reflected sound energy to the incident sound energy. A value of 1 means that all incident sound is absorbed, 0 means all energy is reflected. The proportion of reflection and absorption depends on the characteristics of the material, which will be elaborated in Section 5.7.1.

Reflection can cause interference of sound waves; when two (or more) waves meet they will form a new wave that is the net result of the two. When the waves are in phase, they will strengthen each other and a wave with a higher intensity and thus a louder sound is produced. This phenomenon is called constructive interference. When the waves are out of phase they create a new wave with lower intensity. This is called destructive interference, and is used in active noise control. Reflection from hard surfaces results in clear interference minima at certain frequencies depending on source and receiver height (Embleton, 1996), as a result of cancellation between direct and reflected waves for path-length differences of an odd number of half wavelengths (Piercy et al., 1977). At these points hardly any sound will be heard. Acoustically soft surfaces will not produce such clear minima. Interference can occur locally, but also along a longer stretch.

Reflections cause a sound to persist for a certain amount of time after the source has disappeared or stopped emitting sound. This phenomenon is called reverberation. The most commonly used measure for reverberation is Reverberation Time (RT): the time required, in seconds, for the average sound in a space to decrease by 60 dB after a source stops generating sound.

Proximity to the source is the governing factor determining sound levels in the open field. The presence of buildings and other objects, however, can provide significant shielding, but can also increase sound levels, due to reflections. Morphological properties of outdoor spaces and the acoustic properties of its boundaries are of considerable influence on reflection and absorption, and therewith sound levels and reverberation times, as will be described in the next sections.

§ 5.6.1 Sound propagation in an urban canyon

The sound field in an urban canyon is constituted by the direct field (the sound field where reflections have not yet taken place, close to the source) from one or more sound sources within the street, their reflections from the canyon surfaces and background sounds from sources far away.

For a single point source inside a canyon, the sound level close to the source is highly influenced by the direct field; the reflected field becomes more important with increasing distance from the source. The attenuation of sound is large in the first few meters from the source - in height as well as along-canyon-, but becomes less per unit distance with increasing distance, as can be expected from a point source (see Section 5.6.1). The sound level variation in a cross section also decreases with source-receiver distance. For a street of 20 meters width and 18 meters height (H/W≈1), the sound level distribution in a cross section at 25 meters from the source and beyond varies less than 1.5 dB (Kang, 2002).

Increasing relative street height leads to reduced attenuation, as less sound energy can be reflected out of the canyon at the top. This effect of H/W is negligible in the direct field of a point source (Kang, 2002; Nicol & Wilson, 2004), but increases with distance until a certain point and then levels off (Kang, 2000). It can thus be noted that for a linear source, like a busy road, H/W is of minor importance on sound attenuation along the length of the canyon. Aspect ratio does, however, determine the maximum sound attenuation the top of the canyon, which is about 1.5 dB measured at the façade for H/W=0.5, 3.5 dB for H/W=1 and 6 dB for H/W=2, in case of a linear source (Nicol & Wilson, 2004). Absolute street width highly influences the attenuation with height above the ground at the facade; for a given height the attenuation decreases with increasing street width.

Increasing the street width from 5 to 10 m, for example, decreases the attenuation from about 7dB to about 3,5 dB at 10 m above the ground along the façade; a further 5 m increase of the street width further decreases the attenuation to about 2 dB (Nicol & Wilson, 2004)[36].

Sound decays with distance and with time. Sound decay with time depends on frequency; the Reverberation Time (RT) for low frequencies is higher than for high frequencies (Picaut et al, 2005). Furthermore, RT increases with increasing source-receiver distance (Kang, 2000; Picaut & Simon, 2001; Picaut et al., 2005) and increasing H/W. This effect is most pronounced for canyons with hard, specular-reflecting surfaces. As absorption and scattering coefficients increase, reverberation time decreases and differences between canyons with different aspect ratios become negligible (Onaga & Rindel, 2007).

Reflection of surfaces also plays an important role in the canyon sound field. Diffusely reflecting canyon surfaces lead to slightly higher sound levels close to the source compared to specular reflecting surfaces, due to back-scattering, but to significantly lower sound levels at greater distances from the source. Most urban canyons can be expected to be diffusely reflective due to relief of the facades, street furniture, trees, etc. The interference effect caused by reflection becomes more significant with decreasing street width (Janczur et al., 2001), especially for W<10m (Iu & Li, 2002).

§ 5.6.2 Sound propagation in urban tissues

The effects of crossings

Openings in the canyon, such as street intersections, lead to an extra sound level attenuation of a few dB (Kang, 2001, 2002) and a decrease in reverberation time (Picaut et al., 2005) around the opening in the source canyon. This is caused by sound loss through the opening, partly by diffraction and partly by reflection. More sound is reflected into the crossing canyon(s) as the source approaches the intersection. Sound reflected back from the side street(s) back into the source canyon is negligible.

36 In this calculation by Nicol & Wilson (2004), the distance from the source to the measurement point at the façade increases with increasing street width, as the line source is positioned in the middle of the canyon, and it can thus be expected that the level differences along the façade will vary less with increasing street width due to geometrical spreading. If the source-receiver distance would be the same, for example due to a central reservation in the wider canyon, values of attenuation with height would probably be more similar.

This 'leaking' of sound through an intersection into the street perpendicular to the source canyon is limited in terms of distance; attenuation with distance in the crossing canyon is significantly larger than in the source canyon.

With increasing H/W less sound energy can be reflected out of the canyon top and thus the attenuation with distance from a crossing decreases with increasing H/W. This effect is significantly larger for canyons crossing the source canyon than for the source canyon itself, because the sound field is dominated by reflected sound in the crossing canyon. Placing absorbers in the source canyon is more efficient for the reduction of sound levels in the crossing canyon (and the source canyon) than placing absorbers in the crossing canyon (Kang, 2001).

Sound sources in enclosed spaces

Similar to the sound level in a canyon of H/W=1, the sound level from a source in a space enclosed by four facades with L/W =1, such as a square or a courtyard, decreases significantly with increasing source-receiver distance in the area close to the source (up to distances half the square width) and then becomes approximately stable in the far field (Kang, 2005). Actual sound levels and RT in such an enclosed space will be significantly higher compared to those in a canyon with the same H/W, as the reflection from two more facades adds to the sound level (Hornikx & Forssén, 2008). This is also the reason that increasing boundary absorption in squares or courtyards is (even) more effective than in street canyons.

Sound levels in an enclosed space are not significantly influenced by the reflective behaviour of the boundaries – diffuse or specular - , but RT is. RT is more or less even over the square for both types of boundaries, but much longer (over 4 times in a square of 50m x 50m x 20m; Kang, 2005) with specular reflecting boundaries. In most cases, a sound field resulting from diffusely reflecting boundaries can be expected, as facades and ground usually have some relief, and furniture and/or vegetation is present (Kang, 2005).

For enclosed spaces with L/W >1, sound levels in the direct field are similar to that of a square with L/W=1, but significantly lower in the far field, as the sound path becomes longer. RT is also comparable.

Shielded spaces

Sound sources inside an enclosed space lead to higher sound levels and longer reverberation times than sources inside a canyon with the same H/W, as described above. Sound sources outside the enclosed space and canyon, however, lead to much smaller differences between sound levels and reverberation times between the two types of space. The differences are even negligible when the boundaries are diffusely reflecting. (Hornikx & Forssén, 2008).

In spaces that do not contain direct sound sources and which are shielded from sound by one or more buildings, multiple reflections and far away sources are more important to the sound field than in directly exposed spaces. As a consequence, sound attenuation with distance in a shielded canyon is much smaller than for a directly exposed canyon (Hornikx & Forssén, 2007).

Sound may travel from a source in one canyon to a receiver in another canyon parallel to it – containing backyards, courtyards or other shielded areas - in two ways: by sound 'leaking' through a canyon connecting the source canyon and parallel receiver canyon or by diffraction of sound over the roof(s) of the building(s) separating the canyons. Diffraction over the roof takes place in several ways: from the source directly to the roof of the building separating the canyons and consequently diffracted to the receiver (1), from the source via diffraction and reflection in either the source or receiver canyon to the receiver (2), or via diffraction and (multiple) reflections in both source and receiver canyons to the receiver (3) (Figure 5.34). Sound levels are highest at the top of the shielded canyon, as sound from the parallel canyon is diffracted downwards into the shielded canyon (Hornikx & Forssén, 2007).

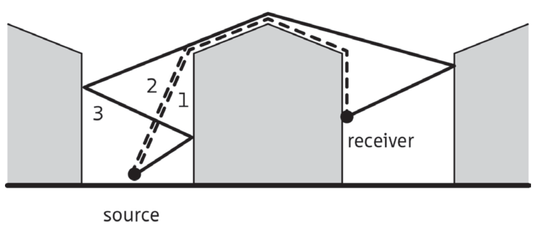


Figure 5.34
Diffraction and reflection over the roof.

Roof shape has a significant influence on sound levels at the shielded side as influences the diffraction of sound from one canyon to another. Van Renterghem & Botteldooren (2010) compared the performance of several roof shapes to that of a flat roof. Pitched (gable), shed, dual pitched, half-monitor roofs and pitched roofs with overhangs all give higher sound levels in the shielded canyon compared to a flat roof. Half-cylinder, quarter-cylinder, mansard, industrial building (saw tooth) roofs and shed roofs with two angles (highest façade facing the shielded side) all perform better than a flat roof; sound levels at the shielded side were up to 5 dB lower for these configurations compared to the flat roof configuration. Similar differences between flat and hip roofs were found by Heimann (2007). Considering that the shielded side of a building with a flat roof is usually 15-20 dB lower than the directly exposed side (Van Renterghem et al., 2006; Salomons et al. 2009), this is a significant difference.

Downward diffraction from the roof is enhanced in case of downwind sound propagation, decreasing the shielding. This decrease in shielding can amount to 10 dB at a wind speed at roof level of 1 m/s (Van Renterghem et al., 2006). The wind effect is stronger for hip or gable roofs than for flat roofs, presumably because the vertical wind speed gradient above the ridge is stronger (Heimann, 2007). In case of upwind sound propagation shielding hardly increases, due to scattering. Furthermore, interference and scattering by turbulence may lead to higher sound levels of higher frequencies in the receiver canyon (Ögren & Forssén, 2004).

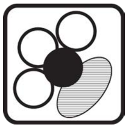
Another difference between shielded spaces and directly exposed spaces is that attenuation increases with increasing frequency in a shielded space, as diffraction decreases with frequency (Ögren & Kropp, 2004; Van Renterghem et al., 2006; Hornikx & Forssén, 2007). This attenuation with frequency increases when absorbers are placed in the shielded canyon, since absorption increases with increasing frequency (see Section 5.7.1). The absence of a direct sound field makes placing absorbers in a shielded canyon very efficient. Absorbing roof materials also help reducing the noise load in the shielded canyon significantly. Next to absorbing roofs, balconies can provide extra sound attenuation at the shielded side, especially for low frequencies (Van Renterghem et al., 2006).

H/W is only of influence on shielding for narrow canyons (H/W>1); the narrower both source and receiver canyon the more shielding, for wider canyons the relative sound level is more or less constant with increasing H/W (Van Renterghem et al., 2006).

Sound levels due to background noise are rather constant in shielded spaces. Especially traffic contributes to this constant noise; not only traffic from the other side of the buildings enclosing the space, but also from roads farther away. Several studies have shown that roads up to a distance of 1000m or more contribute the background noise in shielded spaces, depending on their traffic intensity (Thorsson et al., 2004; Ögren & Kropp, 2004; Salomons et al., 2009). The distribution of traffic over an urban area thus not only has a large influence on noise levels in exposed, but also in shielded areas. A homogeneous traffic distribution may lead to more annoyance than traffic concentrated on a few streets with higher intensities, as more areas – directly exposed as well as shielded - are exposed to sound of a certain level (Thorsson & Ögren, 2005). As mentioned in chapter 4, providing buildings with a quiet side will reduce annoyance; a building with only one side exposed to a given traffic intensity will have sound levels 3dB higher at this exposed side than the same building with two sides each exposed to half the traffic intensity, but also a shielded side with sound levels over 10 dB lower (Salomons et al., 2009).

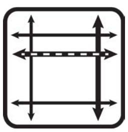
§ 5.6.3 Considerations for urban design

Guidelines

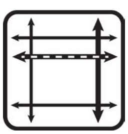
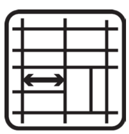


30 On the scale of the city or district it is not preferable to place functions that produce a significant (mechanical) noise, such as industry and heavy traffic, immediately next to recreational green spaces and (low-density) residential areas. Business areas, commercial areas, mixed-use areas or green buffers may be placed in between.

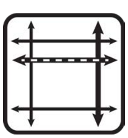
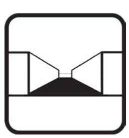
31 Parks or other recreational green spaces should be placed at a considerable distance from busy roads, as traffic noise is found most annoying in green areas, as described in paragraph 4.7.



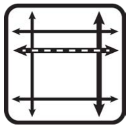
32 On neighbourhood level, placing a few main roads with higher traffic intensity around the neighbourhood, relieving roads in the rest of the neighbourhood, will lead to a larger area with lower noise levels than a homogeneous traffic distribution.

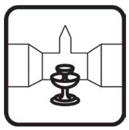
33 Busy roads should be bordered with a continuous row of buildings, with as little intersections as possible, to minimize the leaking of sound to the area behind. When executed with flat and/or green roofs, these bordering buildings will also limit the diffraction over the rooftops, thus providing extra shielding.

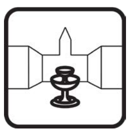
34 Sound absorbing road material (e.g. porous asphalt) is advisable for busy roads, as it will reduce the noise load on the road and its surroundings - even in shielded areas.



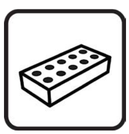
35 Along busy roads, gable, shed, dual pitched, and half-monitor roofs should be avoided (as the only roof shape; a mix of different roofs shapes is advisable, as this increases scattering), unless executed with highly absorbing materials.



36 Enclosed shielded spaces (without internal sound sources), such as courtyards, can be expected to be mostly quiet, as sound can only enter via diffraction over the roof.



37 An elongated square will have quieter areas than a square with sides of the same length and as such may be more suitable for a mix of functions.



38 Avoid specular surfaces (all-glass facades), as they yield higher average sound levels and reverberation times.

Discussion

Source control is the most effective way of reducing sound and related annoyance. The development of electric and hybrid vehicles is promising in this respect. The use of these vehicles, however, needs to increase drastically to have a significant effect on noise levels in the urban environment. Furthermore, electric and hybrid vehicles also produce tyre noise, like any other motorized vehicles. So, even if sound levels due to traffic can be expected to decrease, noise control by urban design measures remains important.

Maximizing distance to the noise source is the most effective way of minimizing sound levels at a site of interest. Creating noise barriers – this can also be in the form of buildings – to create shielded areas is also an effective measure. An extreme variant of this concept is proposed by De Ruiter (2004). He suggests making 'acoustical polders';

traffic-free neighbourhoods protected from traffic noise by 'dike'-buildings around it. The canyons between these buildings form a network from high-intensity traffic. Functions that are not very noise-sensitive, such as storehouses, offices and shops could be placed in the barrier buildings, but from a social point the buildings should also be habitable. For this purpose De Ruiter advises an atrium or second façade at the exposed façade. Such an urban setup may, however, provide problems regarding readability, accessibility, distribution of functions, etc.

When excluding or limiting traffic is not possible (or desirable) at the neighbourhood level, providing shielded areas at block level is important. Perimeter blocks are very well suited for this purpose; sound levels in the courtyard will be low - governed by diffracted sound and background sources. Applying absorbing materials in the courtyard will decrease sound levels even further. Furthermore, enclosed courtyards help create different soundscapes than open city blocks, where sound can propagate between buildings (Berglund & Nilsson, 2006).

Increasing absorption and diffuse reflection can be regarded as corrective measures. They are subordinate to distance and shielding measures, but can still have a significant effect on sound levels and reverberation times. Absorption and reflection are largely determined by materialization and landscaping. Landscaping can furthermore introduce masking sounds; pleasant sounds - such as the rustling of leaves, bird and water sounds - that (partly) conceal the unwanted sound. In addition to their effects on noise, materialization and landscaping have several other effects on the urban microclimate, as will be discussed in the next section.

§ 5.7 Effects of materialization and landscaping

Materialization and landscaping have various effects on the urban microclimate. Paving and building materials mainly affect the energy balance and also have effects on sound. Vegetation has a wide range of effects on the microclimate of its surroundings (Givoni, 1991; Leung et al., 2011). Vegetation provides shade to its surroundings, therewith reducing solar heat gains of the shaded surfaces. Combined with water, it also lowers temperatures through evapotranspiration, improving microclimates in warm periods. Furthermore, vegetation can provide shelter from wind, therewith improving wind comfort for pedestrians and cyclists, but also reducing infiltration of air in buildings – both important mainly in cold periods. Vegetation also filters the air, improving air quality, and diffuses and masks sounds.

§ 5.7.1 Material surface properties

Reflection, absorption and re-emission of solar radiation
The amount of heat stored by a material exposed to radiation (direct, indirect or diffuse) is highly dependent on the thermal admittance and albedo of that material. Thermal admittance is a measure that combines the thermal conductivity and heat capacity of a material and is technically a surface property. A material with high thermal admittance easily exchanges heat with its surroundings when subject to a temperature difference. Such a material stores a lot heat of heat and releases it when the ambient air temperature drops. The surface of a high thermal admittance-material has a relatively small diurnal temperature change. Conversely, a material with a low thermal admittance has a limited ability to store heat and will thus show large diurnal temperature changes. The thermal admittance of some typical interface materials is given in Table 5.5, next to their albedos.

Building and paving materials on average have higher thermal admittances than their rural counterparts, and thus more heat is stored in the urban environment. This can partly be negated by (altering) the albedos of building and paving materials; the higher the albedo of a surface, the higher it's reflectivity, and thus the lower the amount of heat available for absorption and consequently storage by the material.

Albedo depends on the texture, finishing and especially the colour of the surface. Light coloured surfaces have a higher reflectivity than dark coloured surfaces. A theoretically perfectly white surface has an albedo of 1, meaning all radiation is reflected; a theoretically perfect black surface has an albedo of 0, meaning all radiation is absorbed. Polished and specular surfaces have higher albedos than their coarse counterparts. The albedos of some materials common to the urban environment are given in Table 5.5.

Reflection of radiation from surfaces can be specular or diffuse, depending on the texture of the surface. Completely smooth surfaces will reflect specularly, e.g. the angle of incidence equals angle of reflection. Rough surfaces have many different orientations on the micro level, and thus the normal line at the point of incidence is different for each ray, resulting in diffuse reflection. In case of perfectly diffuse reflection, the reflected radiation will be evenly spread over the hemisphere surrounding the surface. Most surfaces reflect radiation somewhere along the range between completely specular and completely diffuse (Figure 5.35).

Material	R	μ
White plaster	0.70 - 0.80 (new)	0.75 – 1.22
Concrete	0.10 - 0.35	1.23 – 2.00
Brick	0.20 - 0.40	0.70 – 1.19
Wood	0.10 - 0.50 (light – dark)	0.38 – 1.03
Asphalt	0.05 - 0.20	1.20
Steel	0.55 - 0.85	14
Soil	0.05 - 0.40 (dark/wet – light/dry)	0.60-2.55 (dry – wet)
Sand	0.10 - 0.30 (wet – dry)	0.15 - 4 (dry - wet)
Grass	0.16 - 0.26	dependent on substrate
Water	0.10 - 1.00	1.55 (at 4 °C)

Table 5.5
*Albedo and thermal admittance kJ/(K*m^2*s$^{1/2}$) of some common building and paving materials. From: Oke (1987), Erell et al. (2011), Van der Linden (2006).*

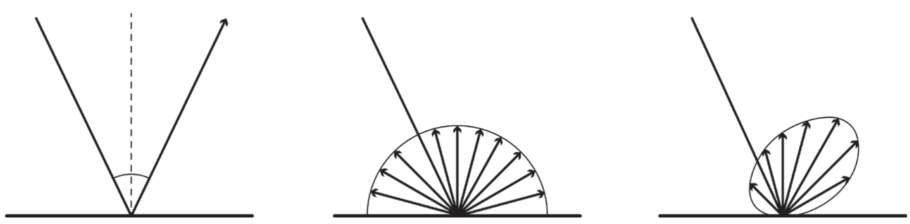


Figure 5.35
Specular reflection (left), completely diffuse reflection (middle) and partly diffuse reflection (right).

The combined influence of thermal admittance and albedo on surface temperature is illustrated by a study by Takebayashi & Moriyama (2007). They measured the surface temperatures of five different surfaces in different seasons; cement concrete, a vegetated surface, bare soil, a surface covered with highly reflective white paint and one with highly reflective grey paint. They found temperature differences between the different surfaces as high as 10 degrees during the warmest period of the day, both in summer and autumn. The cement concrete and highly reflective grey paint surfaces had the highest surface temperatures. The lowest temperature during the day was found for the surface covered with highly reflective paint, the lowest temperature during the night was found for the vegetated surface. The temperatures of these surfaces were very similar, but only during summer; in autumn the vegetated surface was warmer, due to decreased evapotranspiration.

The lower the surface temperature, the less heat radiated to the surroundings in the form of long-wave radiation, resulting in lower Mean Radiant Temperature (MRT) and also lower air temperatures. Simulations by Klok (2010), for example, show that the average air temperature in an urban canyon can be lowered by altering the pavement; replacing asphalt (road) and concrete tiles (sidewalk) with yellow bricks leads to a drop in average air temperature of 0,7 degrees, mainly because of lowered albedo. The same research shows, however, that increasing the albedo of roofs and facades may lead to a small outdoor air temperature increase, caused by the increase of radiation received by the street surface through reflection. This is most likely if the pavement has a low albedo and high thermal admittance. Taha et al. (1988) calculated that increasing the overall surrounding albedo by 15% leads to a drop in ambient air temperature of about 1-4 degrees.

Material surface properties do not only affect outdoor air temperatures, they also influence the cooling demand of buildings; directly, through the surface temperatures of the building envelope, and indirectly, through their influence on the ambient air temperature. Some examples: simulations for Sacramento, America by Taha et al. (1988) show that whitewashing a building can result in savings of up to 14% on cooling peak power [kW] and 19% on electrical cooling energy [kWh] in a period of three hot days in July, and that modifying the overall urban albedo from 0.25 to 0.40 can lead to savings up to 35% and 62% on cooling peak power and electrical cooling energy of the same building, respectively. Akbari et al. (2001) found that increasing the albedo of a roof from 0.2 to 0.6 decreased the surface temperature of the roof by about 25 degrees Celsius on hot summer afternoons. Akbari & Konopacki (2005) show that a reflective roof is very effective in reducing building energy use for cooling, and that penalties for increased heating demand in winter are usually low.

Reflection and absorption of sound waves

Materialization also affects the reflection and absorption of sound waves, in a way similar to that for solar radiation. The most important material property with respect to sound absorption is porosity; the more porous the material, the better the sound absorption. Not all absorbed sound energy will be attenuated; some will be transmitted through the material, into the next space.

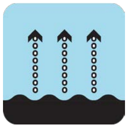
The acoustic properties of a material (or object) are usually expressed by the absorption coefficient (α), which is the ratio of non-reflected sound energy (absorbed + transmitted) to the incident sound energy. A value of 1 means that all incident sound is absorbed, 0 means all energy is reflected. The reflection coefficient (ρ) is the opposite of the absorption coefficient; $\rho=1-\alpha$. A useful overview of absorption coefficients of building materials and components can be found in Szokolay (2008), of which an excerpt is given in The acoustic properties of a material (or object) are usually expressed by the absorption coefficient (a), which is the ratio of non-reflected sound energy (absorbed + transmitted) to the incident sound energy. A value of 1 means that all incident sound is absorbed, 0 means all energy is reflected. The reflection coefficient (r) is the opposite of the absorption coefficient; r=1-a. A useful overview of absorption coefficients of building materials and components can be found in Szokolay (2008), of which an excerpt is given in Table 5.6. As can be seen from the table, the absorption coefficient - and therewith the reflection coefficient - is frequency dependent. As can be seen from the table, the absorption coefficient - and therewith the reflection coefficient - is frequency dependent.

	octave centre frequency		
Regular building materials	**125 Hz**	**500 Hz**	**2000 Hz**
Exposed brickwork	0.3	0.1	0.1
Exposed clinker concrete	0.2	0.6	0.5
Concrete or tooled stone	0.02	0.02	0.05
Glass in windows, 4mm	0.3	0.1	0.05
Glass in large panes, 6mm	0.1	0.04	0.02
Plaster on solid backing	0.03	0.02	0.04
Exposed water surface (pools)	0.01	0.01	0.02
Absorbers			
25 mm sprayed fibres on solid backing	0.15	0.5	0.7
25 mm glass wool on solid backing, open mesh cover	0.15	0.7	0.9
25 mm fibreglass tiles on solid wall	0.1	0.6	0.6

Table 5.6
Sound absorption coefficients (a) of building materials

Reflection of sound from surfaces can be specular or (partly) diffuse, in the same way as described for solar radiation. The reflective properties of surfaces highly influence the attenuation of sound with distance, especially in case of multiple reflections. Diffuse reflection leads to longer average propagation paths from source to receiver compared to specular reflection, and thus to greater sound energy loss with distance. Only in the area near the source sound levels may be higher due to energy reflected back from farther surfaces (Davies, 1978; Kang, 2000; Onaga & Rindel, 2007).

§ 5.7.2 Landscaping: vegetation and water



Cooling: solar shading and evapotranspiration

Trees, shrubs, ground cover, green roofs and vertical greening reduce the short-wave radiation and reflection incident on walls, streets and other urban surfaces as they shade them. Shading reduces the temperature of these surfaces, especially in summer (Robitu et al., 2006), and as a result, the long-wave radiation emission from these surfaces is reduced, warming the surroundings less. This cooling effect by shading can be profound and is usually larger than the cooling effect by evapotranspiration (Shashua-Bar & Hoffman, 2000, Shashua-Bar et al, 2011). The effect of shading does not extend very far; it is limited to the spaces directly beneath the green cover (Ali-Toudert & Mayer, 2007; Bowler et al., 2010). Trees can lower PET significantly through direct shading of the human body, but also by shading of the surroundings, which causes less heat to be emitted and reflected towards the body. Shade trees can therewith lower PET by several tens of degrees (Ali-Toudert & Mayer, 2007). Furthermore, shading can lead to significant saving in cooling energy use of buildings by lowering the mean MRT indoors (Akbari et al., 2001; Akbari & Konopacki, 2005).

Vegetation does not only influence the microclimate by shading, but also by evapotranspiration. Evapotranspiration is the sum of evaporation of water intercepted by vegetation, soil, paved or building surfaces, the evaporation of water from the soil and transpiration by vegetation transpiration. The combined effect of evapotranspiration and shading leads to lower air temperatures during daytime in summer. Several studies show a local cooling effect between 0-5°C for various types of urban greening, including parks, street trees and green facades (Givoni, 1991; Taha et al., 1988; Kurn et al., 1994; Shashua-Bar & Hoffman, 2000; Dimoudi & Nikolopoulou, 2003; Yu & Hien, 2006; Shashua-Bar et al., 2009; Wong et al., 2010; Bowler et al., 2010; Heusinkveld et al, 2010; Klok, 2010). A combination of grass, shrubs and trees – like in a park- seem to be the most effective. Such cooler urban green areas are also called 'Park Cool Islands' (PCI's).

The cooling effect of vegetation depends on its size; the larger the green area, the more likely that it is cooler than its surroundings and the greater the cooling effect. Dimoudi & Nikolopoulou (2003) estimate that an average temperature reduction of 1°C can be expected for every 100m2 of park enlargement. This is thought to have its limits however; beyond a certain size, the climatic conditions in the park and the range of its effects

will hardly change[37]. The same is true for the vegetative cover of neighbourhoods; after a certain threshold, adding more (irrigated) vegetation produces very little additional cooling, while using a lot of water (Gober et al., 2010)[38].
The cooling effect furthermore depends on the ambient air temperature; the higher the ambient air temperature, the greater the cooling effect (Shashua-Bar & Hoffman, 2000).

Most studies show that the cooling effect of a green area only extends up to a few hundred meters into the surroundings. For higher building densities the effect extends less far than for lower densities, because of decreased air mixing. For the same reason, the absolute cooling effect inside the park, however, is larger for higher building densities (Dimoudi & Nikolopoulou, 2003). The effect extends farthest at the leeward side of the green area, into the streets (most) parallel to the wind direction. The wider the streets, the further the cool air is reaches.

The importance of availability of water for evapotransipiration is evident. With enough water available, differences in daily maximum surface temperatures between vegetated and stony surfaces can amount up to over 20°C in warm weather. The temperature of bare soil lies half way between that of vegetated and stony surfaces (Herb et al., 2008). In wet weather, however, these differences are much smaller[39], since all surfaces have water available for evaporation (Berthier et al., 2006; Herb et al., 2008).

The water content of a soil greatly influences its thermal admittance; the wetter the higher the thermal admittance. During the day this helps keeping the surface cool, but during the night it causes the surface to be relatively warm, as more heat is stored in it. Furthermore, evapotranspiration is negligible during the night. Well-irrigated parks or other green areas can therefore be warmer than their surroundings at night. This is especially true if the park has trees; trees obscure the sky and therewith hinder outgoing long-wave radiation. At park edges the SVF is also smaller, and therefore cooling at the edges is also less. This edge effect can extend up to 2.2-3.5 border heights. Conditions that help create PCI during the day – small SVF by shade trees and water availability – thus seem to hinder it during the night. If the park is sufficiently large (>6 border heights) (Figure 5.36), an air circulation can develop that cools the surroundings of the park at night. This cooling effect extends up to about one park-width away from the park (Spronken-Smith & Oke, 1999).

37 The largest park size in the study by Dimoudi and Nikolopoulou was 325 m^2

38 In this specific study the threshold was at about 20% vegetative cover, but this may be different for other climates and cities.

39 In the study of Herb et al. (2008) Differences in monthly-averaged ground surface temperature between ground covers were 2.5°C in wet weather compared 10.4°C in all weather (both in July)

Figure 5.36
Park size (W) in relation to border height (H).

Wind shading
Vegetation also affects the thermal climate by wind shading. Like buildings, vegetation influences the flow pattern in its vicinity. The denser the vegetation, the more the flow pattern resembles that of a solid object like a building; most air is deflected around the (row of) tree(s) or shrub, little air penetrates through the vegetation. The more porous the vegetation, the more air that goes through the vegetation – escaping as small jets at the leeward side – and the less air that is deflected (Figure 5.37). The reduction of wind speed is thus highly influenced by the porosity of the vegetation; the less porous, the higher the maximum wind speed reduction in the wake area behind the vegetation.

Porosity furthermore influences the position of the maximum wind speed reduction relative to the wind barrier. The maximum wind speed reduction is closest to the barrier for dense vegetation, furthest away for semi-permeable vegetation and closer to the barrier again for permeable vegetation. Table 5.7 summarizes the results of studies by Peri & Bloomberg (2002) and Li et al. (2007) (which show some slight differences).

Cooling by convective heat transfer is limited in the wake areas behind vegetation. Furthermore, the replacement of air saturated by evapotranspiration by drier air is reduced as a result of decreased mixing of air. Again, porosity is of influence; the more porous the vegetation, the more air circulation in the wake area.

Vegetation can also help limiting infiltration losses from buildings; trees and/or shrubs near the windward wall and vertical green reduce the wind speed near the wall and thus insulate it. Living wall systems further have the advantage of increasing the R-value of a building through the substrate (Wong et al., 2010).

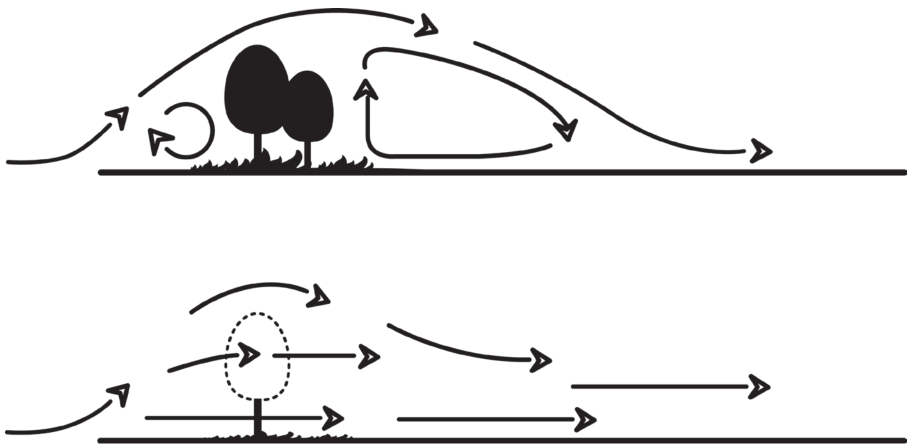


Figure 5.37
Wind flow in the vicinity of vegetation with low porosity (top) and high porosity (bottom).

study	porosity	Max. wind speed reduction	Distance to wind barrier
Peri & Bloomberg (2002)	< 15%	0.85U	1H
	15-45%	0.70U	4H
	> 45%	0.45U	2H
Li et al. (2007)	20-30%	0.80U	1H
	50%	0.70U	2H

Table 5.7
Influence of vegetation porosity on the magnitude and position of maximum wind speed reduction relative to the wind barrier.

Air quality: dispersion, deposition and capturing of pollutants
As vegetation influences wind flow, it also influences the dispersion and deposition of air pollutants. Vegetation placed along a road can give higher concentrations pollutants in the vicinity of the barrier compared to a barrier-free situation, because of reduced wind speeds. Further behind the vegetation however, concentrations will be markedly lower: up to about 30% of the barrier-free values for NO_x and up to 50% for PM_x (De Maerschalk et al., 2008; Hofschreuder et al., 2010).

Vegetation captures air particulates, therewith filtering the air. Not all species are as effective; finer, more complex structured foliage is most effective in capturing particulates. Conifers are thus effective because of their fine structure of hairy needles, but also because they are evergreen, and therefore retain their function in the winter. Common ivy – also an evergreen plant - is also good at capturing particulates, especially the finer fraction $PM_{2.5}$ (Ottelé et al., 2010). Trees are more effective capturers than shrubs, because they have more leaf area and create more turbulent mixing of air, which is important for the dry deposition of particulates (Becket et al., 2000).

Furthermore, vegetation reduces atmospheric CO_2. Directly, through the process of photosynthesis, and indirectly by reducing ambient air temperatures and therewith the energy demand for cooling energy. Reduced air temperatures also lead to less smog.

Sound: noise masking, absorption and diffusion

Vegetation and water can also be employed to reduce sound levels and noise annoyance. As described in Section 4.6, natural sounds are experienced as pleasant by most people and can be employed as masking sounds for less pleasant sounds. Masking sounds should have similar frequencies as the sounds they are masking (Semidor & Venot-Gbedji, 2009). Bird sounds, for example, can be found in midfrequency bands between 200 Hz to 5 kHz, and are therefore suitable sounds for masking traffic noise, which has frequencies between 20 Hz and 2 kHz , with highest levels in lower and midfrequency bands.

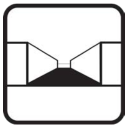
Fountains are especially effective as a masking sound as they can be characterized as a white noise source (Yang & Kang, 2005; Semidor & Venot-Gbedji, 2009).

Vegetation is not a very good sound absorber, but the substrate necessary for most vegetation is. Green roofs and some types of green walls (living wall systems) are therefore good absorbers. An intensive green roof consisting of a 10cm layer of gravel and a 40cm layer of earth (plants not included) can reduce the sound level in a shielded canyon with 6 dB at 1000 Hz compared to the same situation with a rigid roof. Extensive green roofs are also effective, especially at thicknesses between 15 and 20 cm, which is near the maximum thickness (Van Renterghem & Botteldooren, 2009). The thickness of an intensive green roof has no influence, only below 20 cm, but an intensive green roof typically consists of a substrate depth of at least 30 cm. The extra shielding effect of green roofs increases with increasing vehicle speed (Van Renterghem & Botteldooren, 2009).

Furthermore, vegetation - especially trees - are good diffusers of sound and therewith contribute to the reduction of sound levels in their vicinity.

§ 5.7.3 Considerations for urban design.

Guidelines

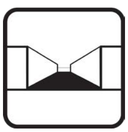
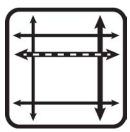


39 Minimizing paved surfaces in general will enhance (the potential for) evapotranspiration.

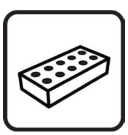
40 Paving materials with relatively low thermal admittance and high albedo will limit the amount of heat stored. Light coloured bricks are a good choice, as brick surfaces also allow water to seep to the substrate, contributing to evapotranspiration.

41 Pervious paving materials applied in parking areas, sidewalks, sitting decks, etc., and if possible open pavements filled with grass further increase evapotranspiration

42 Roads or other surfaces covered with low albedo/high thermal admittance materials (e.g. asphalt) should be shaded as much as possible in summer. (Another option is to use these surfaces as a solar energy collector.)

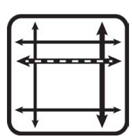
43 Paving materials with a high sound absorption coefficient should be used in busy areas.



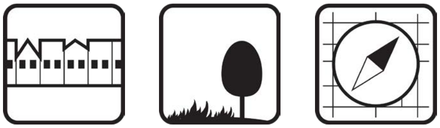

44 Highly reflective building/cladding materials or light coloured finishing (e.g. white paint) will result in relatively little heat stored by buildings (but an increase in radiation towards the street surface). Care should be taken to avoid glare.

45 Reflective roofing materials/finishing will result in relatively little heat stored.

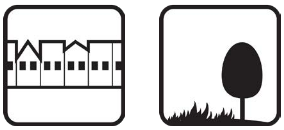




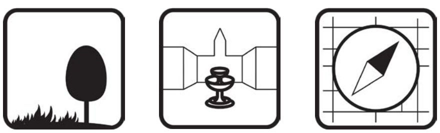
46 Green façades/walls along roads/streets with high traffic intensities filter the air, and if executed as living wall systems also reduce sound levels through absorption. Furthermore they provide cooling through evapotranspiration, which is beneficial as busy roads are often paved with asphalt.



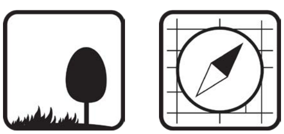
47 Green facades facing (south)west will provide cooling through shading and evapotranspiration at the moment when it is most desirable and furthermore minimize infiltration losses from the building (the governing wind direction in the Netherlands is southwest).



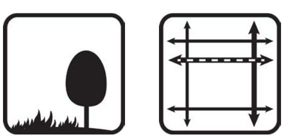
48 Green roofs should be applied where possible, as they absorb sound, cool the air, shade the roof and improve air quality.



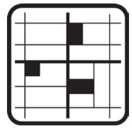
49 A combination of trees and bushes at the southwest side of a large open space will provide wind shelter as well as shading in the (late) afternoon.



50 Deciduous trees on the north side of an east-west running street or on the east side of a north-south running street will provide shade to the facades that need it most and also provide extra shade to the street surface in summer, while providing access to the sun in winter.

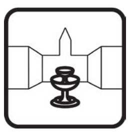


51 Coniferous plants and/or trees or other evergreen vegetation along roads with high traffic intensity provide air filtering year round.

52 Small green areas at small distances (i.e. pocket parks or gardens of about 100m^2 at distances of 200m) that have a combination of well-irrigated grass and trees form a network of Park Cool Islands during the day, cooling the entire urban tissue in their surroundings.

53 Larger green areas with H/W<6 at larger distances (i.e. parks or fields of about 20 hectares at a distance of about 1km) with sparse tree cover will form a network of Park Cool Islands at night, providing nocturnal cooling to the entire urban fabric in their surroundings.



54 Fountains can be placed in public spaces, such as parks or squares, close to or bordered by busy roads for noise masking.

55 Multiple fountains placed along the boundaries of a larger public space will create a quieter, noise free area in the centre.

Discussion

Materialization and landscaping can be employed to improve the urban microclimate to a great extent. In particular in the existing urban environment, where modifications in morphology are difficult (because of high investments and low social acceptability), altering materials or their finishing and/or adding vegetation are good measures to improve the urban climate.

The extent to which it is possible to employ the climatic benefits of materialization and landscaping largely depends on the availability of public space. With increasing GSI the challenge grows; the share of public space in the tissue decreases, rendering the removal of pavement and the planting of vegetation more and more difficult. Executing small, irregular pieces of public space as pocket parks and changing the colour of the pavement may be some of the few feasible urban design strategies in such tissues.

Reflective (cool) roofs and especially green roofs can make a significant difference in tissues with a high GSI, as the surface area covered by roofs is large. Measures at building level, however, require the cooperation of individual building owners, which could prove to be difficult in practice.

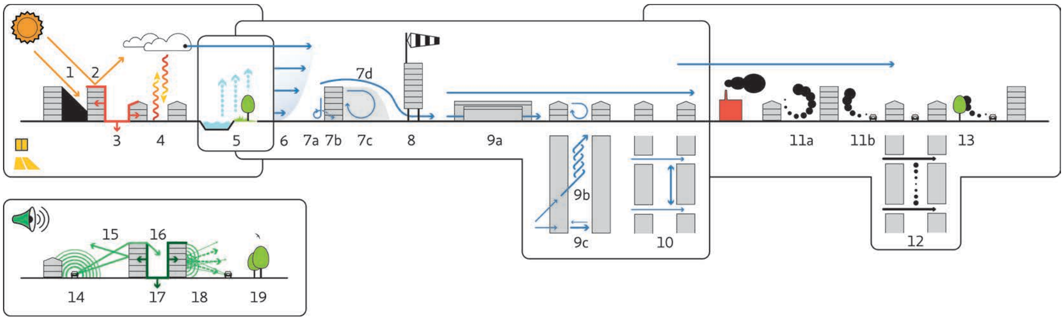
As GSI decreases, the possibilities for altering materialization and landscaping in the public space increase. Replacing pavement with vegetated and/or water surfaces will be easier in such tissues. At building level, the façade gains importance over the roof, and thus measures such as whitewashing buildings and applying vertical greening become more valuable.

In The Netherlands, a large part of the outdoor space in the urban environment is made up out of private gardens (with the exception of post-war high-rise developments). Many of these gardens are paved, adding to the Urban Heat Island effect. Depaving and greening these private areas would greatly increase the natural cooling potential of the urban environment, as well as contribute to air quality and noise control. However, measures at privately owned property – gardens and buildings – requires willingness of owners to execute these measures. Such willingness needs to be promoted through general awareness of the profit of the measures – for the urban microclimate in general and for the owner specifically. In addition, regulations or subsidies help create the necessary incentives for private owners to do their part.

§ 5.8 Conclusion

The literature review above discussed the influence of the urban environment on the different elements of the urban microclimate; solar radiation, daylight, wind, air quality and sound. Different physical principles play a role. These are summarized in Figure 5.38.

For each of the microclimate elements, guidelines for urban design were formulated, based on the literature. In order to be useful for urban design, the information from literature was translated to information that relates directly to the plan elements of urban design. The guidelines aim to help create conditions that benefit the specific microclimate element. Conditions that are beneficial for one climate element however, may not be for another. Table 5.8 lists all guidelines once more, but now sorted by the plan elements they apply to. In this way, it becomes possible to identify conflicts and agreements between guidelines, as shown in the right column of the table. It can be seen that in many cases promising combinations of design solutions can be made. In those cases where conflicts arise, a location-specific assessment should be made of the relative importance of the elements in conflict. Possible weighing factors might be the amount of people affected, the severity of the impact on the microclimate elements concerned, compliance to related regulations and standards and the possibility of compensating measures. Figure 5.39 gives an overview of the design guidelines.



1. direct irradiation/shading
2. reflection
3. absorption
4. diffuse radiation

5. evapotranspiration

6. friction (boundary layer)
7. air flow around a single building
a. frontal vortex
b. corner streams
c. wake (recirculation)
d. shear layers

8. pressure short-circuiting
9. air flow in canyons
a. parallel
b. oblique
c. perpendicular
10. transverse flows

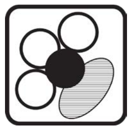
11. dispersion of air pollutants
a. from sources outside the canyon
b. from sources inside the canyon
12. concentrations in perpendicular streets
13. filtering through vegetation

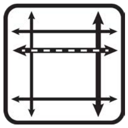
14. geometrical spreading
15. reflection
16. diffraction
17. absorption
18. interference
19. sound masking

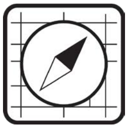
Figure 5.38
Overview of the physical principles of the urban microclimate.

spatial-functional organisation	land use	2	11		23, 24	30, 31	
	main infra-structure			17, 21	25, 26, 27, 46, 51	32, 33, 34, 35, 43, 44, 46	
	water system						
	FSI	1	9				
	GSI	5	10				
city plan	orientation	3, 4, 6, 47, 49, 50	15	19, 20, 21, 49	25, 27, 28		47
	street pattern (length/mesh)	3		19, 20, 21	26	33	
	network large public spaces	7		17			52, 53
	dimensions islands & parcellation	3	12, 13	22		36, 37	
public space design	dimensions (street) profile	4, 5		18	27		
	paving	40, 42, 44				34, 43	39, 41
	vegetation	47, 48, 49, 50		49	46, 48, 51	46, 48	46, 47, 48, 52, 53
	design of large public spaces	6, 7, 49	12	22, 49		36, 37, 54, 55	54, 55
rules for architecture	building line						
	building height		14	16, 17, 18			
	architectural tectonics & articulation	8, 47, 48			29, 46, 48	33, 35, 46, 48	46, 47, 48
	building materials	44, 45		15		38	

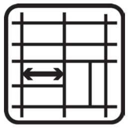
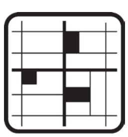
Figure 5.39
Matrix of design guidelines.

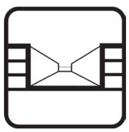
Plan element	Guideline	In Conflict (-) or agreement (+) with guideline(s)
	2. Functions with higher heating needs should be placed on top of functions with lower heating needs.	+11
	11. Functions with the highest daylight demands are best placed at the locations with the highest daylight availability, e.g. on the highest floors of a building (and/or in the potentially passive zone near the façade (the floor area within twice the floor to ceiling height from a façade)).	+1
	23. Areas that generate a lot of air pollution, such as industrial areas, harbours, etc., should be placed downwind from residential areas.	+30
	24. Areas meant for stay, such as squares, bus stops, etc., should not be placed in wake areas near busy roads or other pollution-emitting sources, as particles are accumulated and trapped in these locations for a long time.	
	30. On the scale of the city or district it is not preferable to place functions that produce a lot of (mechanical) noises, such as industry and heavy traffic, immediately next to recreational green spaces and (low-density) residential areas. Business areas, commercial areas, mixed-use areas or green buffers may be placed in between.	+23
	31. Parks or other recreational green spaces should be placed far from busy roads, as traffic noise is found most annoying in green areas, as described in paragraph 4.7.	
	1. Minimizing FSI (or gross floor space) will maximize the potential for direct solar irradiation.	+9
	9. Minimizing FSI will maximize the potential for natural daylighting.	+1
	5. In tissues with a low GSI, buildings are best spaced at considerable distances to allow direct irradiation of the facades. In tissues with a high GSI the roofs are the primary collectors of solar radiation, limiting the importance of street width for passive solar gain of the buildings	+10
	10. For a given FSI, tissues with a low GSI have a better daylight performance than tissues with a high GSI. In other words: high and slender buildings placed at large distances from each other perform better than low and deep buildings placed at short distances and are thus preferable. This effect increases with increasing FSI, as daylight access decreases with increasing density.	+5

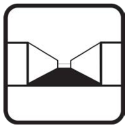
	17. Routes meant for pedestrians or cyclists should preferably not cross the frontal vortex and/or corner streams of tall buildings, nor should areas meant for stay (squares, parks, bus stops, etc) be placed in these locations.	
	21. Roads / streets parallel to the prevailing wind direction should not be directly connected to open terrain, such as rural areas, lakes, rivers, etc, to prevent high wind speeds to penetrate deep into the urban tissue. If this cannot be avoided, such streets are preferably short or have crossings at short intervals (L<4H).	+26 -33
	25. Foot and cycle paths along busy roads are preferably placed on the downwind side of the street, where relatively cleaner air enters the canyon from above and pollutant concentrations are thus the lowest. Streets with two contra-rotating vortices stacked on top of each other form an exception to this rule; in these canyons concentrations are the lowest near the upwind side.	
	26. Busy roads preferably have intersections or side streets at short intervals (L<6H) as this promotes ventilation; through strong vertical flow in streets parallel to the wind direction and through a combination of along-canyon and upward flow in streets perpendicular to the wind direction.	+21 -33
	27. Busy roads should be executed as step-up canyons (in case of perpendicular flow), as this configuration yields the lowest pollutant concentrations.	
	32. On neighbourhood level, placing a few main roads with higher traffic intensity around the neighbourhood, relieving roads in the rest of the neighbourhood, will lead to a larger area with lower noise levels than a homogeneous traffic distribution.	
	33. Busy roads should be bordered with a continuous row of buildings, with as little intersections as possible, to minimize the leaking of sound to the area behind. When executed with flat and/or green roofs, these bordering buildings will also limit the diffraction over the rooftops, thus providing extra shielding.	-21, 26
	34. Sound absorbing road material (e.g. porous asphalt) is advisable for busy roads, as it will reduce the noise load on the road and its surroundings - even in shielded areas.	+43
	35. Along busy roads, gable, shed, dual pitched, and half-monitor roofs should be avoided (as the only roof shape; a mix of different roofs shapes is advisable, as this increases scattering), unless executed with highly absorbing materials	
	43. Paving materials with a high sound absorption coefficient (e.g. porous asphalt) should be used in busy areas.	+34
	44. Highly reflective building/cladding materials or light coloured finishing (e.g. white paint) will result in relatively little heat stored by buildings (but an increase in radiation towards the street surface). Care should be taken to avoid glare.	
	46. Green façades/walls along roads/streets with high traffic intensities filter the air, and if executed as living wall systems also reduce sound levels through absorption. Furthermore they provide cooling through evapotranspiration, which is beneficial as busy roads are often paved with asphalt.	+51
	51. Coniferous plants and/or trees or other evergreen vegetation along roads with high traffic intensity provide air filtering year round.	+46

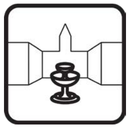


3. A tissue with buildings facing south along east-west running street are preferable, as this yields the largest solar gain in the heating season and the smallest in summer and is most beneficial for outdoor thermal comfort.	+19, 28
4. East-west streets are preferably wider than north-south streets; the impact of H/W on direct solar access to all canyon surfaces is largest for east-west streets and smallest for north-south streets.	
6. Squares, courtyards, gardens and other enclosed outdoor spaces meant for sitting, waiting or recreation are best elongated in the north-south direction and should have a H/W of ¼ or smaller to allow some direct solar access in winter. Solar shading should be provided in summer	-22
15. In canyons with high H/W, materials or colours with a high albedo should be used to maximize reflection. This is most important for east-west canyons (with north/south facing buildings), as they are heavily overshadowed in wintertime.	
19. Street grids normal to the (prevailing) wind direction (sw in the Netherlands) will have streets (and other outdoor spaces) with a high level of shelter (those perpendicular to the wind), but also streets with high wind speeds (those parallel to the wind). Furthermore, these grids have the possibility of transverse flows in streets perpendicular to the wind direction, which may cause discomfort. Grids oblique to the wind direction will have a more 'even' wind pattern, with shielded and windy areas in every street.	+3, 28
20. Street crossings or other openings in canyons and buildings parallel to each other are best placed in line to the (prevailing) wind direction to prevent pressure short-circuiting.	
21. Roads / streets parallel to the prevailing wind direction should not be directly connected to open terrain, such as rural areas, lakes, rivers, etc, to prevent high wind speeds to penetrate deep into the urban tissue. If this cannot be avoided, such streets are preferably short or have crossings at short intervals (L<4H).	
25. Foot and cycle paths along busy roads are preferably placed on the downwind side of the street, where relatively cleaner air enters the canyon from above and pollutant concentrations are thus the lowest. Streets with two contra-rotating vortices stacked on top of each other form an exception to this rule; in these canyons concentrations are the lowest near the upwind side.	
27. Busy roads should be executed as step-up canyons (in case of perpendicular flow), as this configuration yields the lowest pollutant concentrations.	
28. For natural ventilation of buildings, street grids should be placed at an angle to the governing wind direction.	+3, 19
47. Green facades facing (south)west will provide cooling through shading and evapotranspiration at the moment when it is most desirable and furthermore minimize infiltration losses from the building (the governing wind direction in the Netherlands is southwest).	
49. A combination of trees and bushes at the southwest side of a large open space will provide wind shelter as well as shading in the (late) afternoon.	

	50. Deciduous trees on the north side of an east-west running street or on the east side of a north-south running street will provide shade to the facades that need it most and also provide extra shade to the street surface in summer, while providing access to the sun in winter.	
	3. A tissue with buildings facing south along east-west running street are preferable, as this yields the largest solar gain in the heating season and the smallest in summer. Furthermore, the streets in this layout will have a larger solar gain compared to other orientations, averaged over the year. Direct solar access to the street surface, however, will be limited in winter.	+19
	19. Street grids normal to the (prevailing) wind direction (sw in the Netherlands) will have streets (and other outdoor spaces) with a high level of shelter (those perpendicular to the wind), but also streets with high wind speeds (those parallel to the wind). Furthermore, these grids have the possibility of transverse flows in streets perpendicular to the wind direction, which may cause discomfort. Grids oblique to the wind direction will have a more 'even' wind pattern, with shielded and windy areas in every street.	+3
	20. Street crossings or other openings in canyons and buildings parallel to each other are best placed in line to the (prevailing) wind direction to prevent pressure short-circuiting.	
	21. Roads / streets parallel to the prevailing wind direction should not be directly connected to open terrain, such as rural areas, lakes, rivers, etc, to prevent high wind speeds to penetrate deep into the urban tissue. If this cannot be avoided, such streets are preferably short or have crossings at short intervals (L<4H).	-33 +26
	26. Busy roads preferably have intersections or side streets at short intervals (L<6H) as this promotes ventilation; through strong vertical flow in streets parallel to the wind direction and through a combination of along-canyon and upward flow in streets perpendicular to the wind direction.	-33 +21
	33. Busy roads should be bordered with a continuous row of buildings, with as little intersections as possible, to minimize the leaking of sound to the area behind. When executed with flat and/or green roofs, these bordering buildings will also limit the diffraction over the rooftops, thus providing extra shielding.	-21, 26
	7. In dense urban environments, spaces with a high SVF, such as squares and parks with sparse tree cover, should be placed at regular intervals to promote nocturnal long-wave radiation loss in summer. To avoid overheating, (flexible) shading should be employed in these spaces during the day.	+53
	17. Routes meant for pedestrians or cyclists should preferably not cross the frontal vortex and/or corner streams of tall buildings, nor should areas meant for stay (squares, parks, bus stops, etc) be placed in these locations.	
	52. Small green areas at small distances (i.e. pocket parks or gardens of about 100m2 at distances of 200m) that have a combination of well-irrigated grass and trees form a network of Park Cool Islands during the day, cooling the entire urban tissue in their surroundings.	

	53. Larger green areas with H/W<6 at larger distances (i.e. parks or fields of about 20 hectares at a distance of about 1km) with sparse tree cover will form a network of Park Cool Islands at night, providing nocturnal cooling to the entire urban fabric in their surroundings.	+7
	3. A tissue with buildings facing south along east-west running street are preferable, as this yields the largest solar gain in the heating season and the smallest in summer. Furthermore, the streets in this layout will have a larger solar gain compared to other orientations, averaged over the year. Direct solar access to the street surface, however, will be limited in winter.	
	12. Large courtyards, squares or other enclosed spaces have a high potential for indoor daylighting.	-22
	13. Building depth should be minimized for indoor daylighting.	
	22. Square, relatively small (W<2Lg) enclosed spaces (courtyards, squares) give the most wind shelter, as corner streams, frontal vortices and transverse flows are prevented.	-12, 37
	37. An elongated square will have quieter areas than a square with sides of the same length and as such may be more suitable for a mix of functions	-22
	4. East-west streets are preferably wider than north-south streets; the impact of H/W on direct solar access to all canyon surfaces is largest for east-west streets and smallest for north-south streets.	
	5. In tissues with a low GSI, buildings are best spaced at considerable distances to allow direct irradiation of the facades. In tissues with a high GSI the roofs are the primary collectors of solar radiation, limiting the importance of street width for passive solar gain of the buildings	-18
	18. It is possible to design high-rise without (much) discomfort; if all buildings are more or less the same height and placed at distances less than 0.7 building heights from each other, the skimming flow regime will occur, preventing the downwash of high wind speeds.	-5
	19. Street grids normal to the (prevailing) wind direction will have streets (and other outdoor spaces) with a high level of shelter (those perpendicular to the wind), but also streets with high wind speeds (those parallel to the wind). Furthermore, these grids have the possibility of transverse flows in streets perpendicular to the wind direction, which may cause discomfort. Grids oblique to the wind direction will have a more 'even' wind pattern.	
	27. Busy roads should be executed as step-up canyons (in case of perpendicular flow), as this configuration yields the lowest pollutant concentrations.	

	34. Sound absorbing road material is advisable for busy roads, as it will reduce the noise load on and next to the roads themselves as well as in shielded areas	
	39. Minimizing paved surfaces in general will enhance (the potential for) evapotranspiration.	
	40. Paving materials with relatively low thermal admittance and high albedo will limit the amount of heat stored. Light coloured bricks are a good choice, as brick surfaces also allow water to seep to the substrate, contributing to evapotranspiration	
	41. Pervious paving materials applied in parking areas, sidewalks, sitting decks, etc., and if possible open pavements filled with grass further increase evapotranspiration	
	42. Roads or other surfaces covered with low albedo/high thermal admittance materials (e.g. asphalt) should be shaded as much as possible in summer. (Another option is to use these surfaces as a solar energy collector.)	
	43. Paving materials with a high sound absorption coefficient (e.g. porous asphalt) should be used in busy roads and streets	
	44. Highly reflective building/cladding materials or light coloured finishing (e.g. white paint) will result in relatively little heat stored by buildings (but an increase in radiation towards the street surface). Care should be taken to avoid glare.	
	46. Green façades/walls along roads/streets with high traffic intensities filter the air, and if executed as living wall systems also reduce sound levels through absorption. Furthermore they provide cooling through evapotranspiration, which is beneficial as busy roads are often paved with asphalt.	
	47. Green facades facing (south)west will provide cooling through shading and evapotranspiration at the moment when it is most desirable and furthermore minimize infiltration losses from the building (the governing wind direction in the Netherlands is southwest).	
	48. Green roofs should be applied where possible, as they absorb sound, cool the air, shade the roof and improve air quality.	
	49. A combination of trees and bushes at the southwest side of a large open space will provide wind shelter as well as shading in the (late) afternoon.	
	50. Deciduous trees on the north side of an east-west running street or on the east side of a north-south running street will provide shade to the facades that need it most and also provide extra shade to the street surface in summer, while providing access to the sun in winter.	-51
	51. Coniferous plants and/or trees or other evergreen vegetation along roads with high traffic intensity provide air filtering year round.	-50
	52. Small green areas at small distances (i.e. pocket parks or gardens of about 100m2 at distances of 200m) that have a combination of well-irrigated grass and trees form a network of Park Cool Islands during the day, cooling the entire urban tissue in their surroundings.	
	53. Larger green areas with H/W<6 at larger distances (i.e. parks or fields of about 20 hectares at a distance of about 1km) with sparse tree cover will form a network of Park Cool Islands at night, providing nocturnal cooling to the entire urban fabric in their surroundings.	

	6. Squares, courtyards, gardens and other enclosed outdoor spaces meant for sitting, waiting or recreation are best elongated in the north-south direction and should have a H/W of ¼ or smaller to allow some direct solar access in winter. Solar shading should be provided in summer.	-22 +37
	7. In dense urban environments, spaces with a high SVF, such as squares and parks with sparse tree cover, should be placed at regular intervals to promote nocturnal long-wave radiation loss in summer. To avoid overheating, (flexible) shading should be employed in these spaces during the day	
	22. Square, relatively small (W<2Lg) enclosed spaces (courtyards, squares) give the most wind shelter, as corner streams, frontal vortices and transverse flows are prevented.	-6 -37
	36. Enclosed shielded spaces (without internal sound sources), such as courtyards, can be expected to be mostly quiet, as sound can only enter via diffraction over the roof.	
	37. An elongated square will have quieter areas than a square with sides of the same length and as such may be more suitable for a mix of functions.	-22 +6
	49. A combination of trees and bushes at the southwest side of a large open space will provide wind shelter as well as shading in the (late) afternoon.	
	54. Fountains can be placed in public spaces, such as parks or squares, close to or bordered by busy roads for noise masking	
	55. Multiple fountains placed along the boundaries of a larger public space will create a quieter, noise free area in the centre	
	8. Buildings along east-west running streets preferably have single-pitched roofs (highest side facing south), as this benefits both outdoor and indoor solar access.	-29
	29. Pitched roofs (as the only roof shape) should be avoided in roads with high pollutant concentrations, because they decrease ventilation.	-8 +35
	33. Busy roads should be bordered with a continuous row of buildings, with as little intersections as possible, to minimize the leaking of sound to the area behind. When executed with flat and/or green roofs, these bordering buildings will also limit the diffraction over the rooftops, thus providing extra shielding.	
	35. Along busy roads, gable, shed, dual pitched, and half-monitor roofs should be avoided (as the only roof shape; a mix of different roofs shapes is advisable, as this increases sound scattering), unless executed with highly sound absorbing materials. Flat green roofs are preferable.	+29 +48
	45. Reflective roofing materials/finishing will result in relatively little heat stored.	
	46. Green façades/walls along roads/streets with high traffic intensities filter the air, and if executed as living wall systems also reduce sound levels through absorption. Furthermore they provide cooling through evapotranspiration, which is beneficial as busy roads are often paved with asphalt.	

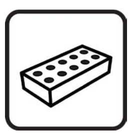
	47. Green facades facing (south)west will provide cooling through shading and evapotranspiration at the moment when it is most desirable and furthermore minimize infiltration losses from the building (the governing wind direction in the Netherlands is southwest).	
	48. Green roofs should be applied where possible, as they absorb sound, cool the air, shade the roof and improve air quality.	+35
	14. Differences in building height increase average and maximum daylight factors.	-16,18
	16. Buildings twice as high or more than fifteen meters higher than the buildings in its surroundings are very likely to cause discomfort, as downwash of high wind speeds will occur. Such differences in building height should therefore be avoided, or, if this is not possible, higher buildings should have their longest side placed parallel to the governing wind direction, so that the frontal vortex and corner steams are minimized.	-14 +18
	17. Routes meant for pedestrians or cyclists should preferably not cross the frontal vortex and/or corner streams of tall buildings, nor should areas meant for stay (squares, parks, bus stops, etc) be placed in these locations.	
	18. It is possible to design high-rise without (much) discomfort; if all buildings are more or less the same height and placed at distances less than 0.7 building heights from each other, the skimming flow regime will occur, preventing the downwash of high wind speeds.	-14 +16
	15. In canyons with high H/W, materials or colours with a high albedo should be used to maximize daylight reflection. This is most important for east-west canyons (with north/south facing buildings), as they are heavily overshadowed in wintertime.	+44
	38. Avoid specular surfaces (all-glass facades), as they yield higher average sound levels and reverberation times.	
	44. Highly reflective building/cladding materials or light coloured finishing (e.g. white paint) will result in relatively little heat stored by buildings (but an increase in radiation towards the street surface). Care should be taken to avoid glare.	+15
	45. Reflective roofing materials/finishing will result in relatively little heat stored.	

Table 5.8
Conflicts and agreements between guidelines

Table 5.8 further brings to light where more research on the influence on the urban microclimate is needed. More complex plan elements such as density and compactness need attention, but also mesh sizes of street patterns and the dimensions of islands and parcels. The influence of these parameters on the urban microclimate may not be straightforward, but is important to investigate nonetheless, as decisions concerning these parameters are often made in an early stage of the urban design process. Furthermore, density, street pattern and parcellation are structural aspects of the city that are fixed for the long term and are thus not easily changed.

This chapter has shown that the urban designer has a large influence on the urban microclimate, though morphology - the carcase of the city – and through materialization and landscaping – the finishing. It is therefore vital that the urban designer can make well-informed design decisions. The next chapter proposes a support tool for the urban designer, which combines the information on the influence on the microclimate on physical well-being information discussed in Chapter 4, and the information on the influence of the built environment on its microclimates and the design guidelines from this chapter.

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PART 3 Integration

6 Framework for a support tool for the dissemination of knowledge on the urban microclimate to the urban design process

§ 6.1 Introduction

In order to preserve physical well-being in a changing climate and an increasingly urban world, information on climate-sensitive design is of crucial importance. Passive building strategies that support physical well-being are preferable as they serve a sustainable development in the urban environment. Correspondence of the requirements that the separate microclimate elements impose on the urban environment should be utilized, conflicts solved in accordance to other design requirements. This asks for a plain presentation of the complex relations of different qualities of the urban microclimate.

The previous parts of this dissertation discussed the two fields necessary for climate-sensitive urban design separately. Part 1 explored the different aspects of urban design relevant for climate-sensitive design and elaborated on the use of expert information by the urban designer. Part 2 addressed the field of urban microclimatology, presenting available knowledge on the impacts of the urban microclimate on physical well-being and related regulations and standards, as well as the influence of the urban environment on its microclimates. Combined, the two parts provide the basis for a framework for a support tool for the dissemination of knowledge on the urban microclimate to the urban design process. This chapter will first draw up a set of requirements for such a support tool (Section 6.2) and elaborate on necessary translation of expert knowledge to design information (Section 6.3), before proposing an actual framework for the support tool (Section 6.4). Finally, some examples are given of the different ways in which the tool can be used (Section 6.5).

§ 6.2 Requirements

On the basis of the previous chapters in this dissertation, a framework for a design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process can be constructed. From Part 1, requirements regarding the form and function of the support tool can be derived. From Part 2, requirements regarding the content can be derived.

§ 6.2.1 Requirements regarding form and function

The support tool should focus on the first phases of the design process. Firstly, because designers collect most information in the beginning of the design process (Section 3.4.3.) and secondly, because decisions made early on in the process generally have a larger impact on the urban microclimate than alterations to the design in later stages. This means that information should be directed at supporting the creative processes of selecting design constraints and generating concepts and less on supporting evaluation.

As discussed in chapter 2, urban design is concerned with shaping the physical environment as a context for many social, economical and physical processes and as such has several physical plan elements as its instruments. These plan elements are related to the spatial-functional organization of the urban area, the city plan, the design of public space and rules for architecture (Section 2.3). The design support tool should link information on microclimate directly to these plan elements. And in doing so, the tool should support decisions from that perspective in the design process.

The process of designing is complex; it does not consist of a predetermined series of activities, but is an iterative process in which focus is shifted between different sub problems and solutions, and wide-scope as well as in-depth approaches are used alternately. Furthermore, the process differs from designer to designer and from project to project. A design support tool should therefore allow for a custom selection of information, fitting the designer as well as the design task at hand, and have different layers of detail. The need for different layers of detail was also mentioned in Section 3.4.5; some designers prefer global information first and more detailed information if needed later on, while others prefer to have all details from the start.

As was mentioned in Section 2.5, urban designers have different design frames, and accordingly, different starting-points. These different design frames could benefit from different kinds of information. The program-oriented designer – who likes to work with known rules and requirements - might like to be informed about desirable climatic conditions, expressed in regulations or standards. Clear design guidelines might further assist the program-oriented designer. The concept-oriented designer is likely to be aided by a basic description of the physical phenomena related to the urban microclimate and its separate elements. The site-oriented designer, starting from the characteristics of the site, could benefit from a description of the influence of the different plan elements on the urban microclimate, to see what site characteristics he/she can use or should alter.

Urban designers are primarily visually thinkers and thus visual representations of information, such as drawings, photographs and diagrams should be abundantly present in any urban design support tool (Section 3.4.1 and 3.4.6). Written text can be used to accompany the visual information and should be kept short and simple where possible. Numerical information should be kept to a minimum, as this type of information is unpopular amongst urban designers.

Example projects can be used to show how certain principles or guidelines are applied in practice (bad examples can also be informative). Example projects are often used by urban designers for inspiration (Section 3.4.1) and are also a suitable tool for communication between all participants in the planning process.

Concluding from the above it can be stated that a design-decision support tool should offer the possibility to approach the same information from different angles, enable navigation through the information at ones personal desires, and make a custom selection of information, fitting the design style of the designer, the project, site and design phase.

Summarizing, the requirements regarding form and function of a support tool for the dissemination of knowledge on the urban microclimate to the urban design process are the following:

- Support first phases of the design process (i.e. selection of constraints and generating concepts)
- Link microclimate information to urban plan elements
- Enable custom information selection
- Provide different layers of detail
- Facilitate different design styles
- Enable different navigation schemes
- Use visual information accompanied by written text, minimize numerical information

Compliance of the tool framework with these criteria will be assessed in Section 6.6.

§ 6.2.2 Requirements regarding content

Requirements regarding the content of the design support tool can be derived from Part 2 of this thesis, consisting of Chapters 4 and 5.

The support tool should give an overview of the impacts of the urban microclimate on physical well-being and related regulations and standards (Sections 4.2 through 4.7). This kind of information stresses the importance of climate-sensitive urban design. It can help setting goals and priorities - for the individual designer, but also for a larger design team and other actors involved in the design process. Nevertheless, it should be regarded as background information and should therefore be concise and comprehensive.

The support tool should contain information on the physical principles (universal phenomena) of the urban microclimate and its separate elements. It should explain the influence of the urban environment and its properties in a clear manner (Sections 5.2 through 5.7). Such information is necessary to fill any potential cognitive gaps that the designer might have and to give insight into the controls that he/she has to 'design' a microclimate.

In addition to descriptive information on the influence of the urban environment on its microclimates, the tool should also provide normative information; desirable and undesirable (interventions in) morphologies and landscaping of the urban environment in relation to the urban microclimate (Sections 5.2.4, 5.3.3, 5.4.4, 5.5.3, 5.6.3 and 5.7.3). Possible conflicts and agreements between design interventions/ decisions should also be indicated. This type of information should enable the designer to make design decisions that create conditions for healthy and comfortable urban microclimates. This information is climate- (and even country/culture-) specific.

Summarizing, the requirements regarding the content of a support tool for the dissemination of knowledge on the urban microclimate to the urban design process are the following:

- Give an overview of the impacts of the urban microclimate on physical well-being
- Give an overview of regulations and standards concerning the urban microclimate
- Explain basic physical phenomena related to the urban microclimate and its separate elements
- Explain the influence of the urban environment on the urban microclimate
- Give design guidelines
- Indicate possible conflicts and agreements between design decisions

Compliance of the tool framework with these criteria will be assessed in Section 6.6.

§ 6.3 Translation of knowledge

Combining the requirements regarding the form, function and content of a microclimate design support tool and the knowledge gained from Parts 1 and 2, it can be inferred that translation of expert microclimate knowledge to design information is necessary with respect to four aspects:

The first aspect is that of ***physics***. The science of physics provides several theories that explain the behaviour of the various (micro)climate elements, such as thermodynamics, aerodynamics, optics and acoustics. A complete understanding of these theories by designers would of course overshoot the mark; to quote De Schiller and Evans (1996): "(…) there is a clear limitation in the degree of detail and complexity that the architect and planner can (and need to) assimilate as input to the design process." However, some simple and basic knowledge of physics formulated in relation to the urban environment will enhance designer intuition for climate-sensitive design.

The second aspect concerns the ***integration of expert knowledge of the different microclimate elements***. There is a significant body of knowledge on the influence of the urban environment on the urban microclimate, as Chapter 5 demonstrated. The majority of expert studies, however, concern only one microclimate element. In order to make the studies useful for design separate focuses should be integrated. Important for the designer is the possibility to assess the relation between different design decisions and to see where conflicts and agreements occur; a certain building configuration might for example be favourable for solar access, but not for noise attenuation.

The third aspect concerns ***the incongruity in use of parameters used in microclimatological studies and the plan elements of urban design***. Most studies on the influence of the urban environment on the urban microclimate investigate the influence of the dimensions and orientation of single buildings, the height to width ratio (H/W) and relative length (L/H) of urban canyons, and simple systems of parallel or crossing urban canyons (see Sections 5.2 through 5.6). This is a logical choice, since the behaviour of the various microclimate elements has a direct relation with these parameters. These parameters correspond to some of the plan elements of urban design (building height, dimensions of the street profile, street mesh and orientation can all be prescribed by the urban designer), but there are many more plan elements (Section 2.3). The influence of some of these plan elements can be deduced from the studies concerning single buildings or canyons, but this is not a straightforward task. Furthermore, decisions concerning street and building design are often made in later phases of the design process. For the earlier design phases, it is more relevant to have for instance information on the influence of the basic layout of the plan area and its building density on the microclimate.

The fourth and last aspect that needs attention is ***the suitability of information for design and (design) communication purposes as opposed to evaluation purposes***. The majority of information and tools available on the subject of microclimates is often evaluative, presupposing a design that is to be assessed regarding its microclimatic performance. To support design, information should be presented in such a way that it helps selecting design constraints (what is to be achieved and why) and generating concepts (how it can be achieved).

The first steps in the process of knowledge translation have been taken in Chapter 5; the influence of the urban environment on the different (micro)climate elements was explained, including the underlying physical principles. A fixed structure was used for the review of the separate climate elements to ease mutual comparison. Furthermore, design guidelines were formulated, incorporating plan elements other than single buildings and (systems of) canyons where possible. Conflicts and agreements between guidelines were also indicated.

Even though further translation, and in some cases additional knowledge, is needed to generate all the content needed for a design support tool, a solid framework for such a tool can be set up, as will be presented in the next section.

§ 6.4 The framework

Based on the requirements listed in Section 6.2 and taking into account the necessary knowledge translation issues discussed in Section 6.3, this section proposes a framework for a design support tool.

The support tool is to be an online knowledge base (www.urbanclimate.nl/tool); a website (plug-in, or web application) has the advantage of the possibility of arranging information in multiple ways, pieces of information can be interlinked and different layers of detail are easily realised through "click-through" options. A website furthermore has the advantage of being easily accessible by any person at any location (as opposed to books or software, for example, that need to be acquired), facilitating collaboration and communication between the different actors involved in the whole design process. The internet is a medium often used by urban designers (Section 3.4.1).

Five main menu categories - "climate elements", "plan elements", "principles", "guidelines" and "example projects" – give different starting points to browse through the knowledge base. For each of these categories there is an overview page of all items within the respective category, including simple and concise visual and/or written explanations. From this overview page, separate pages for each of the category items can be accessed that provide the most relevant information. More detailed information and/or background information can be accessed through collapse or click-through functions (Figure 6.1). Hyperlinks between items of different categories are provided where relations exist (Figure 6.2). Separate item pages can be added to a 'shopping cart' of which the customized content can be saved as a separate file or printed. The shopping cart is accessible from the main menu, as are two more pages with background information: "physical well-being" and "regulations and standards".

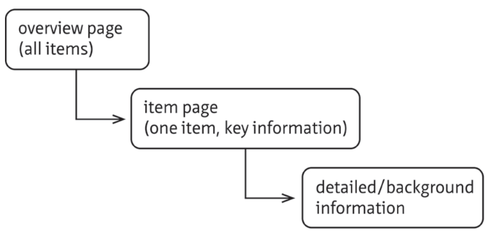


Figure 6.1
Levels of detail.

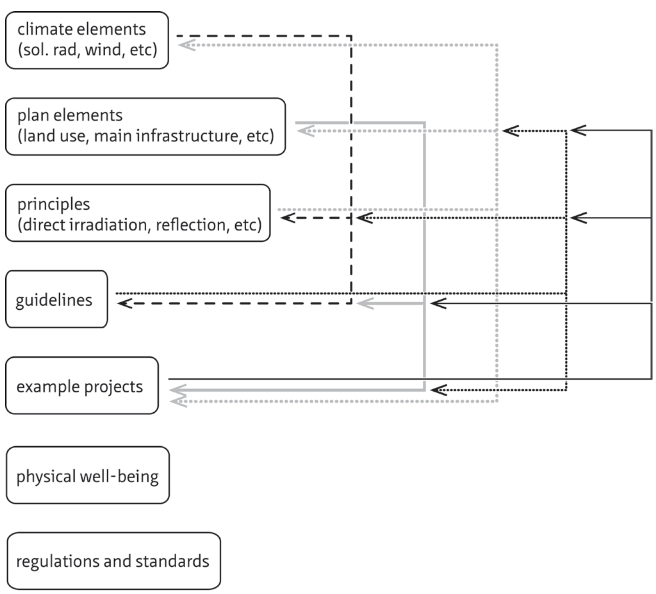


Figure 6.2
Hyperlinks between items of the five main menu categories.

The structure of the support tool and its components can be outlined as follows:

Climate elements category

Climate elements overview page: An overview of all urban microclimate elements – solar radiation, daylight, wind, air quality, sound and moisture, represented by clear graphical icons and accompanied by short captions highlighting the main physical principles (described in Chapter 5) and health effects of each climate element (described in Chapter 4). Hyperlinks to item pages.

Climate elements item pages: An introduction to a separate climate element, elaborating on the information given on the overview page; summarizing the related physical principles and effects on physical well-being. Hyperlinks to related principles and design guidelines.

Plan elements category

Plan elements overview page: An overview of all plan elements, grouped according to level of scale: spatial functional organization, city plan, public space design and rules for architecture (described in Chapter 2). Each plan element is represented by a graphical icon that links to the item page.

Plan elements item pages: Summary of the influence of the plan element on the various microclimate elements, with the possibility of accessing more detailed information through collapse buttons. Hyperlinks to related guidelines and example projects.

Principles category

Principles overview page: A graphical representation of the physical principles related to the urban microclimate, grouped by climate element (described in Chapter 5). Written captions provide access to the item pages.

Principles item pages: A written explanation of the physical principle, describing the influence of the urban environment, accompanied by explanatory drawings. The influence of different plan elements is described in a concise manner. Hyperlinks to related climate elements, plan elements and example projects.

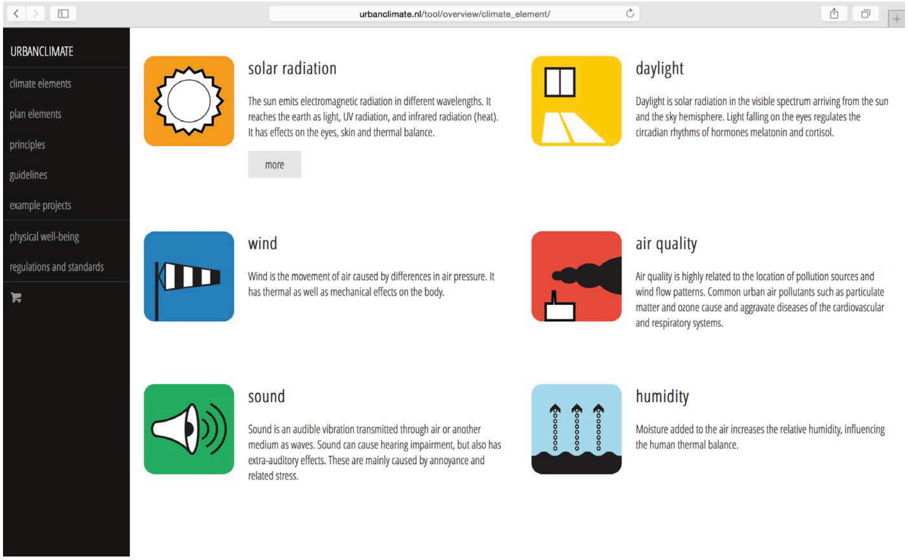


Figure 6.3

Climate elements overview page.

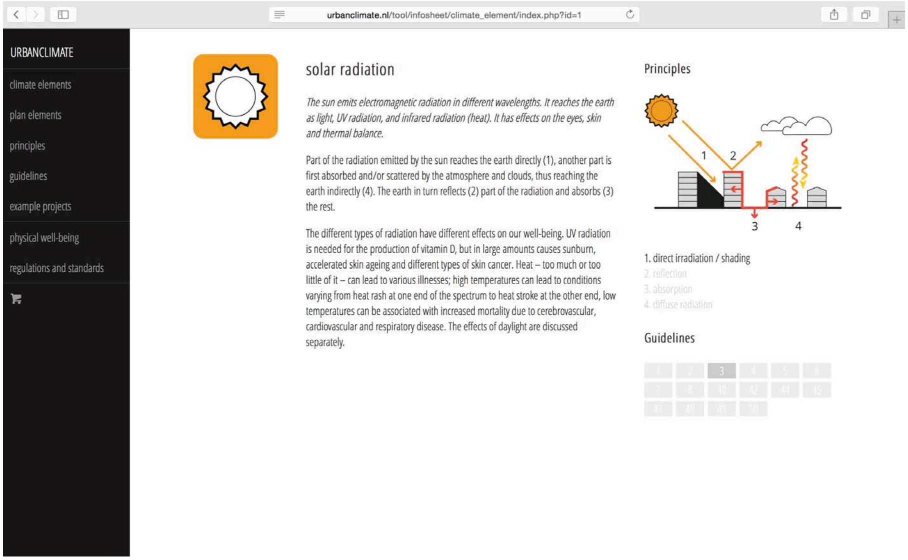


Figure 6.4

Example climate elements item page.

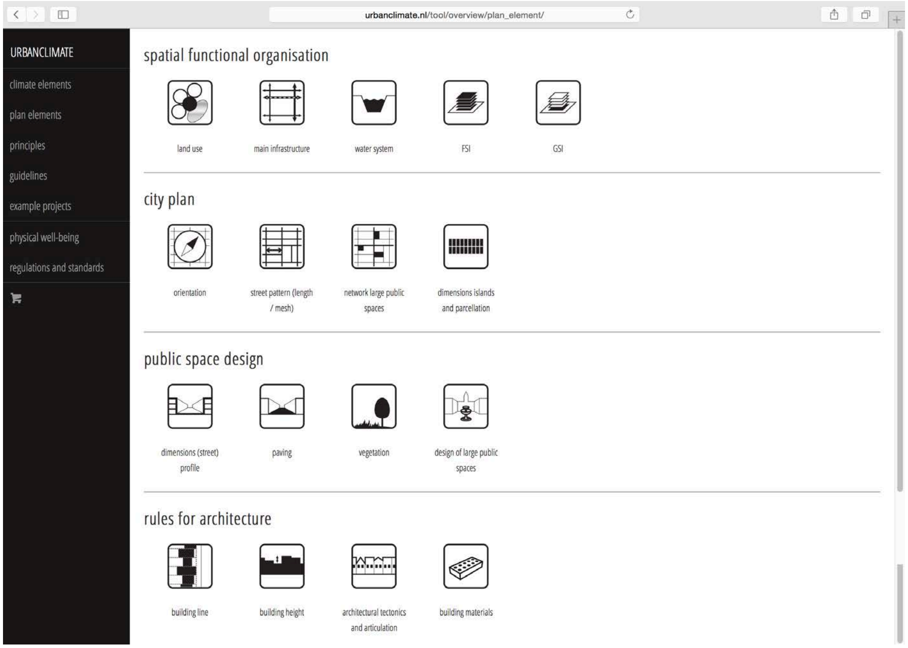


Figure 6.5
Plan elements overview page.

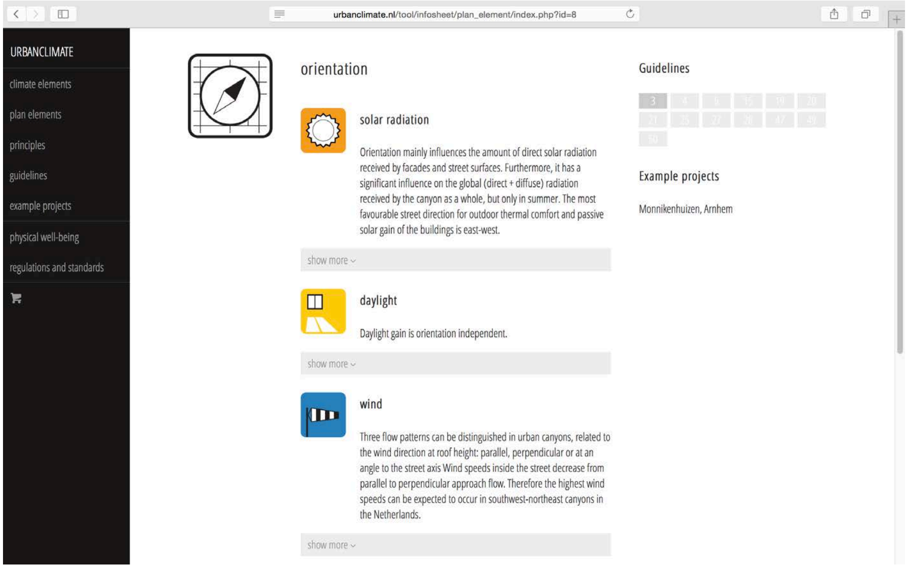


Figure 6.6
Example plan elements item page (partial view).

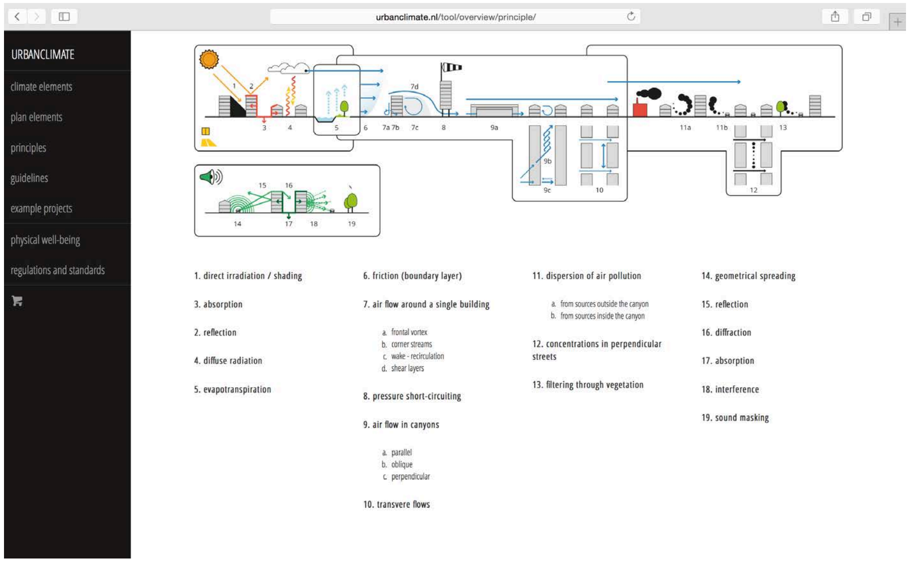


Figure 6.7

Principles overview page.

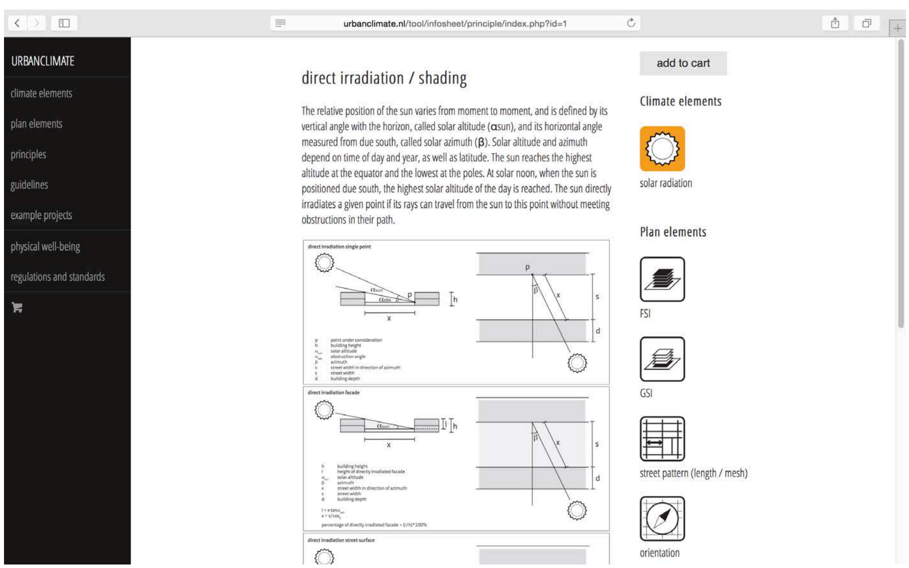


Figure 6.8

Example principles item page (partial view).

Guidelines category
Guidelines overview page: A numbered list of all design guidelines, including possible conflicts and agreements between guidelines. The guideline numbers are also arranged in a matrix that has the climate elements on one axis and the plan elements on the other (Figure 5.39). A number can appear on more than one location in the matrix, when a guideline concerns multiple plan elements and/or climate elements. The numbers in the matrix as well as the written guidelines link to the item pages.

Guidelines item pages: A short description of the design guideline, accompanied by a drawing depicting the guideline. A more detailed explanation of the reasons for the guideline is accessible through a collapse or click-through button. Hyperlinks to related plan elements, example projects, and to related principles in the more detailed information section.

Example projects category
Example projects overview page: Overview of all example projects in photographs and keywords including related climate elements, principles, plan elements and guidelines. The projects can be arranged and selected according to the five categories. The photographs link to the item pages.

Example pages item pages: Short description of the project. Hyperlinks to related principles, plan elements and guidelines.

Physical well-being category
This page lists the effects of the climate elements on physical well-being (Chapter 4) and contains the bioclimatic chart for the Dutch climate, illustrating the combined effect of the different climate elements on thermal comfort.

Regulations and standards category
This page gives an overview of the Dutch regulations and standards concerning the different climate aspects as well as those of neighbouring countries (Chapter 4). A distinction is made between regulations and standards concerning the outdoor environment and those concerning the indoor environment.

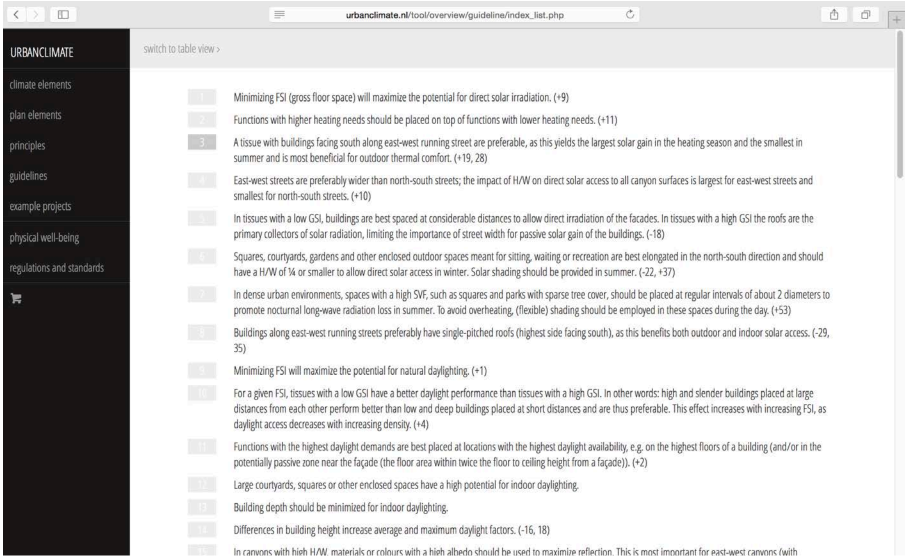


Figure 6.9

Guidelines overview page - list view (partial view).

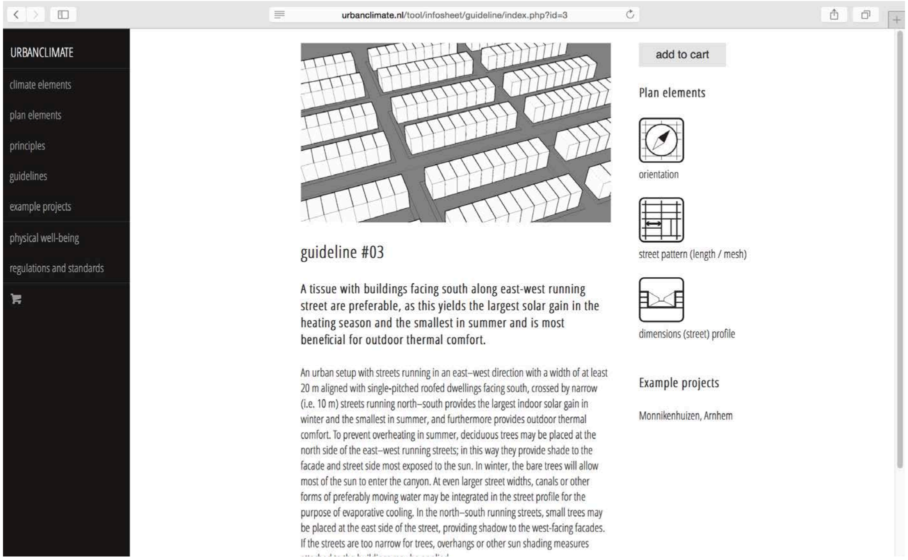


Figure 6.10

Example guidelines item page (partial view).

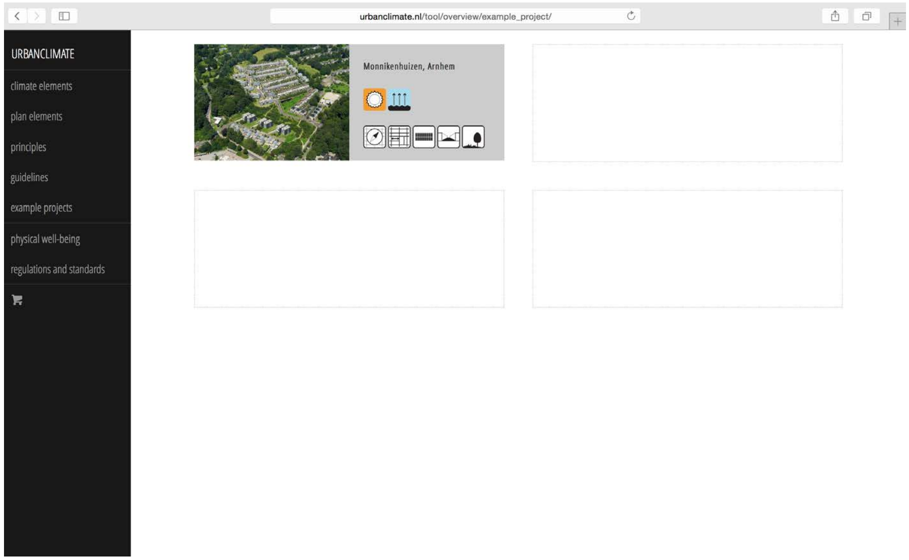


Figure 6.11

Example projects overview page.

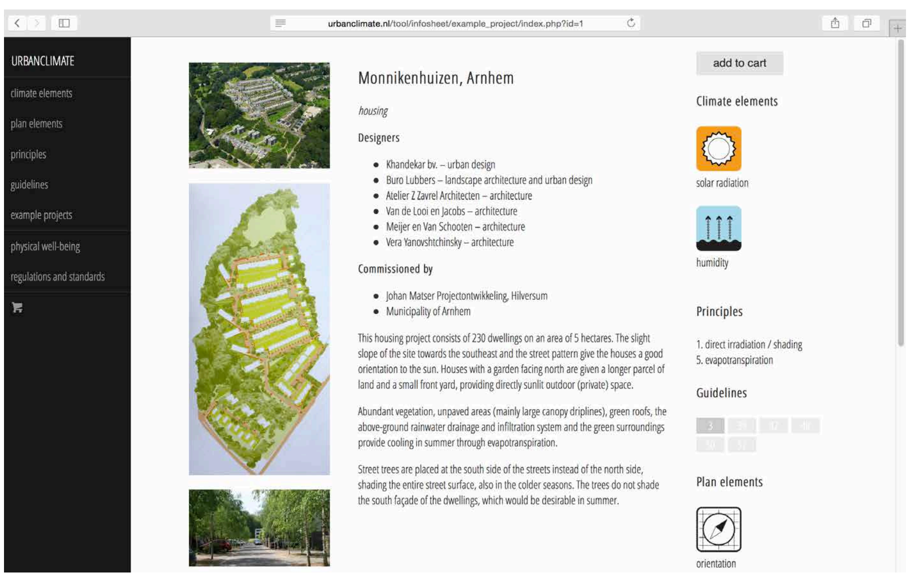


Figure 6.12

Example example projects item page.

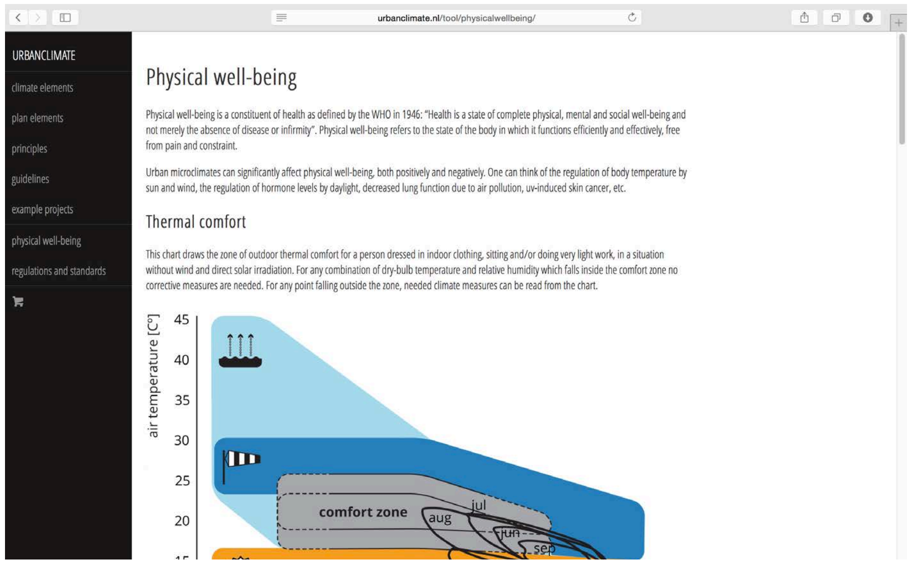


Figure 6.13
Physical well-being page (partial view).

§ 6.5 Navigation schemes

The setup of the design-decision support tool makes it possible to enter and navigate through the information in different ways. Navigation may be determined by the design frame of the designer, described in Section 2.5, but other factors such as the design (sub) task at hand, the design phase, etc., may also play a role. Figure 6.14 shows some examples of possible navigation schemes. The figure lists all items in the five main categories. For one item of each category the hyperlinks are indicated by means of arrows. Dark arrows indicate hyperlinks to elaborated example pages (shown in Figure 6.4, Figure 6.6, Figure 6.8, Figure 6.10 and Figure 6.12), light arrows indicate hyperlinks to item pages that yet need to created for a commercial version of the tool. The build up of the scheme is shown in Appendix III.

Figure 6.14 shows, for example, that from the climate element item page of solar radiation, one could navigate via the item page of direct irradiation/shading, guideline #3 and orientation to example project Monnikenhuizen. Or, one could start at the plan element item page of orientation, navigate to guideline #3, then to the principle item page of direct irradiation/shading and end up the same example project page from there.

These examples show that different routes are possible through the same information, accommodating the designer in his/her work.

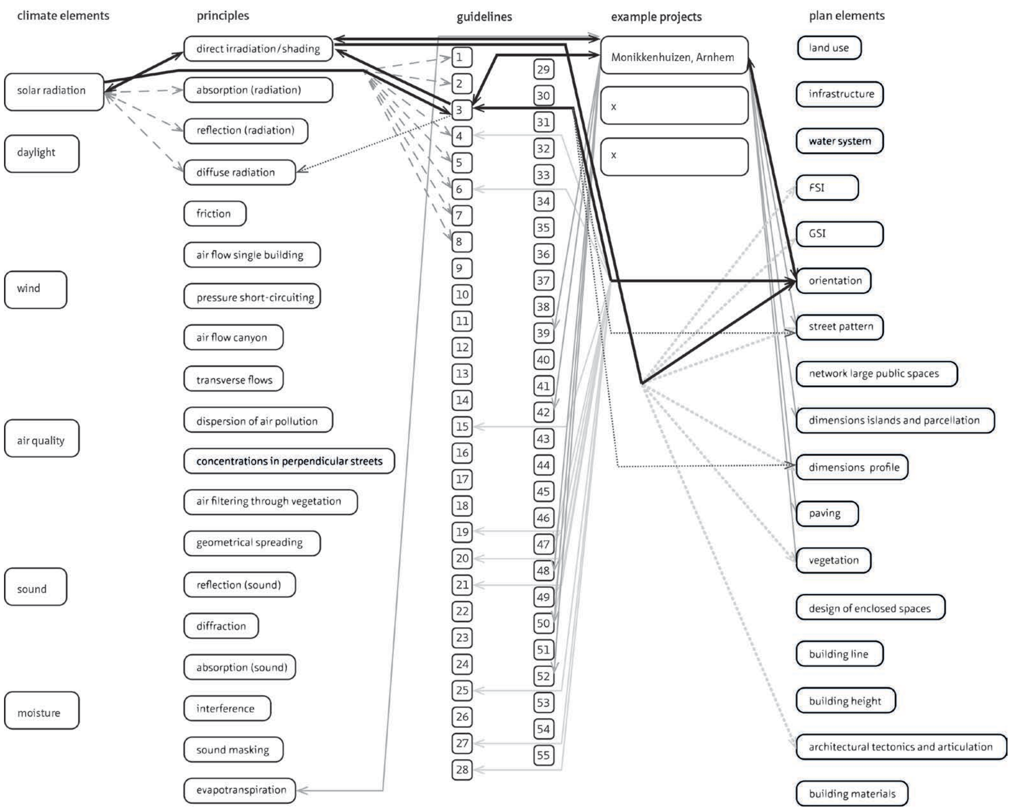


Figure 6.14

Example navigation schemes. Dark arrows indicate elaborated examples, light arrows indicate other first order links.

§ 6.6 Conclusion

This chapter presented a support tool framework for the dissemination of knowledge on the urban microclimate to the urban design process. The requirements for the design-decision support tool were derived from Part 1 and Part 2 of this dissertation and are listed below:

1. Support first phases of the design process (i.e. selection of constraints and generating concepts)
2. Link microclimate information to urban plan elements
3. Enable custom information selection
4. Provide different layers of detail
5. Facilitate different design styles
6. Enable different navigation schemes
7. Use visual information accompanied by written text, minimize numerical information
8. Give an overview of the impacts of the urban microclimate on physical well-being
9. Give an overview of regulations and standards concerning the urban microclimate
10. Explain basic physical phenomena related to the urban microclimate and its separate elements
11. Explain the influence of the urban environment on the urban microclimate
12. Give design guidelines
13. Indicate possible conflicts and agreements between design decisions

The proposed support tool combines information on the different elements of the urban microclimate, with the underlying physical principles, the influence of urban plan elements on the urban microclimate, supported by examples/reference projects and design guidelines. In this way, relations between different possible design decisions come to light, which aids decision-making. Aim is to enable designers to estimate the influence of their design choices on the microclimate and help them in creating conditions for urban microclimates that favour physical well-being. Furthermore, communication between the different actors involved in the urban design process should be supported by the tool.

The tool is to be a web-based knowledge base, consisting of five main menu categories: “climate elements”, “plan elements”, “principles”, “guidelines” and “example projects”. These give different starting points to browse through the knowledge base, respectively giving form to requirements 5, 6, 2, 11, 10 and 12.

For each of the main categories there is an overview page of all items within the respective category, including simple and concise visual and/or written explanations (requirement 7). From this overview page, separate pages for each of the category items can be accessed that provide the most relevant information. More detailed information and/or background information can be accessed through collapse or click-through functions. This fulfils requirement 4. Hyperlinks between items of different categories are provided where relations exist, meeting requirements 5 and 6 again, as well as requirement 13.

Separate item pages can be added to a *'shopping cart'* of which the customized content can be saved as a separate file or printed, satisfying requirement 3. The shopping cart is accessible from the main menu, as are two more pages with background information: "physical well-being" and "regulations and standards", satisfying requirements 8 and 9. The setup of the framework in its entirety meets requirement 1.

Aim of this study was to provide a *framework* for a design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process, not to provide the actual tool itself. However, in order to demonstrate the ways in which the tool supports the design process, show possible navigation schemes and illustrate what the tool could look like, the framework was partially filled with content (Figure 6.3 - Figure 6.13 and www.urbanclimate.nl/tool). In order to be able to provide all necessary content, some translation of expert knowledge to design information as well as additional research is necessary, as was pointed out in Section 6.3. The next chapter illustrates how this could be approached.

7 Expert tools

§ 7.1 Introduction

Chapter 5 described the influence of the built environment on the urban microclimate. The literature review of that chapter showed that most expert studies use the concept of a single building, the urban canyon, or a series of interlinked cayons to study the effects of a single microclimate element. Chapter 6 discussed how these expert studies need translation with regard to several aspects in order to be useful to the urban designer (Section 6.3). This chapter aims to illustrate how this translation can be approached. It will numerically explore the influence of three selected plan elements – FSI, GSI and orientation - on solar irradiation (Section 7.2) and wind (Section 7.3). The results of the calculations will be compared to see where possible conflicts and promising combinations occur with regard to the spatial characteristics that create favourable conditions for each climate element. In addition, the possible employment of other urban design plan elements to improve the microclimate in the studied morphologies will be discussed (7.4).

With this outline, the study focuses on translation tasks 2 and 3 (Section 6.3); the integration of information on multiple climate elements and the study into the influence of (some of the) plan elements that are important in the first phases of the design process. The discussion of the results and, additionally, a discussion on the employment of other plan elements (landscaping and materialization) to improve the microclimate is in line with translation task 4: presenting expert information in a way that makes it suitable for design and (design) communication purposes as opposed to evaluation purposes.

§ 7.1.1 Climate elements

To come to a choice as to which climate elements to study, the bioclimatic chart by Olgyay (1963) was consulted (see Section 4.7). This chart draws the zone of outdoor thermal comfort for a person dressed in indoor clothing, sitting and/or doing very light work, in a situation without wind and direct solar irradiation. For any combination of dry-bulb temperature and relative humidity which falls inside the comfort zone no corrective measures are needed. For any point falling outside the zone, needed climate measures can be read from the chart.

Figure 7.1 shows the bioclimatic chart for temperate European climates (adapted from Reiter & De Herde, 2003). The closed curves represent the average 24-hour data of each month of the year for the Dutch situation. The data are for De Bilt, from the year 1995, which is often used as a reference year.

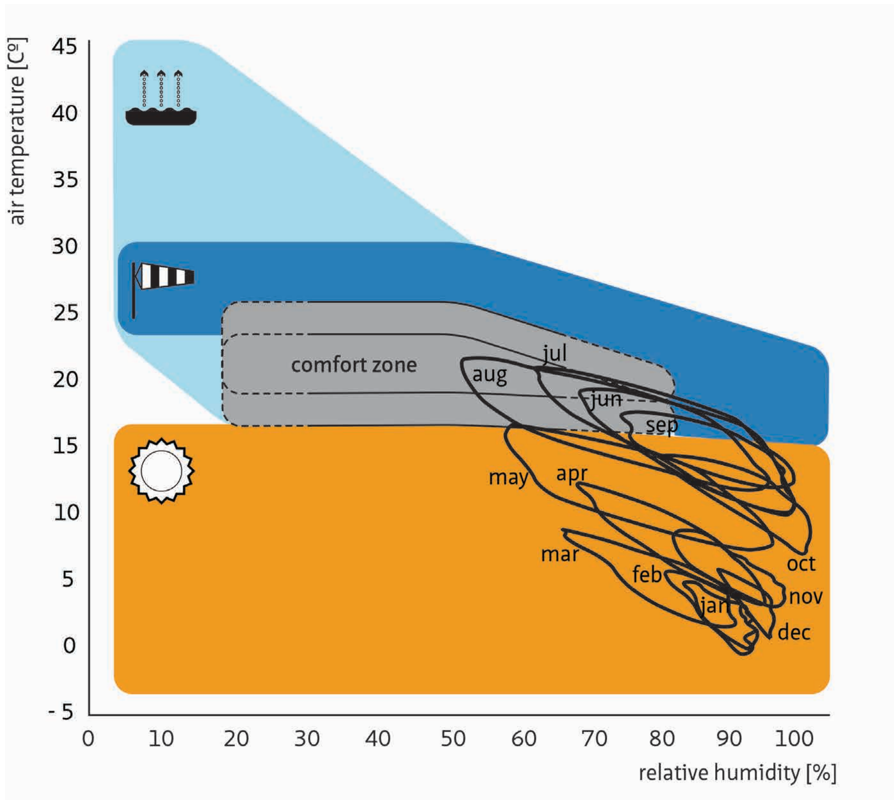


Figure 7.1
Olgyay's bioclimatic chart for European temperate climates (adapted from Reiter & De Herde, 2003), with the Dutch climate situation of an average day of each month of the year.

From the chart it becomes clear that during the largest part of the year solar irradiation and wind shelter are needed. Only during the summer months some shade is needed. Wind is never needed according to the chart, but as the urban situation differs somewhat from the situation at an (ideal) meteorological station due to the Urban Heat Island Effect, a breeze may be welcome during the warmest periods. Furthermore, some ventilation is needed to disperse air pollutants.

As needs and preferences regarding thermal comfort differ from person to person, depending among other things on activity level, clothing and body shape, but also psychological aspects (See Section 4.7), outdoor spaces should offer both sun and shade in order for more people to feel comfortable. In summer more shade may be provided - also to provide protection from UV radiation, which can reach high levels in summer - , the rest of the year predominantly sunny spaces should be offered.

Solar radiation can also contribute to the indoor climate; with proper design measures (part of) the heat demand of a building can be gained from solar radiation, reducing the need for fossil fuels. Careful tuning of solar radiation collection, thermal conservation and diurnal storage decides to what extent solar radiation can contribute to annual space heating (Goulding et al., 1992; Crosbie, 1998; Hestnes et al., 2003). In an urban setting, solar radiation collection of individual houses is constrained by street layouts and the shape of neighbouring buildings. Obstructions put restrictions on the solar exposure of transparent openings in the building skin and thus on the potential of solar radiation to contribute to lowering the heat demand. Conversely, buildings may obstruct solar radiation, leaving surrounding outdoor spaces partly or completely in shade. The spatial requirements for solar access to the outdoors may conflict with those for solar access to the indoor environment and vice versa, as the surfaces of interest – the ground and the facade(s) usually have different orientations.

Wind contributes to thermal comfort by convection. The higher the wind speed, the greater the convective heat transfer between skin and air. Wind also has mechanical effects on the body, which can cause discomfort or even danger (Section 4.4). The built environment influences the wind climate with regard to speed, turbulence intensity as well as direction, often to a high degree. Buildings can provide shelter, but can also direct higher wind speeds at roof level to pedestrian level (Section 5.4). In general it can be said that for the Dutch situation wind shelter is needed, for thermal comfort as well as for mechanical reasons. For air quality purposes, however, some ventilation is needed, outdoors as well as indoors. Natural ventilation of the indoor environment is driven by pressure differences between the different sides of the building. Airflow along the facades is therefore less suitable than airflow at an angle or perpendicular to the facades.

The study described in this chapter tries to find morphologies of urban canyons with a residential function that benefit both outdoor and indoor solar and wind conditions for the Dutch situation; providing as much solar irradiation in colder seasons, shade in warmer seasons and wind shelter all year round, while still providing conditions for natural ventilation.

§ 7.1.2 Plan elements

As can be seen in Chapter 5, most studies on the influence of urban geometry on the urban microclimate investigate the influence of obstruction angles, the ratio of building height to street width (H/W) and relative street length (L/H). This is a logical choice, since the behaviour of the various microclimate elements has a direct relation with these spatial parameters. For urban design or planning choices on a higher level of scale however, those parameters are of less use. Studies into the influence of building density, building types and orientation can give insight into the basic microclimatic conditions of neighbourhoods of a certain layout and density. These conditions can subsequently be fine-tuned in the design of the individual streets.

For this reason, the urban design parameters studied in this chapter are Floor Space Index (FSI), Ground Space Index (GSI) and Orientation. The FSI is the ratio between gross floor space and the ground space of the area and is a measure for the building intensity of the area. The GSI is the ratio between built space (the footprint of the buildings) and the ground space of the area and expresses the compactness of the area. Both parameters have a close relation with average building height, as described in the density method "Spacemate" (Berghauser Pont & Haupt, 2010). Combined, these parameters give a good indication of the type of urban development; i.e. low-rise, mid-rise or high-rise, and block, strip or pavilion type buildings.

Two series of sections through street canyons are studied on solar access and wind climate (Figure 7.2). In the first series the amount of program of the urban tissue is changed (increasing FSI from 0,8 to 4,0 by adding floors), with the same ground coverage (constant GSI). The second series describes different primary distributions or building types (same FSI, but with different ground coverage and height).
For solar access four street orientations were studied: east-west, north-south, northwest-southeast and northeast-southwest. For wind, only the street orientation perpendicular to the wind direction was studied, as this approach flow is possible to study with 2D models in simulation software. Furthermore, perpendicular flow yields the most complex flow patterns.

The models assume a single value for street width for each tissue and do not take into account that street widths can vary with respect to each other within an urban fabric with a fixed density.

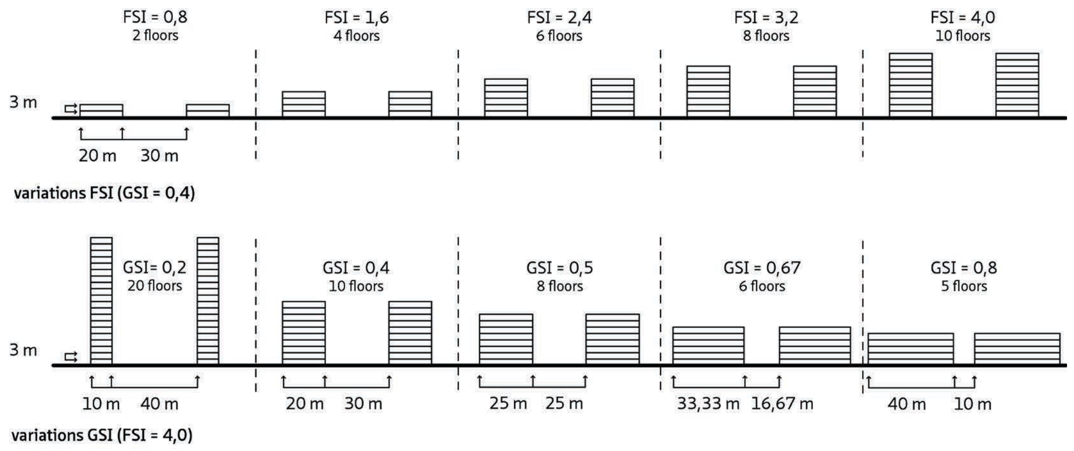


Figure 7.2
Studied variations in FSI and GSI.

§ 7.2 Solar irradiation

§ 7.2.1 Methodology

The calculations for solar access are conducted with actual weather data for De Bilt, The Netherlands (52°06 N and 5°11 E) of the year 1995 (www.knmi.nl). This data set is commonly used as reference. The total annual amount of global radiation was 971 kWh/m^2. Monthly average global radiation values varied from 145 kWh/m^2 in July and dropped under 20 kWh/m^2 in December and January (Figure 7.3). At this latitude the sun reaches a highest altitude of 61° in summer and a lowest altitude of 14° in winter (both 12 am solar time).

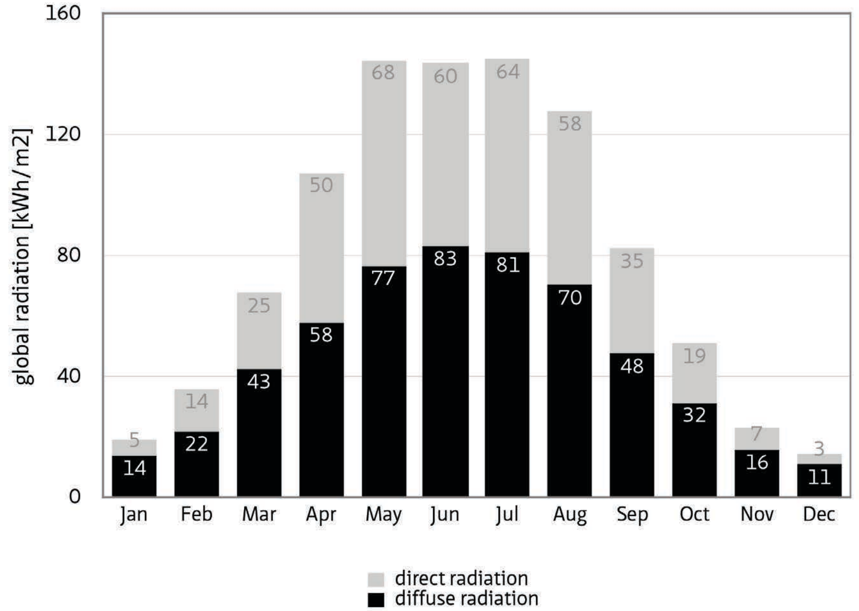


Figure 7.3
Monthly average global irradiation levels split into diffuse radiation and direct radiation. Data labels represent global irradiation values for horizontal surfaces (Figure 5.6 repeated).

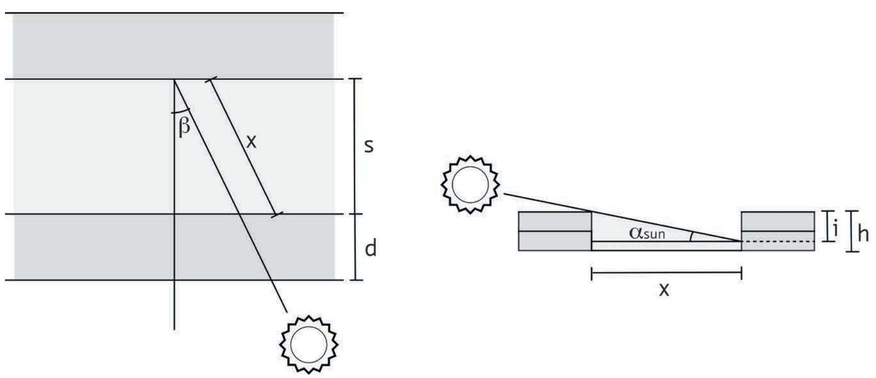
Solar access to the urban canyon is studied for three typical days; the 21st of December, the shortest day of the year and representing the winter season, the 21st of March, representing spring and autumn, and the 21st of June, the longest day of the year and representing the summer season. The hourly solar height and azimuth angles for these days can be found in Appendix IV. For each of these days, both direct and diffuse irradiation is calculated for each of the canyon surfaces separately: the roof (two half roofs), two facades and the street surface (Figure 7.4).

Figure 7.4
Surfaces making up the urban canyon: 2 half roofes, 2 facades and 1 street surface.

Direct irradiation

Hourly percentages of directly irradiated façade and street surface are determined with simple trigonometry as shown in Figure 7.5 and Figure 7.6. Street width (s), height (h) and building depth (d) are given (determined by FSI and GSI), as are solar altitude (α_{sun}) and azimuth (β) for each hour of the three typical days. The façade starts to be directly irradiated if asun > 0°, the street surface starts to be directly irradiated if asun > athr, otherwise it will be in shadow. The roof is always 100% irradiated.

These hourly percentages of directly irradiated surface are multiplied by the corresponding hourly direct irradiation values given by the KNMI (in $kJ/(hr*m^2)$). The KNMI gives values for each of the orientations and inclinations of the different canyon surfaces. The products of all hours are summed to obtain the direct irradiation for the whole day (and divided by 3600 to obtain the value in kWh/m^2). When multiplied by total building height, respectively street width or building depth (in m), the direct irradiation per linear meter surface of the façade, respectively the street or the roof is obtained. The total sum of these values gives the direct irradiation of the canyon as a whole.



h	building height
i	height of directly irradiated facade
α_{sun}	solar altitude
β	azimuth
x	street width in direction of azimuth
s	street width
d	building depth

$i = x \tan \alpha_{sun}$
$x = s/\cos \beta$

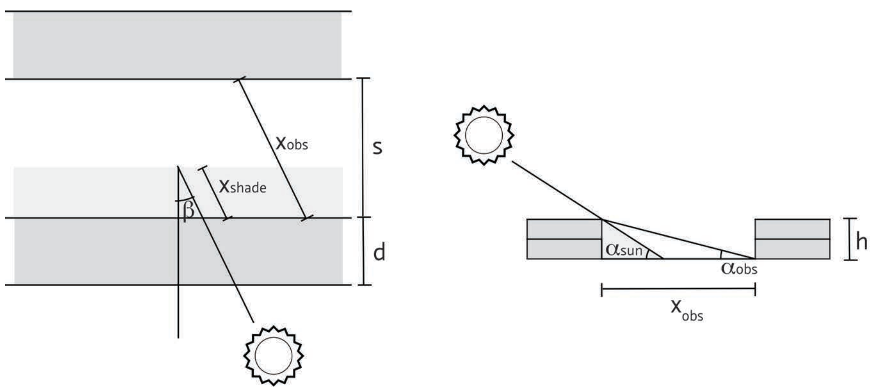
percentage of directly irradiated façade = (i/h)*100%

Figure 7.5
Calculation method of the percentage of directly irradiated façade surface. Top view (left) and section parallel to the solar azimuth b (right).

Diffuse irradiation

The hourly diffuse irradiation values given by the KNMI (in kJ/(hr*m^2) are summed to obtain the diffuse irradiation for the whole day (and divided by 3600 to obtain the value in kWh/m^2). The KNMI gives values for unobstructed horizontal and vertical surfaces. When multiplied by total building height, respectively street width or building depth (in m), the diffuse irradiation per linear meter surface is obtained. This value is multiplied by a correction factor for the sky view of each of the surfaces; the sky view factor (SVF) from the middle of the façade, respectively street surface (Figure 7.7). This is a somewhat crude simplification, but is thought to give a good first estimate of diffuse irradiation of the surfaces.

The sum of the values for the separate surfaces gives the diffuse irradiation of the canyon as a whole.



h	building height
α_{sun}	solar altitude
α_{obs}	obstruction angle
β	azimuth
x_{shade}	width non-irradiated street space in direction of azimuth
x_{obs}	street width for obstruction angle in direction of azimuth
s	street width
d	building depth

$x_{shade} = h/\tan\alpha_{sun}$
$x_{obs} = s/\cos\beta$
$\tan\alpha_{obs} = h/x_{obs}$

percentage of directly irradiated street surface = $((1-x_{shade}/x_{obs})*100\%$

Figure 7.6
Calculation method of the percentage of directly irradiated street surface. Top view (left) and section parallel to the solar azimuth β (right)

Global irradiation is the sum of direct and diffuse irradiation.

Reflections from ground, facades and roofs are not taken into account. The hourly irradiance data for both diffuse and direct radiation are averaged over the whole month, respectively December, March and June, to level out extremities or peculiarities of the three single days. Results for the canyon are given in kWh per linear meter canyon as the canyon is presumed to be infinitely long.

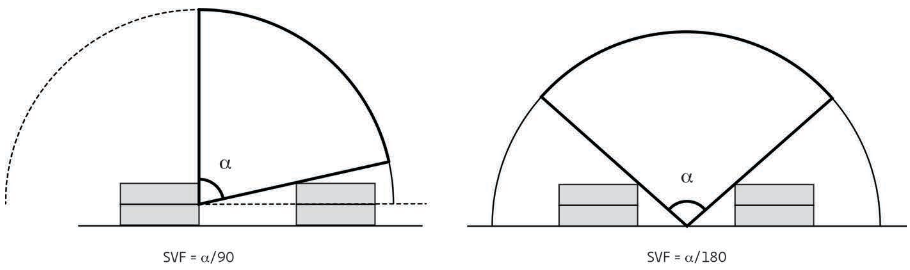


Figure 7.7
SVF for facade and street.

§ 7.2.2 Results

Global and direct radiation yield of the canyon
Table 7.1 shows the influence of increasing FSI. It can be seen that FSI has some influence on the total global radiation yield of the canyon. Increasing FSI leads to an increase in global radiation yield, regardless of orientation. Although the relative increase in radiation yield in different seasons is more or less equal – 1-4% per 0,8 increase of FSI – the absolute increase differs quite strongly; as the radiation yield is rather low in winter an extra 1-4% means only a few tenths kWh/m, while in summer it is an extra 4-9 kWh/m.

The increase in global radiation yield can largely be attributed to the increase in diffuse radiation yield; the direct radiation yield hardly increases December and March, in June the increase is somewhat higher (Table 7.1, lower half), but still is small compared to the diffuse radiation yield increase.

The increase in global irradiation yield is thus mainly caused by the increase in building surface.

	Global irradiation of the canyon (kWh/m)											
	December 21st				March 21st				June 21st			
FSI	e-w	n-s	nw-se	ne-sw	e-w	n-s	nw-se	ne-sw	e-w	n-s	nw-se	ne-sw
0.8	25	25	25	25	107	107	107	107	213	218	216	216
1.6	25	25	25	25	108	108	108	109	217	226	222	222
2.4	26	26	26	26	111	110	110	111	223	234	231	231
3.2	27	27	26	27	115	114	113	115	232	243	241	241
4.0	27	27	27	27	117	116	115	117	239	250	248	249
	Direct irradiation of the canyon (kWh/m)											
	December 21st				March 21st				June 21st			
FSI	e-w	n-s	nw-se	ne-sw	e-w	n-s	nw-se	ne-sw	e-w	n-s	nw-se	ne-sw
0.8	7	7	7	7	37	36	36	37	62	67	65	65
1.6	7	7	7	7	37	36	36	37	64	73	70	70
2.4	7	7	7	7	37	37	36	37	66	76	74	74
3.2	7	7	7	7	38	37	36	38	68	79	77	77
4.0	7	7	7	7	38	37	36	38	69	80	78	79

Table 7.1

Total global and direct irradiation yield of the canyons in kWh/m for increasing FSI and different orientations (GSI 0.4)

	Global irradiation of the canyon (kWh/m)											
	December 21st				March 21st				June 21st			
GSI	e-w	n-s	nw-se	ne-sw	e-w	n-s	nw-se	ne-sw	e-w	n-s	nw-se	ne-sw
0.2	30	30	30	30	129	128	126	129	263	274	273	273
0.4	27	27	27	27	117	116	115	117	239	250	248	249
0.5	27	27	27	27	115	115	114	116	238	247	245	246
0.67	26	26	26	27	113	113	112	113	239	244	243	244
0.8	26	26	26	26	112	112	112	112	241	244	244	244
	Direct irradiation of the canyon (kWh/m)											
	December 21st				March 21st				June 21st			
GSI	e-w	n-s	nw-se	ne-sw	e-w	n-s	nw-se	ne-sw	e-w	n-s	nw-se	ne-sw
0.2	7	7	7	7	38	38	36	39	70	81	79	80
0.4	7	7	7	7	38	37	36	38	69	80	78	79
0.5	7	7	7	7	37	37	36	38	71	80	79	79
0.67	7	7	7	7	37	37	36	37	76	82	81	81
0.8	7	7	7	7	37	37	36	37	80	83	83	83

Table 7.2

Total global and direct irradiation yield of the canyons in kWh/m for increasing GSI and different orientations (FSI 4.0)

Table 7.2 shows the influence of increasing GSI. Like FSI, GSI influences total global radiation yield of the canyon. With every increase of GSI the global radiation yield decreases. Increasing GSI at low values has more effect than increasing GSI at high values; the influence decreases with increasing GSI. Again, the largest absolute decreases occur in summer. As with the increase of global radiation yield with increasing FSI, the decrease in global radiation yield with increasing GSI can largely be attributed to the decrease in diffuse radiation yield. Again, this is a consequence of changes in surface area exposed to radiation; as GSI increases the sum of building envelope surface and street surface decreases.

In summer a noteworthy phenomenon occurs: the global radiation yield first decreases with increasing GSI and then stabilizes or even slightly increases, the direct radiation yield increases from GSI 0,4 upwards. This is caused by the high solar radiation intensity that is received by the roof surface due to the high solar altitude. As the roof area increases with increasing GSI, so does the direct radiation yield of the roof, counterbalancing the direct irradiation losses of facades and street surface and eventually also the diffuse radiation losses caused by the decrease in building envelope surface and street surface area.

Orientation has a very small influence on the total global radiation yield of the canyon in winter, spring and autumn, but a more significant influence in summer. Table 7.1 and Table 7.2 show that the largest differences can be found between canyons running east-west and the other orientations in summer, and that these differences are almost completely attributable to the direct radiation yield. As heat is less welcome in this season, east-west canyons may be preferable. The influence of orientation on the direct radiation yield of the canyon is comparable. In winter, spring and autumn, east-west canyons have the lowest radiation yield, followed by northwest-southeast canyons, north-south canyons, and northeast-southwest canyons have the highest radiation yield. In summer, north-south canyons and northeast-southwest trade places. Differences are most pronounced in summer.

Orientation might hardly influence the global and direct radiation yield of the canyon as a whole; it does however cause differences in the radiation yield of separate canyon surfaces. Figure 7.8 shows the influence of orientation on the relative share of each of the canyon surfaces – street, facades and roof – of the direct radiation yield of the canyon in an urban fabric with FSI 1,6 and GSI 0,4. It can be seen that for with a north–south canyon, the relative share of each canyon surface stays rather constant throughout the seasons. This is because the street axis corresponds to symmetry axis of the solar path.

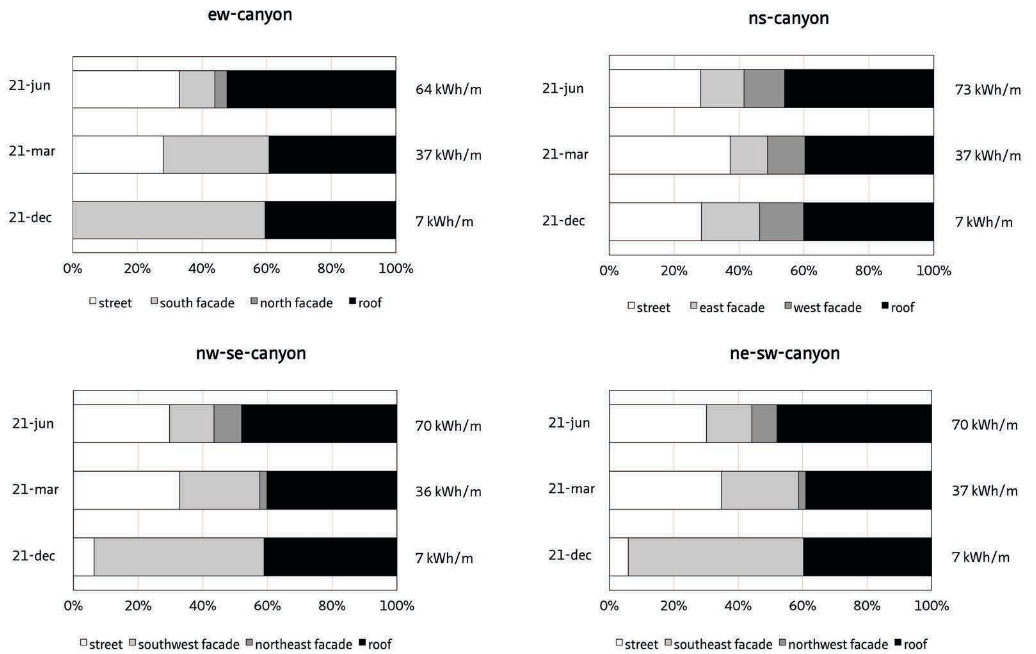


Figure 7.8

Relative share of each of the canyon surfaces of the direct radiation yield, showing the influence of orientation. FSI = 1,6 and GSI = 0,4.

For east–west canyons the pattern becomes more complex. The relative radiation yield of the street surface increases from winter to summer, largely to the expense of the radiation yield of the south façade and in summer also the roof. Unlike the other orientations, the street surface of an east-west canyon doesn’t receive any direct radiation on the 21st of December. The pattern of northwest-southeast and northeast-southwest canyons lies in between that of the east-west and north-south canyons.

Direct irradiation of the street surface

Outdoor human thermal comfort is highly dependent on direct irradiation of the human body by the sun. In this section we will therefore focus on the direct irradiation of the street surface; for convenience it is presumed that the human body is irradiated when the street surface is irradiated. It will be shown that FSI, GSI and orientation all have a significant influence. As can be expected, increasing FSI decreases the percentage of directly irradiated street surface, for all orientations. Figure 7.9 shows the percentage of street surface that is directly irradiated at noon at the 21st day of each month of the year, for an east–west canyon. It can be seen that the influence of FSI is greatest at low solar altitudes and decreases from winter to summer (Figure 7.9 -left side). Northwest-southeast and northeast-southwest canyons show a similar pattern, but with somewhat higher values, especially in the colder months. North-south canyons are completely irradiated around solar noon, all year long, but at other hours show a similar pattern to that of the other orientations.

Figure 7.9 (right side) shows the influence of GSI on the direct irradiation of the street surface of an east-west canyon. It can be seen that the percentage of directly irradiated surface rapidly increases up to a GSI of 0.5 and then decreases again. This has to do with the fact that urban tissues with a low GSI have (broad) streets lined with high buildings and tissues with a high GSI have narrow alleys; both tissues thus have canyons with a relatively high H/W ratio (1,5 with this specific combination of FSI, GSI and building height). The H/W ratios of urban tissues with a GSI between 0.4 and 0.7 are lower (around unity for this value of FSI) and thus have more solar access.

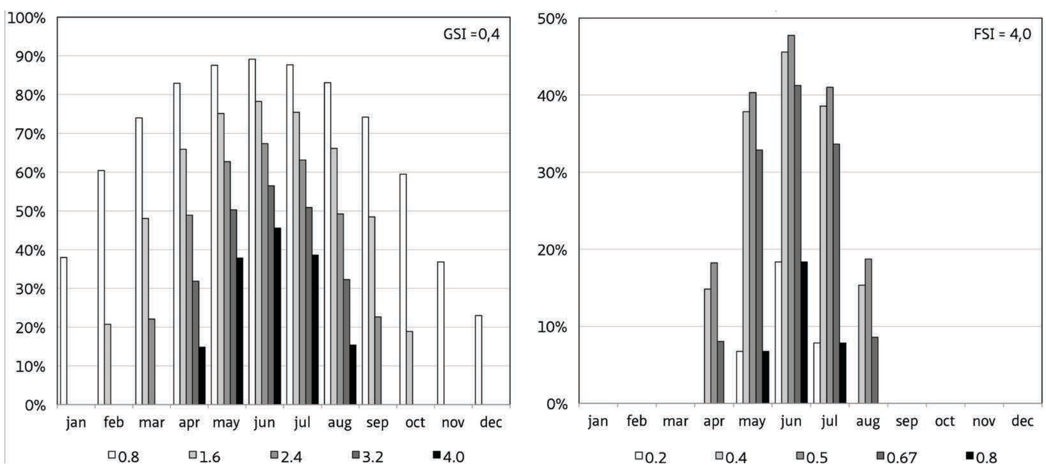


Figure 7.9
Percentage of street surface that is directly irradiated at solar noon for different values of FSI (left) and different values of GSI (right). Orientation is east-west.

Orientation highly influences the diurnal and seasonal pattern of irradiation of the street surface. Figure 7.10 shows the differences between canyons of different orientations with FSI 1.6 and GSI 0.4. The east–west street canyon is in shadow on the 21st of December, throughout the whole day, receiving only diffuse radiation. This is the case for all studied setups. In contrast, the north–south canyon does get some sun on the shortest day of the year, as the sun has unobstructed access to the street around noon. Northwest-southeast canyons also receive sun in winter. For these canyons, the direct irradiation in the afternoon increases enormously until the longest day of the year, in duration as well as in percentage of directly irradiated street surface. This pattern is mirrored around solar noon for northeast-southwest canyons.

In summer, east–west canyons yield large percentages of directly irradiated street surfaces in the morning and afternoon – leading to a prolonged period of warming of the surface and air – but provide some more shade for comfort during the hottest hours of the day. These canyons also have the benefit of rather constant direct irradiation (and shade) in spring and fall.

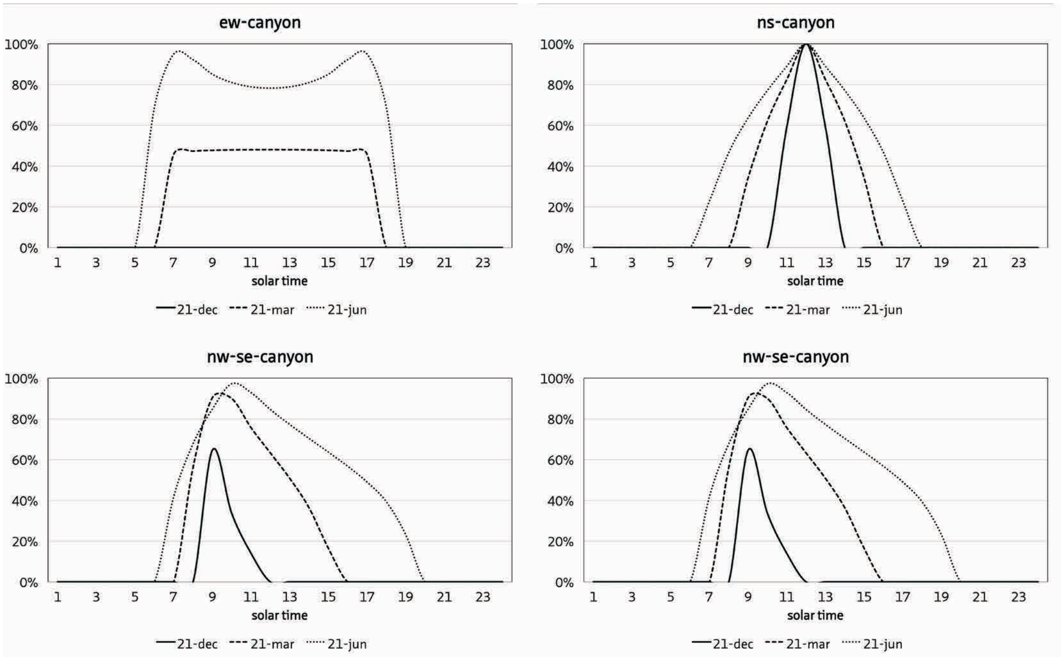


Figure 7.10
Percentage of street surface that is directly irradiated for different orientations and seasons. FSI = 1,6 and GSI = 0,4.

§ 7.3 Wind shelter

§ 7.3.1 Methodology

Three types of approach flow condition are possible: parallel, perpendicular and oblique to the canyon axis. In case of parallel wind the wind speeds gradually increase along the street axis. Near the ground and the walls the wind speeds are lower due to friction. The flow pattern is relatively simple. In case of oblique winds a corkscrew-like flow will be established inside the canyon, with lower average wind speeds compared to the parallel flow case. In case of perpendicular wind the flow pattern in the street becomes more complex. Three flow regimes can be distinguished (Figure 7.11): isolated roughness flow (IRF), wake interference flow (WIF) and skimming flow (SF), as also described in Section 5.4.2. These flow patterns are closely related to the height to width ratio H/W (Sini et al., 1996; Xiaomin et al., 2006)

IRF	$0 < H/W < 0,1$
WIF	$0,1 < H/W < 0,67$

SF $0,67 < H/W$

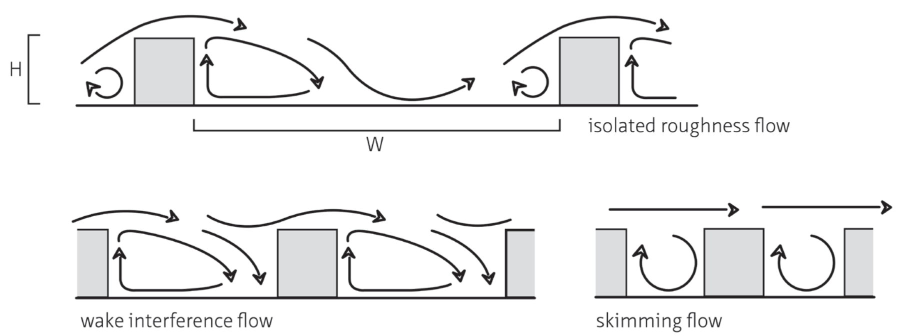


Figure 7.11
Flow patterns in an urban canyon with wind perpendicular to the canyon axis after Oke (1987). (Figure 5.23 repeated)

In case of isolated roughness flow there is a weak interaction between the recirculation area of the upwind building and the frontal vortex of the downwind building. When the street becomes narrower - or the buildings higher - the interaction between the vortices becomes stronger until no recovery zone of the upwind wake is present and the wake interference flow regime is established. This regime can have either two co-rotative vortices (up to H/W ≈ 0,2) or one main vortex. When H/W goes up even further the skimming flow is established with a single vortex or even more contra-rotative vortices on top of each other (from H/W ≈ 1,6) is formed in the canyon and exchange with above roof flow decreases.

This study will only consider wind flow perpendicular to the canyon axis, as this approach flow is possible to study with 2D models in simulation software. Furthermore, perpendicular flow yields the most complex flow patterns.

An analysis is made of the wind factor in three points at pedestrian level (1,75m height) within the canyon: two metres from the upwind facade and two metres from the downwind facade (commonly the pedestrian areas), and in the middle of street. In this research the wind factor g is defined as the ratio of the average wind speed at pedestrian level $U_{1,75}$ to the average wind speed at roof height U_{H0} of the approach flow.

Calculations are conducted with the commercially available CFD software FLUENT. An approach flow wind profile according to the log law is used (see Appendix IV), and the standard k-εmodel for turbulence.

§ 7.3.2 Results

Figure 7.12 (left side) shows the influence of increasing FSI on the wind factor in the three points in the canyon. The wind factors first show an increase before gradually decreasing, due to the changing flow regimes. The street canyon in the urban fabric with FSI 0,8 is just in the transition region of the WIF regime with two co-rotative vortices to the WIF regime with one main vortex. The wind factors are lowest near the downwind wall, since this is where smallest and slowest rotating vortex is positioned. If the FSI is increased the two vortices join and amplify each other - leading to higher wind speeds - and become a single vortex with its centre shifted somewhat downwind; which explains the slightly higher wind factors at two meters from the downwind façade compared to those two meters from the upwind façade. At an FSI of about 2,7 the SF regime is established and a more or less symmetric flow pattern is formed. Wind factors decrease from this point on.

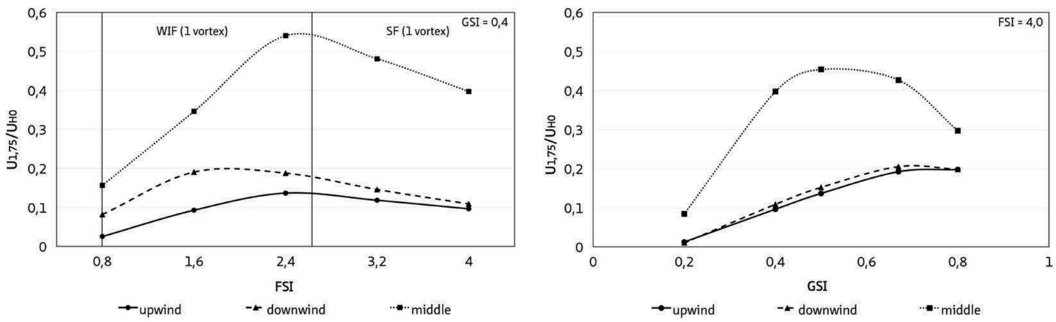


Figure 7.12
Wind factor at 2m from the upwind facade, 2m from the downwind facade and in the middle of the street for different values of FSI (left) and different values of GSI (right). Measuring height is 1,75m.

Figure 7.12 (right side) shows the influence of increasing GSI. All studied canyons are within the skimming flow regime, but the results are not straightforward. All three points show an increasing wind factor up to a GSI of 0,5. From this point only the wind factor in the middle of the street decreases, the wind factors near the facades keep increasing up until a GSI of about 0,7. As the GSI increases from 0,2 to 0,5 H/W decreases, which leads to more interaction with the above roof wind flow and therewith higher average in-canyon wind speeds. Increasing GSI further leads to an increase in H/W and therewith lower average in-canyon wind speeds. The reason for the increasing wind factors close to the facades at higher values of GSI is the difference in absolute dimensions of the canyons. This can be illustrated with the results for GSI 0,2 and 0,8; the canyons of these urban tissues have exactly the same H/W, but different absolute dimensions (see Figure 7.2). At GSI 0,2 canyons are high and wide, at GSI 0,8 canyons are low and narrow. The position of the pedestrian within the canyon, however, is not downscaled and therefore is different in both cases (Figure 7.13). The wind factor in the three measurement points is therefore much lower in the GSI 0,2 case than in the GSI 0,8 case; the wind factors two meters from the facades are a factor 16-20 lower, the wind factor in the middle of the street is a factor 3,5 lower. On the other hand, the reference wind speed at roof height is higher in the GSI 0,2 case – as wind speed increases with height – but not a factor 3,5 – 20 higher, and thus actual wind speeds at pedestrian level will be lower in the high-rise tissue.

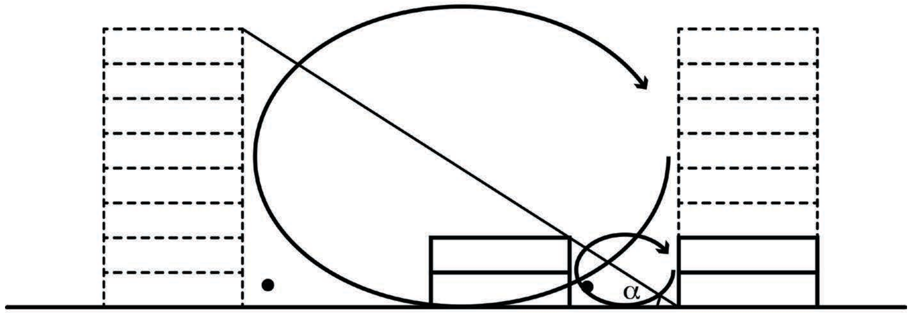


Figure 7.13
The position of the pedestrian level (dots) within two canyons with the same H/W.

§ 7.4 Conclusions & discussion

§ 7.4.1 Conclusions

This chapter explored how expert tools can be employed to support urban design. Specifically, it focussed on the task of translating information to the urban designer and filling gaps in knowledge on the influence of selected plan elements on the urban microclimate.

The influence of FSI, GSI and orientation on solar irradiation and wind shelter was studied by means of numerical simulations. For solar irradiation, the global and direct irradiation of the canyon as a whole was studied, as well as the direct radiation yield of the separate canyon surfaces. This information gives insight in the effects for outdoor thermal comfort as well as the potential for passive solar heating of the dwellings. As outdoor thermal comfort is highly dependent on exposure to direct solar radiation, the direct irradiation of the street surface was also studied; for convenience it was presumed the human body is irradiated when the street surface is irradiated. For wind, the degree of shelter was studied, as this has implications for thermal comfort. In the Dutch climate, solar radiation and wind shelter is appreciated almost all year round, only in summer significant shading and a cooling breeze become important. Conclusions with regard to the influence of FSI, GSI and orientation are listed below:

FSI

- FSI influences the total global radiation yield of the canyon; the more floor space per plan area, the higher the global radiation yield. In summer this influence is significant, in the other seasons it is minor. The increase in global radiation yield can largely be attributed to the increase in diffuse radiation yield by the increased building surface.
- The direct irradiation of the street surface decreases with FSI, which is not desirable for outdoor thermal comfort in winter, spring and autumn, but is positive in summer.
- For ambient wind flow perpendicular to the canyon axis, wind factors inside the canyon will increase with FSI up until the skimming flow regime is achieved and will then decrease.
- The influence of FSI on wind speed is largest in the middle of the street and decreases towards the facades[40].

GSI

- The global radiation yield decreases with GSI as a consequence of the decrease in building envelope area and street surface exposed to radiation.
- In summer, the high radiation intensity received by the roofs causes the direct radiation yield of the canyon to increase with increasing GSI, even though the global irradiation yield decreases.
- Percentages of directly irradiated street surface are highest for a GSI around 0,5 and decrease towards the extremes of GSI.
- For ambient wind flow perpendicular to the canyon axis, the wind factor in the middle of the street will increase up to a GSI of 0,5 and then decrease again. The wind factors near the facades keep increasing up until a GSI of about 0,7. Low and compact fabrics with narrow streets thus do not always provide more wind shelter than high and slender fabrics with wide streets[41].

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40 This study did not consider wind flow parallel or oblique to the canyon axis, but the little literature available suggests that wind average factors for these impact angles will decrease with FSI, as they decrease with increasing H/W (Soulhac & Salizzoni, 2010; Erell et al., 2011)

41 For ambient wind at other angles the influence of GSI cannot be estimated from this study, nor from literature.

Orientation

- The influence of orientation on the global and direct radiation yield of the canyon as a whole is negligible during most of the year, only in summer east-west canyons have a significant lower radiation yield than canyons with other orientations.
- For a north–south canyon, the relative share of direct irradiation yield of each canyon surface is roughly constant throughout the year. This is because the street axis corresponds to symmetry axis of the solar path. The street surface even gets a limited amount of direct radiation on the shortest day of the year.
- For east-west canyons, the relative radiation yield of the street surface increases from winter to summer and that of the dwelling thus decreases, which is positive with regard to passive solar heating (and cooling) strategies. The street surface of an east-west canyon doesn't receive any direct radiation on the 21st of December, and also the ground floor stays in the dark at FSI's above 0,8. In summer, east–west canyons yield large percentages of directly irradiated street surfaces in the morning and afternoon compared to north–south canyons, and provide some shade for comfort during the hottest hours of the day.
- For northwest-southeast canyons, the direct irradiation in the afternoon increases enormously from the shortest until the longest day of the year, in duration as well as in percentage of directly irradiated street surface. This pattern is mirrored around solar noon for northeast-southwest canyons.
- In summer, most of the direct radiation received by buildings is yielded by the roof for all orientations. In winter, most of the direct irradiation is received by the façade most facing south. An exception are buildings in a north-south canyon; for these buildings the roof remains the primary direct irradiation collector year round.

The next section will discuss the implications of these results for urban tissues with different characteristics concerning density and orientation. In addition, suggestions on how to improve the microclimate with the aid of other plan elements will be given.

§ 7.4.2 Urban design measures

From these simulations it can be argued that high building densities (high FSI) lead to an enhanced UHI-effect, as the global radiation yield is high and wind speeds are lower. The chance of thermal discomfort occurring during warm periods thus increases with FSI. Low building densities will have a smaller UHI-effect, but high percentages of directly radiated street surface, which may be uncomfortable in summer, but is highly desirable during the rest of the year. Furthermore, wind discomfort may occur, especially in streets at the city edge that have a direct connection to the rural surroundings of the city and are parallel to the governing wind direction. Climate control strategies like shelterbelts, street trees and flexible overhangs propose a good solution for such urban fabrics.

Within a given building density (FSI), the distribution of building mass (GSI) also influences the thermal climate. Fabrics with a low GSI (< 0,4) will have lower global irradiation yields than fabrics with higher GSI's, limiting the UHI-effect. These fabrics however also have low percentages of directly irradiated street surface, which is undesirable for outdoor thermal comfort during the largest part of the year. Wind shelter will be relatively high, which is desirable for outdoor thermal comfort, but less beneficial with regard to the UHI-effect. Fabrics with a GSI between 0,4 and 0,7 (and a high FSI) will have a higher global irradiation yield, high percentages of directly irradiated street surface, good ventilation of the canyon – the wind factor in the middle of the street is relatively high - and still enough wind shelter close to the facades. Finally, tissues with very high GSI will have a relatively low global irradiation yield, which can be lowered even more by applying highly-reflective roof materials - counteracting the UHI-effect as well as reducing the solar gain of individual buildings in summer. Outdoor thermal comfort will be compromised by low percentages of directly irradiated street surface and relatively high wind factors. Applying trees in such fabrics will lower wind speeds, but also reduce solar access.

Orientation hardly influences the global and direct radiation yield of the canyon as a whole, only in summer east-west canyons have a significant lower radiation yield than canyons with other orientations, which is positive with regard to the UHI-effect.

In summer, most of the direct radiation received by buildings is yielded by the roof for all orientations; this can be counteracted by applying highly reflective roofing materials or green roofs. The effectiveness of these measures will increase with increasing GSI.

In the Netherlands, the prevailing wind direction is southwest and therefore the highest wind speeds can be expected to occur in northeast-southwest canyons; in-canyon wind factors decrease from parallel to perpendicular approach flow (Mills, 1993). Street trees reduce wind speeds and if placed at the northwest side of the canyon also provide shade to the facade and street side most exposed to the sun in summer. In winter, the bare trees will allow most of the sun to enter the canyon. This orientation is least suitable for natural ventilation of the buildings lining the canyon. Natural ventilation is driven by pressure differences between the different sides of the building, therefore, airflow along the facades is less suitable than airflow at an angle or perpendicular to the facades.

The lowest wind speeds can be expected to be found in northwest-southeast canyons, as they are perpendicular to the prevailing wind. This is beneficial for thermal comfort in winter, spring and autumn, as is the good solar access in these seasons. Natural ventilation of buildings is possible with this canyon orientation.East-west and north-south canyons will have wind speeds in between these two extremes.

In east-west canyons, deciduous trees may be placed at the north side of the street to moderate wind speeds and prevent overheating in summer. In the north–south running streets, small trees may be placed at the east side of the street, providing shadow to the west-facing facades.

If the streets are too narrow for trees, overhangs or other sun shading measures attached to the buildings may be applied. These should be adaptable or placed under such an angle that any transparent facade openings as well as the street surface are not shaded in winter and spring. Green roofs and/or shrubs in the canyons, as well as façade relief, setbacks or balconies may then be applied to moderate wind speeds.

As was mentioned before, the simulations do not take into account that street widths can vary with respect to each other within an urban fabric with a fixed density. Each district or neighbourhood has main and secondary roads. These varying street widths of course have an effect on solar access and wind climate within the urban fabric, since this means a difference in height to width ratios, and both climate elements are highly influenced by H/W. A similar remark can be made about the influence of the scale of the urban fabric. The studies are performed for sections of urban fabrics with a large mesh, the building depth (for the FSI series) is 20 metres, the street width 30 metres. When this would be downscaled to a smaller mesh (for example a building depth of 10 meters and a street width of 15 metres) this would also have an effect, since the height of the buildings cannot be downscaled when maintaining the same FSI and GSI. Nevertheless, The trends described can be expected to be the same, the exact values however will differ.

Roof shape should also be taken into account; earlier studies show that the shape of the roof has a large influence on the direct irradiation of the street surface, especially for east-west canyons, and the solar gain of the building (Van Esch et al., 2012). Furthermore, roof shape influences the flow pattern in canyons perpendicular to the wind (Rafailidis, 1997; Kastner-Klein et al., 2004)

This study shows that careful tuning of FSI, GSI and orientation as described above can benefit outdoor thermal comfort as well as the indoor climate. Such climate pre-conditioning can also contribute to a moderation of the UHI-effect and a substantial decrease in energy consumption and related anthropogenic waste heat and costs, and contribute to a more sustainable urban environment.

§ 7.4.3 Discussion

This chapter illustrated how expert tools may be employed to help urban design; the parameters studied correspond directly to the plan elements used by urban designers and information on multiple climate elements was integrated to identify conflicts and agreements. Furthermore, the parameters chosen are plan elements that are decided on in the first phases of the design process and have a significant effect on the final plan.

Using expert tools in this manner helps to fill gaps in the knowledge on the influence of the urban environment on the urban microclimate currently available. The emphasis lies on showing trends and generating generic knowledge. Such studies contribute to the field of urban design in a general way and can be performed independent from any specific urban design process/project.

The traditional way of employing expert tools is to assess a final design or design variants on compliance with regulations and/or standards. This type of utilization of expert tools remains valid and important. It is not meant to be replaced by the design-decision support tool proposed in this dissertation (Chapter 6). The two types of tools complement each other and are useful in different stages of the design process. The design-decision support tool has its main purpose in the early design stages and is directed at the urban designer. It can also be used in the communication with other actors in the design process. Expert tools are of most use in the final design and evaluation phases. They are to be operated by experts, as they demand a thorough understanding of the underlying physics and usually some degree of programming skills are required. Both type of tools thus have a function in the urban design process and should be utilized to improve the practice of climate-sensitive design.

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8 Conclusions and discussion

This dissertation will conclude by answering the main research question as it was stated in Section 1.5:

How can the design of urban neighbourhoods contribute to microclimates that support physical well-being and what kind of information does the urban designer need in order to make design decisions regarding such urban microclimates?

The main question will be answered by addressing the sub questions. Furthermore, this chapter will offer recommendations for further research and practice.

§ 8.1 Answering the research questions

§ 8.1.1 Sub question 1

What aspects of urban design are relevant with regard to the dissemination of expert knowledge on urban microclimates to the urban designer?

Facilitation of information transfer from the specific field of expertize of urban **microclimatology** to the urban design process asks for a basic understanding of the nature of urban design. More specifically, insight into aspects of **content, process and context** of urban design is necessary to organize the dissemination of expert knowledge to the urban designer.

Acquaintance with the **content of urban design** – the actual object of design and the elements of which an urban design plan consists – helps to define the tools an urban designer has to influence the urban microclimate. Insight into the **design process** helps to attune the translation and transfer of microclimate information to the cognitive process of the urban designer. Finally, insight into **the context of urban design** – other actors in the design process and the position and role of the urban designer – helps to determine the functions of the microclimate information.

Content
Shaping the physical environment to facilitate urban life and all the processes associated with it is the main concern of urban design (Section 2.2). **Urban design combines and translates the interest of different stakeholders into spatial requirements and formulates a proposition for the realization of physical-spatial constructs in the urban environment.** In such a proposition – an urban design plan - different plan elements play a role (Section 2.3). These plan elements can be categorized as follows:

- Spatial-functional organization
  - Land use
  - Main infrastructure
  - Water system
  - Floor Space Index (FSI)
  - Ground Space Index (GSI)
- City plan
  - Street pattern
  - Orientation
  - Network of larger public spaces
  - Dimensions islands and parcellation
- Public space design
  - Dimensions (street) profile
  - Paving
  - Vegetation
  - Design of enclosed spaces
- Rules for architecture
  - Building line
  - Building height
  - Architectural tectonics and articulation
  - Building materials

All these plan elements are the tools of the urban designer and it is therefore essential that information on the urban microclimate is linked directly to these plan elements. In doing so, the information should support decisions from that perspective in the design process.

Process
The process of designing the urban environment is complex, because it deals with wicked problems. Many physical, social and economical issues place constraints and quality demands on the design of the urban environment. In order to be able to handle this complexity, designers initially focus attention on a limited **selection of constraints,** restricting the range of possibilities to a small class of solutions that is cognitively manageable. During the design process more and more constraints are incorporated

until a satisfactory solution is reached. The whole process can be described as iterative, in which focus shifts between sub-problems and solutions and both divergence and convergence strategies are used (Section 2.4).

The selection of constraints, also called 'problem-framing', is a subjective matter and is different for each designer. Three main types of design frames can be distinguished (Section 2.5): **program-oriented – starting from functional constraints**, usually based on the design brief, **concept-oriented – starting from formal or symbolic constraints**, looking for a strong image or 'story' and **site-oriented – starting from practical constraints given by the site and its surroundings**.

Taking these aspects of the design process into account, the dissemination of expert knowledge on microclimates should enable custom information selection and provide different ways into and paths through the (same) information. This supports the cognitive process of the designer and facilitates different design frames.

Context

The urban designer operates in a multi-actor environment. Many other actors are involved in the urban design process: the government (local, provincial and/or national), project developers, housing corporations, experts, societal organizations, interest and pressure groups, individual citizens, other designers, etc. These actors can take up the role of client, advisor, assessor, investor, or other. Over the last decade(s), the number of actors involved has grown and the roles they have are changed (Section 2.6). Furthermore, the amount of topics and fields of expertise to be integrated into the design has increased. These two developments have led to **a shift in focus from the outcome of the design process – the design - to the actual process itself**. In this process, the urban designer becomes more of a communicator, trying to establish consensus and acquiring public support. Along with the role of the designer, the role of the design is also changing. It functions more as a medium for deliberation and decision-making as well as a guideline for the exploration of the legal possibilities and consequences of a plan rather than a result of a fixed process (Section 2.7).

Concluding from the above it can be said that the plan elements of urban design - used to shape the physical environment -, the design process of selecting constraints and generating concepts, and the designers role of connector and communicator in a multi-actor environment are the most relevant aspects of urban design to take into account when aiming to disseminate expert knowledge on the urban microclimate to the urban design process.

§ 8.1.2 Sub question 2

How do urban designers collect information and which forms of information presentation do they prefer?

In order to accomplish a successful transfer of information from the expert to the urban designer it is important that the information transfer ties in with **the designer's way of working and his/her cognitive process**. This information transfer is frequently found to present problems in practice and can be attributed to differences in focus, method and values between the fields of research and design.

To gain insight into the ways urban designers collect information and their preferences regarding the form of information, a field research among Dutch urban designers was carried out. The field research consisted of a series of exploratory interviews and an online questionnaire, addressing questions with regard to sources of information, topics, experts, design phases, amount and detail of information and representation forms (Section 3.3).

The results of the interviews and questionnaire present the same image: **urban designers have a clear preference for visual information**, followed by verbal information. **Numerical information is the least popular** form of information among urban designers (Section 3.4.6).

Photographs, drawings and maps are the most important sources of visual information. Clients and colleagues are the most important sources of verbal information, experts are somewhat less popular, but are still consulted frequently. Written information is also consulted, but there are significant differences with regard to the sources of information; books and laws are often consulted, standards and professional journals less often, and scientific hardly ever. The Internet is a very popular source of information, in terms of content and also as a portal to experts and other sources of information (Section 3.4.1).

With regard to **the amount and level of detail of information** desired, there are differences between individual designers. Some of the interviewees indicated to prefer all possible information from the start, while others reported to prefer global information first and more detailed information if needed later on (Section 3.4.5). This correlates with the degree to which information is collected throughout the design process; **most information is collected in the orientation phase**, decreasing through the sketch and elaboration phases. Hardly any information is collected during the evaluation phase (Section 3.4.3).

All interviewees strive to involve experts from the beginning of the design process. However, in the designers' view, experts are often too accurate for practical purposes and seem afraid to make rough estimates or assumptions, which are needed in the first stages of the design process. Furthermore, the designers' experience, **experts often wait with the supply of information until they are absolutely certain of their advice. This hampers the integration of expert knowledge in an early stage** (Sections 3.4.3 and 3.4.4). As making changes to the design becomes increasingly difficult towards the end of the process, including information in a later stage can have serious consequences for the quality of the final plan.

The urban designer involves experts and expert information from many different fields. However, **the physical environment seems to be of more importance** to the urban designers than the non-physical; information is collected much more frequently on topics such as soil, water management, vegetation and infrastructure, than on microclimate, building process and economical developments – although the interviewees do attribute importance to these topics. For almost all topics the considered importance agrees well with the frequency of inquiry on these topics. **For the topic of microclimate, however, there is a remarkable discrepancy; almost all interviewees and respondents find it important, but many of them seldom collect information on it. There is a clear gap to bridge in this respect** (Section 3.4.2).

The above indicates that dissemination of expert knowledge on urban microclimates to the urban designer should focus on the orientation and sketch phases of the design process, provide different layers of detail and using mainly visual information accompanied by explanatory written text. Providing expert information according to these guidelines will fill designers' cognitive gaps and enhance designer intuition and support the way designers work, promoting the actual application of the expert information in practice.

§ 8.1.3 Sub question 3

What is the impact of the urban microclimate and its constituents on physical well-being and what are related regulations and standards?

All components of the urban microclimate – **solar radiation** (Section 4.2)**, daylight** (Section 4.3)**, wind** (Section 4.4)**, air quality** (Section 4.5) **and sound** (Section 4.6) – affect the physical well-being of people, separately as well as combined (Section 4.7). Some of these effects are acute, others develop over a longer period of over/underexposure. Some cause discomfort, others can be life threatening (Table 8.1).

The impact of the urban microclimate on physical well-being can thus be significant. It is therefore vital that the urban microclimate is considered in the urban design process.

Too little UV:
vitamin D deficiency (causing rickets, osteoporosis and osteomalacia)

Too much UV:
sunburn
accelerated skin ageing
solar keratoses (thick, scaly, or crusty patches of skin)
skin cancer (cutaneous malignant melanoma, squamous cell carcinoma of the skin, basal cell carcinoma of the skin)
cortical cataract
pterygium (a fleshy growth on the surface of the eye)
cancer of the eye (squamous cell carcinoma of the cornea or conjunctiva)

disruption of the circadian melatonin and cortisol cycles (causing poor sleep quality, lack of alertness, feeling down, seasonal depression, immune deficiencies and possibly tumour growth)

convective cooling of the skin (positive in summer, negative in winter)
discomfort (disturbance of hair, flapping of clothes, difficulties holding umbrella)
danger because of balance problems

Particulate matter (PM10/PM2.5):
cardiovascular diseases
respiratory diseases
lung cancer
aggravation of asthma, chronic obstructive pulmonary disease and cardiovascular diseases

Ozone (O3):
lung inflammation
decreased lung function

Nitrogen dioxide (NO2):
aggravation of bronchitic symptoms in children
reduced lung function in children

Sulphur dioxide (SO2):
decreased pulmonary and respiratory functions

sleep disturbance (and therewith increased fatigue, depressed mood or well-being and decreased cognitive performance)
annoyance
stress (leading to hypertension, myocardial infarction and total ischemic heart disease)
hearing impairment

Too little heat (cold):
hypothermia
frost bite
aggravation of cardiovascular, respiratory and cerebrovascular diseases

Too much heat:
heat stress (heat rash, heat cramps, heat syncope, thermal exhaustion, heat stroke)
arterial and cerebral thrombosis
aggravation of cardiovascular, respiratory and cerebrovascular diseases

Table 8.1
Effects of the urban microclimate on physical well-being (Table 4.18 repeated).

Legislation demands that the urban microclimate complies with certain minimum criteria (summarized in Table 4.19 in Section 4.8.2) and therewith guarantees that attention is being paid to the urban microclimate in the urban design process. However, **not all requirements regarding the urban microclimate are laid down in regulations**; only those elements that are highly influenced by human activity and having primarily negative influences on physical well-being are regulated by law: air quality and noise. An exception to this rule is indoor daylight access, which is laid down in the Dutch Buildings Decree. For the other elements standards and/or recommendations exist, which are usually not binding. These elements are at risk of being neglected in the urban design process.

Furthermore, the majority of current **regulations and standards are not formulated in a way that makes them practical for design purposes** and in particular not for the first phases of the design process; they often lack spatial information and are focussed on assessment rather than giving design guidelines. As a result, attention given to the microclimate usually is limited to a test by an expert at the end of the design process, as was mentioned in Chapter 3 of this dissertation.

A requirement made by the client or the existence of general awareness of the importance of the urban microclimate is a better incentive, but also more difficult to bring about. **Enhancing the intuition of the urban designer by offering some simple and basic knowledge on the microclimate in relation to built form is necessary to promote climate-sensitive design and related physical well-being.**

§ 8.1.4 Sub question 4

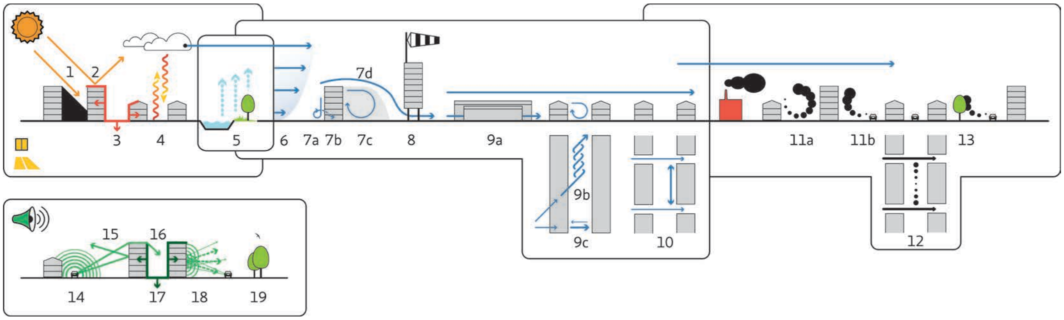
What is the influence of the urban environment on the urban microclimate?

The urban microclimate, existent in the spaces below roof level between the buildings in the urban environment, can vary significantly within a distance of a few metres and is highly influenced by the city's **morphology, materialization and landscaping**. The urban environment influences the different elements of the urban microclimate - solar radiation (Section 5.2), daylight (Section 5.3), wind (Section 5.4), air quality (Section 5.5) and sound (Section 5.6) – through different **physical principles**, summarized in Figure 8.1.

Basic knowledge of these physical principles will enhance the designers' intuition for the influence they have on the urban microclimate. In addition, **design guidelines linked directly to the urban design plan elements** (Section 2.3) of urban design help to create favourable conditions for the various climate elements. These guidelines were formulated in Chapter 5 and listed in Table 5.8.

In many cases **promising combinations** of design solutions can be made. In some cases, however, **conflicts** between guidelines arise; conditions that are beneficial for one climate element may not be for another. In those cases, a location-specific assessment should be made of the relative importance of the elements in conflict. Possible weighing factors might be the amount of people affected, the severity of the impact on the microclimate elements concerned, compliance to related regulations and standards and the possibility of compensating measures.

More research is needed to identify the influence on the urban microclimate of the more complex plan elements, such as density, compactness, mesh sizes of street patterns and the dimensions of islands and parcels. These are structural aspects of the city that are fixed for the long term and not easily changed. Therefore, design decisions concerning these plan elements are essential and their influence on the urban microclimate will persist for a very long time.



1. direct irradiation/shading
2. reflection
3. absorption
4. diffuse radiation

5. evapotranspiration

6. friction (boundary layer)
7. air flow around a single building
a. frontal vortex
b. corner streams
c. wake (recirculation)
d. shear layers

8. pressure short-circuiting
9. air flow in canyons
a. parallel
b. oblique
c. perpendicular
10. transverse flows

11. dispersion of air pollutants
a. from sources outside the canyon
b. from sources inside the canyon
12. concentrations in perpendicular streets
13. filtering through vegetation

14. geometrical spreading
15. reflection
16. diffraction
17. absorption
18. interference
19. sound masking

Figure 8.1
Overview of the physical principles of the urban microclimate (Figure 5.38 repeated).

§ 8.1.5 Sub question 5

What type of design instrument is most suitable for the dissemination of expert information on urban microclimates to the urban design process?

A design-decision support tool for the urban microclimate should **contain all relevant expert information** and – most importantly - **support the way urban designers work**. It should relate to the content of the design and its ingredients, the designer's cognitive process, and to the multi-actor context of urban design. This translates into the following requirements:

Requirements regarding form and function (Section 6.2.1)**:**

1. Support first phases of the design process (i.e. selection of constraints and generating concepts)
2. Link microclimate information to urban plan elements
3. Enable custom information selection
4. Provide different layers of detail
5. Facilitate different design frames
6. Enable different navigation schemes
7. Use visual information accompanied by written text, minimize numerical information

Requirements regarding content (Section 6.2.2)**:**

8. Give an overview of the impacts of the urban microclimate on physical well-being (Table 4.18)
9. Give an overview of regulations and standards concerning the urban microclimate (Table 4.19)
10. Explain basic physical phenomena related to the urban microclimate and its separate elements (Figure 8.1)
11. Explain the influence of the urban environment on the urban microclimate
12. Give design guidelines
13. Indicate possible conflicts and agreements between design decisions (Table 5.8)

Based on these requirements a framework for a design-decision support tool was set up (Section 6.4). The tool is to be a web-based knowledge base, consisting of **five main menu categories**: **"climate elements", "plan elements", "principles", "guidelines"** and **"example projects".** These give different starting points to browse through the knowledge base, respectively giving form to requirements 5, 6, 2, 11, 10 and 12.

For each of the main categories there is an **overview page** of all items within the respective category, including simple and concise visual and/or written explanations (requirement 7). From this overview page, **separate pages** for each of the category items can be accessed that provide the most relevant information. More detailed information and/or background information can be accessed through **collapse menus or click-through functions** (Figure 8.2). This fulfils requirement 4. **Hyperlinks** between items of different categories are provided where relations exist (Figure 8.3), meeting requirements 5 and 6 again, as well as requirement 13.

Separate item pages can be added to a ***"shopping cart"*** of which the customized content can be saved as a separate file or printed, satisfying requirement 3. The shopping cart is accessible from the main menu, as are two more pages with background information: **"physical well-being" and "regulations and standards"**, satisfying requirements 8 and 9. The setup of the framework in its entirety meets requirement 1.

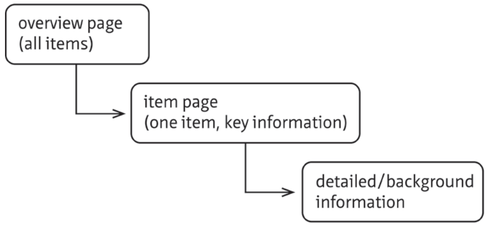


Figure 8.2
Levels of detail (Figure 6.1 repeated).

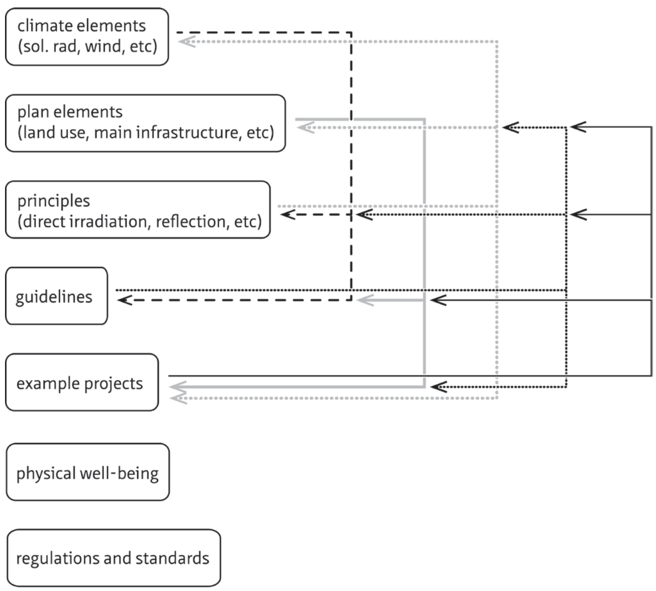


Figure 8.3
Hyperlinks between items of the five main menu categories (Figure 6.2 repeated).

In order for the information that will form the contents to meet this requirement, **expert microclimate knowledge needs to be translated to design information** (Section 6.3). There are four aspects that need attention in this respect:

1. Information on complex **physical phenomena** needs to be formulated in a plain and simple manner and should be related to the urban environment.
2. Expert knowledge on the different microclimate elements should be **integrated** so that the designer has the possibility to assess the relation between different design decisions and can see where conflicts and agreements occur.

3 There is an i**ncongruity in use of parameters** used in microclimatological studies and the plan elements of urban design. Some of the parameters match, but there are many more plan elements that need to be studied. Additional research is needed in this respect.

4 The information presented should be **suitable for design and (design) communication purposes as opposed to evaluation purposes.** To support design, information should be presented in such a way that it helps defining what is to be achieved and why and that gives insight in how the selected objectives can be achieved.

A design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process that is created according to the proposed framework will enable designers to estimate the influence of their design choices on the microclimate, help them identify relations between different possible design decisions and, in doing so, help them create conditions for urban microclimates that favour physical well-being. The tool aims to support the design frames of different urban designers, but can also be expected to support communication between all actors involved in the urban design process.

§ 8.1.6 Sub question 6

How can expert studies be employed to support the first phases of the urban design process?

In order to illustrate how expert studies can be employed to support the first phases of the design process, the influence of plan elements Floor Space Index (FSI), Ground Space Index (GSI) and orientation on climate elements solar irradiation and wind was investigated (Chapter 7). These plan elements were chosen because they are decided on in the earliest phases of the design process, are highly determining for the type of urban tissue and are fixed for the long term. The study therewith focuses on translation tasks 2 and 3 (Section 6.3); the integration of information on multiple climate elements and the study into the influence of (some of the) plan elements that are important in the first phases of the design process. The discussion of the results and, additionally, a discussion on the employment of other plan elements (landscaping and materialization) to improve the microclimate is in line with translation task 4: presenting expert information in a way that makes it suitable for design and (design) communication purposes as opposed to evaluation purposes.

The study shows the following results:

Influence of FSI

- The global irradiation yield increases with FSI. This can largely be attributed to the increase in diffuse radiation yield by the increased building surface. Effects are most prominent in summer (Section 7.2.2).
- Direct irradiation of the street surface decreases with FSI. Effects are most prominent in winter (Section 7.2.2).
- For ambient wind flow perpendicular to the canyon axis, wind factors inside the canyon will increase with FSI up until the skimming flow regime is achieved (which is also dependent on GSI) and will then decrease (Section 7.3.2).
- The influence of FSI on wind speed is largest in the middle of the street and decreases towards the facades (Section 7.3.2).

Influence of GSI

- The global radiation yield decreases with GSI as a consequence of a decrease in surface area exposed to radiation(Section 7.2.2).
- In summer, the large direct radiation yield of the roof counterbalances the direct irradiation losses of facades and street surface from a GSI of about 0,5 and higher (Section 7.2.2).
- Percentages of directly irradiated street surface are highest for a GSI around 0,5 and decrease towards the extremes of GSI (Section 7.2.2).
- For ambient wind flow perpendicular to the canyon axis, the wind factor in the middle of the street will increase up to a GSI of 0,5 and then decrease again (Section 7.3.2).
- For ambient wind flow perpendicular to the canyon axis, wind factors near the facades keep increasing up until a GSI of about 0,7 (Section 7.3.2).

Orientation

- The influence of orientation on the diurnal global and direct radiation yield of the canyon as a whole is negligible, except in summer (Section 7.2.2).
- In summer, east-west canyons have a significant lower radiation yield than canyons with other orientations (Section 7.2.2).
- Orientation causes large differences in the diurnal and seasonal distribution of the direct radiation yield over the separate canyon surfaces – street, facades and roof – and thus in outdoor thermal comfort as well as the potential for passive solar heating of the dwellings (Section 7.2.2).

Combining the results for these three plan elements and the available knowledge on other plan elements (Chapter 5), the following **conclusions and strategies for urban design** can be made (Section 7.4):

- High building densities (high FSI) lead to an enhanced UHI-effect, as the global radiation yield is high and wind speeds are lower. High albedo/low thermal admittance building and paving materials, green facades and green roofs mitigate the effects.
- Low building densities (low FSI) will have a smaller UHI-effect, but high percentages of directly radiated street surface. Furthermore, wind discomfort may occur. Climate control strategies like shelterbelts, street trees and flexible overhangs
- Fabrics with a low GSI (<0,4) will have relatively low global irradiation yields and a relatively high degree of wind shelter, leading to a moderate UHI-effect. Outdoor thermal is compromised during the colder months, as there will be little directly irradiated street surface. Providing large open public spaces at walking distance, such as squares and parks, will provide people with the opportunity to enjoy the sun.
- Fabrics with a GSI between 0,4 and 0,7 will have a higher global irradiation yield, high percentages of directly irradiated street surface and good ventilation of the streets. High albedo/low thermal admittance building and paving materials and street trees will help mitigate the UHI-effect and benefit outdoor thermal comfort.
- Tissues with very high GSI (>0,7) will have a relatively low global irradiation yield, which can be lowered even more by applying highly-reflective roof materials – the majority of the radiation is received by the large roofs. Outdoor thermal comfort will be compromised by low percentages of directly irradiated street surface and relatively high wind factors. Irregular building lines (setbacks), balconies and other façade reliefs will slow down the wind and provide a variety of sheltered and sunny spaces in the narrow streets.
- In the Netherlands, the highest wind speeds can be expected to occur in northeast-southwest canyons, the lowest in northwest-southeast canyons. Furthermore, the first orientation is suitable for the ventilation of the canyon (though not the most suitable), but is least suitable for natural ventilation of the buildings lining the canyon. The last orientation is less suitable for the ventilation of the street, but well-suited for the natural ventilation of the buildings along it. Street trees can be employed to moderate wind speeds and modify wind patterns on a small scale. Placing these trees at the downwind side of the street – north to east – will also provide shade to the facades and street surfaces most exposed to the sun, preventing overheating in summer.

This study shows that **careful tuning of design decisions** in general and FSI, GSI and orientation in particular can **benefit outdoor thermal comfort as well as the indoor climate**. Such climate pre-conditioning can also contribute to a moderation of the UHI-effect and a substantial decrease in energy consumption and related anthropogenic waste heat and costs, and contribute to a more sustainable urban environment.

§ 8.1.7 Main question

How can the design of urban neighbourhoods contribute to microclimates that support physical well-being and what kind of information does the urban designer need in order to make design decisions regarding such urban microclimates?

The main question consists of two parts; the first part focuses on the influence of the urban environment on its microclimates and, consequentially, on the physical well-being of the people in it. This part of the main question largely concerns quantifiable or measurable variables.

The second part of the question focuses on how to disseminate this specific expert information to the more generic field of urban design and largely concerns more 'soft' knowledge.

Concerning the first part of the main question, it can be concluded that the urban environment influences its microclimate through its morphology, landscaping and materialization. This influence can be understood through different physical principles, such as reflection, absorption, dispersion, evapotranspiration and many more. Each of these physical principles can be employed to create conditions for a distinctive microclimate; urban microclimates often deviate substantially from the regional climate, and even vary within a few meters. The urban microclimate can thus be 'designed' to a large extent. Designing the urban microclimate needs to be done with care as it can affect the physical well-being of people significantly. In order to be able to do this, the urban designer needs information that ties in with his/her way of working and cognitive process – leading to the second part of the main question. This means the information should be linked directly to the elements of an urban plan, and support the selection of constraints as well as the generation of design concepts/solutions. It should be highly visual, contain different layers of detail and be easy to navigate through in different ways. Furthermore, the information should be suitable for sharing with all actors in the design process, to aid the decision-making process.

Based on the knowledge gained from answering the two parts of the main question separately, a framework for the design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process was created. The tool is to be a web-based knowledge base, consisting of five main menu categories: "climate elements", "plan elements", "principles", "guidelines" and "example projects". From these different starting points, separate pages for each of the category items can be accessed in different levels of detail. Hyperlinks between items of different categories are provided where relations exist. Separate item pages can be added to a ***"shopping cart"***, which is accessible from the main menu, as are two more pages with background information: "physical well-being" and "regulations and standards".

In order to fill the framework with content completely, translation of expert knowledge to design information is necessary, which in some cases requires additional research. It concerns four aspects, listed in Section 8.1.5.

A design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process that is created according to the proposed framework will enable different types of designers to practice climate-sensitive urban design, contributing to the physical well-being of people.

§ 8.2 Recommendations

- This research was based on the knowledge available on the different ways of problem-framing by architectural designers. This is thought to be justifiable as the professions of architecture and urban design are closely related and often overlap. However, more research is needed on problem framing by urban designers, as there might be some differences between architects and urban designers. With the acquired knowledge, it is possible to fine-tune the design-decision support tool, and relate even more directly to the cognitive process of urban designers.

- This research has shown that urban designers hardly ever consult information on microclimate in general and on air temperature and air movement in particular. This is reason for concern, as microclimate conditions are expected to deteriorate as a consequence of global warming and the urban heat island effect. Specifically, heat stress and air pollution will become more common; two effects that can be mitigated with sufficient knowledge of how to influence air temperatures and air movement by urban design. This knowledge needs to be integrated in the urban design process. Education – in academies, universities and training for professionals – should play an important role in this respect.

- Little information is consulted in the evaluation phase of the urban design process. Monitoring the effects of realised projects on the urban microclimate, however, will increase knowledge on the effects of design decisions on the urban microclimate. This benefits urban design in general, but especially the designers involved in the project, as it directly links to their work. The urban microclimate therewith directly becomes the designers' responsibility.

- More research is needed into the economic benefits of an improved urban microclimate. Direct economic benefits can be expected to be related to decreased health care costs and energy savings. More indirect economic benefits can be related to increased attractiveness of public spaces; improved business and residential climates, increased consumption, etc. These aspects concern the influence of the urban microclimate on other aspects than physical well-being, moving the other end of the well-being spectrum as defined by Machanda en Steemers (Figure 1.3). A better insight into the economic benefits of healthy and comfortable urban microclimates provides an extra incentive for climate-sensitive urban design.

- This research has taken initial steps towards solving the incongruity in use of parameters between the fields of urban microclimatology and urban design. More research is needed, however, into the effects of complex urban design parameters such as density and compactness, water systems, street patterns and the dimensions of islands and parcels. The influence of these parameters on the urban microclimate may not be straightforward, but is important to investigate nonetheless, as decisions concerning these parameters are often made in an early stage of the urban design process. Furthermore, these parameters form structural aspects of the city that are fixed for the long term and are thus not easily changed.

- As a part of this research, urban design guidelines were formulated for each of the elements of the urban microclimate. Furthermore, conflicts and agreements between these guidelines were indicated. In a similar way, possible conflicts and agreements with design guidelines for other sustainability themes (liveability, energy, (waste) water management, biodiversity, mobility, etc.) should be identified in order to be able to make a more integral and therewith more sustainable design.

- Outdoor climate and indoor climate interact. In order to make design decisions that benefit both, more research is needed into this interaction and the role of the building skin as a mediator. Currently, most studies on the urban microclimate stop at the façade, while most studies on the indoor climate hardly take the surroundings into account. This needs to change in order to achieve truly climate-sensitive urban environments.

- In addition to the design-decision support tool developed in this research, a tool or method should be developed for the location-specific assessment of the relative importance of the microclimate elements.

- For the benefit of the urban design process and its outcome, early design phase tools – like the proposed design-decision support tool – and evaluation/simulation tools should be better attuned to each other.

- Similar neighbourhoods may have similar microclimates and may thus benefit from the same design interventions. More research is needed into the microclimates of neighbourhood typologies in order to bring these similarities to light.

- Governments – national and/or local – should impose more requirements regarding the urban microclimate. Ideally, these requirements are accompanied with design guidelines or other information on how to satisfy the requirements. Requirements made by official bodies guarantee that attention goes out to the urban microclimate in the urban design process and therewith also helps to raise awareness of the importance of climate-sensitive urban design.

§ 8.3 Final words

This research aims at supporting the integration of expert information on the urban microclimate in the urban design process. For this purpose, both the field of urban microclimatology and the field of urban design were studied. The first is specific, the second generic. This difference in type of knowledge fields brings the difficulty of acquiring enough in-depth knowledge on the urban microclimate on the one hand, while not compromising the applicability for the wide-scope field of urban design on the other hand. Focussing on two fields of knowledge furthermore involves the risk of incompleteness of knowledge regarding one or both of the fields. This research strives to incorporate all information relevant to support the integration of the two fields, not to provide a comprehensive analysis of both fields.

The research presents a framework for a design-decision support tool for the dissemination of expert information on the urban microclimate to the urban design process. It is based on the knowledge acquired by literature review, interviews and questionnaires. A validation by means of one or more test sessions with urban designers would further improve the framework. However, such a session would be more effective if the framework was filled with content considerably more than it is now; for this dissertation the framework was partially filled with content for illustrative purposes only.

Over the course of this research, focus in the urban design practice has shifted from urban expansions to urban transformation and renewal projects. More and more projects are concerned with small-scale interventions in the existing urban environment. Some of the information and guidelines in this dissertation – in particular those on materialization and landscaping – may be of more use for such regeneration projects than others. However, the urban designer should have an overview of the full scope of possibilities.

Climate change is becoming increasingly prominent; the effects are more and more obvious and society is paying more attention to it. With climate change, the necessity of climate-sensitive design increases. This dissertation aims to contribute to the awareness of this necessity as well as propose possible climate-sensitive urban design measures. As the climate changes some of the proposed guidelines will also need to change. The underlying physical principles, however, will stay the same and the information on these principles presented in this dissertation will therewith remain valid.

This research approached the design of urban neighbourhoods with the smallest parameters (i.e. orientation, street profile, vegetation, materialization, etc), unravelling their separate influences on the urban microclimate. Approaches that identify spatial typologies – streets, squares, parks – such as the work of Lenzholzer (2013), or even neighbourhood typologies, such as the work of Kleerekoper (forthcoming), are also valuable. They concern different combinations of the plan elements used in this research, addressing the complex interplay between the different parameters and can as such be seen as complementary to this research and vice versa.

References

Kleerekoper, L. (Forthcoming). Urban climate design engineering. Improving thermal comfort in Dutch neighbourhood typologies. PhD thesis. Delft, TU Delft.

Lenzholzer, S. (2013). (In Dutch) Het weer in de stad. Hoe ontwerp het stadsklimaat bepaalt. Rotterdam, nai010 uitgevers.

A I Field Survey - interviews

Open vragen (onderwerpen)

Open questions (topics)

1 Welke bronnen van informatie gebruikt u?/ Hoe komt u aan informatie?
Vervolgvragen:

- Wat vraagt u dan?
- Wat zoekt u dan op?

Which sources of information do you use?/ How do you get information?
Supplementary questions:

- *What do you ask them?*
- *What do you look up?*

2 Wat doet u als u met concrete vragen zit (over iets dat u niet weet)?

What do you do if you have concrete questions (about something you don't know)?

3 Raadpleegt u wel eens adviseurs of experts?
Vervolgvragen:

- Welke?
- Waar gaat het dan over?
- Hoe gebruikt u hun informatie?

Do you ever consult advisors or experts?
Supplementary questions:

- *Which?*
- *What do you consult them about?*
- *How do you use their information?*

4 Hoe zit het met de betrouwbaarheid van informatie van anderen? (dubbel checkt u de verkregen informatie?)

How about the reliability of information from others? (Do you double check information?)

5 Heeft u een voorkeur voor een bepaalde hoeveelheid en detail aan informatie?

Do you have a preference regarding the amount and detail of information?

6 Heeft u een voorkeur voor een vorm informatie (beeld, woord, etc.)?

Do you have a preference regarding the form of information (visual, text, etc.)?

A II Field Survey - questionnaire

Bij een stedenbouwkundig ontwerp spelen vele factoren een rol. Op verschillende gebieden wordt er gevraagd om bepaalde kwaliteiten. Gezien de veelheid van factoren en kennisgebieden waarmee de ontwerper te maken krijgt, zal zijn/haar kennis niet altijd helemaal toereikend zijn. Informatie van buitenaf kan dan gewenst zijn. Voor een onderzoek aan de Faculteit Bouwkunde van de TU Delft zijn we geinteresseerd in de rol die informatie speelt in het stedenbouwkundig ontwerpproces. Wat voor bronnen raadpleegt u doorgaans, en wat voor vorm heeft de door u geraadpleegde informatie bij voorkeur? Uw mening en ervaring zijn belangrijk voor het onderzoek en worden zeer op prijs gesteld.

Het invullen van de vragenlijst neemt ongeveer 5 minuten in beslag. Onderaan de vragenlijst is er plaats gereserveerd voor eventuele opmerkingen.

Hartelijk dank voor uw medewerking!

Ir. M.M.E. (Marjolein) van Esch

Email: m.m.e.vanesch@tudelft.nl

Tel: +31(0)639251093

Geef voor de verschillende fasen van het ontwerpproces aan hoe vaak u informatie inwint.

	nooit	bijna nooit	af en toe	regel-matig	vaak	heel vaak	altijd
orientatiefase	o 1	o 2	o 3	o 4	o 5	o 6	o 7
schetsfase	o 1	o 2	o 3	o 4	o 5	o 6	o 7
uitwerking	o 1	o 2	o 3	o 4	o 5	o 6	o 7
evaluatie	o 1	o 2	o 3	o 4	o 5	o 6	o 7

Geef voor onderstaande informatiebronnen aan hoe vaak u ze raadpleegt.

	nooit	bijna nooit	af en toe	regel-matig	vaak	heel vaak	altijd
andere (voorbeeld) projecten	o 1	o 2	o 3	o 4	o 5	o 6	o 7
wetten	o 1	o 2	o 3	o 4	o 5	o 6	o 7
normen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
vakbladen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
wetenschappelijke artikelen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
boeken	o 1	o 2	o 3	o 4	o 5	o 6	o 7
vergadering	o 1	o 2	o 3	o 4	o 5	o 6	o 7
adviseur	o 1	o 2	o 3	o 4	o 5	o 6	o 7
opdrachtgever	o 1	o 2	o 3	o 4	o 5	o 6	o 7
bewoners	o 1	o 2	o 3	o 4	o 5	o 6	o 7
officiele instanties	o 1	o 2	o 3	o 4	o 5	o 6	o 7
internet, op andere bronnen betrekking hebbende dan op bovenstaande	o 1	o 2	o 3	o 4	o 5	o 6	o 7
anders, nl........ (indien niet van toepassing kruis "nooit" aan)	o 1	o 2	o 3	o 4	o 5	o 6	o 7

Geef voor onderstaande vormen van informatie aan hoe vaak u ze raadpleegt.

	nooit	bijna nooit	af en toe	regel-matig	vaak	heel vaak	altijd
mondelinge informatie	o 1	o 2	o 3	o 4	o 5	o 6	o 7
geschreven tekst	o 1	o 2	o 3	o 4	o 5	o 6	o 7
tekeningen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
numerieke informatie (berekeningen, statistieken, etc.)	o 1	o 2	o 3	o 4	o 5	o 6	o 7
schema's	o 1	o 2	o 3	o 4	o 5	o 6	o 7
foto's	o 1	o 2	o 3	o 4	o 5	o 6	o 7
maquettes	o 1	o 2	o 3	o 4	o 5	o 6	o 7
computerprogramma's, zoals reken- en simulatieprogramma's	o 1	o 2	o 3	o 4	o 5	o 6	o 7
zoekmachines op internet	o 1	o 2	o 3	o 4	o 5	o 6	o 7
websites van overheden en kennisin-stanties, projectwebsites	o 1	o 2	o 3	o 4	o 5	o 6	o 7

Geef nu voor dezelfde vormen van informatie aan hoe vaak u ze gebruikt om over uw werk te communiceren.

	nooit	bijna nooit	af en toe	regel-matig	vaak	heel vaak	altijd
mondelinge informatie	o 1	o 2	o 3	o 4	o 5	o 6	o 7
geschreven tekst	o 1	o 2	o 3	o 4	o 5	o 6	o 7
tekeningen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
numerieke informatie (berekeningen, statistieken, etc.)	o 1	o 2	o 3	o 4	o 5	o 6	o 7
schema's	o 1	o 2	o 3	o 4	o 5	o 6	o 7
foto's	o 1	o 2	o 3	o 4	o 5	o 6	o 7
maquettes	o 1	o 2	o 3	o 4	o 5	o 6	o 7
computerprogramma's, zoals reken- en simulatieprogramma's	o 1	o 2	o 3	o 4	o 5	o 6	o 7
zoekmachines op internet	o 1	o 2	o 3	o 4	o 5	o 6	o 7
websites van overheden en kennisin-stanties, projectwebsites	o 1	o 2	o 3	o 4	o 5	o 6	o 7

Geef voor onderstaande onderwerpen hoe vaak u er informatie over inwint.

	nooit	bijna nooit	af en toe	regel-matig	vaak	heel vaak	altijd
ondergrond	o 1	o 2	o 3	o 4	o 5	o 6	o 7
waterhuishouding	o 1	o 2	o 3	o 4	o 5	o 6	o 7
groen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
infrastructuur	o 1	o 2	o 3	o 4	o 5	o 6	o 7
milieu	o 1	o 2	o 3	o 4	o 5	o 6	o 7
microklimaat	o 1	o 2	o 3	o 4	o 5	o 6	o 7
historie	o 1	o 2	o 3	o 4	o 5	o 6	o 7
gebruikers	o 1	o 2	o 3	o 4	o 5	o 6	o 7
bouwproces	o 1	o 2	o 3	o 4	o 5	o 6	o 7
economische ontwikkelingen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
maatschappelijke ontwikkelingen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
anders, nl........ (indien niet van toepassing kruis "nooit" aan)	o 1	o 2	o 3	o 4	o 5	o 6	o 7

Geef voor onderstaande onderwerpen aan hoe belangrijk u het vindt hiermee rekening te houden in het stedenbouwkundig ontwerp.

	nooit	bijna nooit	af en toe	regel-matig	vaak	heel vaak	altijd
ondergrond	o 1	o 2	o 3	o 4	o 5	o 6	o 7
waterhuishouding	o 1	o 2	o 3	o 4	o 5	o 6	o 7
groen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
infrastructuur	o 1	o 2	o 3	o 4	o 5	o 6	o 7
milieu	o 1	o 2	o 3	o 4	o 5	o 6	o 7
microklimaat	o 1	o 2	o 3	o 4	o 5	o 6	o 7
historie	o 1	o 2	o 3	o 4	o 5	o 6	o 7
gebruikers	o 1	o 2	o 3	o 4	o 5	o 6	o 7
bouwproces	o 1	o 2	o 3	o 4	o 5	o 6	o 7
economische ontwikkelingen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
maatschappelijke ontwikkelingen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
anders, nl........ (indien niet van toepassing kruis "nooit" aan)	o 1	o 2	o 3	o 4	o 5	o 6	o 7

Geef voor de volgende onderdelen van het microklimaat aan hoe vaak u er informatie over inwint.

	nooit	bijna nooit	af en toe	regel-matig	vaak	heel vaak	altijd
bezonning	o 1	o 2	o 3	o 4	o 5	o 6	o 7
daglichttoetreding	o 1	o 2	o 3	o 4	o 5	o 6	o 7
windhinder	o 1	o 2	o 3	o 4	o 5	o 6	o 7
luchtstromingen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
luchtkwaliteit	o 1	o 2	o 3	o 4	o 5	o 6	o 7
geluid	o 1	o 2	o 3	o 4	o 5	o 6	o 7
temperatuur	o 1	o 2	o 3	o 4	o 5	o 6	o 7

Geef nu voor de onderdelen van het microklimaat aan hoe belangrijk u het vindt om ermee rekening te houden in het stedenbouwkundig ontwerp.

	nooit	bijna nooit	af en toe	regel-matig	vaak	heel vaak	altijd
bezonning	o 1	o 2	o 3	o 4	o 5	o 6	o 7
daglichttoetreding	o 1	o 2	o 3	o 4	o 5	o 6	o 7
windhinder	o 1	o 2	o 3	o 4	o 5	o 6	o 7
luchtstromingen	o 1	o 2	o 3	o 4	o 5	o 6	o 7
luchtkwaliteit	o 1	o 2	o 3	o 4	o 5	o 6	o 7
geluid	o 1	o 2	o 3	o 4	o 5	o 6	o 7
temperatuur	o 1	o 2	o 3	o 4	o 5	o 6	o 7

Aan welk opleidingsinstituut heeft u uw studie gevolgd?

_ _

In welke richting bent u afgestudeerd?

o Stedenbouw

o Architectuur

o Landschapsarchitectuur

o Real estate & management

o Planologie

o Anders, nl _

Hoeveel jaren werkervaring heeft u?

o <5

o 5 -15

o >15

Bij wat voor bureau werkt u?

o Stedenbouwkundig ontwerpbureau

o Bureau met meerdere ontwerpdisciplines

o Architectenbureau

o Landschapsarchitectenbureau

o Gemeentelijke dienst

o Anders, nl: _

Wat is uw functie?

o Directeur

o Senior ontwerper

o Medior ontwerper

o Assistent ontwerper

o Beleidsmedewerker

o Specialist / adviseur

o Anders, nl: _

Vragen / opmerkingen:

A III Navigation Schemes

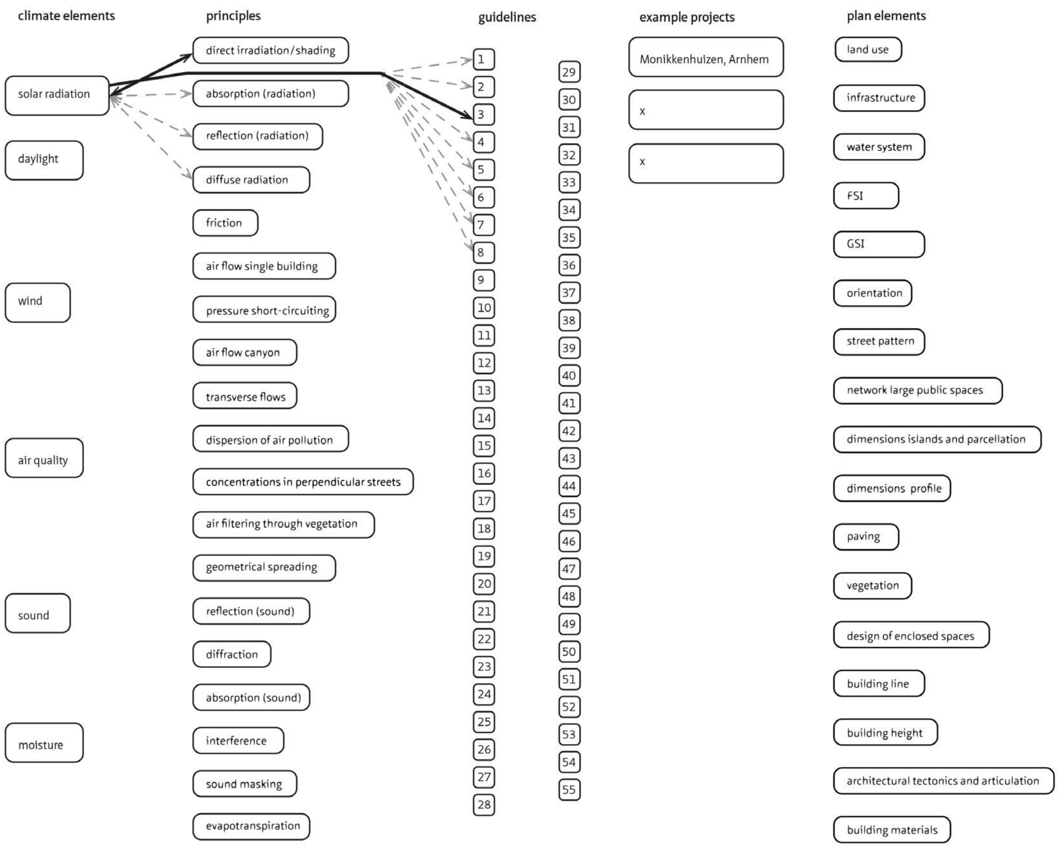


Figure 8.4

Possible navigations from climate element solar radiation. Dark arrows indicate elaborated examples, light arrows indicate other first order links.

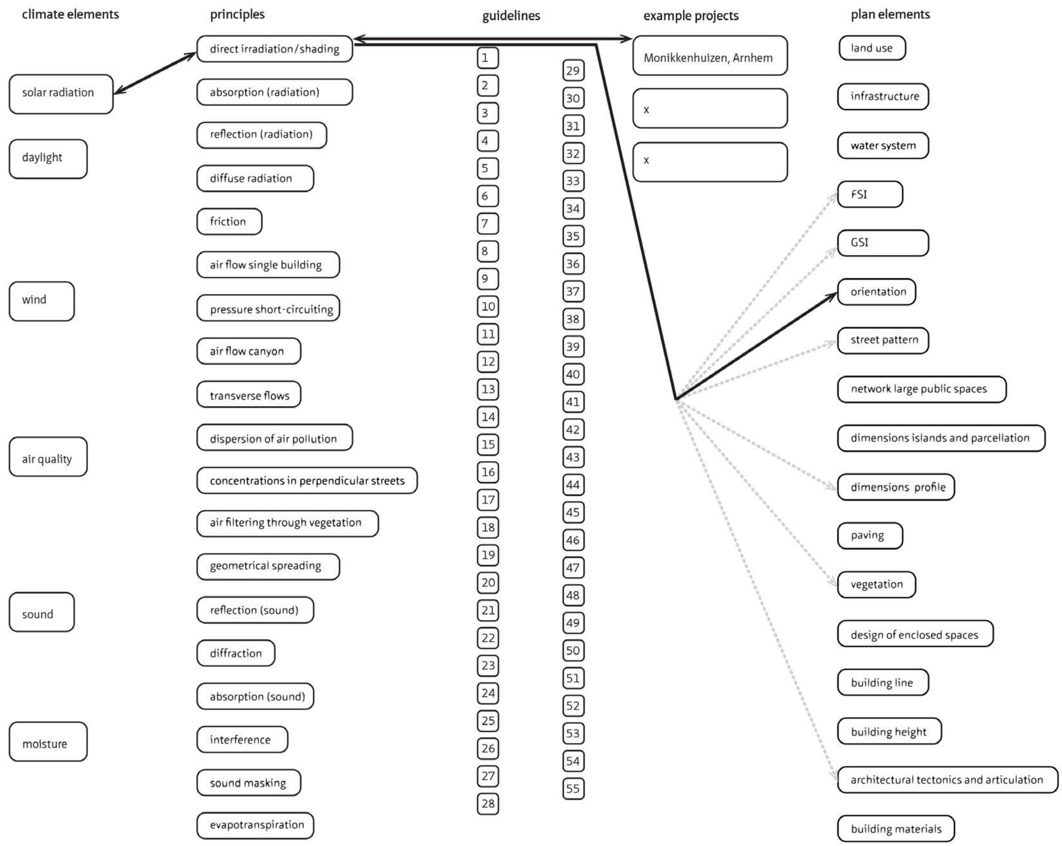


Figure 8.5

Possible navigations from principle direct irradiation/shading. Dark arrows indicate elaborated examples, light arrows indicate other first order links.

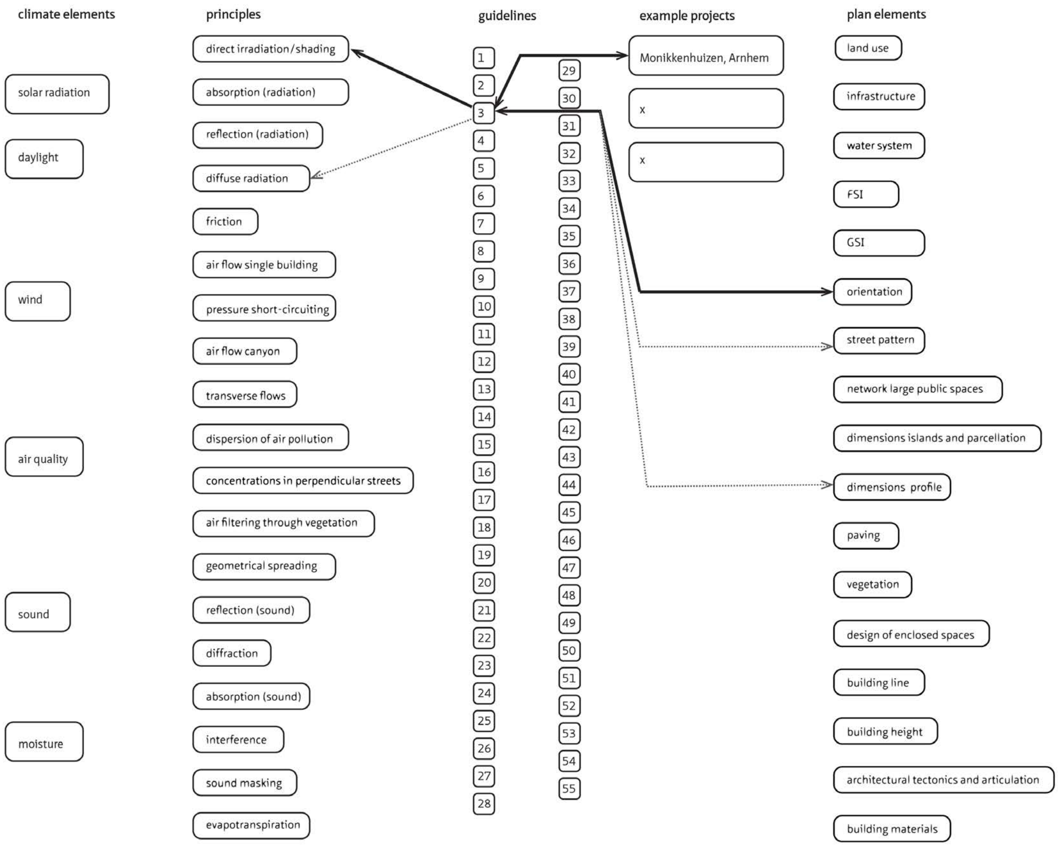


Figure 8.6

Possible navigations from guideline #3. Dark arrows indicate elaborated examples, light arrows indicate other first order links.

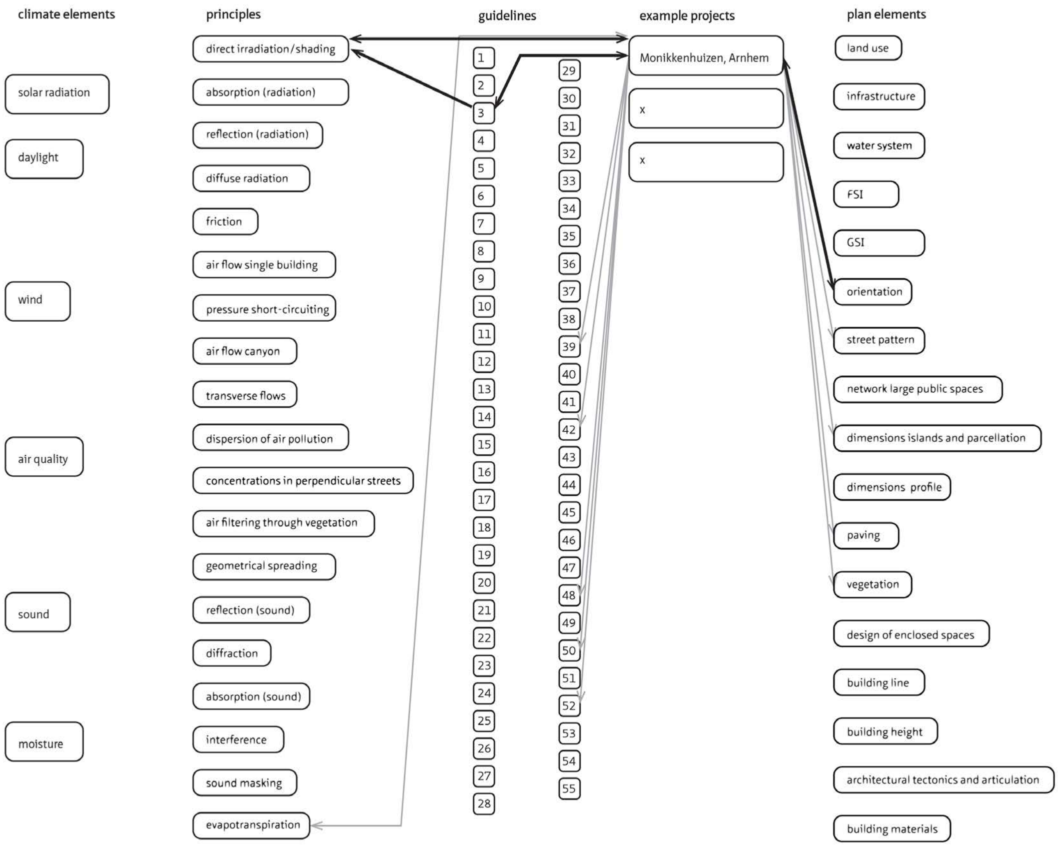


Figure 8.7

Possible navigations from example project Monnikenhuizen. Dark arrows indicate elaborated examples, light arrows indicate other first order links.

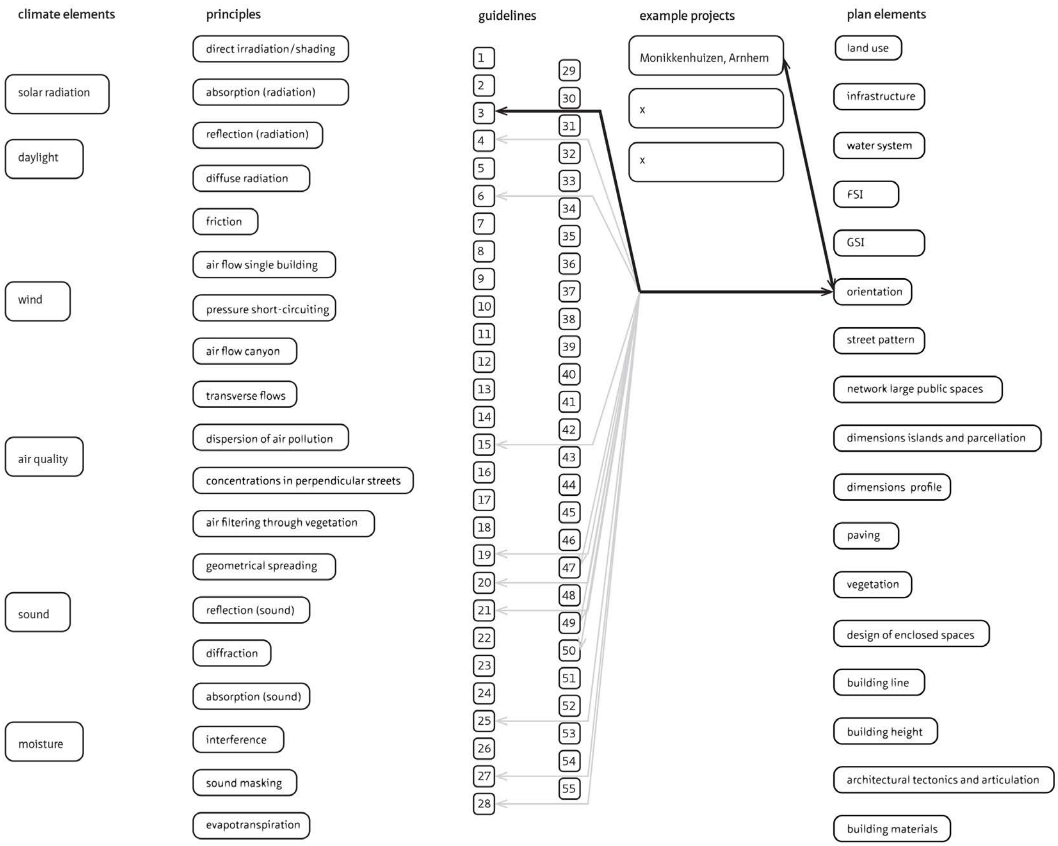


Figure 8.8

Possible navigations from plan element orientation. Dark arrows indicate elaborated examples, light arrows indicate other first order links.

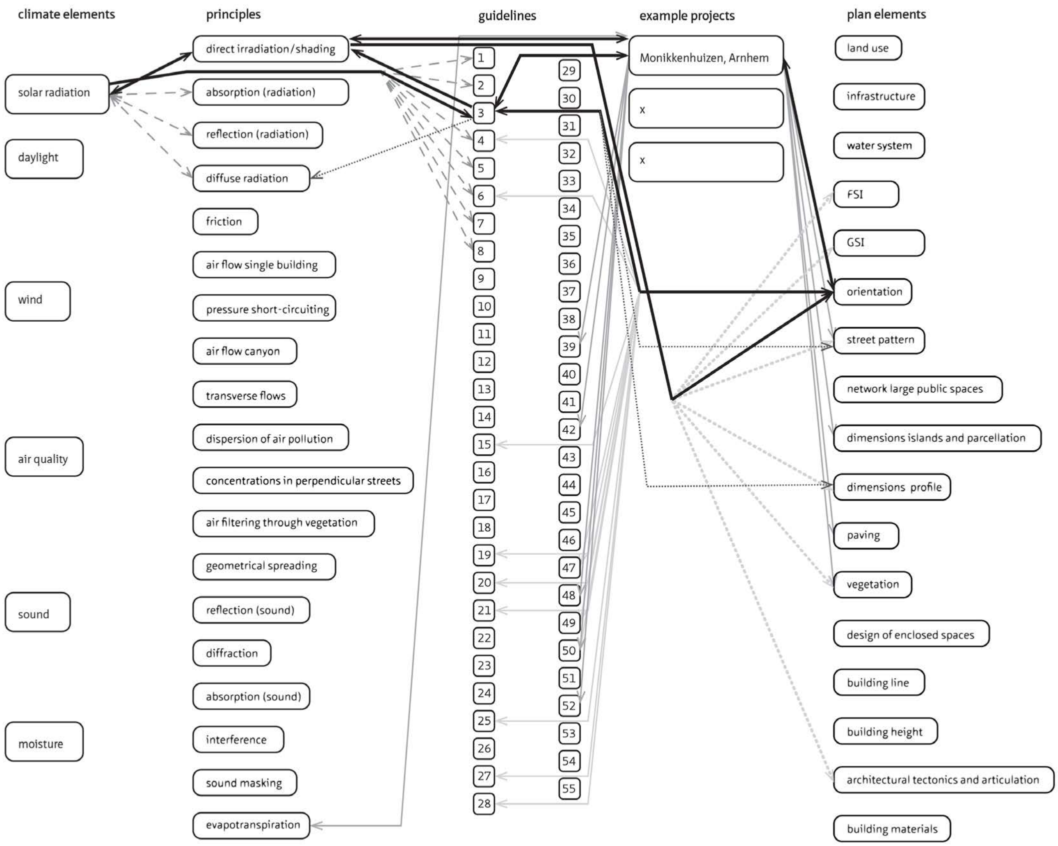


Figure 8.9
Example navigation schemes. Dark arrows indicate elaborated examples, light arrows indicate other first order links.

A IV Input Calculations Chapter 7

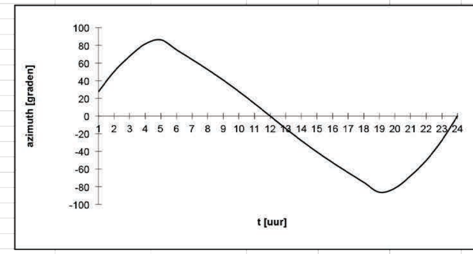
input calculations solar radiation

Blad1

Berekening zonshoogte en azimuth voor een gegeven datum en breedtegraad
Behorend bij handleiding BS/stedebouwfysica/ bezonning

Invoer:

breedtegr.	52		
dag	21		
maand	12	cumul.	334
dagnr	355		
maand	maandnr	dag	cumulatief
jan	1	31	0
feb	2	28	31
maa	3	31	59
apr	4	30	90
mei	5	31	120
jun	6	30	151
jul	7	31	181
aug	8	31	212
sep	9	30	243
okt	10	31	273
nov	11	30	304
dec	12	31	334
	totaal	365	



Berekend

brgr [gr]	brgr [rad]	dagnr	decl [rad]	decl [gr]	tijdstip [u]	uurh [rad]	uurh [gr]	zonsh [rad]	zonsh[gr]	azi [rad]	azi [gr]	azi(rad)	azi(gr)	azim(gr)	20*tan(azim	sch.lengte
52	0,9075712	355	-0,4091014	-23,439783	1	0,2617994	15	-1,03	-59,21	0,48	27,64	2,66	152,36	152,36	-10,47	-1,19
52	0,9075712	355	-0,4091014	-23,439783	2	0,5235988	30	-0,93	-53,38	0,88	50,27	2,26	129,73	129,73	-24,07	-1,49
52	0,9075712	355	-0,4091014	-23,439783	3	0,7853982	45	-0,79	-45,47	1,18	67,68	1,96	112,32	112,32	-48,72	-1,97
52	0,9075712	355	-0,4091014	-23,439783	4	1,0471976	60	-0,64	-36,58	1,43	81,65	1,72	98,35	98,35	-136,30	-2,70
52	0,9075712	355	-0,4091014	-23,439783	5	1,3089969	75	-0,48	-27,36	1,51	86,27	1,51	86,27	86,27	306,76	-3,86
52	0,9075712	355	-0,4091014	-23,439783	6	1,5707963	90	-0,32	-18,27	1,31	75,05	1,31	75,05	75,05	74,93	-6,06
52	0,9075712	355	-0,4091014	-23,439783	7	1,8325957	105	-0,17	-9,63	1,12	64,01	1,12	64,01	64,01	41,03	-11,79
52	0,9075712	355	-0,4091014	-23,439783	8	2,0943951	120	-0,03	-1,78	0,92	52,65	0,92	52,65	52,65	26,21	-64,42
52	0,9075712	355	-0,4091014	-23,439783	9	2,3561945	135	0,09	4,93	0,71	40,63	0,71	40,63	40,63	17,16	23,18
52	0,9075712	355	-0,4091014	-23,439783	10	2,6179939	150	0,18	10,12	0,48	27,77	0,48	27,77	27,77	10,53	11,20
52	0,9075712	355	-0,4091014	-23,439783	11	2,8797933	165	0,23	13,42	0,25	14,13	0,25	14,13	14,13	5,03	8,38
52	0,9075712	355	-0,4091014	-23,439783	12	3,1415927	180	0,25	14,56	0,00	0,00	0,00	0,00	0,00	0,00	7,70
52	0,9075712	355	-0,4091014	-23,439783	13	3,403392	195	0,23	13,42	-0,25	-14,13	0,25	14,13	-14,13	-5,03	8,38
52	0,9075712	355	-0,4091014	-23,439783	14	3,6651914	210	0,18	10,12	-0,48	-27,77	0,48	27,77	-27,77	-10,53	11,20
52	0,9075712	355	-0,4091014	-23,439783	15	3,9269908	225	0,09	4,93	-0,71	-40,63	0,71	40,63	-40,63	-17,16	23,18
52	0,9075712	355	-0,4091014	-23,439783	16	4,1887902	240	-0,03	-1,78	-0,92	-52,65	0,92	52,65	-52,65	-26,21	-64,42
52	0,9075712	355	-0,4091014	-23,439783	17	4,4505896	255	-0,17	-9,63	-1,12	-64,01	1,12	64,01	-64,01	-41,03	-11,79
52	0,9075712	355	-0,4091014	-23,439783	18	4,712389	270	-0,32	-18,27	-1,31	-75,05	1,31	75,05	-75,05	-74,93	-6,06
52	0,9075712	355	-0,4091014	-23,439783	19	4,9741884	285	-0,48	-27,36	-1,51	-86,27	1,51	86,27	-86,27	-306,76	-3,86
52	0,9075712	355	-0,4091014	-23,439783	20	5,2359878	300	-0,64	-36,58	-1,43	-81,65	1,72	98,35	-98,35	136,30	-2,70
52	0,9075712	355	-0,4091014	-23,439783	21	5,4977871	315	-0,79	-45,47	-1,18	-67,68	1,96	112,32	-112,32	48,72	-1,97
52	0,9075712	355	-0,4091014	-23,439783	22	5,7595865	330	-0,93	-53,38	-0,88	-50,27	2,26	129,73	-129,73	24,07	-1,49
52	0,9075712	355	-0,4091014	-23,439783	23	6,0213859	345	-1,03	-59,21	-0,48	-27,64	2,66	152,36	-152,36	10,47	-1,19
52	0,9075712	355	-0,4091014	-23,439783	24	6,2831853	360	-1,07	-61,44	0,00	0,00	3,14	180,00	-180,00	0,00	-1,09
Berekening t_opkomst (met behulp van oplosser):																
52	0,9075712	355	-0,4091014	-23,439783	6,8825966	1,8018596	103,23895	-0,185	-10,609	1,140	65,316	1,140	65,316	65,316	43,515	

t_op	8,2470856	(decimalen)	t_onder	15,752914	(decimalen)
t_op	8,1482513	(uren)	t_onder	15,451749	(uren)

brgr [gr]	brgr [rad]	dagnr	decl [rad]	decl [gr]	tijdstip [u]	uurh [rad]	uurh [gr]	zonsh [rad]	zonsh[gr]	azi [rad]	azi [gr]	azi(rad)	azi(gr)		
52	0,9075712	355	-0,4091014	-23,439783	8,2470856	2,159082	123,70628	0,000	0,000	0,868	49,751	0,868	49,751	49,751	23,626

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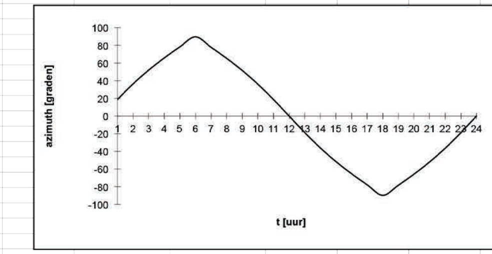
Figure 8.10
Hourly solar height and azimuth on December 21 (winter).

Blad1

Berekening zonshoogte en azimuth voor een gegeven datum en breedtegraad
Behorend bij handleiding BS/stedebouwfysica/ bezonning

	Invoer:		
breedtegr.	52		
dag	21		
maand	3	cumul.	59
dagnr	80		
maand	maandnr	dag	cumulatief
jan	1	31	0
feb	2	28	31
maa	3	31	59
apr	4	30	90
mei	5	31	120
jun	6	30	151
jul	7	31	181
aug	8	31	212
sep	9	30	243
okt	10	31	273
nov	11	30	304
dec	12	31	334
	totaal	365	



Berekend

brgr [gr]	brgr [rad]	dagnr	decl [rad]	decl [gr]	tijdstip [u]	uurh [rad]	uurh [gr]	zonsh [rad]	zonsh[gr]	azi [rad]	azi [gr]	azi(rad)	azi(gr)	azim(gr)	20*tan(azim	sch.lengte
52	0,9075712	80	-0,0070421	-0,4034811	1	0,2617994	15	-0,64	-36,89	0,33	18,88	2,81	161,12	161,12	-6,84	-2,67
52	0,9075712	80	-0,0070421	-0,4034811	2	0,5235988	30	-0,57	-32,60	0,64	36,40	2,51	143,60	143,60	-14,75	-3,13
52	0,9075712	80	-0,0070421	-0,4034811	3	0,7853982	45	-0,46	-26,16	0,91	51,98	2,23	128,02	128,02	-25,58	-4,07
52	0,9075712	80	-0,0070421	-0,4034811	4	1,0471976	60	-0,32	-18,26	1,15	65,77	1,99	114,23	114,23	-44,45	-6,06
52	0,9075712	80	-0,0070421	-0,4034811	5	1,3089969	75	-0,17	-9,49	1,37	78,32	1,77	101,68	101,68	-96,78	-11,96
52	0,9075712	80	-0,0070421	-0,4034811	6	1,5707963	90	-0,01	-0,32	1,57	89,75	1,57	89,75	89,75	4612,97	-360,41
52	0,9075712	80	-0,0070421	-0,4034811	7	1,8325957	105	0,15	8,85	1,36	77,83	1,36	77,83	77,83	92,75	12,85
52	0,9075712	80	-0,0070421	-0,4034811	8	2,0943951	120	0,31	17,59	1,14	65,30	1,14	65,30	65,30	43,48	6,31
52	0,9075712	80	-0,0070421	-0,4034811	9	2,3561945	135	0,44	25,45	0,90	51,55	0,90	51,55	51,55	25,18	4,20
52	0,9075712	80	-0,0070421	-0,4034811	10	2,6179939	150	0,56	31,84	0,63	36,06	0,63	36,06	36,06	14,56	3,22
52	0,9075712	80	-0,0070421	-0,4034811	11	2,8797933	165	0,63	36,09	0,33	18,68	0,33	18,68	18,68	6,76	2,74
52	0,9075712	80	-0,0070421	-0,4034811	12	3,1415927	180	0,66	37,60	0,00	0,00	0,00	0,00	0,00	0,00	2,60
52	0,9075712	80	-0,0070421	-0,4034811	13	3,403392	195	0,63	36,09	-0,33	-18,68	0,33	18,68	-18,68	-6,76	2,74
52	0,9075712	80	-0,0070421	-0,4034811	14	3,6651914	210	0,56	31,84	-0,63	-36,06	0,63	36,06	-36,06	-14,56	3,22
52	0,9075712	80	-0,0070421	-0,4034811	15	3,9269908	225	0,44	25,45	-0,90	-51,55	0,90	51,55	-51,55	-25,18	4,20
52	0,9075712	80	-0,0070421	-0,4034811	16	4,1887902	240	0,31	17,59	-1,14	-65,30	1,14	65,30	-65,30	-43,48	6,31
52	0,9075712	80	-0,0070421	-0,4034811	17	4,4505896	255	0,15	8,85	-1,36	-77,83	1,36	77,83	-77,83	-92,75	12,85
52	0,9075712	80	-0,0070421	-0,4034811	18	4,712389	270	-0,01	-0,32	-1,57	-89,75	1,57	89,75	-89,75	-4612,97	-360,41
52	0,9075712	80	-0,0070421	-0,4034811	19	4,9741884	285	-0,17	-9,49	-1,37	-78,32	1,77	101,68	-101,68	96,78	-11,96
52	0,9075712	80	-0,0070421	-0,4034811	20	5,2359878	300	-0,32	-18,26	-1,15	-65,77	1,99	114,23	-114,23	44,45	-6,06
52	0,9075712	80	-0,0070421	-0,4034811	21	5,4977871	315	-0,46	-26,16	-0,91	-51,98	2,23	128,02	-128,02	25,58	-4,07
52	0,9075712	80	-0,0070421	-0,4034811	22	5,7595865	330	-0,57	-32,60	-0,64	-36,40	2,51	143,60	-143,60	14,75	-3,13
52	0,9075712	80	-0,0070421	-0,4034811	23	6,0213859	345	-0,64	-36,89	-0,33	-18,88	2,81	161,12	-161,12	6,84	-2,67
52	0,9075712	80	-0,0070421	-0,4034811	24	6,2831853	360	-0,67	-38,40	0,00	0,00	3,14	180,00	-180,00	0,00	-2,52
Berekening t_opkomst (met behulp van oplosser):																
52	0,9075712	80	-0,0070421	-0,4034811	6,8825966	1,8018596	103,23895	0,136	7,784	1,383	79,251	1,383	79,251	79,251	105,349	

t_op	6,0344298	(decimalen)	t_onder	17,96557	(decimalen)
t_op	6,0206579	(uren)	t_onder	17,579342	(uren)

brgr [gr]	brgr [rad]	dagnr	decl [rad]	decl [gr]	tijdstip [u]	uurh [rad]	uurh [gr]	zonsh [rad]	zonsh[gr]	azi [rad]	azi [gr]	azi(rad)	azi(gr)		
52	0,9075712	80	-0,0070421	-0,4034811	6,0344298	1,57981	90,516448	0,000	0,000	1,559	89,345	1,559	89,345	89,345	1.748,423

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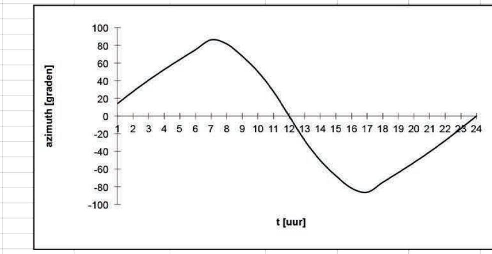
Figure 8.11
Hourly solar height and azimut on March 21 (spring/autumn).

Blad1

Berekening zonshoogte en azimuth voor een gegeven datum en breedtegraad
Behorend bij handleiding BS/stedebouwfysica/ bezonning

Invoer:

breedtegr.	52		
dag	21		
maand	6	cumul.	151
dagnr	172		
maand	maandnr	dag	cumulatief
jan	1	31	0
feb	2	28	31
maa	3	31	59
apr	4	30	90
mei	5	31	120
jun	6	30	151
jul	7	31	181
aug	8	31	212
sep	9	30	243
okt	10	31	273
nov	11	30	304
dec	12	31	334
	totaal	365	



Berekend

brgr [gr]	brgr [rad]	dagnr	decl [rad]	decl [gr]	tijdstip [u]	uurh [rad]	uurh [gr]	zonsh [rad]	zonsh[gr]	azi [rad]	azi [gr]	azi(rad)	azi(gr)	azim(gr)	20*tan(azim	sch.lengte
52	0,9075712	172	0,4091014	23,439783	1	0,2617994	15	-0,23	-13,42	0,25	14,13	2,89	165,87	165,87	-5,03	-8,38
52	0,9075712	172	0,4091014	23,439783	2	0,5235988	30	-0,18	-10,12	0,48	27,77	2,66	152,23	152,23	-10,53	-11,20
52	0,9075712	172	0,4091014	23,439783	3	0,7853982	45	-0,09	-4,93	0,71	40,63	2,43	139,37	139,37	-17,16	-23,18
52	0,9075712	172	0,4091014	23,439783	4	1,0471976	60	0,03	1,78	0,92	52,65	2,22	127,35	127,35	-26,21	64,42
52	0,9075712	172	0,4091014	23,439783	5	1,3089969	75	0,17	9,63	1,12	64,01	2,02	115,99	115,99	-41,03	11,79
52	0,9075712	172	0,4091014	23,439783	6	1,5707963	90	0,32	18,27	1,31	75,05	1,83	104,95	104,95	-74,93	6,06
52	0,9075712	172	0,4091014	23,439783	7	1,8325957	105	0,48	27,36	1,51	86,27	1,64	93,73	93,73	-306,76	3,86
52	0,9075712	172	0,4091014	23,439783	8	2,0943951	120	0,64	36,58	1,43	81,65	1,43	81,65	81,65	136,30	2,70
52	0,9075712	172	0,4091014	23,439783	9	2,3561945	135	0,79	45,47	1,18	67,68	1,18	67,68	67,68	48,72	1,97
52	0,9075712	172	0,4091014	23,439783	10	2,6179939	150	0,93	53,38	0,88	50,27	0,88	50,27	50,27	24,07	1,49
52	0,9075712	172	0,4091014	23,439783	11	2,8797933	165	1,03	59,21	0,48	27,64	0,48	27,64	27,64	10,47	1,19
52	0,9075712	172	0,4091014	23,439783	12	3,1415927	180	1,07	61,44	0,00	0,00	0,00	0,00	0,00	0,00	1,09
52	0,9075712	172	0,4091014	23,439783	13	3,403392	195	1,03	59,21	-0,48	-27,64	0,48	27,64	-27,64	-10,47	1,19
52	0,9075712	172	0,4091014	23,439783	14	3,6651914	210	0,93	53,38	-0,88	-50,27	0,88	50,27	-50,27	-24,07	1,49
52	0,9075712	172	0,4091014	23,439783	15	3,9269908	225	0,79	45,47	-1,18	-67,68	1,18	67,68	-67,68	-48,72	1,97
52	0,9075712	172	0,4091014	23,439783	16	4,1887902	240	0,64	36,58	-1,43	-81,65	1,43	81,65	-81,65	-136,30	2,70
52	0,9075712	172	0,4091014	23,439783	17	4,4505896	255	0,48	27,36	-1,51	-86,27	1,64	93,73	-93,73	306,76	3,86
52	0,9075712	172	0,4091014	23,439783	18	4,712389	270	0,32	18,27	-1,31	-75,05	1,83	104,95	-104,95	74,93	6,06
52	0,9075712	172	0,4091014	23,439783	19	4,9741884	285	0,17	9,63	-1,12	-64,01	2,02	115,99	-115,99	41,03	11,79
52	0,9075712	172	0,4091014	23,439783	20	5,2359878	300	0,03	1,78	-0,92	-52,65	2,22	127,35	-127,35	26,21	64,42
52	0,9075712	172	0,4091014	23,439783	21	5,4977871	315	-0,09	-4,93	-0,71	-40,63	2,43	139,37	-139,37	17,16	-23,18
52	0,9075712	172	0,4091014	23,439783	22	5,7595865	330	-0,18	-10,12	-0,48	-27,77	2,66	152,23	-152,23	10,53	-11,20
52	0,9075712	172	0,4091014	23,439783	23	6,0213859	345	-0,23	-13,42	-0,25	-14,13	2,89	165,87	-165,87	5,03	-8,38
52	0,9075712	172	0,4091014	23,439783	24	6,2831853	360	-0,25	-14,56	0,00	0,00	#GETAL!	#GETAL!	#GETAL!	#GETAL!	-7,70
Berekening t_opkomst (met behulp van oplosser):																
52	0,9075712	172	0,4091014	23,439783	6,8825966	1,8018596	103,23895	0,459	26,284	1,482	84,924	1,659	95,076	95,076	225,163-	

t_op	3,7529144	(decimalen)	t_onder	20,247086	(decimalen)
t_op	3,4517487	(uren)	t_onder	20,148251	(uren)

brgr [gr]	brgr [rad]	dagnr	decl [rad]	decl [gr]	tijdstip [u]	uurh [rad]	uurh [gr]	zonsh [rad]	zonsh[gr]	azi [rad]	azi [gr]	azi(rad)	azi(gr)		
52	0,9075712	172	0,4091014	23,439783	3,7529144	0,9825107	56,293716	0,000	0,000	0,868	49,751	2,273	130,249	130,249	23,626-

Pagina 1

Figure 8.12
Hourly solar height and azimut on June 21 (summer).

input wind profile for FLUENT simulations

```
#include "udf.h"

/* BOUNDARY PROFILES FOR REFERENCE WIND SPEED    U10    = 10 M/S */
/* TERRAIN ROUGHNESS IS SET TO                   Zo     = 0.25 M */
/* FRICTION VELOCITY CORRESPONDS TO              U*     = 1.08 M/S */

real yo = 0.25;
real uf = 1.08;

/* CALCULATION OF THE PROFILE FOR HORIZONTAL WIND SPEED */

DEFINE_PROFILE(inlet_u_vel_v10, thread, nv) /* function name, thread and variable
number */

{
    face_t f;
    real x[ND_ND];
    begin_f_loop (f,thread)
    {
     F_CENTROID(x,f,thread);
    F_PROFILE(f,thread,nv) = (uf/0.4)*(log((x[1]+yo)/yo));
    }
    end_f_loop(f,thread)
}

/* CALCULATION OF THE PROFILE FOR TURBULENT KINETIC ENERGY */

DEFINE_PROFILE(k, thread, nv) /* function name, thread and variable number */

{                                            face_t f;
    real x[ND_ND];
    begin_f_loop (f,thread)
    {
     F_CENTROID(x,f,thread);
    F_PROFILE(f,thread,nv) = 3.3*uf*uf;
    }
    end_f_loop(f,thread)
}

/* CALCULATION OF THE PROFILE FOR DISSIPATION */
```

```
DEFINE_PROFILE(e, thread, nv) /* function name, thread and variable number */

{
     face_t f;
     real x[ND_ND];
     begin_f_loop (f,thread)
     {
      F_CENTROID(x,f,thread);
     F_PROFILE(f,thread,nv) = uf*uf*uf/(0.4*(x[1]+yo));
     }
     end_f_loop(f,thread)
}

DEFINE_PROFILE(Cs,t,i)

{
 face_t f;
 begin_f_loop(f,t)
  {
    F_PROFILE(f,t,i) = 8,3;
  }
 end_f_loop(f,t)
}
```

Curriculum Vitae

Marjolein Pijpers-van Esch was born June 8, 1980 in Tilburg, The Netherlands. She studied at the Faculty of Architecure of the Delft University of Technology, from which she graduated as an urban designer in 2005. In 2000, she interrupted her studies for a full academic year as Chief of Orchestra and Secretary of External Affairs of the Delft Student Choir and Orchestra “Krashna Musika”.

In 2006 she started working as a research fellow at the Faculty of Architecture in Delft, resulting in the initiation of a PhD research project on urban microclimates. During her PhD research she published several journal and conference papers and was actively involved in the educational program.

In 2011 she founded “Designlab 2902”, a design and advice firm for climate, comfort and sustainable development in the built environment, together with Remco Looman.

List of publications related to the PhD research

2012

Esch, M.M.E. van, Looman, RHJ & Hordijk, GJ. The effects of urban and building design parameters on solar access to the urban canyon and the potential for direct passive solar heating strategies. Energy and Buildings, 47 (pp. 189-200)

Kleerekoper, L., Esch, M.M.E. van & Salcedo, B.T. How to make a city climate-proof, addressing the urban heat island effect. Recources, Conservation and Recycling, 64 (pp. 30-38)

2010

Looman, R.H.J. & Esch, M.M.E. van. Passive solar design: where urban and building design meet. In Carpi, A. & Brebbia, C.A. (Eds.), Design and nature V - Comparing design in nature with science and engineering (pp. 129-138). Southampton: WITpress.

2009

Esch, M.M.E van. Knowledge on Urban Microclimates in the Urban Planning and Design Process. In Dobbelsteen, A. van den, Dorst, M. van & Timmeren, A. van (Eds.), Smart Building in a Changing Climate (pp. 187-200). Amsterdam: Techne Press.

Esch, M.M.E. van & Dorst, M.J .van. Transferring Knowledge on Urban Microclimates in the Urban Planning and Design Process. In s.n. (Ed.), SASBE 2009 Proceedings (pp. 1-8). Delft: Delft University of Technology.

2007

Esch, M.M.E .van & Haupt, P.A. Daylight and Urban Density. In Bekkering, H.C., Hauptmann, D., Heijer, A. den, Klatte, J., Knaack, U. & Manen, S. van (Eds.), The Architecture Annual 2005-2006 (pp. 86-91). Rotterdam: 010 Publishers.

Esch, M.M.E. van, Hordijk, G.J. & Duijvestein, C.A.J. The influence of building geometry on the physical urban climate: a revival of "ligth, air and space". In Wittkopf, S.K. & Tan, B.K. (Eds.), PLEA 2007 - Sun, wind and architecture - 24th International conference on passive and low energy architecture (pp. 396-403). Singapore: National University of Singapore, department of architecture.

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2006

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