Temple of Mobility

25 June 2010

Graduation Project of Building Technology & Architectural Engineering

Karin Hoekstra

Eric van den Ham, Ype Cuperus and Patrick Teuffel

Foreword

This report is a description of the project “Temple of Mobility”, a graduation project of the Architectural Engineering and Building Technology lab at the faculty of Architecture at the Delft University of Technology. The objective of this lab is to combine architectural design with building technical research and to integrate both in the design of a building. The project started off in November 2008. The first semester is spent on the analysis of the assignment, the sketch design and the preparation of the building technical research. The second semester is spent on the building technical research and the last is spent on the architectural design and the integration of both. The project will be finalized on July 1st 2010.

Karin Hoesktra, TU Delft Faculty of Architecture, June 25 2010

Contents

1. Introduction

Temple of Mobility is a project that combines architectural design and building technical research. Research and design are developed simultaneously and in the end integrated in the final design. This introduction gives a short explanation of the assignment. It describes both the architectural problem area in the form of a scenario and the building technical problem statement relating to that scenario. Finally, the structure of the project and this report are explained.

1.1 Assignment

This project is based on the assignment of an Architectural Engineering design studio. The assignment is inspired by a vision on the Randstad in 2040. This vision proposes the Randstad as a metropolis of the Netherlands that could compete with other large cities and networks of cities in Europe, like London and Paris but also like the Flamish Diamond in Belgium and the Ruhr Area in Germany (*Figure 1.1: Network of metropoles in Europe*). In order to accomplish this, the four large cities that are separated by a considerable distance should work together as one coherent entity (*Figure 1.2: Randstad as a betwork of large cities*). Mobility and infrastructure are the key to this cooperation; mobility is the way to link the unique specialties of each city, infrastructure is the means to provide this mobility.

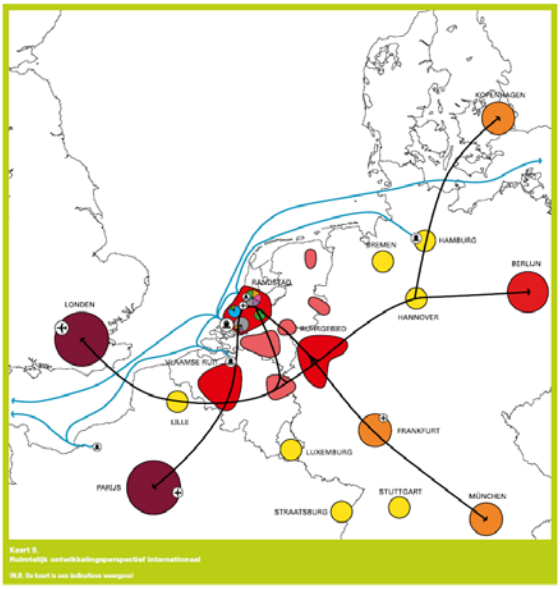


Figure 1.1: Network of metropoles in Europe

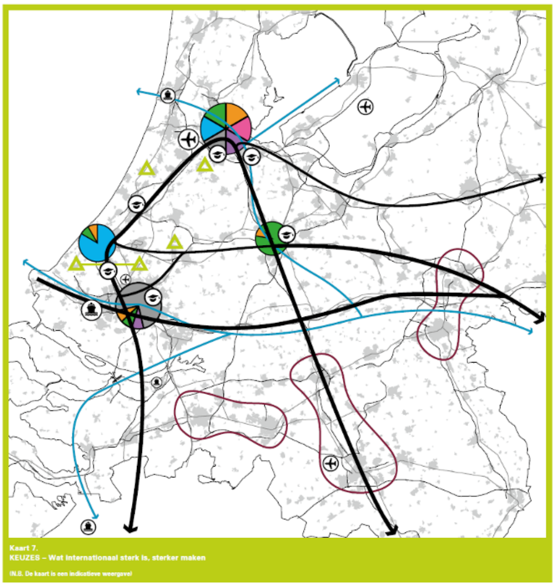


Figure 1.2: Randstad as a betwork of large cities

Infrastructure thus plays a very crucial role in this new vision. Especially the junctions, where one direction connects to the other, are the center of the metropolis that is the Randstad. These junctions gain a new potential where connectivity and the cheap land price will result in high density building. In addition, the government stimulates building in higher densities around cities in order to save travel costs and energy and to prevent the disappearing of nature in the Netherlands.

The Prins Clausplein in The Hague is one of the most important junctions for the network of the Randstad; it connects east and west (Utrecht-The Hague) and north and south (Rotterdam-Amsterdam via The Hague). The Prins Clausplein is the entrance to The Hague on one hand and on the other hand it is a gaping hole in the city of The Hague because building close to it is still avoided for the noise and pollution that is emitted from the traffic (Figure *1.3: Postion of the Prins Clausplein*).

Figure 1.3: Postion of the Prins Clausplein

Figure 1.4: Regional infrastructure

The assignment of the Architectural Engineering studio is to build in this unlovable area and transform it into a lovable area by tackling the problems that are created by the infrastructure and by designing a building that is suited for the location.

1.2 Scenario

The urban environment of the Prins Clausplein as it is now is still underdeveloped. The Hague is expanding ever since the motorways have been realized and the city is literally clamped between them. Still there is the tendency to avoid the noise and pollution of the areas surrounding the motorways (*Figure 1.5: Growth of The Hague*). However, new techniques are being developed to overcome these problems. Cleaner and less noisy cars are being developed (i.e. in the form of electronic cars) as well as measurements in the built environment to cope with the problems of noise and pollution. The scenario of a high density built environment around the Prins Clausplein is therefore very viable.

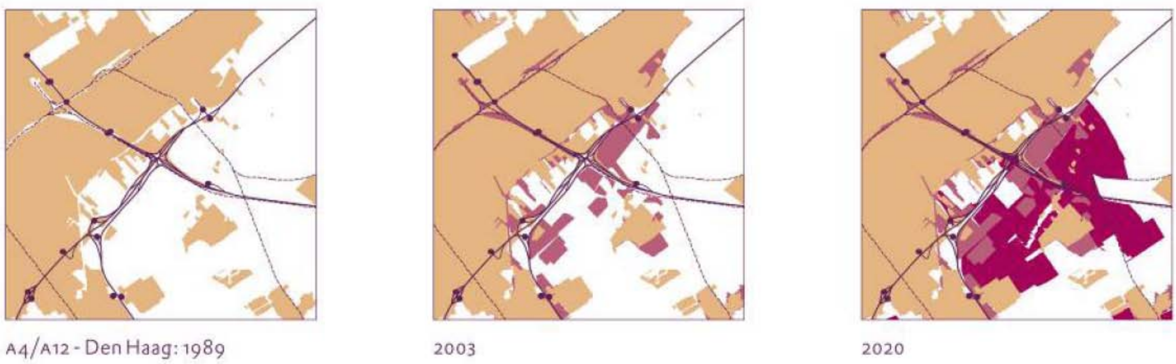


Figure 1.5: Growth of The Hague

Based on this future scenario, a proposal for the urban plan of the Prins Clausplein is developed. This proposal is part of the design project and is the starting point for the architectural design. It is based on three different proposals from the government of The Hague which form the policy for the Prins Clausplein (Dienst Stedelijke Ontwikkeling, 2006). The demand of the government to build in high densities around junctions is met. Commercial buildings are placed along the highways as a buffer for noise and pollution. Dwellings and mixed live-and-work units are built around it, altered by green strokes that reach over or under the highway to connect the areas on both sides of the highway. Parallel to the highway runs a boulevard that functions as the artery of the plan providing regional transport routes and a line of the Randstad rail. (*Figure 1.6: Proposal for the urban plan*).

Figure 1.6: Proposal for the urban plan

Moving from the urban scale to the architectural one, the rest of the project focuses on the architectural design and the building technological problems that are involved. The architectural design is originated from the potential of the Prins Clausplein as a building area; its accessibility. In the previous paragraph, the importance of a vital network for the Randstad is pointed out. Mobility is one of the key elements in this network. Developments in communication and transport techniques have caused the world to become smaller and smaller. Society nowadays has become dependent on transport to get to work, family or friends. The Prins Clausplein is of course very well connected to the national automobile transport network but is also close to regional motorways as well as the railway system and the tram system; individual as well as public transport types are all easily accessible. There are opportunities to create an optimal link in the chain of the transport network for the Randstad. In order to really provide a flawless mobility from city to city, all different types of transport need to be connected so that people will be able to use the type of transport that is most suitable for their situation and destination.

The objective of the architectural design is to create a transport terminal at the Prins Clausplein that efficiently connects all types of transport (public as well as individual) and that stimulates urban development around the junction.
In this goal lies a paradox since urban development can be initiated by important access points to transport networks but is at the same time hindered by the negative effects of the infrastructure itself. The transport terminal is the key element in the issue of building near infrastructure and is therefore most suitable to improve not only the link between different types of transport but also to improve the link between the urban fabric and the autonomous works of infrastructure. Only when this link can be accomplished, the area can really flourish as an attractive living area.

1.3 Problem statement

The integration of urban structure and infrastructure inside a transport terminal forms the foundation of the research and the design of this project. Apart from the architectural problems that are involved with this integration, building technical problems arise. To really integrate urban activities like living, working and shopping, with transport activities like traveling and waiting, the feeling of comfort is very important.

1.3.1 Subject

The current situations in railway stations and near highways do not create the conditions to attract people and to stimulate them to use the space for urban activities. The cause of this problem lies of course in the noise and pollution from the highway but also in the influences of sun, rain and wind in relation to the different activities that take place inside and outside the building. The combination of different activities results in the demand for a semi-outdoor climate that is never met in these situations (*Figure 1.7: Building physical aspects influencing comfort inside the terminal*)

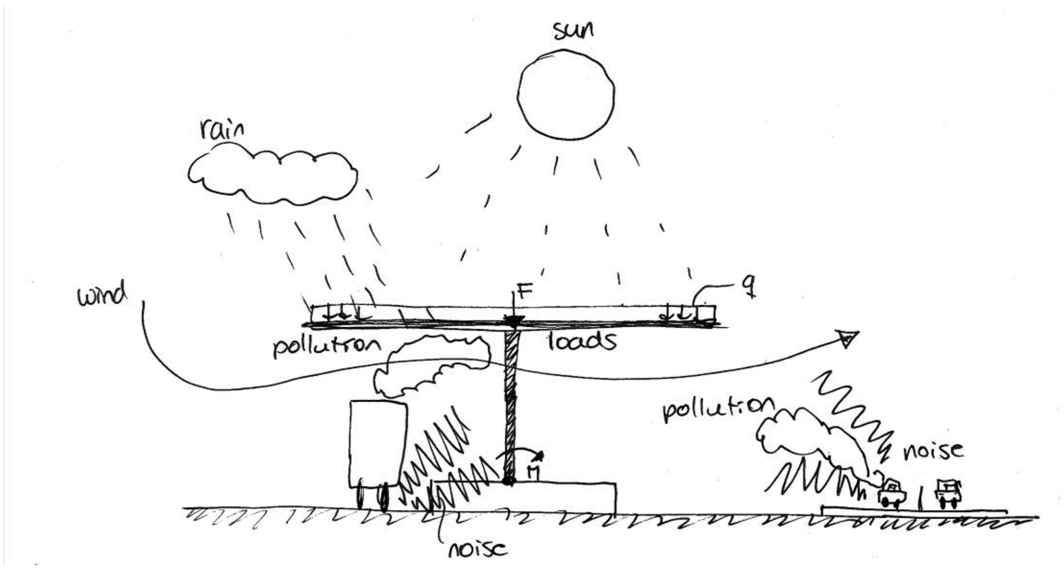


Figure 1.7: Building physical aspects influencing comfort inside the terminal

1.3.2 Research question

To solve this problem in the design of a transport terminal, a building technical research into the different building physical aspects that influence the climate and the way to regulate them in such a building is needed. This results in the following research question:

- What passive and sustainable methods can be used to regulate the climate inside a transport terminal in such a way that a comfortable semi-outdoor climate is provided and what is the best way to apply them to the design of a transport terminal?

This question can be divided into three main topics; comfortable semi-outdoor climate, methods to regulate climate and application of methods to the design. The research question can thus be formulated in three sub questions:

- What is the definition of a comfortable semi-outdoor climate for a transport terminal?
- What sustainable methods are possible to regulate the physical aspects involved in the feeling of comfort and what is their performance?
- What is the best way to apply these methods to the design of a transport terminal at the Prins Clausplein so that the technical and architectural demands can be met?

1.3.3 Objective

The objective of this research is to provide a solution for the problem defined for the design of a transport terminal at the Prins Clausplein. The aim is to find a passive and sustainable climate system for the transport terminal that influences the parameters of comfort in the most optimal way. Optimal in this case means that the system works efficiently to create a comfortable climate and that it contributes to the architectural design as a whole.

1.4 Structure

The Temple of Mobility project is divided into three parts; the architectural design, the building technical research and the integration of both in the final design. The focus of this report lies on the building technical research but it also describes the simultaneous development of research and design. The final product of the project and the integration of both specialties in the final design is the most important part of the report.

Following these three categories and the structure of the research questions, the report is divided in three parts as well. The next two chapters are a general orientation of the building technical research; chapter 2 deals with the question of comfort in semi-outdoor situations, chapter 3 further explores the methods and their techniques to influence the aspects that are involved with comfort. Chapter 4 and 5 explain the building technical research and relate them to the architectural design. Finally, chapter 6 gives a description of the final design and explains the way research and design are integrated in the final design. This report concludes with an evaluation of the research and design process and of the integration of the two in the whole project.

2. Comfort in semi-outdoor situations

Before exploring the possibilities to regulate climate in order to solve the problem, the problem itself needs to be researched more thoroughly. It is clear that the current situation at the Prins Clausplein is not satisfactory. However, why this situation is unsatisfactory and what factors cause this situation isn't clear yet. In the main research question, this problem is implicitly described in defining the desirable situation as the 'comfortable semi-outdoor climate', as it is not yet clear what this 'comfortable semi-outdoor climate' is and what the demands are.

The term 'comfortable semi-outdoor climate' is deliberately chosen. It contains two elements that define the desired situation for this design; comfort and semi-outdoor. Comfort so that the space provides opportunities for the different activities and semi-outdoor to maintain a relation with the outside city while still assuring shelter from harsh weather. This chapter is an analysis of this desired situation, it aims to give a definition of a comfortable semi-outdoor climate and in doing so, refining the problem. To get a better grip on the term comfort in semi-outdoor situations, researches on comfort inside as well as outside are being studied.

2.1 Environmental Quality

Comfort to humans is determined by a lot of different factors. It is very dependent on the physical and mental state of each individual and is closely connected to the functioning of the human body. For this research, the subject of mental state is only touched upon. Especially where architecture is concerned, mental state can not totally be denied, but a full explanation on that part would reach far beyond this research. However, the mind still does play a large role in the physical feeling of comfort. Body and mind are connected through the five senses that register light, odor, sound, taste, palpation and more indirectly temperature and vibration. The physical aspects that are involved in the feeling of comfort are determined by what is registered by the senses and make up the environmental quality (Marsh, 1990) *(Figure 2.1: Factors determining the environmental quality)*; Thermal comfort quality, air quality, sound quality, lighting quality, vibration quality and odor quality.

Figure 2.1: Factors determining the environmental quality

The environmental quality can be validated by relating environmental factors like sound level and frequency to personal factors like sensitivity of the human ear.

2.2 Indoor comfort

A lot of research has been done on indoor comfort. In most researches, comfort is directly linked to the thermal quality, which is the most intensely perceived factor in the environment (Marsh, 1990). For this reason, this paragraph is primarily focused on thermal comfort.

2.2.1 Theory of Fanger

The most important research in this matter is the research of Fanger, who developed a theory to relate outside conditions to human factors to predict the level of satisfaction with the environment (Fanger, 1972). Most other researches are based on this theory; therefore, a short description is incorporated in this paragraph.

Activity	Metabolism (M) in W
laying down	85
sitting	105
standing	125
walking slow	130
walking fast	160

Table 1: metabolic rate for different activities

Fanger's theory describes four environmental factors that influence the thermal comfort: air temperature, radiation temperature, air velocity and humidity. These are the factors that are perceived by the human body and their relation to comfort is closely related to the different heat regulating systems of the body; convection (heat transfer through air), evaporation (heat transfer through water), radiation (heat transfer from matter to matter) and conduction (direct contact heat transfer).

Clothing type	Insulation (Iclo) in clo
unclothed	0
bikini	0,05
short trousers	0,1
tropical clothes	0,3
light summer clothes	0,5
light business suit	0,8
normal suit	1
heavy suit	1,5
antarctic clothes	3,5

Table 2: Clothing levels for different clothing

Convection of heat from the skin to the outside or the other way around, depends on air temperature and air velocity (the refreshment of air determines the air temperature close to the body). The system of evaporation largely depends on the relative humidity and the air velocity (again through refreshment of air the humidity close to the body is also determined). Radiation from the human body to another body or the other way around, depends on the temperature of the surrounding objects, described in the Fanger theory by the mean radiant temperature of all surrounding surfaces. Conduction is not included in the Fanger theory as it assumes a situation of a standing person which is a situation with very minimal direct contact.

The personal factors also relate to the body's heat transport systems and depend on the person's activity and situation: metabolic rate and clothing level. The metabolic rate is the energy that is generated inside the body by the body processes and is dependent on the activity of a person. Muscles consume a lot of body energy, in this process the most heat is generated and transported through the blood to other parts of the body. Therefore, the metabolic rate grows with the intensity of the activity (*Table 1: metabolic rate for different activities*).Besides the internal processes of the body, the clothing that covers the skin influences the body temperature and thus the thermal comfort. Clothing prevents the body from loosing heat dependent on the insulation it gives. The clothing level gives the insulation of different types of clothes (*Table 2: Clothing levels for different clothing*).

In the theory of Fanger all these different factors are included in a formula with which the Predicted Mean Vote (PMV) can be calculated. The PMV describes the level of thermal comfort in relation to the percentage of people that will be satisfied. Since comfort is dependent on personal factors, it is also very individual. With the same environmental conditions, some people will be satisfied while others will still be too cold or too hot. Unfortunately, for this reason, it's very difficult to satisfy everyone. However, since the percentage of satisfied people is distributed normally, it is still possible to create conditions that will satisfy a majority of people. This optimum is valued as 0 in Fanger's theory. Based on this theory, the thermally optimal conditions for the indoor environment can be calculated by setting the PMV to the optimum of 0 thus deriving the desired air temperature, radiation temperature, air velocity and air humidity from the formula.

2.2.2 Research on indoor comfort

Until very recent, all criteria for indoor thermal comfort quality were derived from Fanger's theory. However, there have been some developments that proof the theory to be not completely valid in every situation. Field measurements indicate that a discrepancy can be found between the PMV and the actual thermal sensation (Linden, 1999).
The cause of this discrepancy can be found in the following errors in the statistical model:

- While clothing is a factor that is used as input, in reality it is an adaptive variable. People actually use their clothing to remove their feeling of discomfort.
- The metabolism that occurs with specific activities is quite different from person to person and thus causes a large variation in the formula. It's difficult to take one value for the metabolism to account for everyone inside the indoor environment and there hasn't been done much research on the topic.
- The theory depends upon steady-state situations; dynamic thermal behavior is not taken into account in the statistical model.
- The statistical model only includes physical personal factors while psychological and sociological factors, like expectation and the possibility to change the situation, are important to the feeling of comfort.

- The first two errors are quite easy to solve; by varying the input data for metabolic rate and clothing level while obtaining thermal criteria the variety of adjustment and difference per person can be accounted for, although of course this variation has to be defined very carefully. The use of a steady-state model instead of a dynamic one can't be an important issue for most indoor situations since the thermal behavior in climate controlled buildings can easily be simplified to a steady-state situation. However, for the situation of a natural ventilated building, or more important the situation of a transport terminal, the thermal behavior will be much more dynamic so some of the possible discrepancy will certainly be caused by this simplified mathematical model.

According to many researches based on field measurements though, the most important argument proofs to be the theory's disregarding of psychological effects (Busch 1990, de Dear et al. 1991, Rowe 1995, Oseland 1995). In a research based on a large database of field measurements it was shown that although there might be some errors in the theory, the formula can be used to create a proper fit of the PMV with the actual thermal sensation (people's evaluation of the thermal comfort) for buildings with a centrally controlled climate system. For naturally ventilated buildings however, the tolerance for differing climate conditions is much larger than the formula can ever predict (*Figure 2.2: Static and apdaptive models for buildings with centralized HVAC and buildings with natural ventilation*).

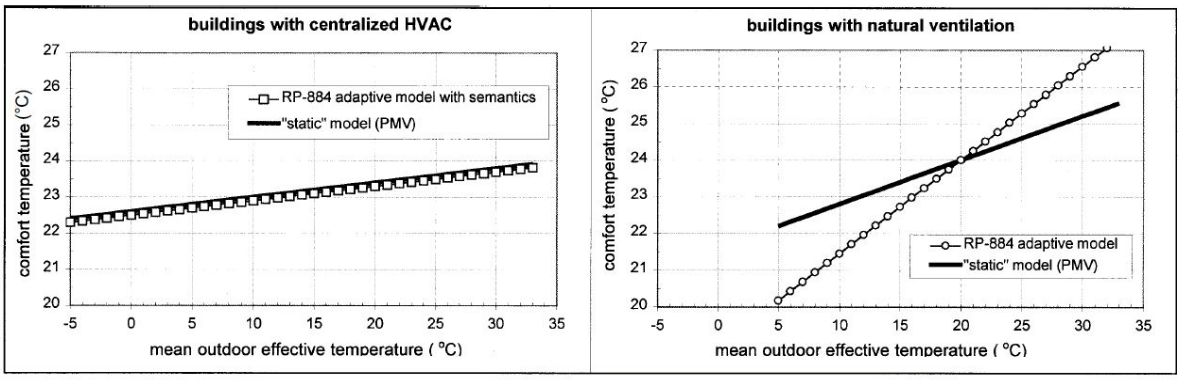


Figure 2.2: Static and apdaptive models for buildings with centralized HVAC and buildings with natural ventilation

In the same research, it is made plausible that this misfit is caused by psychological adaptation, which is developed in humans by their expectation, experience and the opportunities to personally change the situation of discomfort (Dear & Brager, 1998). In their research, de Dear and Brager propose an adaptive model, based on the theory of Fanger, which accounts for the psychological adaptation. Through linking the comfort zones of the model to average outdoor temperatures, dependent on day or month, the actual thermal sensation can be predicted quite precisely.
The contemporary opinion about indoor comfort among researchers is based on this new adaptive model. All in all, for the definition of indoor comfort, the difference with that of Fanger is very small. The environmental factors are still temperature, air velocity and humidity. The physical personal factors are still metabolic rate and clothing level. The difference is that some errors have been taken care of and that the psychological effects have been acknowledged as very important ones that can not be denied in a model for thermal comfort.

2.3 Outdoor comfort

Looking at the field of outdoor comfort, theory is not as extensive as that on indoor comfort. Research on outdoor comfort started more recently and most theories are still to be developed. Besides that, more research is needed to get a grip on the total picture of outdoor comfort. While for indoor situations the activities and the environmental conditions are quite similar in every situation, for outdoor situations the conditions but also the activities vary a lot over time and place and the situation is less controllable. All in all, the field is a lot more difficult to research and the applicability of models or criteria can be doubted. Not only because of the dependence on local climate but also because of the measurements that can be taken in order to control the situation. This is probably the reason why a lot of research is again based on Fanger's theory and the emphasis lies again on the thermal comfort.

2.3.1. Physiological Equivalent Temperature

One of the more recent theories on thermal comfort, applicable to both indoor and outdoor situations, is that of Hoppe (Hoppe, 1999). He proposes another method to express thermal comfort by translating the scale of comfort to a scale of temperatures. These temperatures are chosen so that people can relate to them referring to their own cultural, sociological and local framework. The physiological equivalent temperature (PET) expresses the thermal comfort using the circumstances of a neutral thermal situation as a basis. The thermo-physiological stress of the actual situation is then weighed against this basis to get the thermal comfort expressed in a PET value (*Figure 2.3: Examples of physiological Equivalent Temperature (PET)*). The PET value gives a better impression of the effect of certain circumstances on the feeling of comfort for outdoor situations than the PMV because the different behavior and expectance of people in outdoor situations is to some extend taken into account.

values for different climate scenarios. T_a air temperature, T_{mrt} mean radiant tempertaure, v air velocity, VP water vapour pressure

Scenario	T_a (°C)	T_{mrt} (°C)	v (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**

Figure 2.3: Examples of physiological Equivalent Temperature (PET)

2.3.2. Research on outdoor comfort

As stated in the introduction of this paragraph, a lot of research on thermal outdoor comfort is still going on. Outdoor circumstances and thermal comfort are researched by taking field measurements, taking questionnaires and doing observations. They are then related to the known models on indoor comfort in order to find differences and similarities that can lead to an outdoor comfort model on its own.

The most important conclusion based on a lot of different field measurements is that indoor models can not be directly applied to outdoor situations (Nikolopoulou & Lykoudis, 2006). This is probably caused by the errors in Fanger's theory that are mentioned earlier in the paragraph about indoor comfort. Clothing and metabolism are in an outdoor climate more variable as they are related to the type of activity and the weather itself, Fanger's steady-state model doesn't apply at all in the dynamic behavior of outdoor climate and the psychological effects that are neglected in the model are of much more influence outdoors than indoors. The errors are amplified in the outdoor situation. There even seems to be a trend towards a larger discrepancy between the Actual Stated Vote (ASV) and the Predicted Mean Vote (PMV) when the effect of the outdoor circumstances on the measured climate becomes larger. The research of the Dear (Dear & Brager, 1998); discussed in 2.2.2) shows this discrepancy for naturally ventilated buildings, Nikolopoulou shows an even larger discrepancy for outdoor situations (*Figure 2.4: discrepancy PMV and ASV in* outdoor situations) (Nikolopoulou & Lykoudis, 2006).

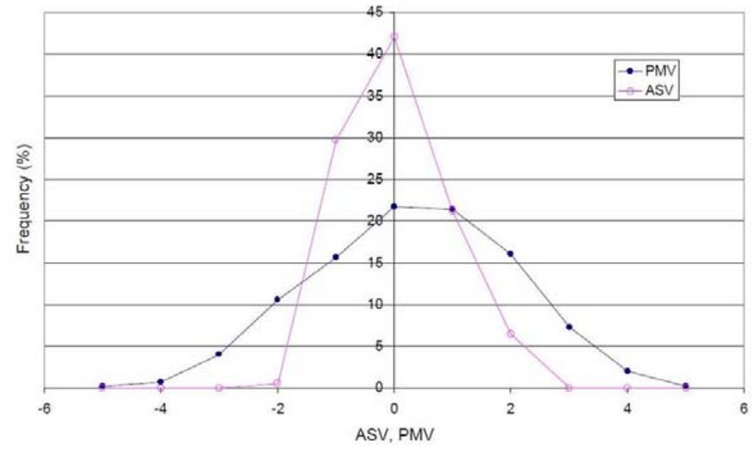


Figure 2.4: discrepancy PMV and ASV in outdoor situations

Along with the trend of discrepancy with the PMV, the level of acceptance grows for outdoor situations (Nikolopoulou & Lykoudis, 2006) (Oliviera & Andrade, 2007). People are more easily satisfied and are willing to accept less preferable circumstances. This acceptance seems to be originated from behavioral, physiological and psychological adaptation resulting in lower expectancies and a better acclimatization. Again the effects of adaptation, like that of the errors in indoor models, seem to be amplified by the outdoor situation. This is a very logical result because outdoor circumstances are more demanding on human adaptability and therefore the body will develop systems to overcome the discomfort imposed by this situation.

Although the level of thermal comfort in outdoor situations will in general be larger than for most other situations, there are some factors that can dramatically change the feeling of comfort. Unlike in indoor situations, precipitation, solar radiation, and wind play a major role in the outdoor thermal comfort quality (Nikolopoulou & Lykoudis, 2006) (Oliviera & Andrade, 2007) (Scudo & Dessi, 2006) Precipitation is of course totally neglected in indoor research and also in outdoor research not much information about the influence of precipitation can

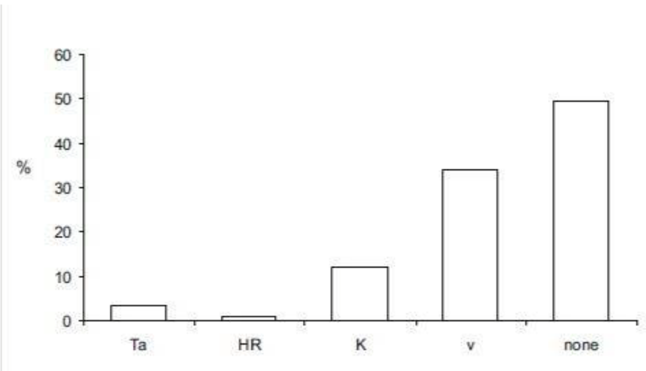


Figure 2.5Negatively reported factors in outdoor situations

be found. Probably nuisance caused by precipitation is so obvious that little has been mentioned. Air temperature and sun radiation however, are mentioned very often and are very critical to outdoor thermal comfort. Although all factors together determine the overall comfort, a slight change in either air temperature or solar radiation will influence the balance heavily (*Figure 2.5Negatively reported factors in outdoor situations.Air temperature (Ta), relative humidity (RH), suhnload (K) and windspeed (V)*).
The most intensely and most negatively perceived factor is wind. As all models on indoor comfort work with low air speeds (0,1 – 1 m/s), the influence of higher wind speeds that are more common in outdoor situations (3 – 6 m/s) has never been researched thoroughly. Wind is therefore a factor that should be looked at very carefully because while the sensitivity of outdoor situations to temperature can be incorporated in the existing models for thermal comfort, the influence of higher wind speeds cannot be translated directly into the model.

Connected to the sensitivity of the outdoor thermal comfort to these parameters is the preference for niches in outdoor climates. Inside buildings, the environment is controlled and the conditions are stable and attuned to the activities (mostly low metabolism activities). Outside though there is a time and place-dependent variety of weather scenarios in which a lot of different activities take place. In order to account for the different needs and the variations in climate, niches are very important. Especially the highly determining and fluctuating factors of solar radiation, precipitation and wind can be intercepted by creating shelter or providing shadow. “Niches” is not a term that is strictly used for climatical variety though, the term “niches” embodies the total attunement to specific activities, for example by providing seats or by avoiding glare (Scudo & Dessi, 2006).
This interest in niches is creating a tendency towards a more holistic approach towards outdoor comfort (instead of only focusing on thermal comfort). The Urban Climate Space project is a large research project that is investigating the influence of different local outdoor climates in many different places all over the world, studying the influence of architecture, psychology and climatology on outdoor comfort (Westerberg, Knez, & Eliasson, 2004. With this and other projects, science is close to unraveling the underlying principles of comfort related to person, place, space and time.

2.4 Explorative research

The previous paragraphs describe the factors that are involved in the environmental quality and especially the thermal comfort quality. They showed that indoor and outdoor comfort might depend on the same factors, but that they play very different roles in each situation. Although there seems to be a relation between the amount of influence of the outdoor climate on the measured climate and the importance of certain factors, it’s difficult to determine the interrelations of factors for a semi-outdoor climate. In order to create insight in the semi-outdoor situation of a transport terminal, a small qualitative research on comfort in railway stations in the Netherlands is done. This paragraph briefly describes the objective and the results of this research. A further explanation on the methodology, the setup and the processing of the results is added in appendix I.

2.4.1 Objective

This research is meant to give insight in comfort in semi-outdoor situations. The objective is not to extensively evaluate and investigate comfort in Dutch railway stations, it is merely to give an idea of what determines comfort in situations like this. Given the short time available for this research and the aim to only capture the essence of the problem, a very simple and fast way of researching was selected. Therefore, this research has no real scientific value and the results have to be interpreted critically. Bearing this in mind, it is still possible to answer the following research question:

What are the factors that influence the feeling of comfort in railway stations for passengers and other users and how are they related to each other and to comfort?

The research question is explicitly focused on comfort in general as not only the thermal factors but also (and maybe especially) the other factors are interesting for this research. Of course some hypotheses, based on the previous analyses of indoor and outdoor comfort, can be made. The expectance is that the same factors involved in indoor as well as outdoor comfort will determine the semi-outdoor comfort. Drawing from the results of outdoor researches there will probably be a discrepancy between the PMV and the measured value for thermal comfort, and wind will be the most intensely and negatively perceived factor. These hypotheses will be compared to the results in order to draw conclusions from this explorative research.

2.4.2 Results

The approach of this research is comparable with most researches on indoor and outdoor comfort. Outcomes of questionnaires and measurements are compared to the theory of Fanger. Although in this research the comparison is made very roughly, some observations can be made and results can be recognized from other researches on indoor and outdoor comfort.

An important outcome of the research is that all factors that are involved in the total environmental quality (thermal quality, air quality, sound quality, lighting quality, vibration quality, odor quality) are mentioned in the questionnaires. This means that indeed all factors do play a role in the overall comfort. A remarkable addition to this is that there was a lot of response on non-climatical aspects like the amount of seats or the amount of people inside the station. This has probably a lot to do with the focus of the research on the total comfort instead of only the thermal comfort; the questions in the questionnaire are very open to interpretation and explicitly meant to evoke unconventional responses (see appendix I). However, this does indicate that other aspects are essential to the feeling of comfort. Figure 2.6 shows all factors that are mentioned by the interviewees and the frequency with which they are being mentioned. From this graph it becomes clear that, as expected, wind is reported most frequently and most negatively. Another peak shows that the factor seats is at least as important and as negatively rated, although there are some positive ratings too. Because of the large response on non-climatical factors, the decision to categorize the factors is made. In general, all factors can be divided between climatical and architectural or building-related factors. The line between those two is sometimes very fine, for example the roof is strictly spoken an architectural factor while the cause of it being mentioned is probably because it gives shelter to rain and sun. Still the division between climatical and architectural aspects gives an insight in the importance of architecture and its psychological effects on comfort (*Figure 2.7: Frequency of reporting*. Physical factors: wind, acoustics, odor, air quality, lighting and temperature. Architectonic aspects: architecture, seats, organization, shelter, space, peace, business, roof.

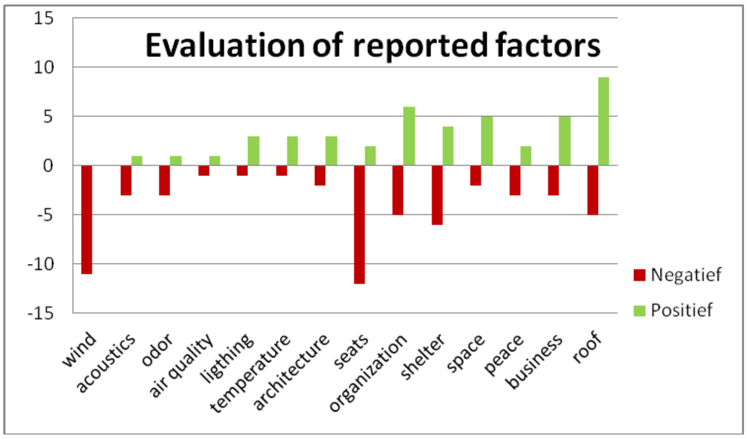


Figure 2.6: Evaluation of all reported factors: wind, acoustics, odor, air quality, lighting, temperature, architecture, seats, organization, shelter, space, peace, business, roof

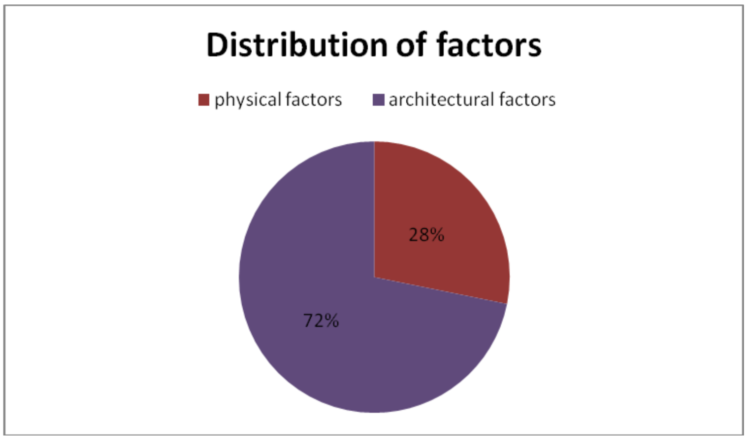


Figure 2.7: Frequency of reporting. Physical factors: wind, acoustics, odor, air quality, lighting and temperature. Architectonic aspects: architecture, seats, organization, shelter, space, peace, business, roof

The expected discrepancy between the PMV and the ASV is a lot more difficult to validate by this explorative research. Since the amount of people that are interviewed is very small and the measurements of the environmental conditions are taken from the nearest meteorological stations instead of from the location itself, there is a large error margin. The conclusion that can be drawn from this research is that in most cases the theoretical PMV does not seem to match the reported experimental PMV (average difference of 1 point at the PMV scale) and that the reported level of comfort seems to be more positive than the calculated, theoretical one (*Figure 2.8: Discrepancy between experimental and theoretical PMV*)

This result matches the outcomes of other research on comfort (Dear & Brager, 1998)(Nikolopoulou & Lykoudis, 2006) and the trend of a higher level of acceptance (and thus a higher adaptability) for situations of which the conditions are closer to the outside conditions.

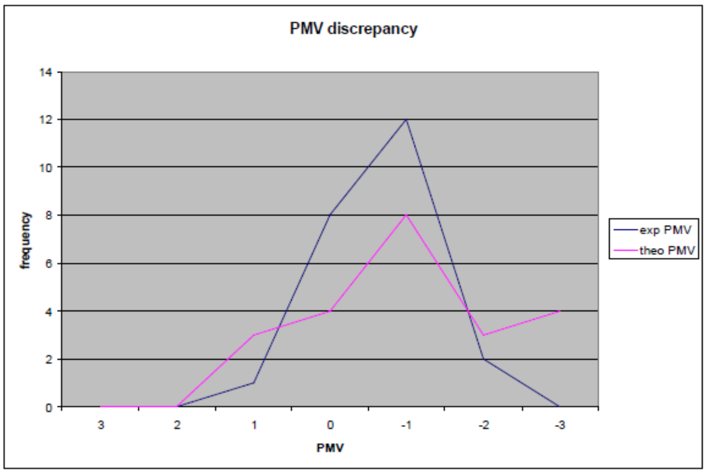


Figure 2.8: Discrepancy between experimental and theoretical PMV

2.5 Conclusion

This chapter started off with the search for a better definition of a comfortable semi-outdoor climate. The literature studies on indoor and outdoor comfort provide a clear insight in the factors that influence the feeling of comfort and to what extend this can be predicted for a given situation. The explorative research gives an indication of the importance of certain factors for a semi-outdoor situation and how to relate the situation of a transport terminal to other researches of different situations on comfort.

2.5.1 Comfort

It's very difficult to give a scientific definition of comfort. The feeling of comfort to a person is very dependent on his physical and mental state but also on his cultural and sociological background. This means that every person will have a different definition of comfort. This is why comfort is mostly described in terms of factors that influence the feeling of comfort. To what extend each factor influences comfort depends largely on the total context.

2.5.2 Factors

For each situation, the factors involved in the total comfort, appear to be the same. Environmental factors, determining the climate, are dependent on the location and are of course very important in each situation (in most researches the cases are categorized by their environmental situation). Personal factors are related to the physical systems and the senses of the body and depend on things like genetical heritage, age, physical healthiness etc. but also on the physiological adaptive systems (Dear & Brager, 1998). The last category of factors is that of the psychological factors. They cause the sociological and psychological adaptation and are dependent on the mental state of the person but also the person's experience with the situation (expected level of comfort) and the possibility to change the situation in a more desirable one. Especially the psychological factors are not researched thoroughly yet and are very determining for all situations (especially for situations that resemble the outdoor circumstances). In addition, the category covers a really large array of factors that are very different in origin. For example, the architectonic aspects are included in this category through the influence they have on the mental state of a person. Although all factors together form the ultimate validation of the situation, the psychological factors are to be dealt with care.

The explorative research shows that the influence of the architectural aspects cannot be neglected and this is also concluded in some of the researches on outdoor comfort (Picot, 2004). In fact, most of the preferences for certain architectural aspects in the semi-outdoor situation could also be related to the preference of niches in outdoor situations. The factors seats, roof, shelter and space all indicate a desire to accommodate inside the circumstances of a given situation. As stated before, the pure possibility to modify the situation adds to the level of comfort. Other aspects that are mentioned and categorized as architectural in the explorative research are organisation (of spaces and routing), business or peacefulness and the architectural appearance of the building.

While the architectural aspects are included as psychological factors, the climate aspects are the result of the interplay between environment and the human body. The way the environment determines the feeling of comfort (air flow, temperature, relative humidity) in the human body and the way the body's systems (metabolism and clothing on a secondary level) determine what environmental situation is desirable is described in paragraph 2.1. This interplay is for the thermal situation included in Fanger's theory and is what has been researched a lot. From all researches in the literature study as well as the explorative research, there is no indication that this interrelationship was incorrectly assumed by Fanger. On the contrary, probably for indoor situations this interplay has been described correctly by the formula, the emphasis on certain factors might change and some other psychological factors need to be taken into account, but the basis can still be used as a starting point. For situations that approximate the outdoor situation though, comfort is a quite different story. It is important to look carefully at the assumption of a steady-state heat transport, which could cause large errors for the dynamic flows that exist in these situations. Besides that, it is very crucial for the design of comfortable indoor, outdoor or semi-outdoor situations, that the other climate aspects are included. Environmental aspects like air quality, sound and lighting should be included to get a complete picture of comfort and all the factors that are involved. The factors of odor and vibration are scarcely mentioned in researches on comfort. Further investigations might be necessary to include these aspects too but they seem to be less connected to the other factors and thus could very well be treated separately.

2.5.3 Semi-outdoor climate

Since the factors that are at play are the same for every situation, determining the definition of a "comfortable semi-outdoor climate" depends on the sensitivity of the situation to certain factors. Once the importance of each factor and the relation between the factors is clear, criteria can be formed.

It would go beyond the time frame and profundity of a graduation project to describe a model with which the comfort in semi-outdoor situations could be predicted. The research in this project is very limited and the results are not suitable to transform into criteria. However, it is possible to draw conclusions by comparing the researches from indoor and outdoor situations, together with the explorative research to find the criteria that can be applied in the building technological research. Comparing all researches, the semi-outdoor situation (at least the one of transport terminals) tends to lean towards the outdoor situation more than to the indoor situation. The results from the explorative research seem to match more or less the results of the outdoor researches: the acceptance is much higher than in indoor situations (people are more easily satisfied), wind is the most intensely perceived factor and other factors than only Fanger's play a significant role in semi-outdoor situations. Furthermore, although it cannot directly be concluded from the explorative research, it does seem that in semi-outdoor climates, like in outdoor climates, the microclimate (niches) has to be evaluated in order to determine comfort. Adaptations to the environment cause a large variation on the level of comfort predicted by indoor models.

Although the resemblance between outdoors and semi-outdoors is large, there are some essential differences caused by the presence of a roof in semi-outdoor situations:
Air temperature and solar radiation are critical values for outdoor comfort, in semi-outdoor, this effect, especially that of solar radiation, is probably flattened out to some degree.
The factor of rain or snow is not mentioned in research on outdoor situations because the comfort is obviously very bad then, in semi-outdoor situations people value protection from the rain very much therefore it is also decisive to the feeling of comfort when the roof doesn't suffice.

Lack of lighting during the day isn't described in the outdoor research but probably plays a role in semi-outdoor situations (light at night is a different case).
Since the objective is to create a comfortable semi-outdoor situation that provides a better climate than outside it is also very important to draw some lessons from indoor comfort research:
People are more easily satisfied in outdoor situations because they don't expect a high level of comfort. In indoor environments the expectations are higher because the situation is generally more satisfying. There is a balance for outdoor, semi-outdoor and indoor situations. The criteria, drawn from the Fanger models might be too tight for the expectance of comfort in semi-outdoor situations but shouldn't be totally matched with the outdoor situation either.
The critics on Fanger's theory for indoor situations are very valuable for semi-outdoor situations too: clothing is something that can be seen as an adaptive parameter, metabolism is variable per person and per activity. Adaptive dynamic thermal comfort models can be used (in a modified way) for the semi-outdoor situation.

Altogether, the factors that determine the comfort in a semi-outdoor environment are the same as the ones that are discussed in literature on indoor and outdoor situations. Wind and seats are most definitely the factors that need attention in the design.
Criteria can be determined through evaluation of the criteria for outdoor as well as indoor situations, bearing the similarities and differences between the results of field researches for each situation in mind.

3. Methods to regulate climate

As concluded from the previous chapter, comfort is determined by the factors that influence it. These factors all have a smaller or larger contribution to the overall comfort of a place and also interact with each other. In order to create a comfortable transport terminal it is important, not only to improve one factor but to improve the interplay between those factors. This chapter is an exploration of the methods that can be used to improve the environmental factors separately but also evaluates the systems at their opportunity to influence the other factors and their interrelationship. Possible methods are selected by their sustainable and passive workings to comply with the architectural concept to create a transport terminal with a natural and friendly environment.

3.1 Wind

Although Fanger includes the factor of wind as just one of the variables in his formula for thermal comfort, the previous chapter has proved that the wind plays an especially important role in the feeling of comfort in a semi-outdoor situation. Therefore, in the rest of this report, wind is taken as a subject on its own in the whole subject of environmental quality.

Like for almost all physical aspects, there's a balance between too much and too little wind. Too much wind causes people to be cold or disturbed or even in danger of falling over, too little wind causes problems with moisture and air quality. The key to create a situation with a comfortable climate is to find a balance between the two.

3.1.1 Current situation

To achieve the balance that is described above, there are a few common methods, divided in indoor and outdoor methods. Because of the differing demands of the situations, there's a difference in approach. Since the comfort zone involved in this report is a semi-outdoor situation both approaches are described here.

Air flow has always been an important issue in building. Whereas the first buildings could only block the wind and give a little shelter, as glass was discovered, buildings grew ever more wind tight and problems with moisture and air quality arose. In the past, this problem was solved just by infiltration through leaks in the construction and by opening windows (Stichting Kennisbank Bouwfysica, 1999). Nowadays, in most buildings mechanical ventilation systems that press the air through the building are used. Often there is a combination of mechanical with natural ventilation which provides the possibility to open windows. With the trend of sustainability and renewable energy, natural ventilation is getting more attention again and the principles of air flow (difference in pressure caused by wind or by temperature) are being used to really design natural ventilation systems that can control the air flow coming in.

In the outdoor situation the issue with wind is a bit different. The problems with air quality and moisture almost never occur while nuisance and thermal comfort problems occur very often. These problems in outdoor situations have been neglected for a very long time. Only since the past 50 years there is more attention for wind in outdoor situations and it’s found out that wind speeds in the built environment can be three times higher than in open field while at some places there is no wind at all.

Especially these differences influence the feeling of comfort negatively.
To improve the situation in the city, in many cases wind screens or green is being placed to block the wind at the places where people stay. Better methods are to take wind problems into account at the design stage. A lot of research has been done to get a better picture of the way urban patterns and building shapes influence wind behaviour (Bottema, Blocken, Visser). However, there are quite a lot of bridges yet to take; wind is very dependent on the specific properties of the location, preliminary designs are very difficult to test and behaviour of wind in urban situations is very unpredictable.

3.1.2 Possible methods

From the chapter about comfort it can be concluded that the semi-outdoor situation resembles the outdoor situation and the critical problem will be too high instead of too low wind speeds. Most of the methods that are used outside can‘t directly be applied to the semi-indoor situation though. The scale of the outdoor methods (whole neighbourhoods) is quite different from that of most semi-outdoor situations (atria, railway stations, terminals). Besides, the criteria for the semi-outdoor situation will probably be higher too. Another reason why the semi-outdoor situation is different is because the presence of a (large) roof can cause significant overheating problems in case of lack of wind in summer. This problem will be discussed in the next paragraph about temperature.

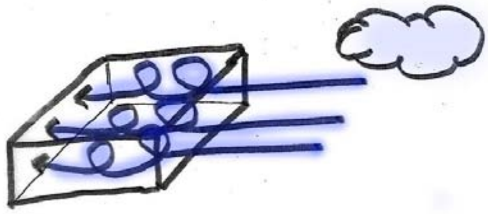


Figure 3.1: Slowing down the wind by volume using the principles of natural ventilation

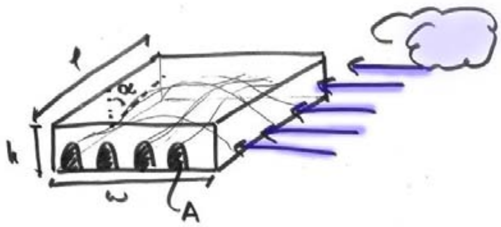


Figure 3.2: Reducing the wind inside the building by using shape and openings

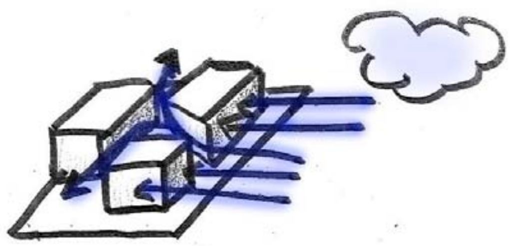


Figure 3.3: Blocking the wind using volumes inside the building

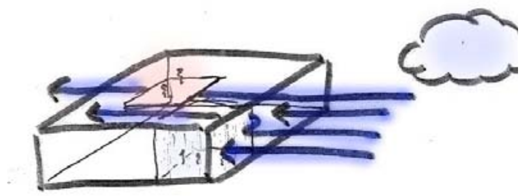


Figure 3.4: Placement of functions according to different demands of wind comfort

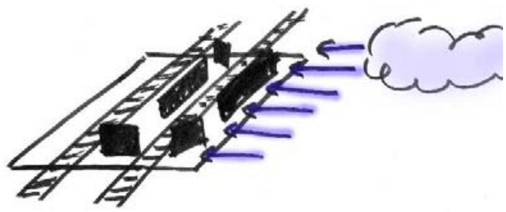


Figure 3.5: Blocking the wind by the placement of wind screens

One of the possible methods to avoid nuisance and discomfort from hard winds is to use the principles of ventilation for the purpose of slowing down the wind speed. Avoiding or reducing the difference in pressure is the key to this method for example by avoiding passages that connect one side of the building (over pressure) with the other (under pressure) or by

enlarging the volume of the building directly after the opening *(Figure 3.1: Slowing down the wind by volume using the principles of natural ventilation).*
Relating to the principles of reducing the difference in pressure is the method to reduce over pressures at the upwind facade by shaping and dimensioning the building in such a way that wind can easily flow around it (*Figure 3.2: Reducing the wind inside the building by using shape and openings*). The downwind facade should then be shaped in such a way that the disturbance of the building in the wind profile is as small as possible and the flow pattern can recover, this will reduce the under pressure at this side of the building.
Another possibility is to organize the internal volumes in such a way that the wind can smoothly move around them so that no extra high wind speeds will occur (Figure 3.3: Blocking the wind using volumes inside the building). This can also be turned the other way around; functions can be placed where the risk of high wind speeds is low (*Figure 3.4: Placement of functions according to different demands of wind comfort*).
The last method is drawn from outdoor situations and is usually seen as the last resort; the use of wind screens or green to block the wind (*Figure 3.5: Blocking the wind by the placement of wind screens).* If tactically placed at spots where wind speeds need to be extra low the method can work very well because directly behind the screens there will be no wind at all. However, the risk of higher wind speeds around the screens is high, dependent on the height and length of the screen. The use of porous screens or trees partly solves this problem by allowing some of the wind to flow through but the situation behind them is of course not as good as with screens that totally block the wind.

3.1.3 Opportunities

The first method of using the principles of ventilation is very interesting because ultimately, reducing the pressure difference is the most effective method to reduce the overall wind speed in the building. This method is applied in the ECT terminal in Rotterdam designed by Van den Broek and Bakema (*Figure 3.6: Application of the principles of natural ventilation in the ECT terminal in Rotterdam*). To really regulate the wind and find a balance between too little and too much wind might be a problem though because regulating natural ventilation without the use of adaptable systems is difficult.

Figure 3.6: Application of the principles of natural ventilation in the ECT terminal in Rotterdam

Drawing also from the principle to reduce difference in air pressure using the shape of the building is an effective method too. Quite a difference can be achieved by optimizing length and width. About further modifications of the shape by using curves and free-form shapes little is known but the idea is promising. Not only to create a comfortable climate but also to find interesting architectural shapes.

Organizing volumes or windscreens inside the building or attuning the functions of the spaces to the wind conditions are methods that can be combined with other methods easily (for wind as well as for other aspects). Instead of organizing the volumes or windscreens it might be better to not make them at all since the effect of creating higher wind speeds is undesirable. To create niches though, volumes, screens and green provide good opportunities in a design.

3.2 Temperature

A lot of research has been done on thermal quality; it's one of the most obvious factors to influence the environmental comfort quality. People directly experience a sensation of cold or heat when the temperature is not well controlled. Subsequently this sensation is directly linked to a feeling of discomfort. Although this linking of temperature to comfort is less strong in semi-outdoor situations, it's still a determining factor that has to be treated carefully. Too hot or too cold circumstances will definitely ruin the feeling of comfort although the other factors are taken cater of.

In the semi-outdoor situation this means that it's not necessary to regulate the temperature to a fixed degree. What is necessary though is to keep it between the boundaries of acceptable temperatures and not to exceed extreme temperatures.

3.2.1 Current situation

A lot of methods for regulating temperature are available, conventional as well as more innovative and sustainable. Just like in the case of wind, there are methods used for inside situations and ones for outdoor situations and the challenge is to find a balance.

Indoor temperature is generally regulated by heating in winter and ventilating in summer. In cold climates it's important to build wind tight and with insulating materials to keep the cold outside. In summer, a combination of sunscreens and ventilation is generally enough too cool down the building sufficiently. In hot climates the heat has to be kept outside. Before air-conditioning was invented, this was done by using heavy materials that could absorb the heat and by using intelligent natural ventilation principles. Another tactic was to keep the heat outside by using insulating materials like in the winter situation for cold climates. Nowadays, a lot of the cooling is done by mechanical ventilation through air-conditioners in combination with the prevention of solar heat by the use of sunscreens. The heating is mostly done by convectors but there is a tendency towards radiation heating through heating systems in the floor.

Outdoor temperature regulation seems to be an expertise that is taken care of by landscaping architects and other designers of public spaces. There are quite some known methods to improve the thermal comfort in parks and squares but they don't seem to be researched scientifically until very recently. Regulating temperature in outdoor situations depends largely on blocking the sun for hot days and on sheltering from rain and wind for cold ones. To block the sun, sun screens, parasols but also trees are very effective. Trees also add the effect of evaporative cooling to lower the temperature. Water is also used for this purpose apart from providing people a place to refresh themselves. In cold circumstances wind screens and plants are used to block the wind (Scudo & Dessi, 2006). A new development is to use local radiation heating (for example the red lights above terraces) to create niches with a warmer climate.

3.2.2 Possible methods

Temperature control in semi-outdoor situations is very difficult. Because of the semi-situation, people expect a better thermal comfort than if they would be outside the building but the conditions are still very comparable with the outside situation. This means that apart from the shelter against rain and wind that the building provides, there are no passive methods to provide a warmer climate in extreme situations without sunlight. Therefore, in order to create some warmer spots, the active local radiation heating should be considered. For the summer situation there are a lot of methods that can be used to prevent too high temperatures or to lower them. For less extreme winter situations there are some opportunities to use direct sunlight as a heating source.
The first measurement that effects both winter and summer is the choice of building materials. The balance between transparent and opaque, reflecting or mat, heavy and light and good and bad insulating materials determines the heat gain and heat loss of the space (*Figure 3.7: Regulating the amount of heat coming in and going out by the material properties of transparency (ZTA) and insulation (w)*). By choosing the materials carefully, both situations can be accounted for. There are even some materials that capture solar energy by turning opaque when a lot of direct sunlight is coming in so that there is less heat gain. When the sunlight is gone, the material releases the heat and becomes transparent again (Kristinsson, 2002).

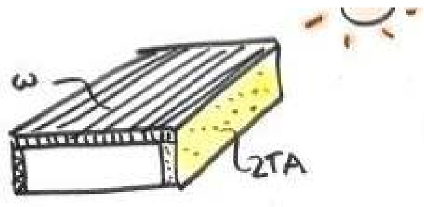


Figure 3.7: Regulating the amount of heat coming in and going out by the material properties of transparency (ZTA) and insulation (w)

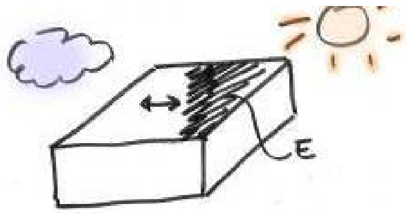


Figure 3.8 Blocking the sunlight with phase-change material using solar energy (E) to darken

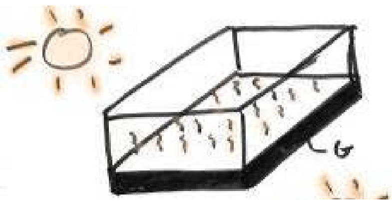


Figure 3.9: Using the thermal mass of the floors as a buffer

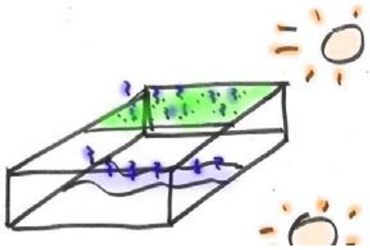


Figure 3.10: Cooling down by evaporation from water and green

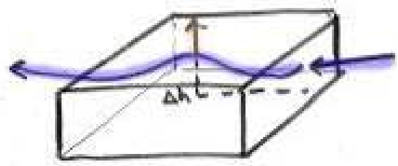


Figure 3.11: Cooling down by ventilation using the heat-stack effect

Another form to use transparent and opaque materials to regulate the temperature is in the form of sun shading (*Figure 3.8 Blocking the sunlight with phase-change material using solar energy (E) to darken*). By placing the shading screens in a certain pattern or in a certain angle the situation can be optimized to prevent heat gain in summer but at the same time allowing direct sunlight and heat gain in winter.
The method of buffering is actually also based on the material property of high density which causes a material to absorb heat. It is listed as a different method here because thermal mass can be created from other than just building materials. Building below ground level makes the ground itself a buffer and water is an excellent buffer too. Heat is absorbed in the material and released with a little delay and when the outside temperature is lower than that of the material (*Figure 3.9: Using the thermal mass of the floors as a buffer*).
The use of the evaporative cooling effect of green and water is also an option (*Figure 3.10: Cooling down by evaporation from water and green*). In a hot environment water evaporates and plants and trees tend to "sweat" by evaporating water encapsulated in the leaves. Evaporation is the effect of water using heat energy to change its physical state from fluid to gas. The amount of water that can be evaporated also depends on the relative humidity. Additionally, plants and trees provide shadow when it is needed most, while allowing light and heat from the sun in winter (if they lose their leaves).
A widely used method to regulate the thermal comfort is ventilation. By blowing fresh air into the building, the hot air is transported outside (*Figure 3.11: Cooling down by ventilation using the heat-stack effect*). For the passive and sustainable method of natural ventilation the amount and placement of openings in the building play an important role. For extreme summer situations when no wind is blowing, the natural ventilation depends entirely upon the heat stack effect (air flow caused by difference in pressure from difference in temperature). This effect is driven by the rise of hot air so a low inlet and a high outlet are optimal.
Like for the aspect wind, for the temperature it would be especially useful to look at the placement and orientation of the functions in relation to the circle of the sun. The spaces that are not directly used by people can very well be too hot but only if this doesn't cause problems for the spaces that are occupied.

3.2.3 Opportunities

For thermal methods, there are a lot of opportunities. The choice of materials has to be made in every architectural project and it's easy to at least regard the possibilities of using material properties and the buffering effect of heavy materials to regulate the thermal climate. In fact, this is being done in most projects already but finding the balance so that the system works in winter as well as in summer is the difficult part. Sun shading is already used as a solution to this problem but is quite determining for the appearance of the building and quite often, the sun shading contradicts with the architectural concept. Still, if the principles of these methods are considered together with the first conceptual ideas, there are great opportunities to implement these methods. Conflicting demands from winter and summer situation as well as those of the other aspects (lighting and sight, construction and acoustics) have to be dealt with very carefully.

Using green and water inside a building is not as easy as it sounds, although in semi-outdoor situations, the opportunities are there. For the plants to survive, the semi-outdoor climate has to be as close to the outdoor climate as possible. Plants need the fluctuations in temperature (day and night but also seasonal) and a high lighting level. The use of water is a little bit easier but a high ventilation rate is needed to transport the moisture that comes along with it and often a high level of maintenance is needed to keep the pool or fountain clean. In addition, both water and green need a thick and heavy floor to carry them, this does also work as a buffer however. While the application of this method might be difficult; it's still a challenging method to use in the design. The architectural opportunities of green and water to enliven and at the same time soften a space are very interesting.

Ventilation is again a very effective method but hard to control. By placing openings at the right spot and by making use of the effects of the wind, a lot can be accomplished. The conflict between the demands of summer and winter are numerous though. In winter, wind has to be kept outside and in summer preferably all the available wind is used. Still, an adaptable system or a clever use of the heat stack effect in summer and lowering the pressures in winter could lead to very beautiful and sustainable solutions.

3.3 Air quality

The factor air quality is not included in the models on thermal comfort; it does however play an important role in the environmental quality. A difficult problem with air quality is that, only for very extreme situations a poor air quality can be sensed directly by the human body. Poor air quality might be sensed through smell or irritated eyes and nose but most of the time people will just feel sick after being exposed to a poor air quality for a while (Thomson Higher Education, 2007). Therefore, air quality is not directly connected to the feeling of comfort but can be determining for long term stays.

3.3.1 Current situation

In the recent past, there wasn't much attention for air quality, exactly for the reasons stated above; good or bad air conditions are difficult to detect by the human body, the problems were always searched elsewhere. Nowadays, the attention for air quality is growing for indoor as well as outdoor situations.

Indoors, air quality is determined by the materials and the organisms (including humans) that are inside. In a totally closed environment, humans would simply ultimately die of lack of oxygen, which is the most important component in air to assure good air quality for humans. Other organisms like bacteria, moulds and fungi and building finishing materials like plywood, paint or textile all pollute the air in different ways (U.S. Environmental Protection Agency, 1995). In most cases, ventilation, mechanical or natural, is the solution to this problem. Ventilation refreshes the air and in doing so, lowers the concentration of pollution in the air. Ventilation also prevents the air and the surrounding material of becoming too moist; a moist environment stimulates the growth of fungi, moulds and bacteria. Most mechanical ventilation systems also have a filter to extract the polluting particles (in outside air as well as inside) from the air. Other measurements include avoidance to use "bad" materials or to remove or exclude pollution (Straube & Acahyra, 1998).

The outdoor situation is somewhat different from the indoor situation since the polluters are much less controllable than in indoor situations. Polluters in the outside environment are by-products from industry, cars and from volcanic outbursts and other processes in nature (*Figure 3.12: Outdoor polluters*).

Conventional ways of treating the problem of poor outdoor air quality are to avoid the area or to encapsulate the source like for example placing screens along highways. Lately, a lot is being done to reduce pollution by reducing the burning of fossil fuels which for the largest part causes the pollution from industry and cars.

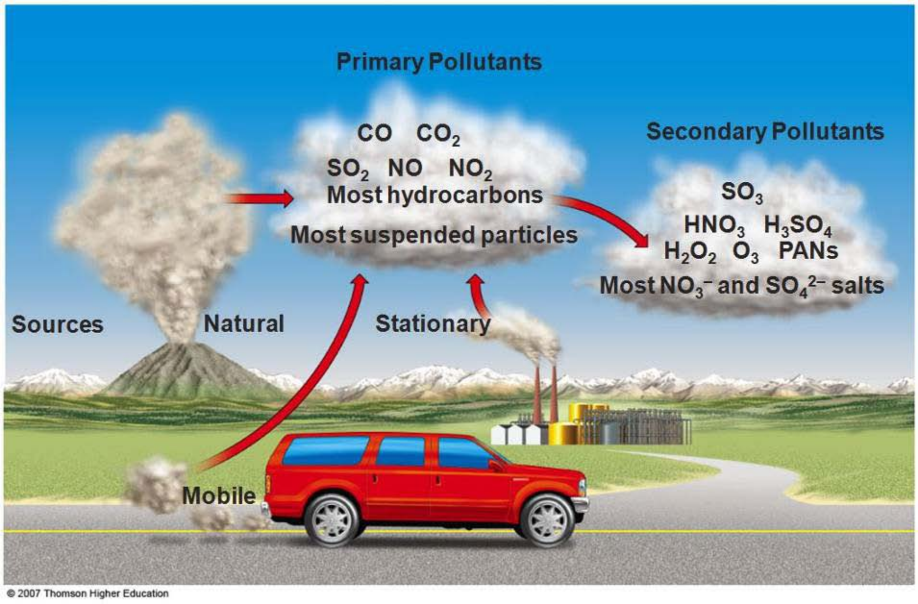


Figure 3.12: Outdoor polluters

3.3.2 Possible methods

To deal with the problem of poor air quality in a semi-outdoor situation, there are a few methods that can be used.

The first method, derived from an indoor method, is natural ventilation (*Figure 3.13: Refreshment of air by natural ventilation*). In most semi-outdoor situations, the necessary openings to use natural ventilation are already available. For the system to really clean the inside air, it's important to use fresh air from outside that is not already polluted. In rural areas or near highways, the air at ground level might be too polluted. Clean air must then be drawn from greater heights for example by placing the inlets at a high level or by using the building to guide the air from a high level downward.

Another possibility is to use materials that can absorb pollutant particles or that react chemically with them. Materials with a high porosity but with small cells are perfect to imprison the particles so that they are extracted from the air (Straube & Acahyra, 1998). This method works best in combination with ventilation so that the particles can be led along the surface of the materials. Using a particle absorbing material with a rough surface for the floor will also improve air quality because particles that sink to the floor won't be stirred up and return in the air again (*Figure 3.14: Capturing of particles by absorbing materials with a rough surface*).

Filtering is actually a variation on the method of using absorbing materials. Porous material is placed perpendicular to the direction of the air flow so that the air is pushed through the material and the particles are extracted (*3.15: Cleaning air by filtering*). For this method, a quite large amount of air flow and air pressure is necessary.

One of the most sustainable and effective methods is to use the filtering capacities of plants and trees (*Figure 3.16: Capturing and processing of particels by plants and soilFigure*). The configuration of the branches and leaves create a filter that catches the pollutant particles and attaches them to the leaves. The particles stay attached to the leaves until rain washes them away. Then the actual processing of the particles begins; the soil and the roots work as a biochemical filter that breaks down the contaminants (Kristinsson, 2002). However, the most important cleaning capacity of plants lies in the process of photosynthesis. By photosynthesis the glass house gas carbon oxide is directly taken from the air by the leaves and oxygen is given back.

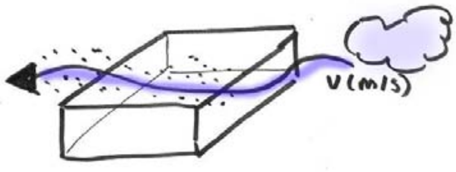


Figure 3.13: Refreshment of air by natural ventilation

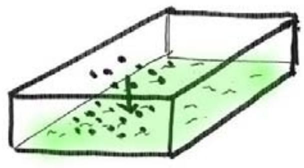
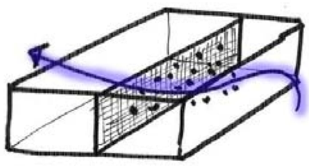


Figure 3.14: Capturing of particles by absorbing materials with a rough surface



3.15: Cleaning air by filtering

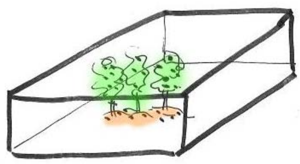


Figure 3.16: Capturing and processing of particels by plants and soilFigure

3.3.3 Opportunities

The proposed methods can be divided into methods that extract particles from the air and methods that reduce the concentration of contaminants by refreshing the air. For all methods air movement is necessary or at least useful. Thus the method of natural ventilation can be used to improve the workings of the other systems while the ventilation itself also improves air quality. Plants and absorbing floors don't need an air flow since gravity also directs the particles towards the systems. The methods of filtering or the use of absorbing materials in the walls do need a directional air flow. Since the design doesn't allow a mechanical system, this means that the latter are dependent on the workings of the ventilation system and are likely to fail if there is no wind and the air speed is not sufficiently high.

3.4 Acoustics

One of the climate aspects that didn't get so much attention yet is sound quality or acoustics. The acoustics can be very important, especially in concert halls and cinemas but also for buildings that have other purposes the sound quality is important. Bad sound quality can cause people to be disturbed by noise or be disoriented. Disorientation is caused when the visual information does not match the sound information this happens for example if a large room would not echo at all. In addition, the acoustics inside a building determine the clarity of speech, which is very important for human conversation.

3.4.1 Current situation

Inside buildings (especially dwellings) a lot of acoustical measurements are taken in order to keep the sound level (loudness) and the reverberation time (reflection of sound waves) low. Noise from traffic or people outside is isolated by using heavy materials or absorbed by using porous materials. Contact noise, like the sound of footsteps on a floor is reduced by creating flexible contact points in the detailing or by using sound isolating materials for the floors. Inside the building to ensure clarity of speech and to provide the acoustical quality to play music etc. absorbing materials are placed along the walls. In most cases, carpets, curtains and furniture also contribute to keep the reverberation time low.

Outdoors, there's a lot less attention for acoustics. Most of the time, no attention is needed because the surrounding amount of air reduces the sound level and reverberation time sufficiently. In urban areas and around highways however, some noise control is necessary. The first approach is always to reduce the noise at the source; a lot of research on how to make cars more silent is going on. The most frequently used methods are then to encapsulate the source by isolating materials or to place reflecting or absorbing screens. In public urban areas, sometimes the reverberation time is reduced by using absorbing materials like wood or isolating ones like concrete.

3.4.2 Possible methods

In semi-outdoor situations, both problems of indoor and outdoor situations occur. However, the acoustic demands are very dependent on the function of the building; functions like dwelling or offices require very low sound levels while for most public functions (which are most likely for a semi-outdoor setting) low sound levels would be a bit confusing. Besides that, the problems of too much reflection (echo) and induction (contact noise) can, as in outdoor situations, be solved quite easily because of the large amounts of air inside the space. This means that the situation is more comparable with an outdoor situation where the traffic noise is determining. Still, to overlook the possible sound problems would influence the comfort negatively.

The most logical method of reducing the sound at source is of course always the most effective method and is the one that should be pursued before applying other methods (*Figure 3.17: Reducing the noise at the source*).

From the previous paragraph it already becomes clear that the use of material properties is for acoustics, like for temperature, very determining. Absorption, reflection, isolation and induction of sound are all determined by the material properties. The building materials should be considered from an acoustical point of view, besides the thermal point of view. In addition to that, certain properties of materials can be used in the form of tunnels (*Figure 3.19: Capturing noise by encapsulating source with isolating and reflecting material*) or screens (*Figure 3.18: Absorbing sound waves by screens of porous materials*) Instead of artificial screens, green fences can be used too; the structure of the branches and leaves absorbs a certain amount of sound waves (Freeman, 1995)

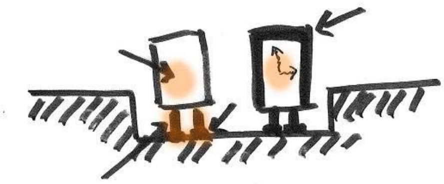


Figure 3.17: Reducing the noise at the source

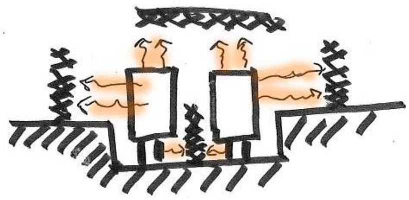


Figure 3.18: Absorbing sound waves by screens of porous materials

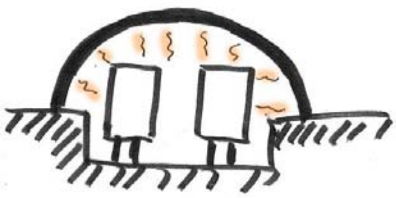


Figure 3.19: Capturing noise by encapsulating source with isolating and reflecting material

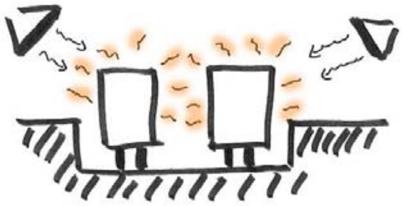


Figure 3.20: Even out the noise by anti-noise

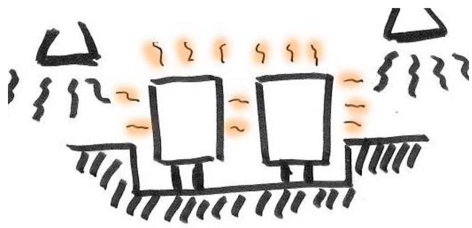


Figure 3.21: Overpowering the noise with friendlier noise

Possibilities that form a total different category are the ones that will help to overcome the problem without actually reducing sound level or reverberation time. One is to produce anti-noise that flattens out the sound waves of the noise from the initial source (*Figure 3.20: Even out the noise by anti-noise*). Another option is to overpower the noise that is already there by a more comfortable noise (*Figure 3.21: Overpowering the noise with friendlier noise*) like for example the overpowering of traffic noise by the sound of streaming water like is done on several places in New York.

3.4.3 Opportunities

As mentioned before, the most effective way to reduce sound levels is by reducing the noise at the source. A lot of research is going on to make cars, trains, trams and airplanes more silent (ProRail, 2007). For most situations though, this method is beyond the domain of building and is therefore dependent on other parties.

The use of material properties to create a good acoustical ambience is a method that is proved to be working in the building industry. If used in a semi-outdoor situation merely in the building itself, the materials could work to reduce the reverberation time or reduce contact noise but to lower the sound level is a more difficult problem because of the open nature of a semi-outdoor building. To create a silent space, closing off the room is necessary. Reducing the sound level can be accomplished by using sound screens, green fences or tunnels around the source. The most effective way is to encapsulate the noise by a tunnel, allowing none of the noise to escape. In most cases though, it is very difficult to completely close off the source. The use of screens or fences has good opportunities then, although the tactical placement of these elements is very determining and the architectural appearance is very much influenced by these methods.

Using anti-noise will be very difficult to reduce traffic noise in semi-outdoor situations because it is very dependent on the direction of the sound waves, from the source as well as the emitter of the anti-noise. This makes it difficult to create more than one specific place of silence because the emitter can only direct towards one spot. A moving source like traffic is therefore problematic too. The other option of overpowering the noise is of course a last resort because the mere presence of a high sound level is not only annoying because of the nature of the sound but also the sound level and moreover because of the impact on the physical health of a person (tiredness or headache).

3.5 Lighting

The last factor that makes up the balance of comfort is the lighting quality. In this chapter it is the last factor that is being mentioned but that does not mean it is less important. In fact, it might be one of the most important aspects on comfort. People need light in order to see and the human biorhythm of sleeping and being awake is determined by daylight. The absence of light would thus be totally uncomfortable as would be an overdose of light since this can be blinding. Good lighting conditions are more subtle though and are often overlooked.

3.5.1 Current situation

Inside buildings, the presence of light is very important. Daylight is allowed inside through windows in the facade or in the roof. In the places where daylight cannot penetrate far enough, artificial lighting is added to keep the lighting level high enough for people at least to be able to see without trouble or at best to read without effort. Often, reflecting walls or ceilings are used in combination with artificial lighting. At places where there is too much direct sunlight or where the contrast between the lighting levels becomes uncomfortable for the eye (glare), sun shading or glare protection is used. At night, artificial lighting is used to illuminate the spaces.

Outdoors, the situation is quite different. During the day there is always sufficient lighting for people to see and read so additional lighting is unnecessary. Too much (direct) lighting and glare are determining problems in outdoor situations. The measurements are comparable to that of the indoor situation; sun shading in the form of parasols, sun screens or trees and glare protection and protection against too much lighting in the form of sunglasses. At night the situation is very difficult. Indoors there are enough walls, floors and ceilings to reflect the artificial lighting so that a bit of light already creates a high illumination level. Outdoors, the floor is often the only reflector and a lot of artificial lighting is needed for a place to be comfortable. In addition, outdoor spaces are often larger in dimension so that the problem of artificial light (which is much weaker than sunlight) not penetrating far enough becomes relevant.

3.5.2 Possible methods

Since the problems for indoor and outdoor situations are quite different, the methods to avoid these problems are quite different as well. For the semi-outdoor situation, the problems of both situations can occur.

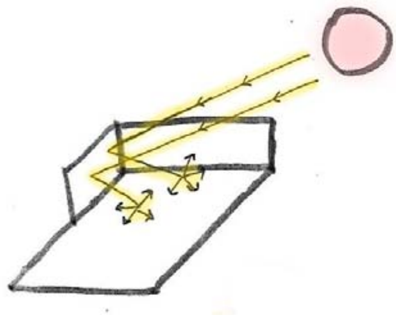


Figure 3.22: Enhancing the lighting conditions using reflective or light colored materials

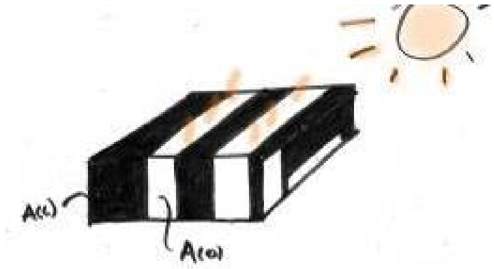


Figure 3.23: Allowing light to enter the building at the right place by the composition of transparent and opaque materials

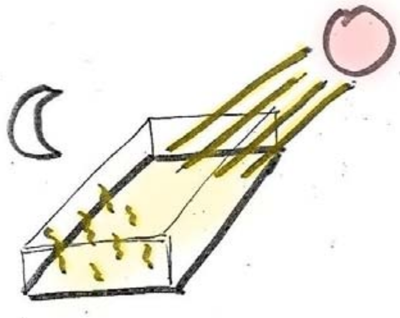


Figure 3.24:Lighting at night by the use of photoluminiscent material

The first and most obvious method is used in both indoor and outdoor situations; clever use of material properties. Just like the other aspects, lighting conditions are for a large part determined by the properties of the surrounding materials. Transparency, reflectivity and colour are the properties that influence lighting. In outdoor situations good materialization can avoid problems with glare. For indoor situations, materialization can do a lot. Like in outdoor situations it can minimize glare but it can also work the opposite way; reflective or light coloured materials can really improve the efficiency of the available light sources (*Figure 3.22: Enhancing the lighting conditions using reflective or light colored materials*). Obviously the transparency of a material, especially in the roof or in the facades, determines the amount of incoming daylight.

Related to the method that uses material properties is the method of using the configuration of the materials in the envelope. The amount and area of transparent materials determines the total amount of light coming in (*Figure 3.23: Allowing light to enter the building at the right place by the composition of transparent and opaque materials*).

Depending on the composition of the facade, the orientation of spaces in relation to the facade can contribute to good lighting conditions for the assigned functions.

To avoid glare or too much lighting, shading devices can be used but trees also provide a good alternative.

For the situations where day light is not penetrating sufficiently to provide good lighting conditions or for the night situation, there are not much passive methods. Reflective materials can be used in the form of light tubes that transport day light from the envelope further inside the building. There is another possibility that is certainly very sustainable and very charming; the use of photoluminiscent material. Photoluminiscent material charges during the day, capturing the light energy. At night this light energy is released again in the form of lighting. However, further research is needed to investigate the efficiency of this method (*Figure 3.24:Lighting at night by the use of photoluminiscent material*).

3.5.3 Opportunities

The methods used for lighting can be divided into four categories: light allowing, light enhancing, light avoiding and light providing methods. As stated before, the semi-outdoor situation experiences all problems, thus all methods are relevant. Different from the outdoor situation though, the most influencing methods are the use of the material's transparency and the composition of transparent and opaque areas in the envelope. These methods determine the amount of light coming in and thus the necessity of other additional methods to enhance or avoid lighting.

Shading is probably not needed frequently because the presence of the roof but dependent on the transparency of the roof, extra shading might be useful. Shading in the form of trees is then preferred because a shading system can be very fragile and might not be so suitable for semi-outdoor situations.

Different from the outdoor or indoor situation, semi-outdoors the factor of light at night to guarantee safety seems to play a very large role. This is why the method to use photoluminiscent material to light spaces at nigh is a very interesting one. Besides, this method has a great architectural opportunity as well.

3.6 Conclusion

There are a lot of sustainable and passive methods that can be used to regulate the climate inside a building. This chapter is only a mere investigation of the possibilities and opportunities and there are probably some methods that haven't been mentioned but it gives a good impression of the range of possibilities for sustainable methods to regulate climate. A precise estimation of each method's performance can only be given when applied to a building. However, this chapter shows the way different methods can be applied to the situation of a semi-outdoor building and it shows examples of the way they are applied in other situations. This way, it gives an indication for the range of methods that are interesting to use in a transport terminal.

To reduce wind problems in the semi-outdoor situation, the reduction of pressure difference by either principles of natural ventilation or by shape and openings is proofed to be effective. Especially for semi-outdoor situations it is very useful since it is not possible to completely close the space. Placing screens, green or building volumes in order to create lee places are methods with a lot of negative effects but they are very effective to create real comfortable niches.

Good thermal comfort in semi-outdoor situations is very dependent on the amount of sunlight entering the building and the amount of heat exiting the building thus on the materials used in roof and walls and the openings in the building determining the wind flow through it. To control this, a good natural ventilation system and the right choice of materials for roof and walls or a good sun shading system are always crucial (this also applies to most buildings with active systems). The use of green and water to cool in summer are additional methods that are difficult to apply but can be very effective.

To create a good air quality, ventilation is always the most effective method. In active systems, the combination of airflow through a filter even improves the inlet air quality. For passive systems though, this method won't work properly. The use of the right materials with the right detailing will definitely prevent a lot of problems although for most semi-outdoor situations there is enough air flow not to experience the problems with 'bad' materials. About the use of absorbing materials little is known but a rough surface on a floor might help to capture particles. The use of specific plants and trees has proven to be a really effective method to improve air quality.

For acoustics, the most effective method is always to reduce the noise at source. Material properties can also be used to absorb or isolate noise. That last one is quite difficult because isolation is only possible when the noise is completely banned and in semi-outdoor situations there are always too much openings. A good solution is then to use sound screens or green to reduce the noise. However, tactical placement is crucial then.

To create good lighting conditions in semi-outdoor situations, the transparency of the materials in the skin and the amount of transparent area need to be balanced. Designing with this method is really quite effective because it determines the conditions in the first place. The use of reflectivity and colour of materials can improve lighting comfort but need to be used in combination with other methods. The method to use photoluminiscent material to light up spaces at night has potential but needs further research.

4. Development of research and design

Now that the definition of comfort in semi-outdoor climates is given and the methods to create this comfort are investigated, the research can be applied to the design of a transport terminal at the Prins Clausplein. The factors that determine comfort - wind, temperature, air quality, acoustics and lighting - are very dependent on the location of a building. The exact demands for each factor are very dependent on the function of a building. In this chapter, research on the climate system and the design of a transport terminal at the Prins Clausplein are being developed together, interacting with each other, making the output of the research influence design decisions and the other way around.

4.1 Site analysis

The location of the transport terminal poses a lot of boundary conditions to research as well as design. It is a starting point to create a design that really fits into its surroundings and it provides the research with an exact input of the environmental conditions.

4.1.1 Infrastructure

In the introduction of this report, the location Prins Clausplein with all its infrastructural connections and opportunities was discussed. The exact site of the design is at the crossing of the boulevard (the regional route and artery of the urban plan) in one direction and the highway and railway in the other. Since cars can only access the site from other, slower routes, the highway doesn't have a direct connection with the building. For the railway and the boulevard with regional car traffic, busses, taxis, trams, Randstadrail and of course bikers and pedestrians, there can be a relation. Besides that, one of the green links from the urban vision connects the site and the Vliet with the other side of the highway and Ypenburg (*Figure 4.1: Analysis of the urban plan and the directions of the infrastructure with the site for the transport terminal indicated*).

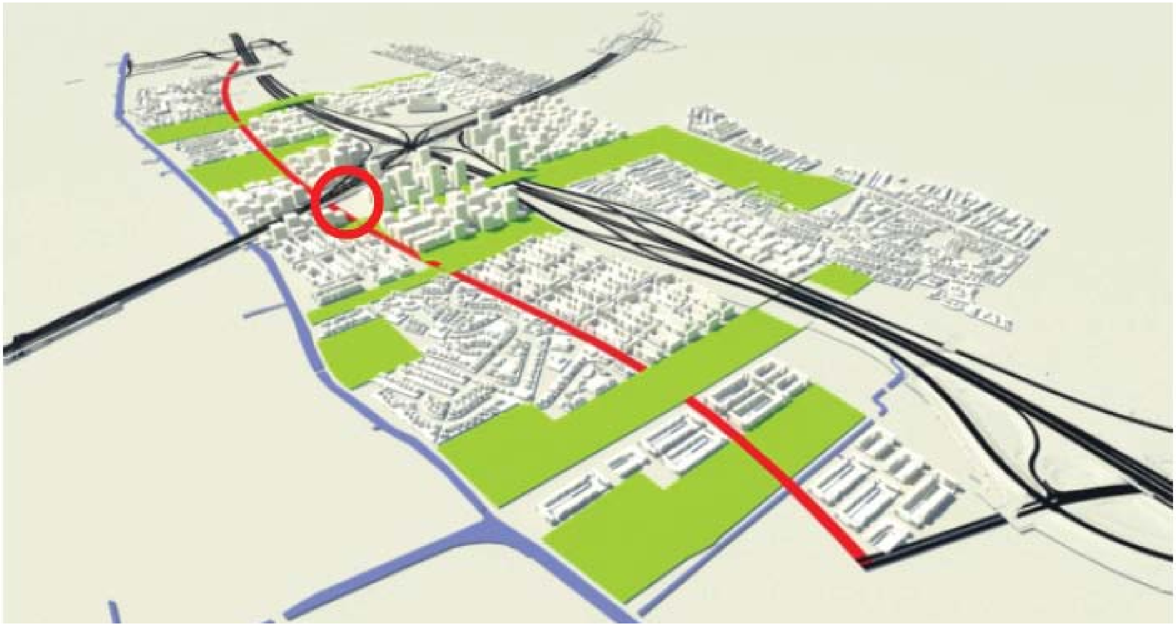


Figure 4.1: Analysis of the urban plan and the directions of the infrastructure with the site for the transport terminal indicated

4.1.2 Urban fabric

To integrate infrastructure and urban activities inside one building, a good connection to the urban fabric is necessary. Since the urban fabric is non-existent yet, the transport terminal can only provide the kind of functions and activities that will generate the demand for certain building typologies. The envisioned typology is that of a dense fabric with high-rise commercial functions and offices along the highways with lower mixed functions and dwellings towards the Vliet and the rest of The Hague. This fabric is penetrated with green strokes, connecting one side of the highway with the other and providing space in the urban plan for recreational activities.

4.1.3 Environmental conditions

The environmental conditions of the factors that influence the level of comfort are determined by the location and orientation of the building.

Wind conditions depend on the local wind speed and direction. They are determined by both the global place on earth (south west coast of The Netherlands) and the local place (Prins Clausplein) in which the configuration and height of the building volumes influence wind direction and speed (see Appendix II.I). Climatological wind data is often provided as the potential wind speed. This is a measure for the local wind speed at 10 meters height corrected for disturbance of buildings in the direct surroundings. Average wind speeds over 10 minutes, one hour or one year are given (Esch, 2009). Since nothing is known yet about the actual building height and size in the direct surroundings of the transport terminal, this climatological value is a good indication for a start. For the location of the Prins Clausplein this means a yearly average of 6 m/s (*Figure 4.2: Yearly average potential wind speed (1971-2000)*)

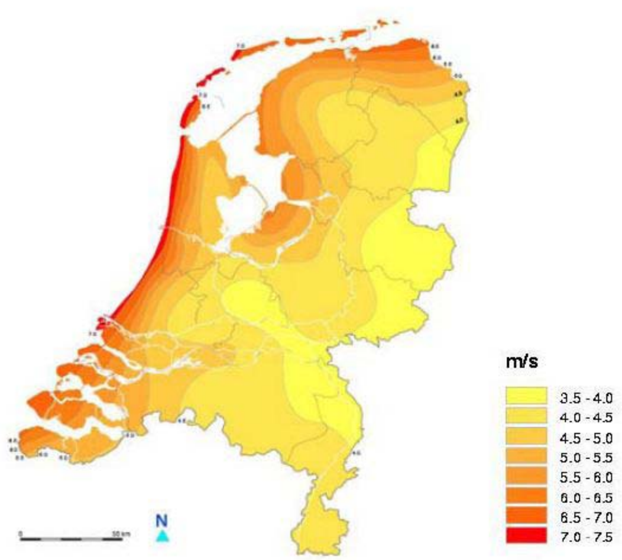


Figure 4.2: Yearly average potential wind speed (1971-2000)

Like the wind speed, wind direction is monitored by local weather stations too. The yearly results are represented in a wind rose (Figure 4.3: Prevailing wind direction projected on the site).In the wind rose, the different directions are indicated as directions in the circle, the wind speeds are indicated as intervals in blocks getting darker and wider as the wind speed grows, the length of each block indicates the percentage of the time that the wind came from that direction. The wind rose shows that south west is the prevailing wind direction with the highest wind speeds and that around 60% of the time the wind blows from the direction between south and west.

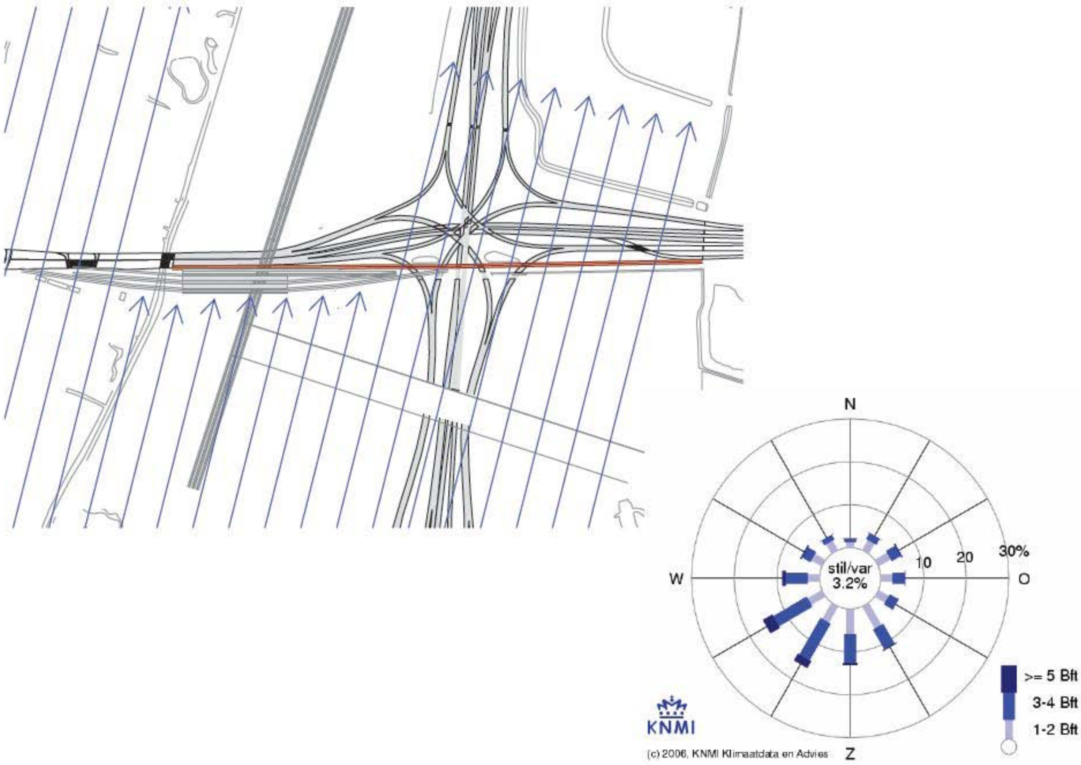


Figure 4.3: Prevailing wind direction projected on the site

Thermal and lighting conditions are determined by the path of the sun, coming up in the east and going under in the west. In The Netherlands, days are long in summer and short in winter and the sun is much more powerful in summer, standing high in the sky shining in a right angle through the atmosphere while in winter the sun is weaker and standing lower (Stichting Kennisbank Bouwfysica, 1999). Besides that, because of the sea climate, the climate is moderate. At the Prins Clausplein the average temperature is around 4 degrees Celsius in winter and 16 degrees Celsius in summer (KNMI, 1979-2000). The light intensity is dependent on the angle the sun makes with the surface of the earth; this means the highest intensities are reached in summer at midday and the lowest in winter at sunrise or sunset (*Figure 4.4: Path of the sun projected on the site*). Besides that, the clearness of the atmosphere and the cloudiness (cloudiness (average of 78% in winter and 61% in summer (KNMI, 1979-2000)) play a role in the light intensity that reaches the building. At this location the sun comes up from the direction of the Prins Clausplein and moves along the boulevard to go under at the Vliet

(*Figure 4.4: Path of the sun projected on the site*).

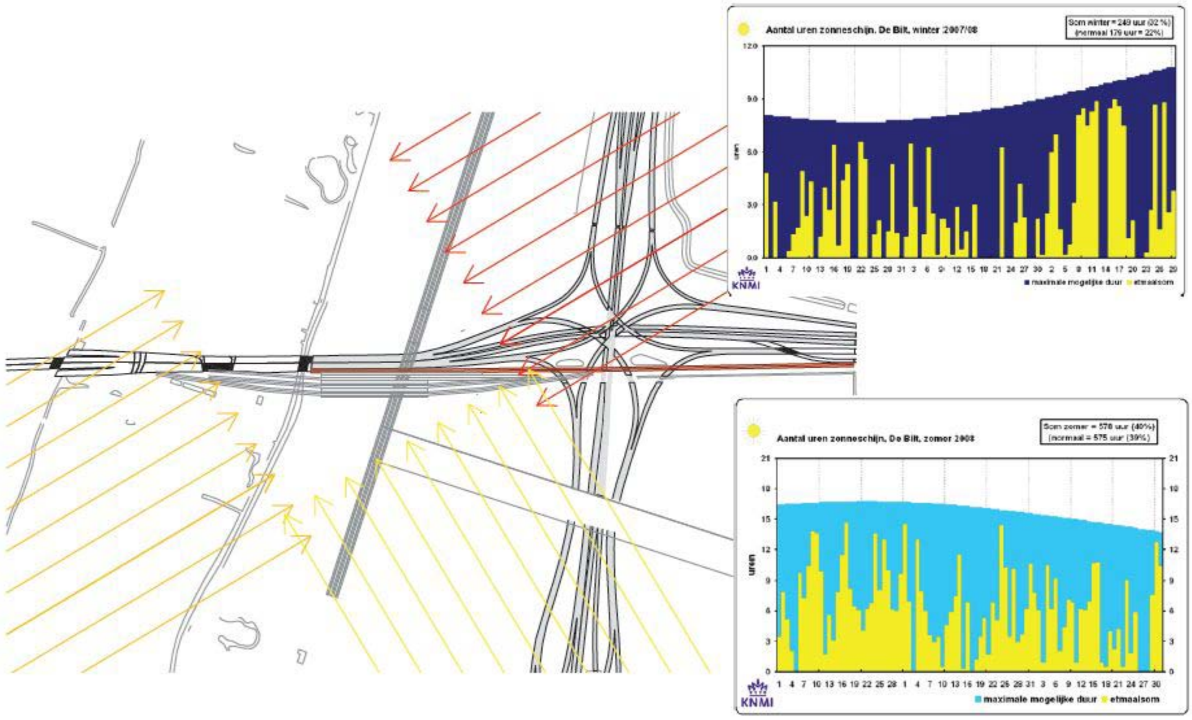


Figure 4.4: Path of the sun projected on the site

The air quality is more difficult to measure because it randomly varies in time. The average air quality at this site however is very bad; the NO2 concentration is around 50 µg/m3 and the PM10 around 35 µg/m3 (measured only in peak moments the concentration of PM10 is even higher *(Figure 4.5: Yearly average concentration of Nitratedioxide (NO2) and Particulate Matter (PM10) in the air near the Utrechtsebaan).* These high concentrations are caused by the emission of NO2 and PM10 by cars. The time of exposure to these concentrations is the indicator for the effect on human health (Ministerie van Verkeer en Waterstaat, 2006).

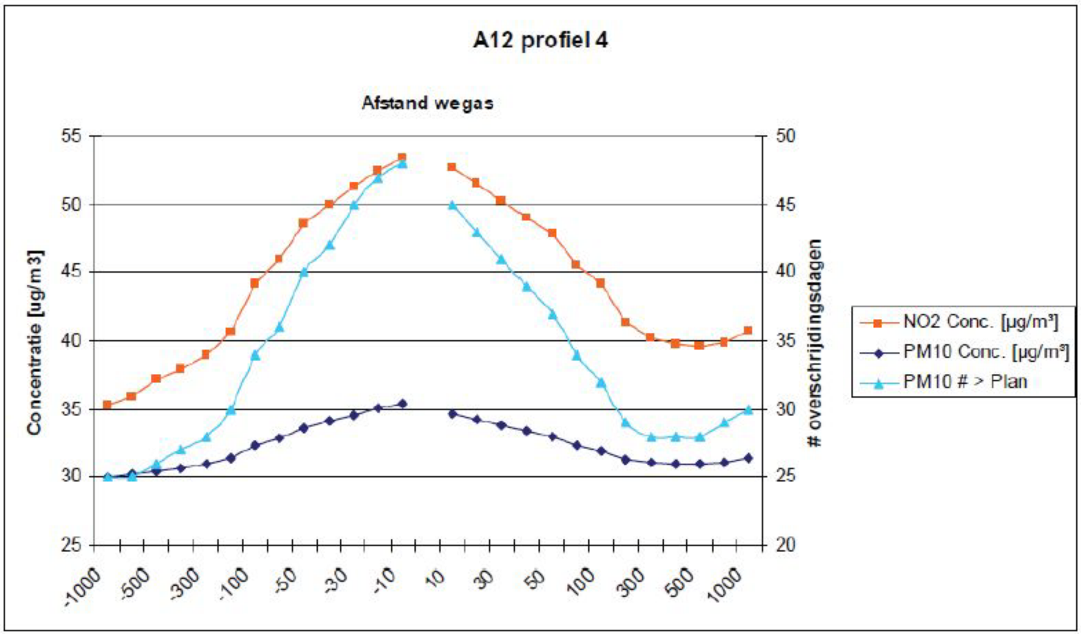


Figure 4.5: Yearly average concentration of Nitratedioxide (NO2) and Particulate Matter (PM10) in the air near the Utrechtsebaan

The sound level at this site is very high too, around 70 dB, which is the kind of noise that makes it difficult to communicate. This noise is for a great part caused by cars (*Figure 4.6: Sound contour levels of traffic noise from cars and trains at the Prins Clausplein* (Legend: national highways, sound screens, silent areas, local government boundaries)) which give a monotonous drone but also by passing trains. This is when the sound level adds up to the drone of cars and causes an even higher noise level of around 75 dB.

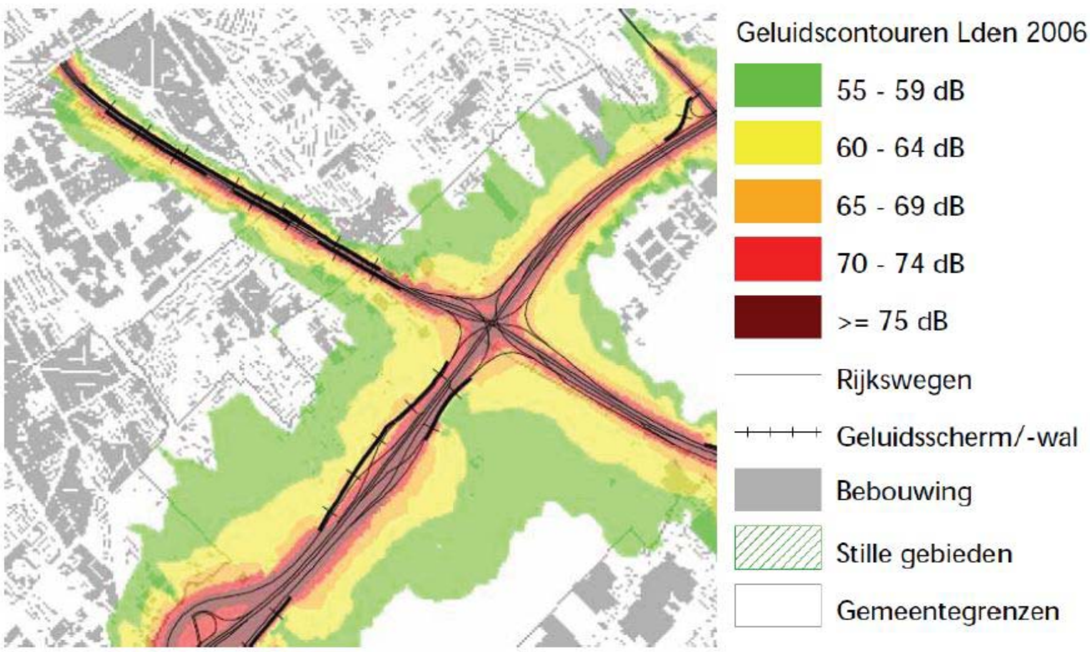


Figure 4.6: Sound contour levels of traffic noise from cars and trains at the Prins Clausplein (Legend: national highways, sound screens, silent areas, local government boundaries)

4.2 Strategy

From the previous paragraph it becomes clear that there are some great opportunities for this site as a place for a transport terminal and for the development of other functions around it. At the same time, problems with noise and pollution arise from the infrastructure and to create a comfortable semi-outdoor climate the influences of the weather have to be dealt with care. In order to use the architectural elements of the site and to deal with the building technical problems a strategy is needed.

4.2.1 Transport concept

To create a relation between the traffic streams –train, car, Randstad Rail, tram, bus, bikers and pedestrians- and the urban activities at the site, the different transport types need to be divided over different levels and connected vertically (*Figure 4.7: Creating separate* levels for each transport type connecting to urban functions at ground level *and Figure 4.8: Allowing transport* types to cross to create a vertical link between them).

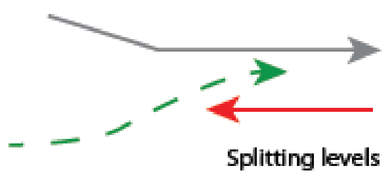


Figure 4.7: Creating separate levels for each transport type connecting to urban functions at ground level

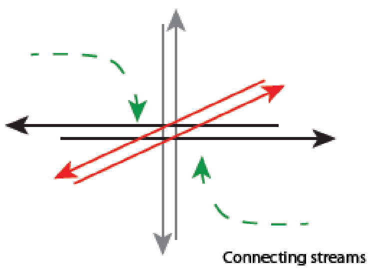


Figure 4.8: Allowing transport types to cross to create a vertical link between them

Figure 4.9: Using the direction and the morphology of the landscaping to soften the infrastructure

This assures a fast flow of traffic at one hand and the possibility to relate a certain transport type to a building function on the other. Besides that it also assures a fast and efficient transfer from one transport type to the other. One of the most important routes from an urban point of view is the green route bridging the areas at each side of the highway. In the vision for the Prins Clausplein these green strokes are meant to allow for recreational activities. As a strategy to combine the urban pattern with the infrastructure inside the terminal, the green route is pulled inside the terminal so that the infrastructure is complimented with the landscape (*Figure 4.9: Using the direction* and the morphology of the landscaping to soften the infrastructure

4.2.2 Architectural concept

In the introduction, the transport terminal as the key to integrating infrastructure and urban structure is mentioned. The building has an important function for the surrounding area and therefore needs to reflect that in the architecture (*Figure 4.10: Expression of the* important function of a transport terminal).

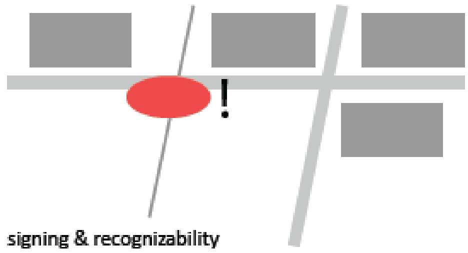


Figure 4.10: Expression of the important function of a transport terminal

Figure 4.11: Building volumes covered by a hovering roof

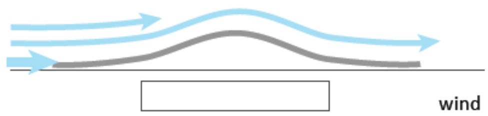


Figure 4.12: Reflection of the research in the design

The elements that build up this transport terminal are the different traffic streams running through the building and the concept of creating building functions around those streams. The directions of the different routes reflect the autonomy of infrastructure in the area; while the highway and the boulevard are following the regime of infrastructure, the green strokes and the Vliet are dictated by the morphology of the landscape and of the urban fabric. To emphasize this disconnection between infrastructure and landscape and the intention of the building to reunite them, the different directions need to be visualized strongly in the architecture of the building (*Figure 4.11: Building volumes covered* by a hovering roof). Finally, to house functions of such large scale of infrastructure and urban structure a large scale of building is needed. To continue the urban pattern inside the building it needs to be a small city on its own. This is why the choice for a building made up of small volumes, covered with a large but light, hovering roof, is made (*Figure 4.12: Reflection of the research in the design*).

4.2.3 Climate concept

Having a strategy to develop the design of the building, developing a strategy to regulate the climate is easy. From all the different methods to regulate wind, temperature, air quality, acoustics and lighting, a selection can be made so that they can be combined in an integrated climate concept for the design. In the conclusion of the previous chapter, the potential of each method in general is given. Together with the design specific demands from location, function, transport concept and architectural concept, a set of rules - a climate concept for this building - can be formed.

The location and the accompanying environmental conditions have a lot of influence on the workings and efficiency of each method. The Netherlands have a moderate sea climate. Days with only direct sunlight are scarce which means that the strength of the sun is not that great. Passive regulating systems rely on the weather so it's very important that they are suitable for the climate. Therefore the climate system must be attuned to the local climate as good as possible. Besides that, the location is dominated by the presence of the highway which causes extra problems with noise and pollution. This has to be kept in mind when designing the system.

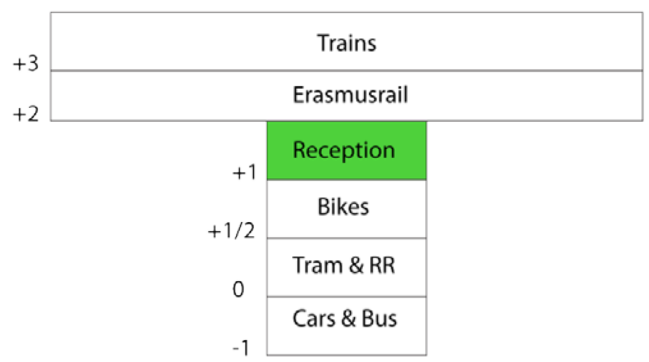
Transport terminals are generally quite practical buildings that are large and are built up of heavy structures to carry the infrastructure. They are built for their function; allowing trains, trams, busses and other transport types inside and providing an efficient flow through and transfer. This means that the building needs to be quite open, which is why a semi-outdoor situation was assumed from the beginning. The openness also means that the building is exposed to influences from outside and that it’s difficult to close at night so that it’s vulnerable for vandalism and the like. Therefore the system needs to be durable and not too fragile, it needs to be easy to clean and not too sensitive for getting dirty. From a user point of view, the building provides an efficient transfer from one type of transport to the other so easy navigation and therefore overview is important. The system must not obstruct the view or the transfer flow.

Finally, to get a fully integrated design, the concepts for transport and design have to be considered before choosing the methods. The transport concept of splitting levels implies that the vertical routing has to be efficient which again means no obstructions from the climate system. The choice for pulling the green stroke inside the terminal results in a preference for methods that contribute to the construction of a landscape inside the terminal like green and water. The ideas for the architectural design like showing the importance of the building (signing), identity and lightness of the roof have more subtle consequences for the climate concept. Methods that emphasize the important and sustainable image of the building are preferred. Moreover, the system must not weaken the architectural idea of the building.

4.3 Sketch design

The design of the building is developed using the concepts described above. The way the building should interact with its surroundings, the general appearance, the organization of the different transport types and that of the functional program are all defined in this sketch design.

4.3.1 Infrastructure



Since the building will be a transport terminal, the most important link with the site is through the infrastructure. This specific site is chosen because of the intersecting of eight different transport types; car, bus, taxi, tram, Randstad Rail, train, bike and also the pedestrian should be seen as a separate traffic stream. Following the transport concept, all these differrent traffic streams are organized in different levels. The site is excavated to allow the motorway with cars, taxis and busses, to run through a tunnel below ground level. This makes the continuous flow of motor traffic but also the connection of those transport types with the building possible without disturbing the connection of pedestrians with the tram and Randstad rail, situated at the new ground level. Bikes are allowed to move around the building at this ground level but the connection with the bikes and the other transport types is one level higher to create the possibility of a fast and efficient transfer for bikes. Above that, the reception hall is situated. At this level the connection between the building and the recreational area in the urban plan is created as well. The train and the Erasmus Rail are running in a different direction above this reception hall (*Figure 4.13: Organization of traffic streams per level*).

Figure 4.13: Organization of traffic streams per level

4.3.2 Appearance

The transport terminal is going to be one of the most important buildings in the area therefore the architectural appearance should reflect this. As explained in the architectural concept, in order to relate to the urban structure, the building will exist out of several volumes covered by a canopy. Following this line of thought, the volumes are in line with the urban fabric, placed along the boulevard. At the same time, the volumes are reflecting the schism between infrastructure and urban structure by their shape following the direction of the railway. However, since the volumes are covered by the roof, the most expressive element of the building is the roof. Therefore the roof is an extravagant object with a distinguishable shape. Besides expressive it is made as light and transparent as possible to really create the suggestion of a city underneath a floating canopy and to provide the spaces underneath with natural daylight.
Besides relating to its function in the urban plan and to the urban pattern, the building also relates to the landscape in the urban plan. The park, envisioned in the urban plan to link one site of the highway to the other, is connected inside the building to the green route along the Vliet. This is a cycling and recreational route running from the “Delflanden” to the “Green Heart”. As a result recreational activities can take place along the route as well as inside the building (*Figure 4.14: Relation of the building to infrastructyure, urban structure and landscape*).

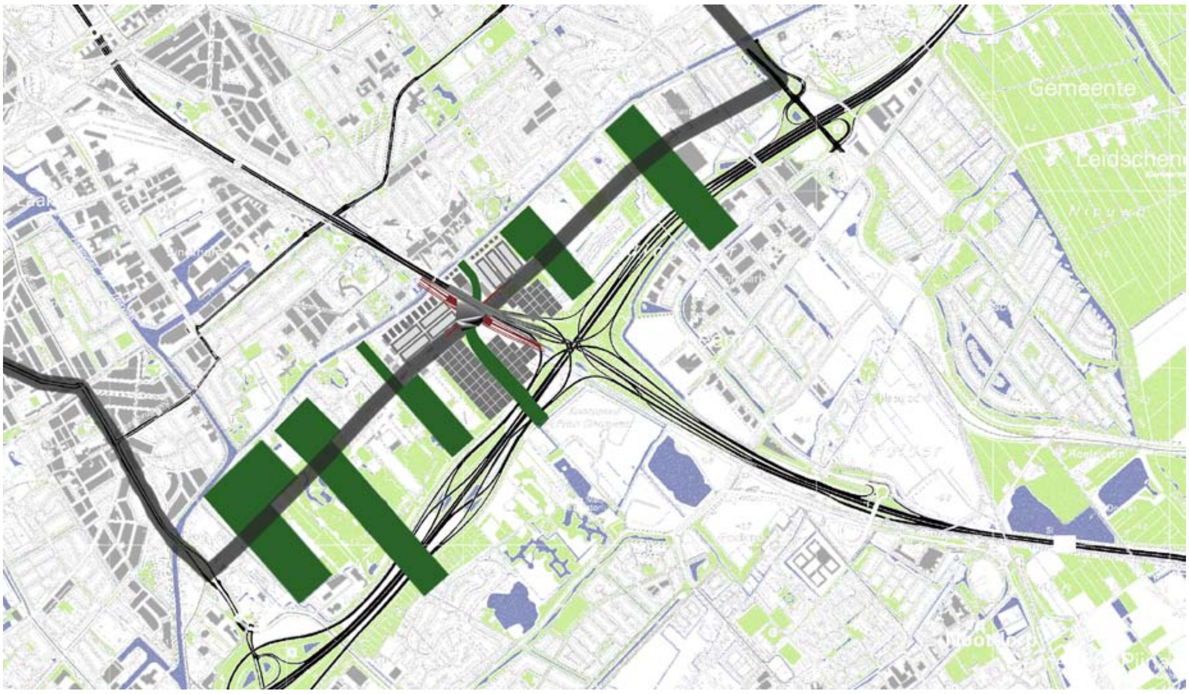


Figure 4.14: Relation of the building to infrastructyure, urban structure and landscape

4.3.3 Program

As stated in the architectural concept, the program of the building should encourage the building of the envisioned functions. In the urban plan, offices and commercial buildings are envisioned at the site of the Prins Clausplein. At the other site of the boulevard, low-rise dwelling relating to the scale of the buildings on the opposite of the Vliet is planned. In order to facilitate the inhabitants of the low-rise dwellings, a supermarket and some small scale shops along the boulevard are located inside the building as well as a skate park and a tennis field at the ends. On the other side of the boulevard, a cinema/theater serves as a cultural facility for the commercial and office area (*Figure 4.15: Relation of the program to the surrounding urban functions*).

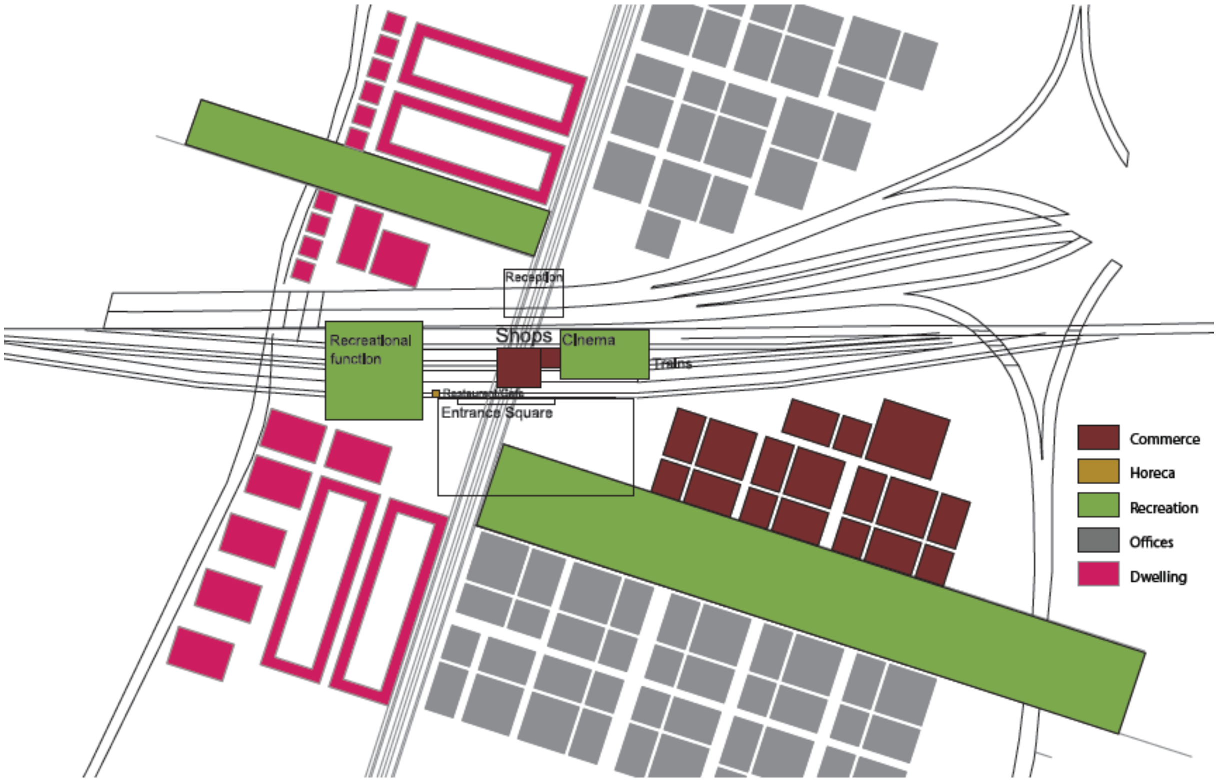


Figure 4.15: Relation of the program to the surrounding urban functions

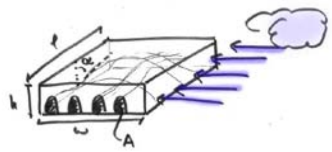
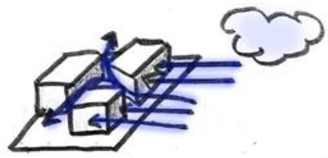
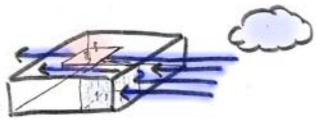
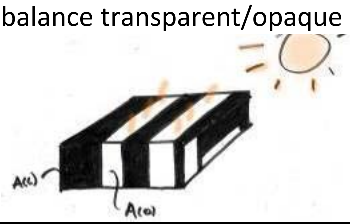
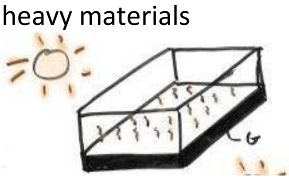
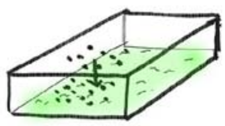
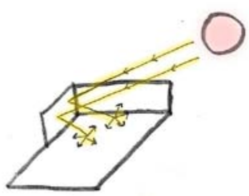
4.4 Climate design

Together with the architectural design, the climate design is developed. The system relies on the selection and combination of the separate methods described in chapter three and it also takes into account some of the design decisions that are made during the development of the architectural design.

4.4.1 Choice of methods

Methods are selected using the set of rules from the climate concept and the estimation of their performance based on the experience from previous applications. The methods are not listed in categories as in chapter three but they form one column. In this way, the multifunctionality of each method, and thus the possibility of combining it with others into one system, can be validated as well (*Table 3: Evaluation of the methods for wind (V), temperature (T), Air quality (A), Sound quality (S) and Lighting (L)* based on their suitability for the location and function of the building, their efficiency for transport and their contribution to the design).

	V	T	A	S	L	loc.	funct.	transp.	archit.	rating
ventilation: shape & openings	x	x	x	x	x	o	+	+	+	+

										
wind/sound screens/volumes 	x			x		+	-	-	o	-
placement of functions 	x	x	x	x	x	+	o	o	+	+
material properties 		x	x	x	x	+	+	+	+	+
balance transparent/opaque 		x			x	+	+	+	+	+
heavy materials 		x		x		+	+	+	o	+
absorbing materials 			x	x		+	-	+	o	-
reflective material 		x			x	+	+	+	+	+
photoluminiscent material					x	o	o	+	+	+

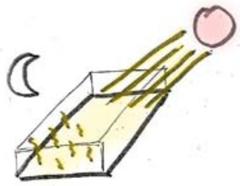
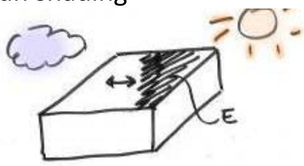
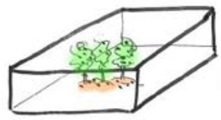
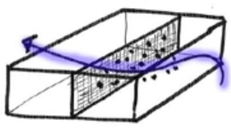
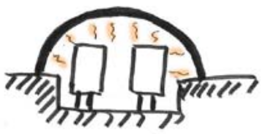
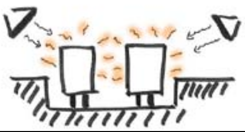
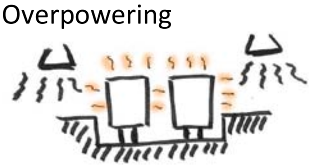
										
sun shading 		x			x	+	-	+	o	-
green & water 	x	x	x	x	x	+	o	o	+	+
Filter 			x			+	-	-		-
Tunnel 			x	x		+	-	o	-	-
anti-noise 				x		o	-	+	o	-
Overpowering 				x		+	+	+	o	+

Table 3: Evaluation of the methods for wind (V), temperature (T), Air quality (A), Sound quality (S) and Lighting (L) based on their suitability for the location and function of the building, their efficiency for transport and their contribution to the design

Based on the table above, the following methods are chosen;

Multifunctional methods:

- Ventilation through shape, dimensions and openings
- Placement of functions and orientation of spaces

- Use of material properties which also includes balancing the properties of transparency, mass, absorption and reflectivity
- Green (fences) and water which also includes streaming water to overpower noise

Additional methods:

- Organization of internal volumes because although rated negatively as a method, volumes inside the building are inevitable so placement might as well be done bearing the principles in mind
- Photoluminiscent material, which could be very interesting but needs some more research in order to apply it to the building

Evidently, this list of methods is not yet a system. The way they are combined and integrated in the design is explained in the following paragraphs. Since a lot of the factors to be regulated are dependent on the seasons, the workings of the system in summer and winter are treated separately. The ultimate goal is to create a balance between these two situations and to design a system that works as well in summer as in winter with as less additional methods as possible to achieve this.

4.4.2 System

In winter, the principles of natural ventilation are used to keep as much wind outside as possible. To accomplish this, the shape should guide the wind over the building and openings should be as small as possible. Of course, some ventilation is necessary to assure good air quality but since this building will have enough openings to ensure a continuous air flow, this won't be a problem. In summer, on the other hand, wind has to provide natural ventilation to prevent the building from overheating. To make use of the heat-stack-effect openings on the lower levels in combination with openings in the roof are ideal. To assure a flow through all the spaces and to allow the daylight shining through the roof to enlighten as much spaces as possible, openings in the floors are necessary as well.

Placement and orientation of functions is organized in such a way that the most important spaces have the most optimal conditions. Waiting spaces are placed on the higher levels where, because of the translucent roof, a lot of daylight and sun enters the building. In winter, the sun can heat up these spaces significantly. They are also situated in the center of the building where the wind speed is lower than on the ends. In summer, the risk of overheating at these places exists so other methods should be used to lower the temperature at these places in summer. To avoid too much noise from the highway and from passing trains to enter the building, the site of the building near the highway is closed off with sound isolating materials.

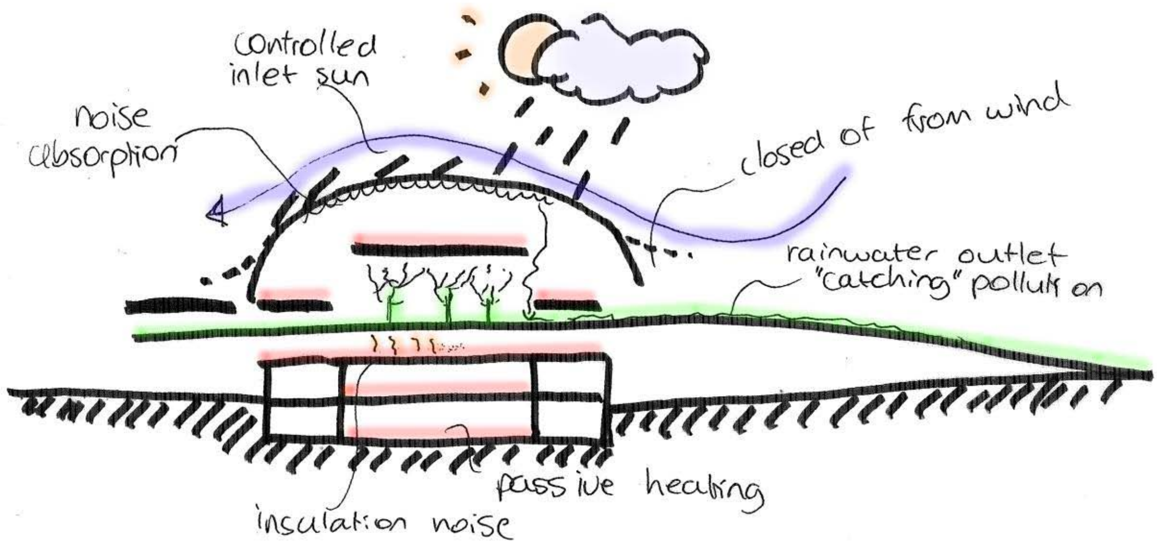


Figure 4.16: Application of the methods in the climate design for the winter situation

The materialization of the roof is light and translucent. This allows sunlight to enter the building to heat and light up the spaces. The translucency has to be balanced in such a way that in summer there won't be too much incoming heat from the sun. From the perspective of construction, a light material is logical because of the large dimensions. In contrast, the floors are made of a heavy material, since it needs to carry the infrastructure this is a logical choice. Besides that it also provides good sound insulation and thermal capacity so that heat from the sun can be captured and prevent spaces from heating up in summer while in winter heat can radiate into the space. The surface of the floors is rough in order to capture sinking particles to improve air quality. To exploit the amount of daylight coming in, reflective or light-colored materials are used to reflect the incoming daylight as much as possible.

Plants and trees inside the building can help to reduce sound level and wind speed and they can improve the air quality. At the waiting spaces in the reception hall, plants and trees lower the temperature in summer by blocking some of the sunlight and by evaporation. Broad-leaved trees and plants are preferred so that in winter no sunlight is blocked. The soil, like the floors, can function as a buffer. Besides that it can improve the air quality even more and it can gradually drain off rain water. At the boarding platforms, the rain water is collected in reservoirs that are also used to cool down the waiting spaces in summer.

The additional methods can improve the climate further. The use of internal volumes (for example in the form of little shops) can create lee places, especially in winter this is important. The photoluminiscent material can be integrated in the roof to enlighten the spaces inside the building at night. However, further research is needed to test the efficiency of this method.

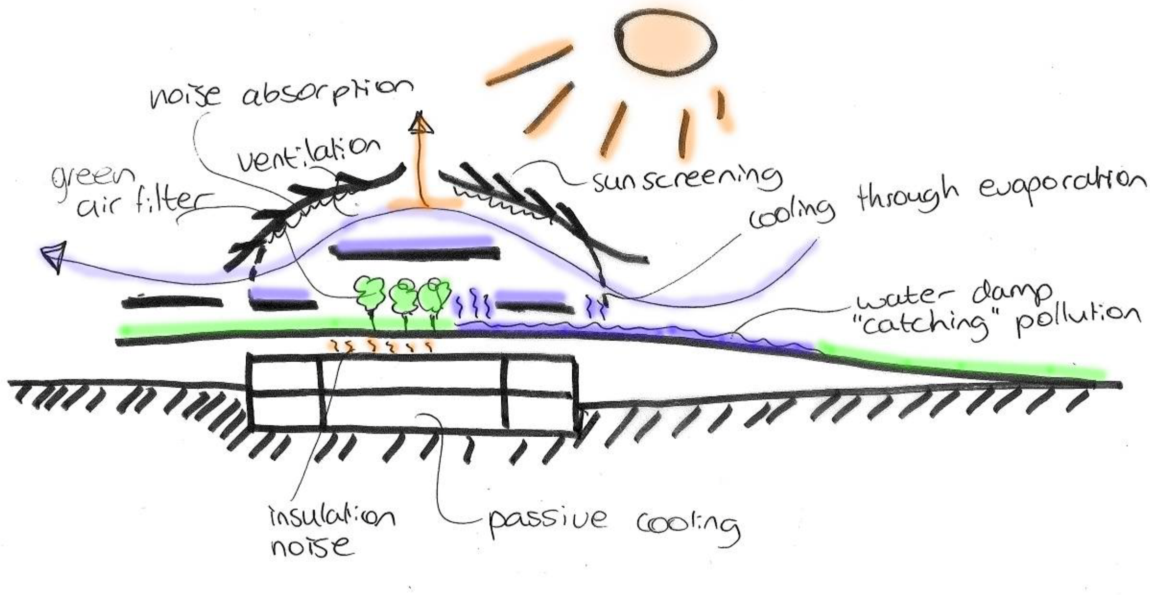


Figure 4.17: Application of the methods in the climate design for the summer situation

4.4.4 Variables

To further develop the climate system and to optimize the performance of the system, the starting point for further research needs to be defined. This can be done by defining the givens and the variables of the system. As shown in the scheme below, the organization and the dimensions as defined by the architectural design are limiting the variables of the system and are defining their broad location inside the building (*Figure 4.18: Variables of the climate system indicated in the sketch design).*

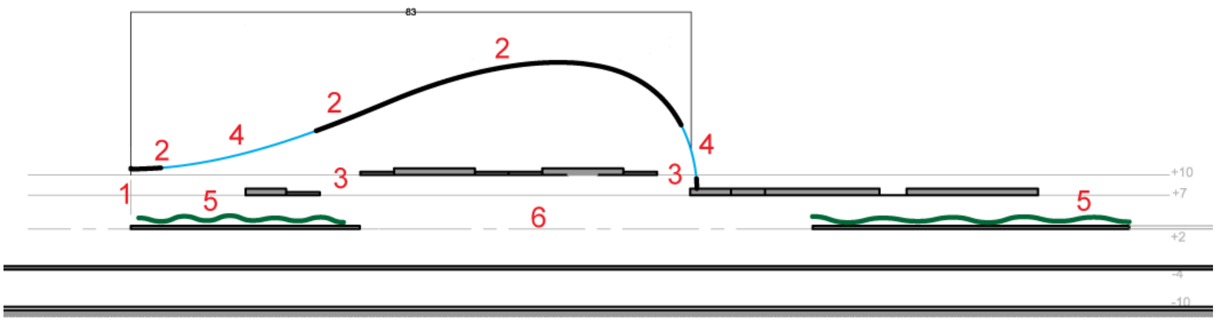


Figure 4.18: Variables of the climate system indicated in the sketch design

1. Size and amount of openings
2. Slope and dimensions of the roof
3. Amount of thermal mass
4. Material properties of skin, floors and walls
5. Amount and placement of green and water
6. Area of atria for vertical transport, overview and light incidence

5. Research on wind and temperature

With the analysis and the design ideas of the previous chapter, a basis is formed for further research and design. This chapter illustrates the application of specific methods to the design; it investigates the regulating methods and their working principles and how they can be optimized for the design of a transport terminal at the Prins Clausplein. Research is done on two factors of comfort; wind and temperature. These factors are chosen as the most interesting ones because they determine for a large part the level of comfort in respectively winter and summer. Wind is the most intensely and negatively perceived factor in winter in outdoor situations as well as in train stations. Because the roof is intended as a large, light and transparent structure, heat gain through sunlight will be a large problem in summer. This is why temperature will be determining the level of comfort in summer. Of course the factors air quality, acoustics and lighting are all playing a role too so they are evaluated in the final design but the focus in this part of the research is on wind and temperature.

5.1 Analysis of working principles

To optimize the variables, summed up in the previous chapter, it is important to understand something about the principles that are at work. In the appendix, a short explanation of the theory of wind and temperature are given (Appendix II). In this paragraph, only the applicable principles are derived from the theory. Understanding these working principles means understanding the workings of the described methods and allows for refining them to optimize them for this design.

5.1.1 Wind

Wind is driven by pressure differences and influenced by the roughness of objects in its way (see appendix II.I). Therefore all methods use either friction or pressure difference to influence and regulate the air flow. Four basic principles can be distinguished.

The first, most simple and most obvious working principle is blocking the wind. This principle makes use of an obstacle, preferably perpendicular to the direction of the wind in order to create roughness. Since wind can't flow through the object, it's forced to go around the object, creating a calm zone directly behind the object. As a side-effect, a microclimate with small but high-velocity flows behind and at the sides of the object occurs, just in the same way as described in the theory about air flows around buildings. In this design, blocking could be in the form of small building volumes or wind screens.

The second principle is related to the first and is also based on obstruction. It's the principle of slowing down the wind or in other words reducing the wind speed. Using the option to influence wind by friction it uses a semi-permeable object, for example plants or trees, that partly blocks the wind and partly allows it to flow through small holes. In this way, the effect of blocking occurs in a less prominent way; the zone behind the object is less calm but the pattern in the zones around the object is also less disturbed. Besides that, the small holes create a resistance so that the wind is forced to slow down in order to flow through. A semi-permeable obstruction can also be created by a large volume of still air. Moving air then collides with standing air, causing part of the still air to move and part of the moving air to stop moving, this gives relatively low disturbance of the wind pattern (Haartsen, 2005)

Another principle that affects air flow is to reduce or maximize pressure difference. Especially on the small scale of the building, clever design can assure connection or disconnection between zones of under pressure and those of over pressure. For wind pressure this means that the placement of openings on the downwind facade directly in line with those on the upwind facade stimulates air flow through the building (Blocken, 2009). For thermal pressure this means that the difference in height between the inlet and the outlet are determining. Besides the placement, the size and amount of openings of course also determines the pressure difference between inlet and outlet and thus the speed of the air flow. For a transport terminal, at most places entrance and exit must be in line to allow fast flow of traffic. However, size and height of the openings can be modified.

Finally, the influence of roughness on the wind can be used in quite a different way. Besides affecting the velocity, an object can also affect the direction of the air flow. In the case of blocking, the flow is forced to drastically turn its direction. However, this can be done in a more subtle way using the adhesive properties of air. Air has the tendency to flow along a surface; by gradually changing the direction of a surface wind can be directed towards the desired spot without disturbing the flow pattern and with little reduction in speed (Blocken, 2009).

5.1.2 Temperature

The principles that are at work in influencing temperature can all be deducted from the heat balance, which states that the incoming energy is equal to the outgoing energy (Appendix II.II).

The first variable in the balance is the amount of heat that is produced in a space. The most effective way to regulate temperature is therefore regulating this heat gain. The largest part of the heat gain comes from the radiation of the sun. Sun rays are being transmitted, reflected or absorbed at the material surface dependent on the material properties. Transmittance depends on the transparency of a material, reflection on the roughness of the surface (and thus on the hardness of the material) and absorbance on the thermal capacity of the material. Reflection of the heat waves prevents heat from coming in. Transmittance and absorbance have the same overall effect: transmittance allows surfaces behind the surface of the skin to heat up by the waves that are let through; absorbance causes the surface of the skin to heat up. Then, all surfaces that are heated radiate their waves to other, colder objects in space, this results in a higher air temperature (Stichting Kennisbank Bouwfysica, 1999). Heat production can thus be regulated by modifying the material properties or the configuration of materials. For a translucent material, such as imagined for the transport terminal, a lot of transmittance takes place. Other heat sources, like organisms (humans produce heat by the processes inside their body) or electronic devices (armature produces heat besides light) are kept out of this research because regulating their heat production is outside its scope.

Besides the production of heat from the sun or other heat sources, the variables of convection and transmission can cause heat gain. In most cases though, they cause heat loss and they are therefore included as another variable in the formula. Loss of heat through convection is caused by the movement of air. Moving air doesn’t allow for long exposure to a heat source and thus for heating up much. Besides that, replacement of hot air with cold air causes heat to be transported elsewhere (Stichting Kennisbank Bouwfysica, 1999). The amount of heat loss caused by convection is dependent on the air temperature and the air velocity. The colder the replacement air and the faster it is moving, the larger the heat loss. As explained in the previous paragraph, air movement is caused by pressure and temperature differences.

Transmission is the conduction of heat through a material and dependent on the insulation value of the material. The insulation value of a material is built up out of the transmission value of the material and the thickness of the surface, a thicker surface insulates better. The speed with which a material conducts heat is dependent on the temperature difference. The higher the temperature difference the faster the transmission (Stichting Kennisbank Bouwfysica, 1999).

Another variable in the heat balance has to do with the slowing down of the process of heating or cooling as a whole caused by thermal mass. The thermal capacity and the density of the construction materials and that of the air inside the space are determining to what extend the process is slowed down. The difference between the influence of thermal capacity and that of the effects mentioned above is that no heat energy is lost. Instead it is captured; absorbed by the material until its temperature exceeds the temperature of the objects surrounding it, then it starts to radiate the heat back into the space. The effect on the final temperature is thus turned around at a certain point; when the material is colder than the surrounding materials (including the air) the process of the space heating up is slowed down, when the material is warmer than the surrounding ones the process of cooling down is lengthened. How large the effect is depends on the temperature difference between the object and the surrounding ones (Stichting Kennisbank Bouwfysica, 1999).

All variables in the heat balance are now mentioned. Still there is one more principle that is related to the regulating methods that are mentioned in chapter three; cooling down by evaporation. In the formula it can be incorporated as a negative heat gain as is the case for all other cooling methods. The process of evaporation uses heat energy to transform water from its liquid state to its gas state. Heat energy is extracted from the ambient air but moreover from the sun radiance. The process is driven by the difference in vapor pressure between the surface (water or plant) and that of the air surrounding it. Just like the process related with thermal mass, evaporation is time dependent. When the evaporation proceeds, the ambient air saturates, the pressure difference becomes smaller and the process slows down. Therefore, the process is largely influenced by air movement (replacing the saturated air). The process of evaporation by plants is the same as with water, the process of transpiration of the plant is only an extra link in the chain. In this case, the evaporation is dependent on the transpiration and the other way around, extra variables include the type of plant, the type of soil and the way they are cultivated (Allen, Pereira, & Smith, 1998).

5.2 Criteria

To really test and optimize the climate system for wind and temperature, the specific needs of the building need to be clarified. In the second chapter, an analysis of what comfort means in semi-outdoor situations is made. The conclusions from that chapter can now be taken to a higher level; criteria can be defined. In order to do so, known criteria from different situations are compared and transformed to a new criterion for the specific situation of the transport terminal.

5.3.1 Wind

For indoor situations, most wind criteria (or rather criteria for maximum ventilation) are derived from Fanger's theory and expressed in m/s. Dependent on temperature and activity the maximum wind speed for a comfortable climate varies between 0.15 and 0.40 m/s (Stichting Kennisbank Bouwfysica, 1999). For a semi-outdoor situation, this is very low. Even if the weather is calm and there's almost no wind, these values are easily exceeded. Besides that, concluding from the analysis in chapter two, comfort in semi-outdoor situations resembles comfort in outdoor situations more than indoor situations.

Looking at the outdoor situation, the maximum wind speed for comfort is more than 10 times larger than for indoor situations: around 5 m/s. Furthermore, the criteria are much more diverse and complex. There are three different categories of criteria: maximum mean wind speed, maximum mean wind speed with a maximum burst speed added to that and the maximum burst speed. In a semi-outdoor situation, bursts are likely to be less violent than in outdoor situations since the building construction and the objects inside provide quite some shelter. Because of this and because simulation and prediction of wind bursts is very complicated, wind bursts are not incorporated in the criterion for this building. The design of this building is not sufficiently developed to incorporate these subtle differences anyway. However, since even small fluctuations in wind speed have quite a large influence on comfort, in a detailed research where all parameters are already determined, wind burst can't be neglected.

Comparing indoor and outdoor situation, the differences between the criteria are so large that it's difficult to draw conclusions. Although the semi-outdoor situation resembles the outdoor situation, a maximum wind speed of 5 m/s seems extremely high, keeping in mind activities like reading a book or pick-nicking. To allow a better comparison, the scale of Beaufort can be introduced. This is the scale used in meteorology and navigation and it relates different categories of wind speeds to the accompanying sensation (*Figure 5.1: Scale of Beaufort indicating wind speeds in several ways*).

Schaalcijfer Beaufort	m/s	Nederlands boven zee	boven land	English Engels	Beschrijving van de zichtbare uitwerking van de windkracht op objecten in het binnenland
0	0 – 0,2	Stilte	Windstil	Calm	Rook stijgt recht of bijna recht omhoog.
1	0,3 – 1,5	Flauw en stil	Zwakke wind	Light air	Windrichting goed herkenbaar aan rookpluimen.
2	1,6 – 3,3	Flauwe koelte		Light breeze	Bladeren beginnen te ritselen en windvanen kunnen gaan bewegen. Wind begint merkbaar te worden in het gelaat.
3	3,4 – 5,4	Lichte koelte	Matige wind	Gentle breeze	Bladeren en twijgen zijn voortdurend in beweging.
4	5,5 – 7,9	Matige koelte		Moderate breeze	Kleine takken beginnen te bewegen. Stof en papier beginnen van de grond op te dwarrelen.

Figure 5.1: Scale of Beaufort indicating wind speeds in several ways

These descriptions of sensations make it easy to interpret wind speeds for any person. If the scale of Beaufort is now compared to the different criteria, the desired situation for semi-outdoor comfort can be derived. A good description of the criterion for maximum wind speed in the transport terminal, related to the activities and the desired thermal comfort, is the point where air movement becomes noticeable. Wind will become notably present but doesn't exceed thermal comfort zones nor cause nuisance for the proposed activities. This point of noticing air movement is 2 at the scale of Beaufort, accompanying the sensation of "rustling leaves and a breeze along the face". Transforming this to m/s this means a wind speed of 1.6 to 3.3 m/s, rounding it off, the criterion than becomes a maximum wind speed of 3 m/s. This criterion fits well in between the criteria for indoor and outdoor situations.

5.3.2 Temperature

To define a criterion for temperature, the same approach as for the criteria for wind can be taken. Since wind is assumed as the most determining factor in winter and temperature as most determining in summer, the criteria for temperature will only apply in summer situations. Of course the temperature in winter can be very important for comfort but since the temperature comfort in winter will be largely dependent on active systems and this research is focused on passive methods to regulate climate, it is left out of the research.

Like the criteria for indoor wind speeds, most criteria for indoor temperature comfort are based on the theory of Fanger. Criteria are set on the air temperature while the radiant temperature is assumed to have the same value. For a hot summer situation in which people wear light clothing, the comfortable temperature varies between 23 and 30 degrees Celsius. This is quite a large range which means that the activity level has a large influence on the desired temperature. However, for a transport terminal the activities are not predetermined as tightly as for example in an office building. This means that people will be able to adapt their behavior when experiencing high temperatures so that for the maximum temperatures only the upper values of the temperature range can be evaluated.

For outdoor situations criteria are difficult to be found. They can be derived from Nikolopoulou's proposed adapted formula for outdoor comfort though (Nikolopoulou, Lykoudis, & Kikira, 2003). In this formula, the adaptive character of clothing and metabolic rate are already dissolved which leaves only the temperature, the relative humidity and the wind speeds as variables. The radiant temperature is, unlike the calculations for indoor situations not assumed to be the same as the air temperature but narrowed down to the most important radiant source; the sun. Since solar radiance is reported as one of the most significant values, the table shows desired temperatures for different sun loads and ASV (the Actual Sensation Vote; the outdoor counterpart of the PMV) (*Table 4: Actual Sensation Vote (ASV) for different temperatures and sun loads*).

Sunload W/m2	ASV			
	-0,5	0	0,5	0,8
0	-1	14	29	37
200	-1	13	28	37
400	-2	13	27	36
800	-3	12	26	35

Table 4: Actual Sensation Vote (ASV) for different temperatures and sun loads

Comparing indoor and outdoor desired temperatures it's interesting to see that within the same comfort zone, the desired temperature range is overall higher than indoors; between 26 and 37 degrees Celsius. This underlines the conclusions of the second chapter; that in outdoor situations people are more tolerable than in indoor situations. In this case though, because the criterion is designed for extreme summer situations and high sun loads can be expected, the lower temperature values should be evaluated.

As for the different wind criteria, the differences between indoor and outdoor criteria for temperature are again very large. On one hand the indoor criteria don't incorporate the adaptive behavior of people; on the other hand the outdoor criteria suggest a very large tolerance which might not comply with the semi-outdoor situation while on the other hand the direct sun load might not be of such a large influence underneath a roof. Research on other in-between situations like that of the naturally ventilated building or the atrium (Dear & Brager, 1998) shows that adaptation is the most significant factor in determining criteria for temperature. Since this adaptation of the human body (behavioral, physical and psychological) is dependent on the outdoor climate, criteria are based on the outdoor temperature. In this way, a flexible maximum and minimum temperature can be obtained. Looking at the criteria for Dutch climates proposed by van der Linden (Linden, Boerstra, Raue, & Kurvers, 2004), the situation of the transport terminal would fit best with the naturally ventilated building with an acceptance of 80%. Van der Linden describes a formula from which the criterion for the indoor operative temperature (Toper) can be extracted. This indoor operative temperature is the average of the air temperature (Ta) and the radiant temperature (Tr) and is based on the outdoor reference temperature (Te,ref). The outdoor reference is obtained from the average air temperature over several days. The criterion for the transport terminal then becomes:

$$T_{oper} < 21,3 + 0,31 \cdot T_{e,ref}$$

For a hot summer day in The Netherlands the Tref is 22 C so that the maximum operative temperature becomes 28 C. Just like the criterion for wind, this criterion fits in between (the upper region of) the indoor criteria and (the lower region of) the outdoor criteria neatly.

5.3 Research method

Corresponding with the third research question, this research is about the application of methods to the design. The aim is to optimize the parameters influencing wind and temperature in such a way that an effective climate system is created while at the same time the demands of the architectural design are met. In this paragraph, the input data for this research are defined through scenarios.

Furthermore, the methods to predict and calculate air flow and temperature and to test the design parameters are explained and then applied to each scenario.

5.3.1 Scenarios

In the introduction of this chapter a separation is made between winter and summer situation. In winter, wind is the determining factor, in summer it is temperature. This means that the climate system should be tested for a winter scenario with focus on wind speed and a summer situation with focus on temperature. Based on Dutch climate data, two probable scenarios are chosen for each situation.

For the winter scenario, extreme and average climate data of the past 30 years from the weather station closest to the Prins Clausplein are used. This means that for an average winter day the local wind speed is 6 m/s and for an extreme winter day it is 25 m/s. The wind rose of January shows that 60% of the time wind is blowing from south, south west or west and that the wind coming from south west is the strongest (Figure 5.2: Wind roses for the average wind speed and directon in january of De Bilt and Vlissingen). For the winter situation temperature is not tested, however since the density of air and thus the movement of air is dependent on temperature the average winter temperature of 3.8 degrees Celsius is chosen as input.

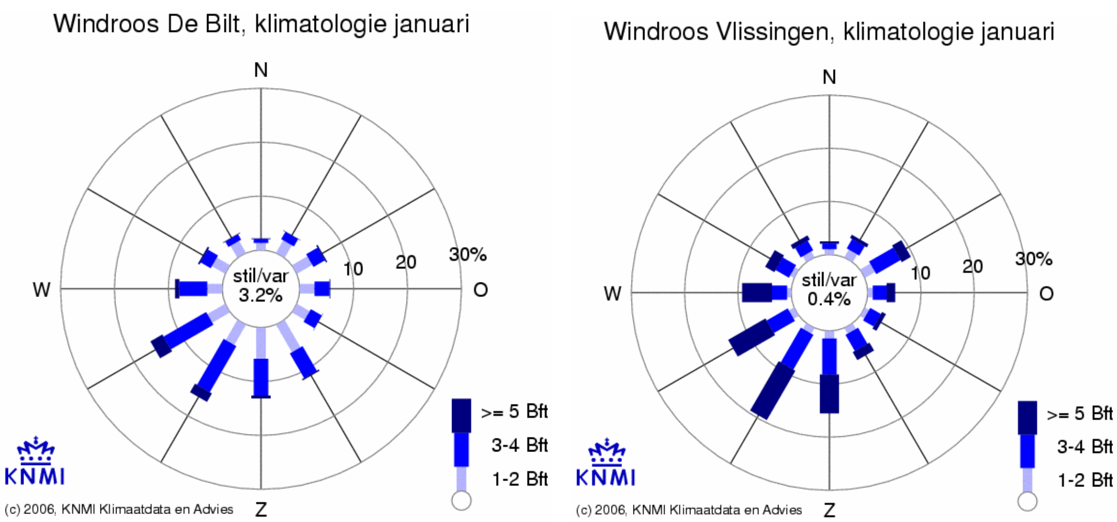


Figure 5.2: Wind roses for the average wind speed and directon in january of De Bilt and Vlissingen

The scenario for the summer is formed using an average hot summer day in The Netherlands as a reference. A clear day with only direct sunlight is assumed and the clearness of atmosphere is set to that of a large city (T=4). Sun diagrams are used to create an hourly sun load and accompanying outside temperature for the scenario which means a maximum outside temperature of 25 degrees and a maximum sun load of 750 W/m2 at a horizontal surface (Stichting Kennisbank Bouwfysica, 1999).

5.3.2 Method

From the theory and the analysis of the working principles, design parameters can be identified. These parameters can be optimized to suit the comfort criteria as well as the architectural demands of the transport terminal.To meet the demands for both an effective climate system and an integrated design the method of testing design variants is chosen. A basis variant, corresponding with the sketch design is chosen. The design variants are a version of the first model, modified in such a way that the parameters can be tested while still being kept within the allowances of the architectural design. The performance of the different variants is then compared so that the effect on comfort of each variant and the effect of varying certain parameters can be evaluated.

In order to test the performance of each model for winter and summer situation, two different computer programs are introduced; Contam and a macro sheet called Summertemp for Microsoft Excel. Contam is a program that calculates air movement inside a building based on the pressure difference model explained in the theory of wind (Appendix II.I). Summertemp is a macro that is designed specifically for the purpose of calculating temperatures with the one-zone model for heat balance (Appendix II.II).

5.3.3 Schematization

The exact input for the computer programs that are used is shown in Appendix III. However it is important to indicate the schematization necessary for the calculation in these programs so that the results can be seen from the right perspective.

Contam is a very abstract program in which the only input to define the configuration of the building is:

- Volume of a zone (the space for which flow rates are calculated)
- Orientation towards the wind and towards other zones
- Area of openings in the zone
- Wind pressure on the openings of a zone (which can be calculated by the program itself) using the input for the environmental conditions).

For the calculation of air movement it is important to know that shape is not incorporated in the model. Furthermore, it is not possible to calculate disturbances of the air flow by objects. To deal with these limitations, the design variants are modelled as multi-zone buildings, built out of many different small zones so that shape and objects can be simulated through varying the properties of the zones (*Figure 5.3: Schematization of the design in zones for calculation in Contam*). This division in zones also assures a more detailed calculation of the air flow on a certain spot.

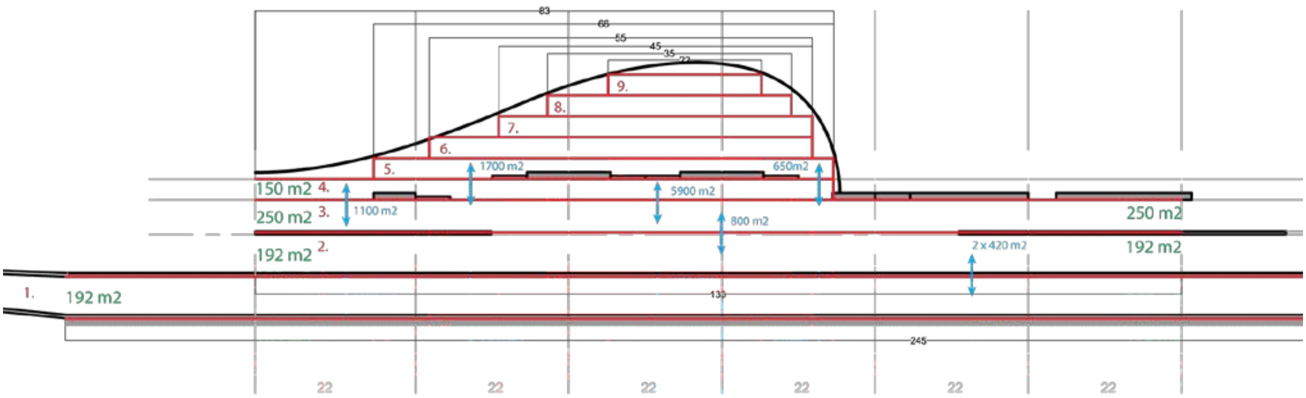


Figure 5.3: Schematization of the design in zones for calculation in Contam

Like Contam, Summertemp is abstract too and purely works with the variables of the function. This means that the building can be defined by:

- Area of the enveloping surfaces and their U-value and ZTA-value (for transparent surfaces)
- Weight of the total effective thermal mass of the building
- Ventilation rate
- Hourly cooling capacity

Again, the effect of the shape can't be calculated directly, it can only be simulated by using the different surface orientations. What is important too is that unlike Contam, Summertemp does not work with volume nor area of openings but only with a ventilation rate. The whole building volume and the total amount of fresh air coming in are the only variables included in the ventilation rate. To calculate the effect of natural ventilation on the temperature inside the building, Contam is used (see appendix III for further explanation on this working method). For the cooling by evaporation, only an hourly cooling capacity can be given as an input. The most important limitation, not as much of the program itself but of the formula incorporated in the macro, is that the building as a whole is only seen as one zone, one volume. Thus, differences in temperature for different rooms or different levels are not calculated. As a result, only the building volume as a whole with its surrounding surfaces can serve as an input (*Figure 5.4: Variables in the one-zone model*).

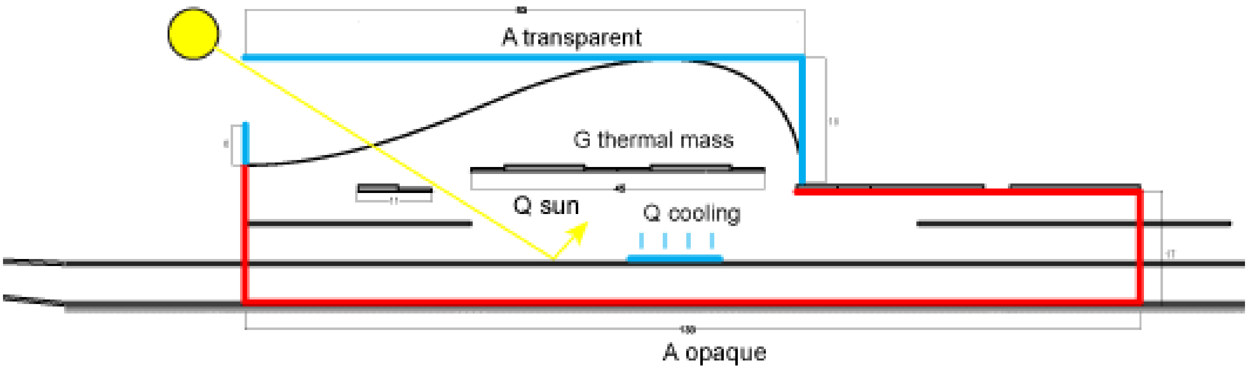


Figure 5.4: Variables in the one-zone model

5.3.4 Winter

With the analysis of the working principles and the limitations of the computer programs explained, the variables of the climate system described in chapter four can be applied to the winter scenario. Four parameters can be identified:

- Roughness in the form of obstacles or cleverly placed walls
- Resistance in the form of semi-permeable objects like plants or a large amount of still air
- Placement, amount and size of openings
- Dimensions and shape of the building

As explained in the method section, the first model is based on the sketch design. Since design and research are continuing along with each other in the process, the sketch design is already developed using the basic principles of wind. This means that the dimensions and shape of the building as well as the volume (which contributes to the resistance) are determined. Therefore, these parameters are fixed and the variables of the research are narrowed down to roughness through obstacles, resistance and placement, amount and size of openings.

In the first model, no obstacles are placed in the building besides the floors and walls that are in the sketch design. The volume is relatively large as is the total area of openings. The openings are placed where necessary to allow the flow of traffic through the building (*Figure 5.5: Schematic representation of Model 1* (basis model), Model 2 (small openings) and Model 3 (top opening). The openings are indicated in black.). This is a requirement that has to be met for all the other design variants as well. Mark that the placement of most of the openings is thus already determined by the design; this makes the degree of freedom limited.

total area of openings in m2	Model 1	Model 2	Model 3
SW	784	525	710
NE	634	450	634
NW	252	260	252
SE	252	260	252
roof	0	0	1932

Table 5: Table with the areas of the openings in the façade for southwest (SW), north east (NE), north west (NW), south east (SE) and horizontal surfaces for Model 1 (basis model), Model 2 (small openings) and Model 3 (top opening)

The second model works with smaller openings to maximize the effect of resistance from the volume and to minimize the amount of air coming in. The area of the openings is kept to the absolute minimum and entrances that don't need to be opposite each other (like those for pedestrians in contrast with those for trains) are placed in more tactic places. Furthermore, walls are placed in the path of the flow in order to block the wind where possible (*Figure 5.5: Schematic representation of Model21*).

The third model allows for larger openings again but expands the tactical placement of the openings. It tries to guide the air flow towards the top of the building by placing a large opening in the roof. At this place, users of the building can't experience high wind speeds but ventilation might be useful, especially on warmer days. The obstacles in the building are placed in such a way that they contribute to the desired air flow towards the roof (*Figure 5.5: Schematic representation of Model 3*) *(Table 5: Table with the areas of the openings in the façade for southwest (SW), north east (NE), north west (NW), south east (SE) and horizontal surfaces for Model 1 (basis model), Model 2 (small openings) and Model 3 (top opening)*).

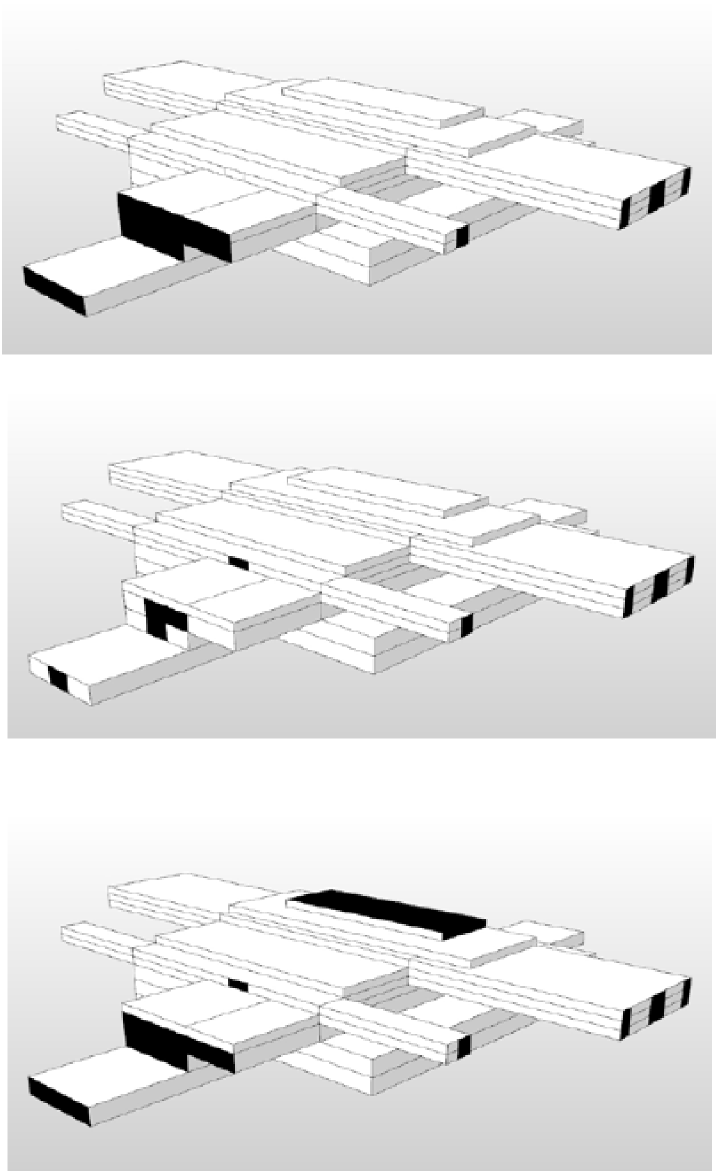


Figure 5.5: Schematic representation of Model 1 (basis model), Model 2 (small openings) and Model 3 (top opening). The openings are indicated in black.

5.3.5 Summer

The parameters for the summer situation, like those for the winter situation, can be derived directly from the working principles:

- Amount of sunlight coming in, determined by the transparency and the area of the skin

- Ventilation rate, determined by the parameters of the winter situation and by the temperature difference between inside and outside
- Heat transport through the skin
- Thermal mass in the form of heavy floors but also soil and water
- Cooling capacity generated by evaporation from plants and water

Since there are so many variables for the summer situation, the approach to test the design parameters is a bit different than that of the winter situation. The sketch design is taken as a starting point again. However, to narrow down the variables a small test is performed in which a variable is altered only one at a time (regardless of the possibilities in the design). In table 5 the input of the sketch design and the way the variables are altered is given. Since the summer scenario assumes a hot summer situation, the most effective variables are those that can really lower the temperature inside the building. The test shows that there are four variables that are especially interesting: transparency of the roof (the horizontal surface), area of transparent material on the roof, ventilation rate and cooling by evaporation of water (*Figure 5.6: Effect of the different design parameters on the indoor temperature*).

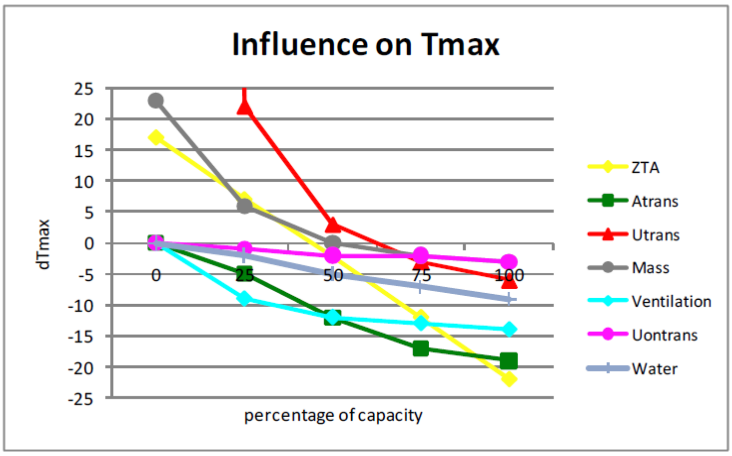


Figure 5.6: Effect of the different design parameters on the indoor temperature

	model 3 basis	model 4 ZTA	model 5 water
G	14000000	14000000	16000000
Hv	2381435	2381435	2381434,5
horizontal	26000	20000	26000
NE	7200	7200	7200
SW	2400	2400	2400
ZTA	0,45	0,45 0,2	0,45
water	0	0	10000

Table 6: Input data for mass (G), Ventilation rate (Hv), Transparent horizontal and vertical areas (horizontal,NE, SW), transparency (ZTA) and amount of water/green (water) for the summer models

Based on this conclusion, two extra models that do regard the architectural design are developed.

In the first test case, the influence of natural ventilation on the summer situation is tested. Because the same factors are at play in the summer situation, the models used for the winter situation are calculated in Contam for the summer situation as well. Since Summertemp only works with ventilation rate, this is the only variable that is altered for the three models. This is why, for the summer situation, these models are regarded as one case with different ventilation rates (*Table 6: Input data for mass (G), Ventilation rate (Hv), Transparent horizontal and vertical areas (horizontal,NE, SW), transparency (ZTA) and amount of water/green (water) for the summer models*).

Then the parameter of incoming solar radiation is tested in the fourth model. This parameter is determined by the area of transparent material and by the transparency of that material. This model is based on the third model because the expectation is that in summer, the third model will give better performance than the first or the second. The transparent area of the roof is diminished and the material used for that area has a lower transparency.

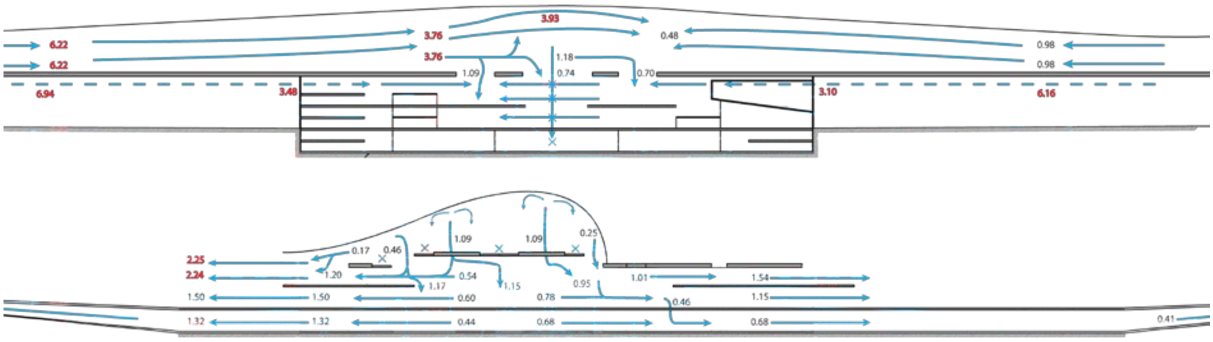
The last model is designed to evaluate the application of water and plants in the design. It is a variant of the third model again but with a large amount of water and plants added. Besides the cooling capacity, the weight of the water and the soil also influences the thermal mass of the building which means this parameter is tested as well.

5.4 Results

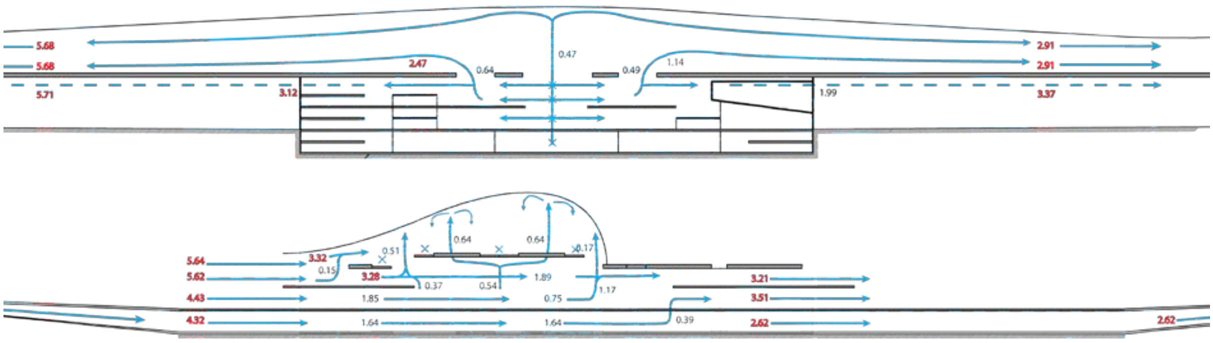
The models listed above are calculated and then evaluated on their performance. This is done by comparing the results with respectively the criterion for winter and that for summer.

5.4.1 Winter

The three models, described in the previous paragraph are calculated in Contam. The environmental input is determined by the winter scenario. This means there are two different cases for each model. For both cases the extreme wind speed is 25 m/s and the temperature 3.8 degrees Celsius. However, there are two determining wind directions; south west for the first case and west for the second. To create a reference case, model 1 is also calculated for the average wind speed of 6 m/s (see Appendix IV). The resulting wind speeds are calculated for different zones in the building. Besides that, the direction of the air flow through the different zones of the building is calculated. The following images show the results for each model (*figures 5.7 t/m 5.9; air flow in different models for west and south west wind at 25 m/s*).



Model 1: winter situation extreme wind speed 25 m/s west



Model 1: winter situation extreme wind speed 25 m/s south west

Figure 5.7: Air flow and pattern for model 1 in winter for south west and west wind with a wind speed of 25 m/s

Remarkable for both wind directions and all models are the high wind speeds at the entrances. These high wind speeds are the result of the use of the resistance principle. Small openings create high resistance so that less wind will penetrate the building. However, the air that does flow through is squeezed together so that higher wind speeds occur at the opening. The positive effect of this resistance can also be seen in all models; wind speeds are very low in the centre of the building. This means the starting point for the sketch design, on which all models are based, was good.

Looking at the first model, comfort can be guaranteed right in the centre of the building but for south west wind, problems occur at the front of the reception hall and at the Erasmus boarding platforms, caused by under pressure at that level. For west wind, the opposite happens; wind is pulled downward by the under pressure in the lower part of the building, causing high wind speeds at all boarding platforms.

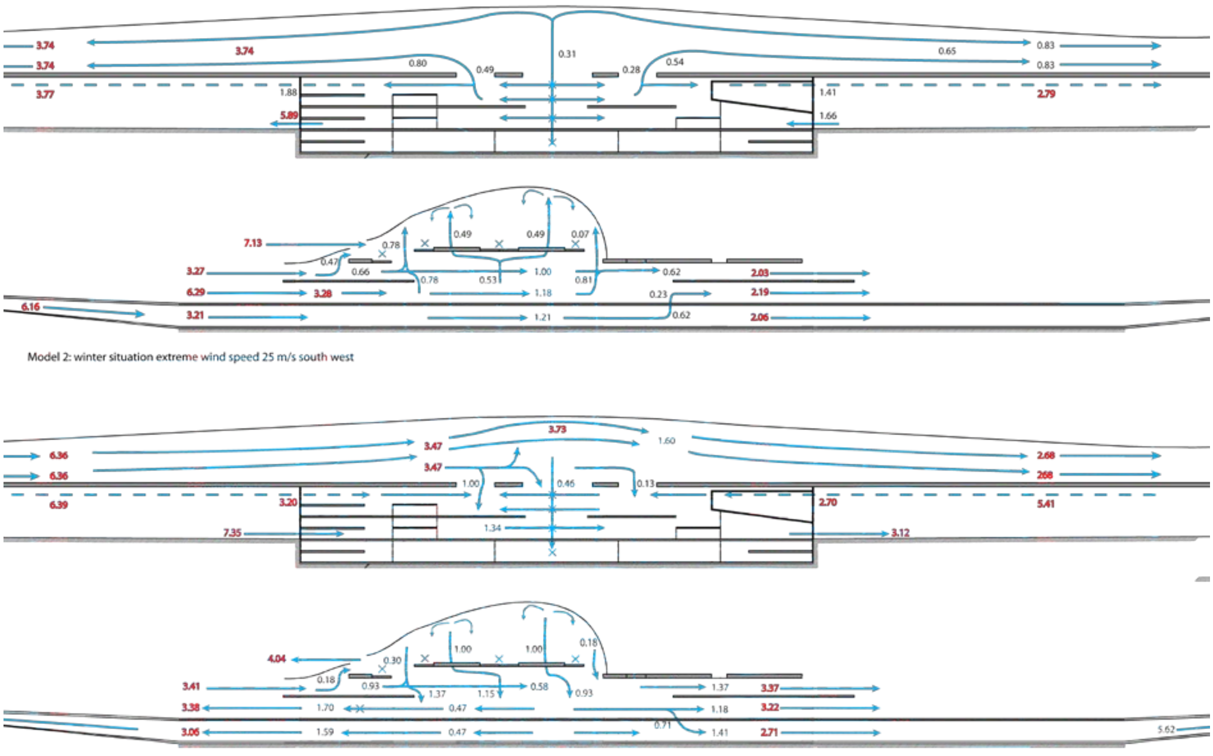


Figure 5.8Air flow and pattern for model 2 in winter for south west and west wind with a wind speed of 25 m/s

The second model shows even higher wind speeds at the entrances but also lower wind speeds in the core of the building. For south west wind, almost all problems are solved except for some exceedence of the maximum wind speed at the reception hall and a very high wind speed at the newly designed pedestrian entrance. For west wind however, the flow pattern is almost the same as in model 1 and this also causes the same high wind speeds at the boarding platforms. The moving upward of the opening at the Erasmus rail does not seem to affect the whole flow pattern although it does seem to reduce the wind speed at the pedestrian level (3m above the floor) of the Erasmus rail.

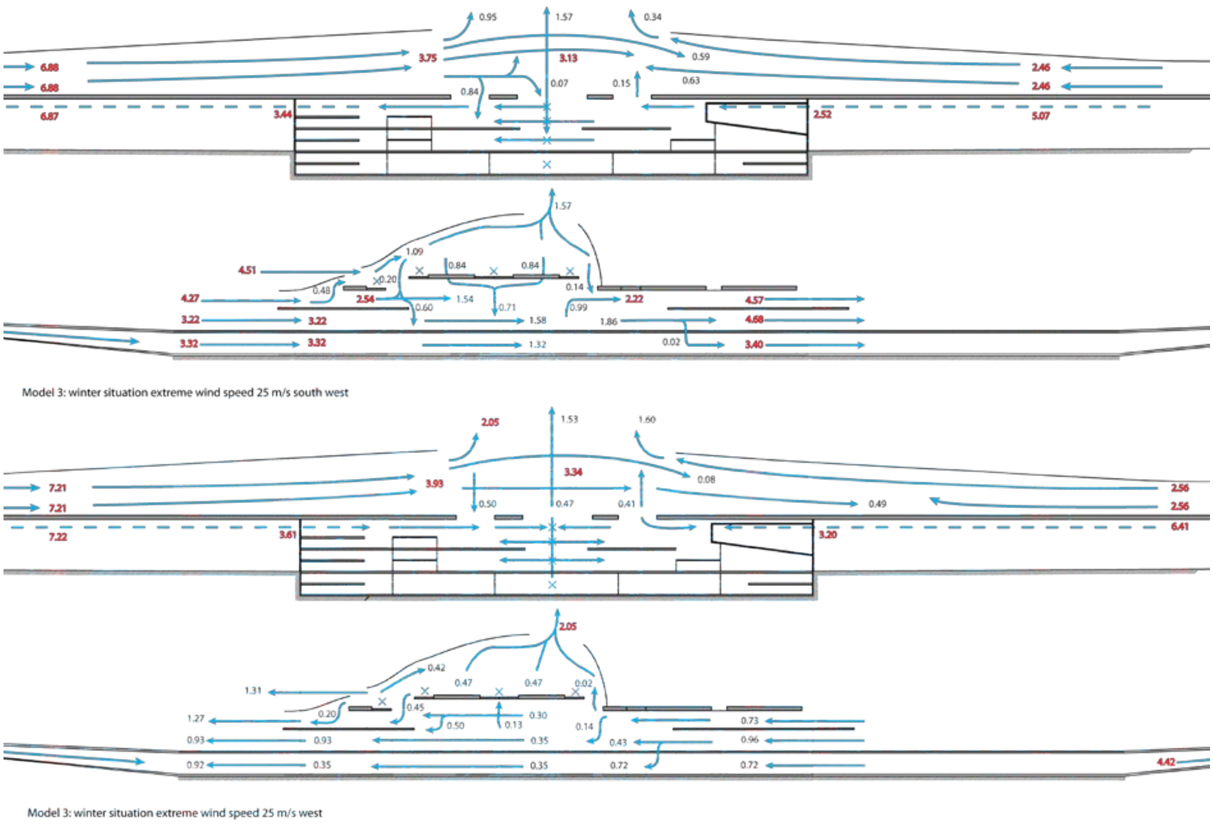


Figure 5.9: Air flow and pattern for model 3 in winter for south west and west wind with a wind speed of 25 m/s

As expected, the third model shows the largest displacement of air through the building. The addition of an opening in the roof creates more air movement and a totally different flow pattern. Although wind speeds with south west wind are a bit higher at the front of the reception and tram level, the wind speed at the core is still comfortable. With this wind direction, wind speeds at the boarding platforms are even slightly lower than in the other models, however the disturbed flow pattern can also cause nuisance. For west wind comfort in the reception hall, tram level and car level is much better, probably because air can flow outward not only through the lower levels but also through the roof. At the boarding platforms, the maximum wind speed is still exceeded.

To check the performance of each model and to compare them, the results are also plotted in graphs (*Figure 5.10: Wind gradient through the cross section for the different models for level -1, 1 and 3*). All models meet the comfort criterion at the lower levels in the core but exceed the maximum wind speed at the boarding platforms. Remarkable is that model 2 performs best in the first case when the wind direction is south west while model 3 performs best in the second case with west wind. The performance of the base model is in both cases average.

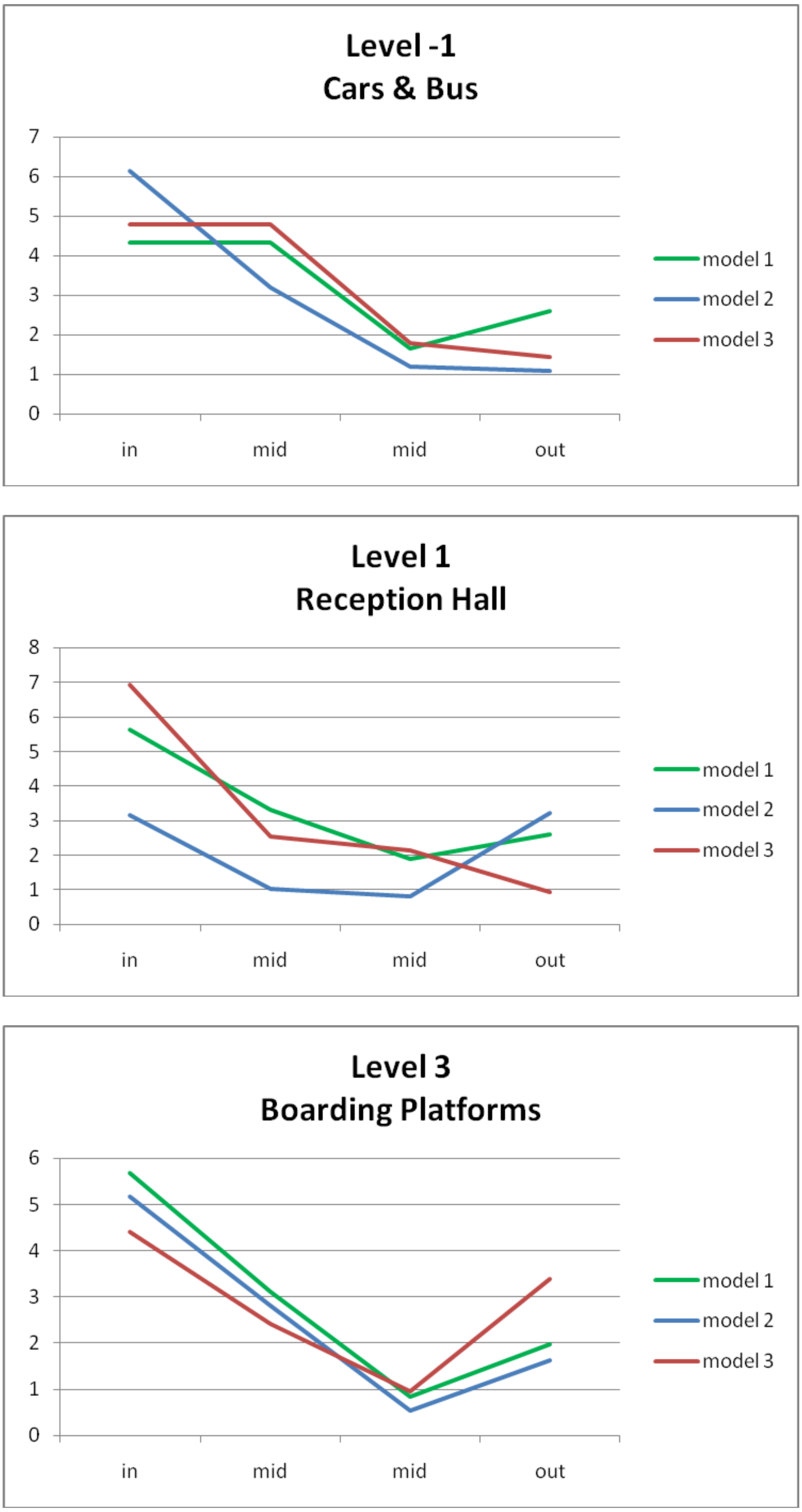


Figure 5.10: Wind gradient through the cross section for the different models for level -1, 1 and 3

5.4.2 Summer

Since in summer, a wind speed of 0 m/s is assumed, there are no different cases for wind directions. This is why for the summer situation one case is calculated for all models; that for a hot summer day in the Netherlands with a maximum outdoor temperature of 25 degrees Celsius, a sun load of 850 W/m2 maximum and a wind speed of 0 m/s. For the first three models (designed to calculate the effect of different configurations on airflow) calculations are made in Contam to define the ventilation rate. The effect of these three models on the air flow in summer are different than that for winter since no wind is acting on the facades but the temperature difference is much larger. For summer, this flow pattern can be shown in the same way as for the winter situation (figure 5.11 and 5.12; Air flow and pattern for model 1 and 3 in summer with a wind speed of 0 m/s). Only model 1 and 3 are compared since model 2 is not expected to generate a flow pattern that differs much from that of model 1.

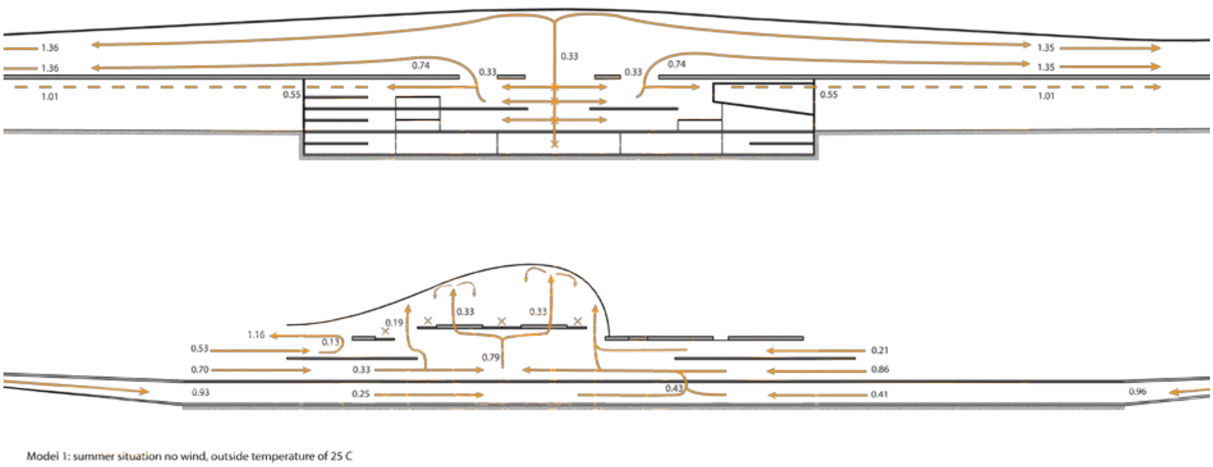


Figure 5.11: Air flow and pattern for model 1 in summer with a wind speed of 0 m/s

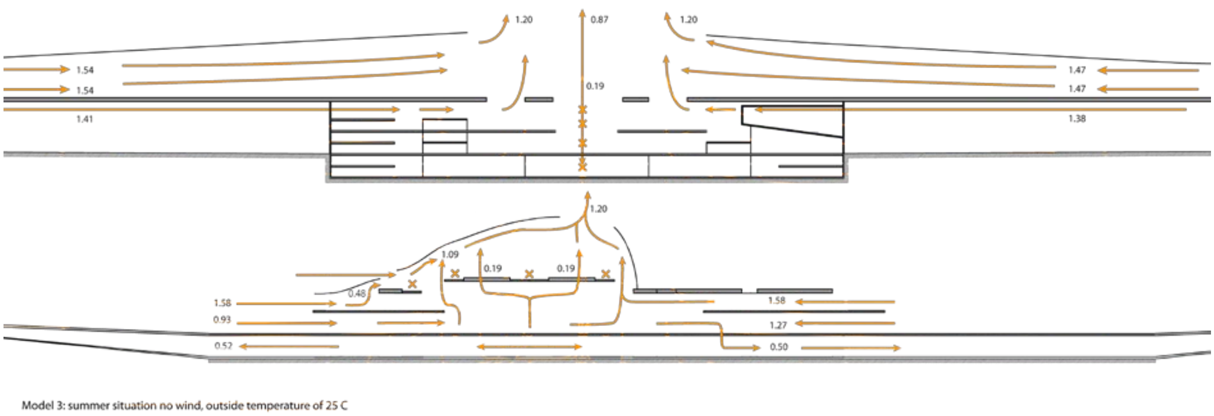
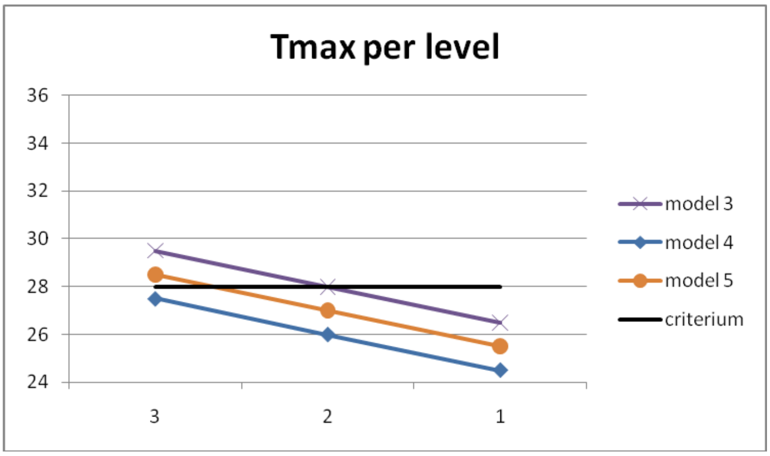


Figure 5.12: Air flow and pattern for model 3 in summer with a wind speed of 0 m/s

Looking at the air flow patterns, the difference between model 1 and model 3 is quite big. In both models the air is sucked from below and pulled upwards. Model 1 then pushes the air back downward so that it escapes through the entrances of the trains. At the entrance of the reception hall air is even pushed outward again. Model 3 on the other hand allows the air to flow all the way to the top and outward. This massive flow upward also pulls air from the train entrances inside and to the top. This way much more outside air is pulled inside which results in a higher ventilation rate. Remarkable is that the wind speed in model 3 is not significantly higher than in model 1, probably because the air flow is not disturbed and can easily escape the building.

The ventilation rates of the three models calculated by Contam are used as an input for Summertemp. For model 4 and 5 the highest ventilation rate of model 3 is assumed. For all models, the maximum temperature for the whole building as one zone is calculated with Summertemp and then an estimation is made of the temperatures per level (see Appendix IV). The results of these calculations are shown in the graphs below (*Figure 5.13: Maximum temperature (Tmax) for the most important levels compared to the criterion*. Model 1 (basis),2 (small openings) and 3 (opening top) only differ in ventilation rate. Model 4 (transparency) and 5 (water and green) are based on model 3but have modified values for transparency and water.). To give a clear insight in the level of comfort in the building, only the most important levels that are at risk of overheating and that are occupied by people are depicted. These are the reception hall (level 3), the Erasmusrail (level 4) and the boarding platforms (level 5). Figure XX gives an indication of the general temperature gradient throughout the building. This picture is purely an indication since temperatures for each zone are only estimated but it gives an impression of the warmer and cooler places in the building.



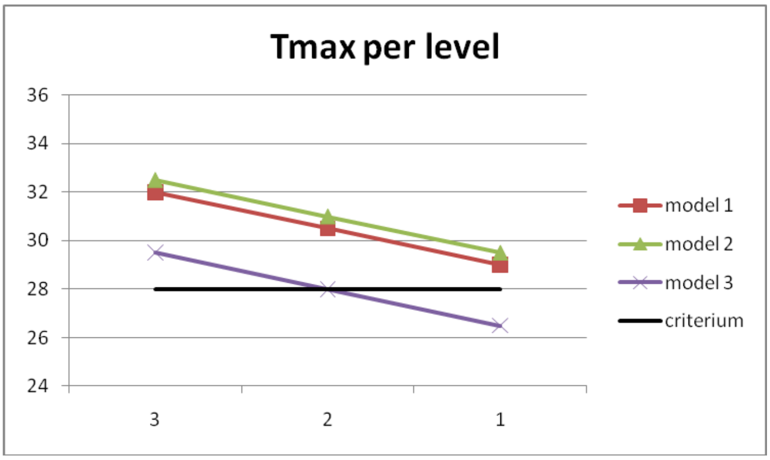


Figure 5.13: Maximum temperature (Tmax) for the most important levels compared to the criterion. Model 1 (basis),2 (small openings) and 3 (opening top) only differ in ventilation rate. Model 4 (transparency) and 5 (water and green) are based on model 3but have modified values for transparency and water.

The graphs clearly show that both the base model and the second model, without extra regulating methods, generate too little air flow to keep the maximum temperature within tolerances. The third model is designed to guide the air flow along the roof upward, based on the heat-stack-effect. Therefore it is not strange that this model performs much better and generates enough air flow to stay within the boundaries of comfort at level 3 and 4. However, level 5 is still suffering from overheating; extra methods are needed.

Model 4 and 5 work with these extra methods, respectively by influencing the incoming sunlight and by cooling the space with evaporation. Model 4 performs really well; temperatures are comfortable enough in the whole building. Model 5 does not perform quite as good but the reception hall and the Erasmusrail are comfortable and the temperature on the boarding platforms only exceeds the maximum temperature by half a degree.

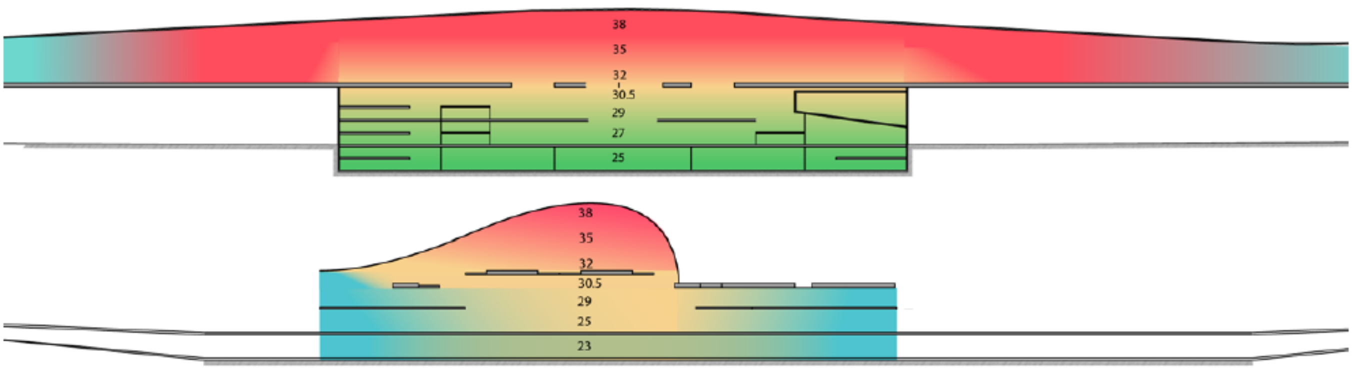


Figure 5.14: Representation of the resulting temperature gradient inside the building. This is merely an indication to give insight.

5.5 Conclusion

The goal of this research was to find the best way to apply the methods for regulating wind and temperature to this specific design. The optimal system is defined as the one meeting the technical as well as the architectural demands. Because of the ambiguity of this building technical research, the choice to include the architectural design in the process was made. This method is really efficient since the impossible or extreme technical solutions are eliminated from the beginning. Besides that, it stimulates to think about the architectural design in an innovative way from the start. However, it is also less scientific and the results are therefore sometimes difficult to interpret. Of course, some general conclusions can be drawn and they will be very helpful in the development of the design.

5.5.1 Winter

The first, most obvious conclusion is already mentioned in the results. The principle of slowing down the wind with the use of small openings and a large volume works very well for this transport terminal. The sketch design was developed with this idea from scratch and all the models (all based on this design) show already a large reduction of the wind speed from 25 m/s to a maximum of around 7 m/s and a minimum of almost 0 m/s. However, the site effect of this method is also noticeable in all models: uncomfortably high wind speeds at the entrances. Little can be done to avoid this effect so to solve this problem clever design has to make sure these spaces are used as little as possible. From the results of model 2, which is optimized for this working principle, it can be concluded that there are still possibilities in the design to exploit this method. However, reducing the size of the openings perpendicular to the wind direction (in this case south west), might create problems when wind is blowing from another direction (when blowing from west higher wind speeds occur on the boarding platforms).

Another conclusion that can be drawn from the results of all models is that comfort at the boarding platforms is difficult to achieve with the used methods. Although reduced, the wind speed is still too high in all models in the case of west wind and for model 3 even in the case of south west wind. Looking at the small differences in performance on the boarding platforms of the different models some conclusions can be drawn. Model 2 performs best in the case of south west wind, wind speeds are well below the maximum. This is because the openings perpendicular to the wind are smaller and less air is coming in, as a result less air needs to escape at the boarding platforms. Thus, the concept of model 2 can be very useful when wind is blowing from south west. Model 3, although still exceeding the criterion, performs best for west wind. Incoming air can escape, not only by flowing downward and to the entrances of the reception hall and tram level, it can also flow right to the roof and escape there. Besides improving comfort at the boarding platforms this also improves the comfort at the lower levels significantly. This principle of creating an opportunity for the wind to escape, guiding the wind towards the roof where no one can be disturbed by it, can be used to solve some of the problems here. To achieve full comfort additional methods might be necessary. Volumes or wind screens could be used to block the wind but also to help guide the wind upward.

When the direction of the wind is south west, model 2 and 3 show an exceedence of the criterion directly behind the entrances on level 1 and 2 while model 1 shows this exceedence at level 3 and 4.

These problems are probably caused by the lack of possibilities for the air to escape. The principle of creating a large volume behind small openings is not used correctly in these parts; the openings become pipes. The volume, created by the atrium in the centre of the building is too far away to be effective for the spaces directly behind the openings. Moving the atrium closer towards the entrances or creating other vertical openings so that air can escape, solves the problem.

Concluding the findings of the winter research, the resistance effect works really well but does not suffice to create a comfortable climate at the boarding platforms. Besides that, problems at the entrances and directly behind the entrances occur. Overall comfort is not achieved by either one of the models but the outside wind speed is reduced significantly. A configuration that combines the positive aspects of each model in combination with some volumes to block and guide the wind where necessary will most probably lead to overall comfort.

5.5.2 Summer

Like in the winter situation the principles of natural ventilation to keep the wind out work very effectively, in summer the heat-stack-effect is very effective. Model 3 shows that just by adding an opening at the top the flow rate more than doubles. The effect could be optimized even more by closing off the higher entrances but the architectural design does not allow for that. The optimal flow rate by natural ventilation is thus pretty much reached with the configuration of model 3. Higher flow rates would not even be that effective anymore since the air temperature inside approaches more and more the outside temperature until more ventilation has no effect at all. This effect can also be seen in the graph of the test to diminish the amount of variables (*Figure 5.6: Effect of the different design parameters on the indoor temperature*).

From this small test it can also be concluded that after ventilation in the beginning, reducing the transparent area and the amount of transparency are methods that become more and more effective. The results of model 4 confirm this; it is the only model that assures total comfort. While the significant levels of model 1 and 2 are all suffering from overheating and model 3 can only provide comfort in level 3 and lower, model 4 stays within comfort zones for all levels. However, the optimum is still not reached because the architectural design allows for more alterations. This means that the method of reducing the incoming sun load is very effective and can even be more effective. Then the limiting factor will be the amount of daylight needed for the architectural design, which is determined by the minimum amount of daylight for plants to grow.

The last model and the graph of the effect of different parameters show that the cooling by evaporation can be a very effective method too. However, large amounts of water or plants are necessary to cool the large volume of the building. The amounts used in model 5 are already near the limits of the amounts possible in the architectural design as it is. This means that the method can be used but that it needs to be combined with other methods in order to reach a comfortable temperature. Besides that, note that the way the cooling by evaporation is included in the calculation is a bit simplified. It does not include the effect of the air temperature or the humidity on the process of evaporation but uses an hourly average to estimate the effect which probably predicts a slightly more positive effect then in reality would occur.

The general conclusion of the summer research is that the methods that are used are really effective but that it is difficult to achieve comfort using only one method. However combining different methods is a real good possibility and can certainly lead to a very good design for summer comfort.

6. Final design

The final objective of this project is to create an integrated design for a transport terminal at the Prins Clausplein. This chapter describes the solution to the architectural assignment as well as the ultimate research question in the form of the final design. It starts with an analysis of the findings of research and design, with which the ideas for the final design are developed. After that, the final design is explained technically and architecturally. Using the different design aspects as a guide, the way the architecture and the climate system work together is explained. The aspects of air quality, acoustics and lighting are also implemented in the final design as they form a part of the overall comfort in the terminal.

6.1 Analysis of design parameters

To create a starting point for the final design, a comparison between the results of the research of the previous chapter and the sketch design is made. The comfort aspects of wind and temperature are compared to the architectural design. This comparison provides a clear overview of the findings but also the restrictions in research as well as design and shows how the two can be integrated in the final design. This paragraph does not include the aspects of air quality, acoustics and lighting but they are considered in each design solution for the final design discussed in the next paragraphs.

6.1.1 Technical demands

In the conclusion of chapter 5, the results of the research on the optimization of the design parameters are explained and evaluated. For the final design, these conclusions and some conclusions drawn from the theory of wind and temperature can be used as a technical guideline to create a comfortable climate. The conclusions for winter as well as summer situation are translated to the technical demands below. The symbols are indicating the influence of the demands on the design parameters that are shown in the figure below (*Figure 6.1: Symbols of the design parameters indicated in the sketch design.* Openings skin (Oskin), floors (Ofloors) and top (Otop), Transparent area of the skin (Atrans), Mass of the floors (Mfloors) and skin (Mskin), Obstructions (obstr) and Evaporation (E).).

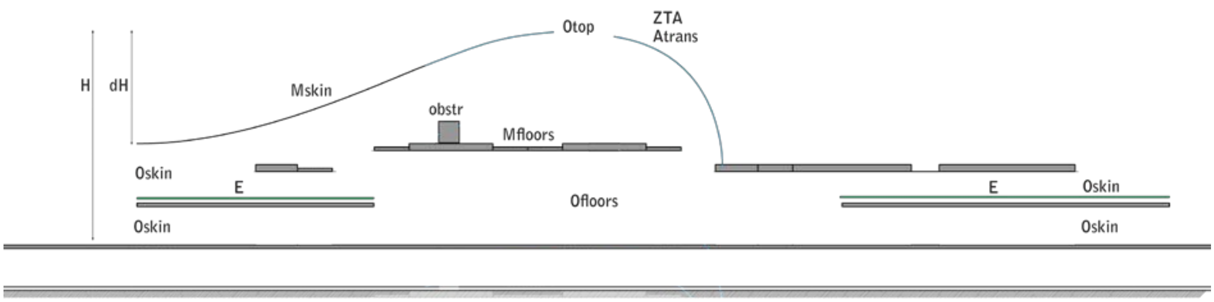


Figure 6.1: Symbols of the design parameters indicated in the sketch design. Openings skin (Oskin), floors (Ofloors) and top (Otop), Transparent area of the skin (Atrans), Mass of the floors (Mfloors) and skin (Mskin), Obstructions (obstr) and Evaporation (E).

Winter:

- The height of the building has to be kept to a minimum so that the amount of wind “caught” at greater heights is limited (<H).
- Openings have to be kept as small as possible and the building volume directly connected to the openings as large as possible (<Oskin, >V, >Ofloors)
- Places in the building suffering from high wind speeds often lack the possibility for wind to escape. An opening in the roof can provide this possibility without disturbing the climate at passenger level (Atop).
- A logical additional method would be using building volumes inside the transport terminal to guide and/or block the wind at the right places (>obstr).

Summer:

- To generate good natural ventilation, openings in skin as well as between spaces have to be large enough to allow an easy air flow. A large difference in height between inlet and outlet is optimal; placement of an opening at ground level and an opening in the roof works best (>Askin, >Afloors, >dH, Atop).
- Too much incoming sun load has to be avoided which means the transparent parts in the skin have to be kept to a minimum. At the places where daylight is desired, the transparency of the material should be as low as possible (<Atrans, <ZTA).
- Profits of the effects of thermal mass and evaporation only occur when large amounts are applied. The ratio between the area of transparent material (incoming heat) and the area that can be used for cooling and thermal mass is decisive for the effect on the temperature (>Mfloors, >E).

6.1.2 Architectural demands

In chapter 4, the transport concept and the architectural concept are explained and translated into the sketch design. The sketch design gives shape to the abstract concepts and turns them into concrete architectural demands:

- The most important function of the building is the connecting of transport types. Therefore the building has to be suited for all the different transport types and the connection between them. This means that openings for each different transport type are required and space is required for parking or boarding (>Oskin, >Mfloors).
- Connection is also established by the passengers themselves. Navigation and a clear overview are important. In the sketch design openings in the floor to connect the different levels visually and as little objects in between these visual connections provide this (>Ofloor, <obstr).
- The shape and program of the building relates to the location. This means that, to make a distinction between this important building and all the tall buildings in the area, it should be relatively small. It also means that the different directions of the transport types should be visible in the architecture to guide the passenger and that the program needs to fit in the

scenario for the Prins Clausplein. The reception hall that forms the link between the scenario’s recreational areas and the Vliet needs to resemble a park; therefore a lot of green and water is required (<H, >E).

- The roof is the most expressive element of the architecture and therefore it needs to reflect the importance and the function of the building. Besides that, the illusion of a hovering canopy is important so light and transparent materials are preferred (<Mroof, >ZTA, > Atrans).

6.1.3 Integration of research and design

Now that the guidelines and demands are listed, the boundaries of both research and design are made visible. For the integration of research and design, the similarities and differences between the two are important. Whenever a conflict between the two is detected the importance of each parameter for research and design is evaluated. Depending on the validation of the parameter a design solution is developed that is either favoring research or design, or is a compromise between the two. In the figure below (*Figure 6.2: Design tool showing the relation between the technical demands froms the research in summer and winter and the architectural demands*. Conflicting demands are indicated in red) the relation between the demands of research and design is shown. The conflicts between the design parameters are indicated in red.

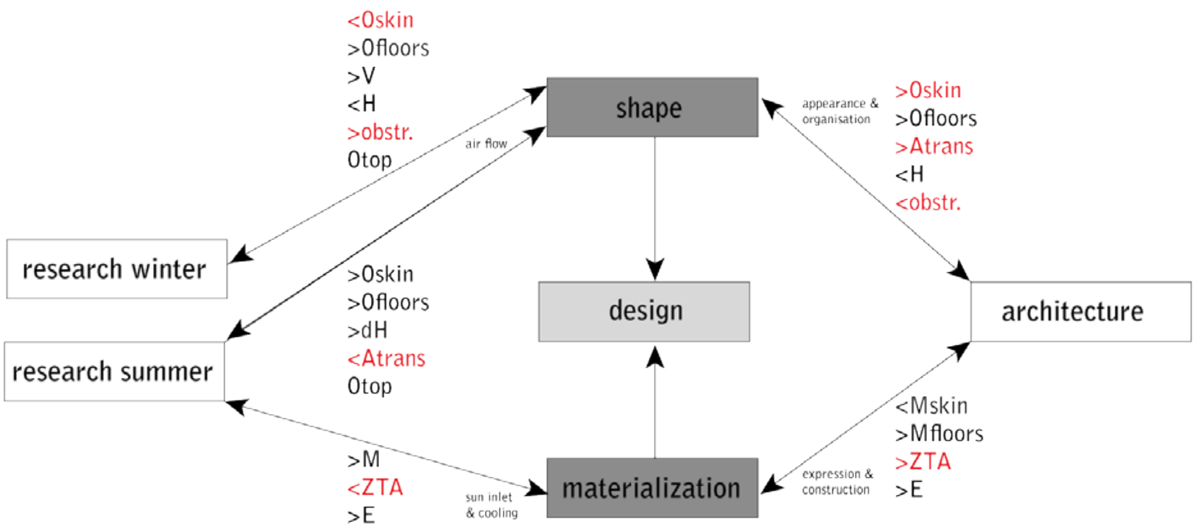


Figure 6.2: Design tool showing the relation between the technical demands froms the research in summer and winter and the architectural demands. Conflicting demands are indicated in red

Looking at these conflicts, the following parameters need a design solution:

- Openings in the skin (Oskin); in winter it is very important to keep the openings small while for the summer situation and for the architectural design large openings are preferred.

- Obstructions (obstr); in winter to achieve full comfort, additional obstructions in the form of wind screens or building volumes are necessary. In summer and in the architectural design, these obstructions block the natural ventilation and the view.

- Transparent area (Atrans) and transparency of the material (ZTA); In summer the transparent area and/or the material's transparency have to be kept to a minimum to avoid overheating, in winter and in the architectural design, large transparent or translucent areas are desired to allow daylight into the building.

Besides conflicts, there are also similarities between the demands and some parameters that are important for one aspect do not play a role in the other. This means that some decisions on how to use the parameters in the design can already be made:

- The height of the building (H) can be kept relatively low. Although a maximum difference in height between the openings is preferable for the summer situation, the calculations of the previous chapter show that good performance in summer can already be achieved with the height chosen in the sketch design.

- A large building volume (V) to create optimal conditions in winter can easily be obtained in this architectural design and has no negative effect on the summer situation.

- To create this large volume, large openings in the floors (Ofloors) can be used. These atria not only provide a great resistance against high wind speeds but strangely enough they also provide a better air flow between the levels in summer. For the architectural design, these atria are very desirable to create overview and to help passengers with their navigation through the building.

- An opening in the top of the skin can be created (Otop). This is very important for the summer situation and there are profits for the winter situation as well. From a design perspective wet areas caused by the opening in the roof could have negative effects but if placement is done cleverly, disturbance can be avoided.

- The material mass of the building can be quite large (M). This mass can act as thermal capacity for summer as well as winter situation. Because the architectural design needs heavy floors and a basement enclosed by earth, sufficient mass can be provided. The roof however, needs to be light weighted so that the span can be large and the impression of lightness is strong. In combination with a large transparency of the roof this only contributes to prevent overheating in summer. A light material allows the incoming heat to escape easily by transmission while a heavy material would block this heat flow outward.

- Large amounts of water and green (E) can be applied. This is desirable for the summer situation as well as the architectural design. In summer to cool the building down by evaporation. In the design to emphasize the recreational link between the urban plan for the Prins Clausplein and the Vliet and to create the ambience of a park at the reception hall.

With the insights on the relation between research and design given in this paragraph, design solutions for the final design are developed. In the next paragraphs, these solutions and their implementation in the final design are explained. Besides the aspects of wind and temperature, the other aspects of air quality, acoustics and lighting are evaluated.

6.2 Appearance

The way the building expresses itself in the urban situation and the way it organizes people and spaces inside is very important for the architectural design. However, decisions on dimensions, shape and openings can have far reaching consequences for comfort as well. In this paragraph the design parameters of height (H), volume (V), shape, openings in the floor (Ofloors) and openings in the skin (Oskin and Otop) are investigated and the solutions for the final design are explained. Air quality, acoustics and lighting are introduced in the design again and mentioned where relevant.

6.2.1 Dimensions

Shape influences air movement and thus wind, temperature and air quality. Although the influence of the shape of a building on air movement around it is large, theory explains that for the air flow inside a building in winter as well as in summer, not so much the shape but the dimensions are important. The height of the building determines the pressure difference while the volume determines the flow rate inside.

As explained in the previous paragraph, the preferable values for the design parameter height are similar for design as well as research. A total height of around 30 meters is chosen. This is high enough to impress the pedestrians at ground level but low enough to connect with the low recreational areas and distinguish from the tall office buildings (*Figure 6.3: Height of the building in relation to the surrounding buildings).* With this height, in winter the pressure on the facade is relatively low and in summer sufficient difference in height can be created to stimulate natural ventilation.

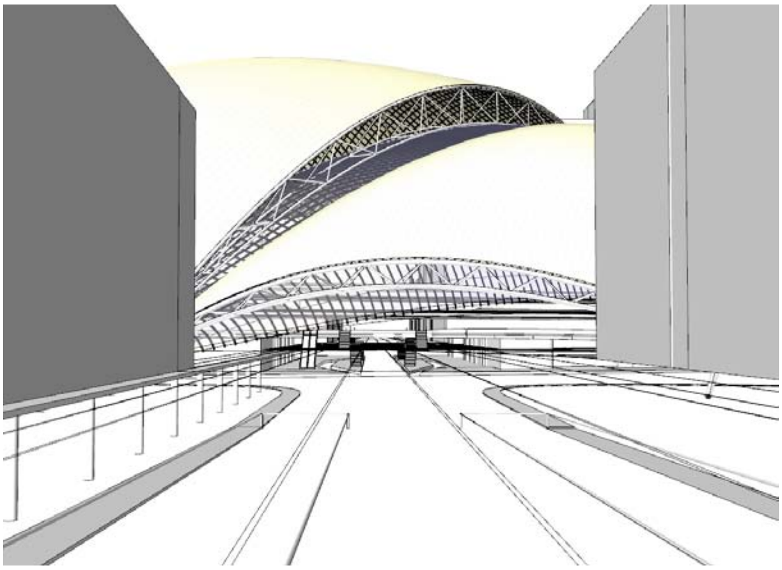


Figure 6.3: Height of the building in relation to the surrounding buildings

Volume is also a quite free parameter. In winter, a large volume is desired while for the summer situation and the architectural design, the parameter can be chosen freely. The infrastructure running through the transport terminal has a large scale; subsequently the building and thus the building volume are large. In the final design, compared to the sketch design, the building volume is enlarged a bit more so that the method of resistance in winter is even more effective. Besides air movement, a large volume also affects acoustics; the large amount of air absorbs noise and provides the conditions for conversation without disturbance from surrounding sounds. For the architecture a large volume works positively as well; it emphasizes the architectural concept of a city underneath a canopy.

6.2.2 Shape and openings

To use this volume at its full potential, the openings in the floors are important. All demands point in the same direction; large openings in the floors. For the architectural design to create overview and for the comfort in winter and summer to allow vertical air flow but also to allow daylight to penetrate to the lower floors. Besides the size, the position of the openings is crucial; the flow of passengers should be able to move easily through the terminal and the high wind speeds can only be reduced if the vertical openings are directly behind the openings in the skin. In the final design, the largest atria are placed directly behind openings in the skin instead of in the center of the building, as is the case in the sketch design. This allows both for a better traffic flow and a better air flow pattern. Lighting conditions are slightly reduced because light cannot penetrate to the center of the building. However, additional lighting will always be necessary and the amount needed is still much lower than in ordinary terminals.

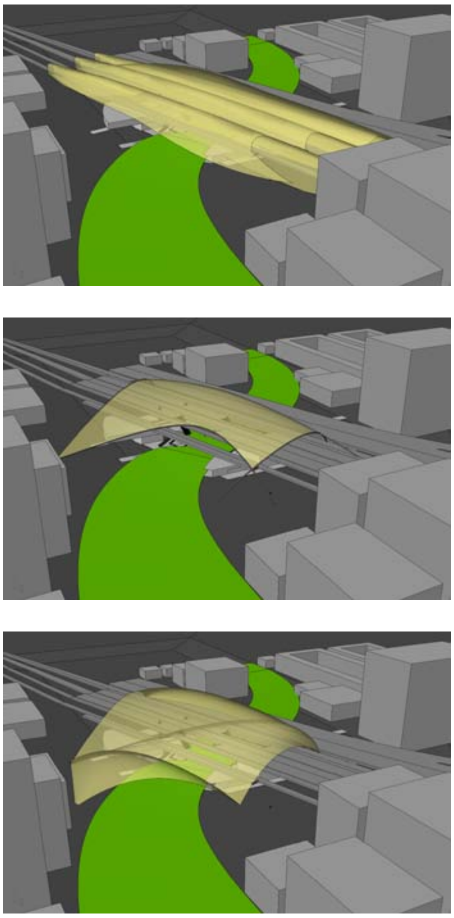


Figure 6.4: Roof study. From top to bottom, model 1,2and 3

For comfort as well as for architecture, openings in the skin of the building are very determining. Demands for the size of the openings contradict. This means that the design possibilities and their effect on comfort and architecture should be weighed very carefully. As has been mentioned in the paragraph about architectural demands, openings in the skin of a transport terminal need to be relatively large because trains, trams, cars and busses have to be able to enter and exit the building. From an architectural point of view, it is very important that the openings that serve as an entrance are clearly recognizable and inviting. They should be easily visible and, according to the concept of following the directions of the different transport types, a guidance for the passenger. Keeping this, and the opted lightness and expressiveness in mind, an architectural study on the shape and openings of the skin has been performed (*Figure 6.4: Roof study. From top to bottom, model 1,2and 3*).

The first roof has the shape of that used in the sketch design. It is inspired by the working principles to keep wind outside. The openings are kept as small as possible which is expressed by the pipes in the shape. The architecture expresses the idea of an integrated design but the shape does not reflect all the different directions of the traffic streams and it appears quite closed and uninviting. Concluding from the research this shape works quite effectively for the winter situation but for the summer situation an extra opening in the roof is necessary. Natural ventilation is needed to reduce the temperature and improve the air quality. The closed shape does promise better acoustic performance since noise from the highway can be kept outside.

The second design strongly expresses the idea of a floating roof. It is a very open and inviting shape and the asymmetry vaguely suggests the different directions. However, the comfort performance is low; in winter the wind speed is hardly reduced because the shape is too open to create a resistance. This openness also implies a bad acoustical performance; noise from inside will be absorbed by the large volume of air but noise from the highway cannot be isolated. In summer, the performance is a bit better; there are enough openings to ventilate the building although the heat-stack-effect is still not used efficiently since there is no opening in the top.

The last model is built out of several shapes to reflect the different directions in the design more strongly. Although the directions are not literally translated to the shape, the asymmetry and the openings create a strong basis to accompany the directions but also to guide the traveler towards his destination; the joint of traffic streams. The openings are larger than in the first model but are still enclosing the volume. The reduction of the wind speed in winter will be less than in the first model but it is difficult to predict how much. In summer, there is obviously more openings to induce air flow but still an opening in the top would improve the situation. Like for the other aspects, the acoustical performance will also be moderate; worse than the first but better than the second model.

For the final design, the last model is chosen. The expression of the different traffic streams is very important for the architectural appearance and functioning of the building and there are measurements possible to improve the performance on comfort. An important advantage of the first model is that the research is made visible in the architectural appearance of the design, in this design the technical improvements are used to visualize the integration of architecture and engineering. For shape and openings, these improvements consist out of two important modifications; the openings at the lower levels are closed off a bit to reduce wind speed in winter and openings in the top are added to improve the air flow in summer. Both modifications are done using the several parts of the shape. Instead of connecting in one point, in the final design the shells are overlapping so that they extend downward and partly close off the openings suggested by the neighboring shell. The shells are not connected where they meet but a distance between them forms an opening at the top of the roof. An additional method to partly close off the openings at the boarding platforms is used. The shells opening up towards the trains are extended downward so that the large openings are partly closed and only the necessary openings remain (*Figure 6.5: Openings in the final design*).

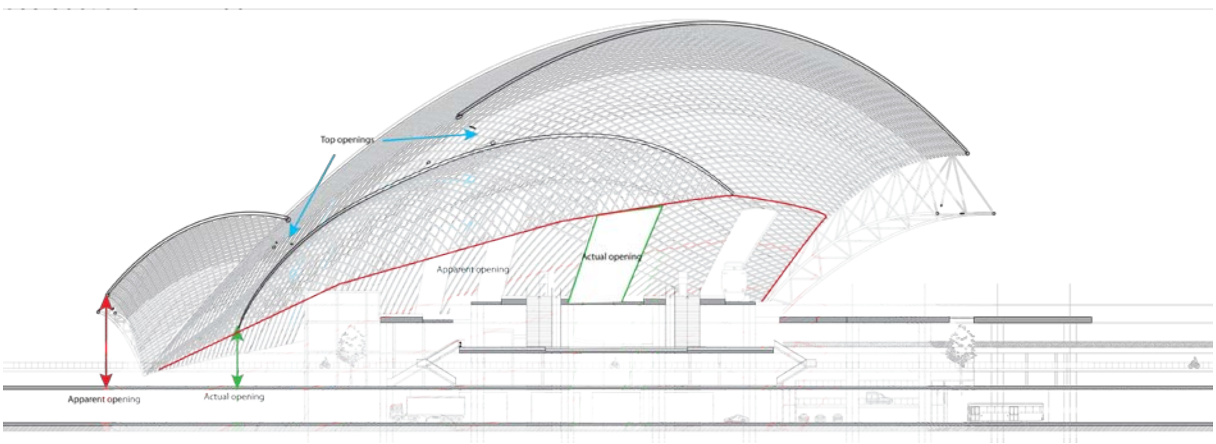


Figure 6.5: Openings in the final design

6.3 Program

Besides the function of connecting different transport types, an additional program is included in the design. The type and placement of functions determine what activity takes place in which area of the building. This has consequences for the architecture but also for the level of comfort since the demands for both are dependent on the activity. By selecting the right functions for the right spots in the design and the other way around, satisfying niches, fitting the activity can be created inside the building. The type of functions, their placement, the methods taken to make them comfortable (obstr) and the way green and water (E) are integrated in the program are discussed in this paragraph.

6.3.1 Functions

As explained in paragraph 4.3.3, commercial, recreational and horeca functions are chosen to integrate with the transport streams in the building. Following the line of the architectural concept, these functions are relating to the other functions in the surroundings but also to the accompanying infrastructure. This is very important for the architectural design; the purpose of the transport terminal is in the first place to integrate infrastructure and urban structure. The success of the design is dependent on the way functions and transport routes are placed in the building. This is why the choice for the placement of functions is purely architectural.

For each transport type (and thus level in the building) a different theme is developed. Cars and busses enter the building below ground level. This route is meant as the fast route and should therefore be as functional as possible. On ground level, the boarding platforms of the tram are accompanied by small shops at each side of the route as a continuation of the main artery in the masterplan in which shops run along the length of the boulevard. The theme is therefore commercial. Continuing this line of thought, the reception hall that connects with the recreational area in the urban plan should relate to recreational functions; a park accompanied by a tennis field and a cinema are envisioned for this level of the building. The top level, where the trains enter the building, is the most prestigious level. It is the level that forms the entrance of The Hague for the visitor. Because the goal of this project is to create a comfortable terminal, the train level should reflect this comfort (*Figure 6.6: Ambition for the atmosphere on the different levels*).

Figure 6.6: Ambition for the atmosphere on the different levels

Although the placement of functions is determined by the architectural concept, it has consequences for comfort as well. Wind, temperature and acoustic conditions will be best at the lower floors thus for the activities of parking, waiting and shopping, while lighting and air quality will be better at the higher floors for the recreational and horeca activities but also for waiting (*Figure 6.7: Placement of the additional program of shops, horeca, recreation and storage/technical space*).

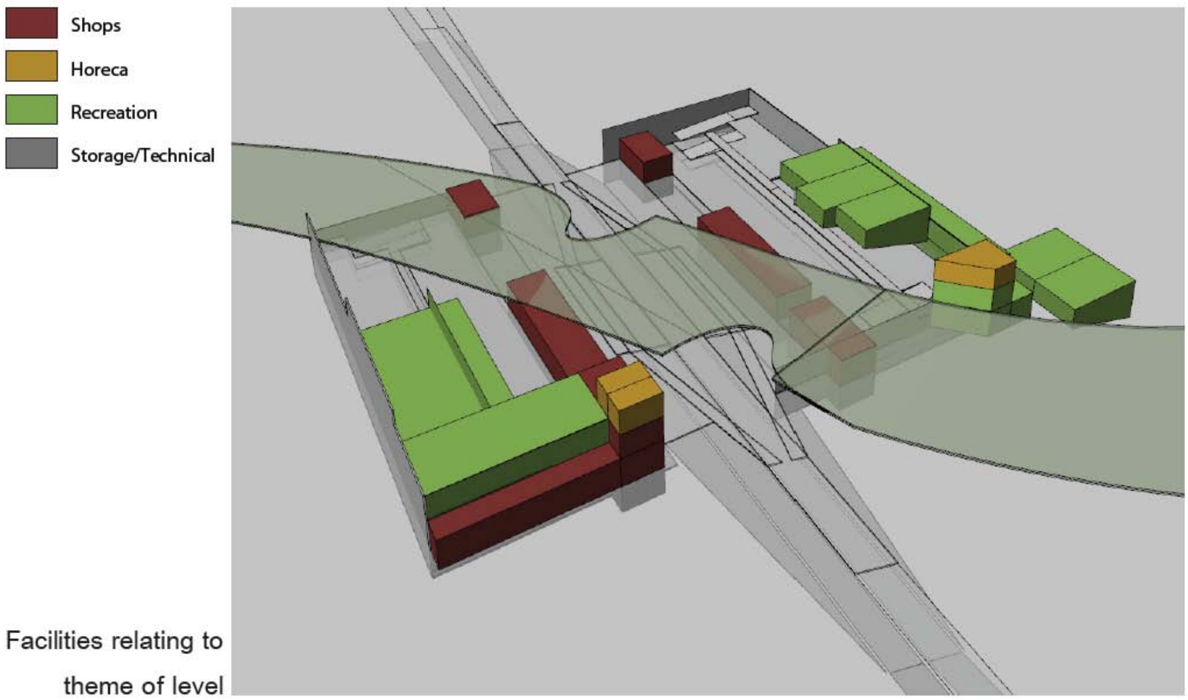


Figure 6.7: Placement of the additional program of shops, horeca, recreation and storage/technical space

The climate in the shops, the cafes and the cinema is actively regulated, therefore their placement is not that much dependent on the outside conditions. For the tennis field, the transfer areas and the waiting areas however, this is different. To create good comfort, not only the general placement but the exact place, orientation and the surrounding walls, floors and objects are important. In chapter 2 and 3, regulating the climate in a space by placement and orientation is already mentioned; in the next paragraph the application of niches in the final design is discussed.

6.3.2 Niches

Niches are sub places in a larger space that have different climate and architectural conditions so that different activities can take place in the same space and so that people are able to choose their desired conditions. In the previous paragraph the importance of a good architectural approach for the placement of functions is argued. However, for the activities to really take place at the desired spots, comfort is very important. Therefore, in the final design the comfort of the passively regulated functions is assured by the use of niches. This paragraph explains how the niches for tennis field, transfer areas and waiting spaces are formed in the final design.

The activity tennis especially requires good air quality and ventilation for comfort. The spatial requirements are freedom to move in space but at the same time privacy and distance from the other activities in the terminal. To achieve this, a double height of eight meters is taken. This way the space is large enough to move freely and the lower height of the ticket office can be used as a physical boundary between the transfer functions and the tennis field. Because the reception hall is very open and there will be quite a lot of air flow this low boundary also functions as an obstruction for wind. The space directly behind it close to the ground is lee while the higher layer of air above provides the necessary ventilation. Lighting is also an important aspect for tennis. Daylight is shining in from the adjacent atrium to the boarding platforms but additional lighting is needed. This can be located at the ceiling under the boarding platforms. This ceiling also protects the place from rain (*Figure 6.9: Different niches in the final design*).

Transfer areas include passage ways in the form of walkways, ramps, stairs escalators and lifts, boarding platforms and parking spaces. Passage ways are not places that need to be conditioned since they are not used to stay. Therefore the passage ways are not designed as niches but they are discussed in the section about routing. The boarding platforms are somewhat different since they are used to stay although for a short while. At the boarding platforms a division in zones is applied to distinguish a niche for each different activity (*Figure 6.8: Zones at the boarding platforms*. Sites of the platform: walking zones (light gray), center of the platform: waiting zone divided into standing (dark gray), waiting outside (green) and waiting inside (red)).

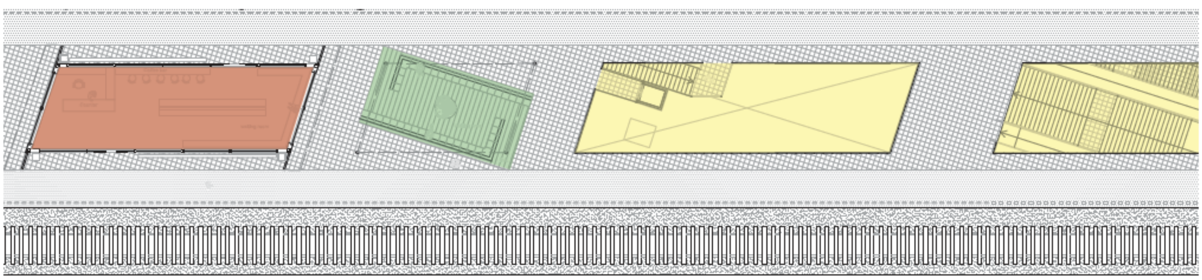


Figure 6.8: Zones at the boarding platforms. Sites of the platform: walking zones (light gray), center of the platform: waiting zone divided into standing (dark gray), waiting outside (green) and waiting inside (red)

For the activity of transferring only the part of the platform closest to the railways is reserved (indicated in light gray). The most important requirement for this zone is that there is enough space to walk along the railways and to enter and exit the vehicle. This is why the transfer zone runs along the full length of the boarding platform. The parking spaces are used for a longer stay, not for people but for vehicles. Safety is the most important requirement. This means some distance from the other functions and the possibility to close it off at night are needed. This is why the parking spaces are situated at the lower levels where they can be separated from the more public part by the shops. The surrounding walls and roof assure a dry, calm and cool climate. Little daylight enters the building at this place so although lighting requirements are not very strict artificial lighting is attached to the ceiling.

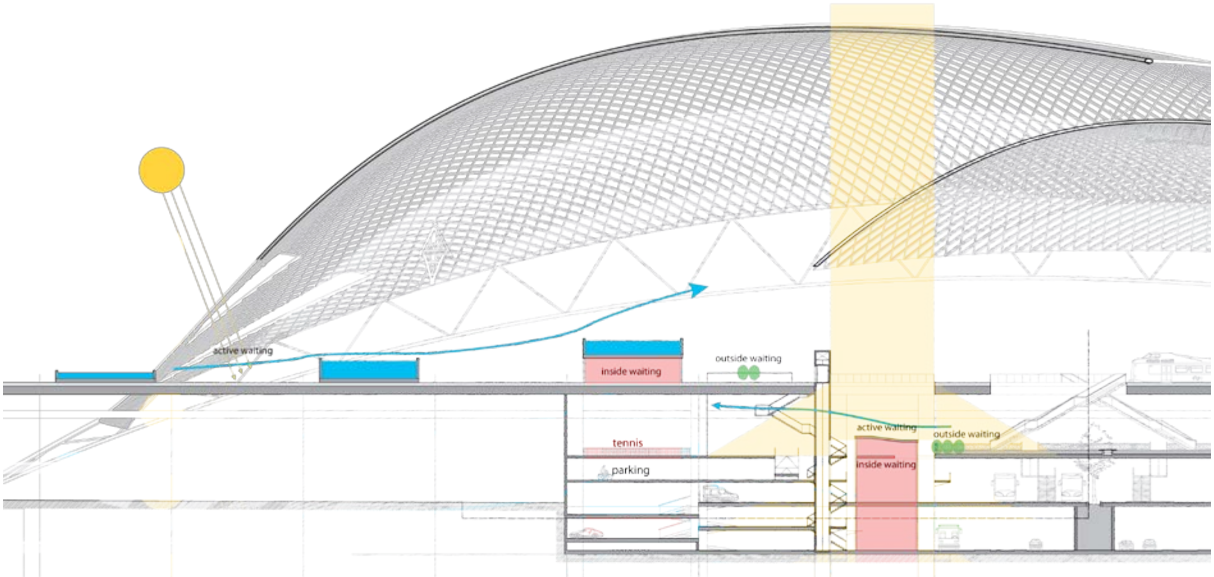


Figure 6.9: Different niches in the final design

There are a lot of waiting areas in the transport terminal. These waiting areas are not only meant as places for passengers to wait but also as recreational areas where people can stroll, eat, drink and relax. At both the reception hall and the boarding platforms, three different types of waiting areas can be distinguished; active waiting areas, outside sitting areas and inside sitting areas. All three types need different conditions. For active waiting the space should be large enough to freely move around. To invite people to really use it as a recreational space, outside conditions should be matched a bit; sufficient day lighting and good air quality but also some refreshing breeze in summer as well as in winter are desired. The outside sitting area requires a bit more thermal comfort; the space should be lee and dry in winter and cool enough in summer. Acoustical quality needs a bit more attention here because conversation is important. For the same reason, the space should be a bit more intimate. Lighting is especially important at night to ensure safety. The inside waiting areas require an even better climate. In winter extra heating and in summer extra cooling is required.

At the reception hall these different types of waiting areas are all situated around the ticket office (*Figure 6.9: Different niches in the final design*). The active waiting area is constructed out of boarding on top of the ticket office and inside sitting area (1). They are differing in height in order to encourage playing and movement. This difference in height also separates the space from the others. Since there are no obstructions, wind can freely move along the area and day light can enter directly through the atrium to the boarding platforms. The outside waiting area is located adjacent to the active area and the ticket office (2). The area is separated from the flow in the passage way by a small difference in height of the floor and by plants forming a visual boundary. Pick-nick tables and furniture provide comfortable sitting places but it is also possible to sit at railings. The plants used as boundary also provide shelter from high wind speeds in winter and from sun and overheating in summer. Besides that they improve air quality and absorb some of the noise from the transfer activities. Lighting is again provided through the atrium to the boarding platforms. The inside waiting area is situated directly beside the ticket office and inside the sandwich bar. Heating and cooling can be provided by the active system and the space is closed off entirely so acoustical problems can be solved. Glass windows provide the visual connection with what is happening inside the terminal and a limited amount of day light to enter.

At the boarding platforms, the waiting areas are all at the inner zone of the platforms. The active waiting zones are situated at the ends of the boarding platforms where there is the possibility to sit directly in the sun and where all other conditions approach outside climate. Water basins give a lively atmosphere, emphasizing the contact with the outside climate and cooling down the area in summer (1). The outside waiting areas are located in between the atrium and the kiosk and in between the basins. This tactical placement in between building volumes assures comfort in winter but because air can pass in the layer above, ventilation in summer can take place. Extra cooling in summer is provided by the water from the basins and by the plants in the centre of the space. The waiting areas are separated from the passage ways by the use of boarding for the floors and by the furniture that forms a half height barrier. The lighting, attached to the furniture to light the space at night, only distinguishes the place more (2). For the inside waiting space, the same method as for the reception hall is applied. Inside the kiosk there is room for waiting, sufficient furniture is placed and the active system assures good climate in winter and in summer (3).

6.3.3 Green and water

Although green and water are not an actual part of the program, the park is. From an architectural point of view, the park at the reception hall is very important for the connection of the route between Delflanden and de Vliet with the green zones in the urban plan. To really stimulate people to use this link it should be attracting activity. To achieve this, green and water are implemented in the design to provide a recreational space that softens the hard works of infrastructure. Looking at the building technical problems with wind, temperature, pollution and acoustics, green and water will only have positive effects on comfort as well. Therefore, the aim for the final design is to create an actual park at the reception hall level. Since plants need a lot of daylight there are often problems with growing plants inside buildings. Tactical placement and the choice of the right species are essential. Implementing water is not easy either; a lot of construction and clever use of gravity are needed to avoid polluted or stinking water. This paragraph explains what measurements are taken in the final design to create a park inside the terminal.

Green in the form of trees and plants are of large value for parks; they create niches, not only for people but also for birds, insects and other animals. In winter, trees and plants can provide shelter from high wind speeds. On the urban scale, trees are especially effective when placed in multiple layers. For the temperature in winter and in summer it is best to use deciduous plants or trees. In summer they block the sun most efficiently and also evaporate more than conifers. In winter, deciduous trees and plants lose their leaves so that no sun or light is blocked. This blocking of light is of course a quite important consequence of using plants and trees. To ensure good day light conditions in the building, a careful balance must be found. In contrast with the other aspects, to improve air quality conifers are more efficient; they work for both summer and winter and with their needles they form a better filter and processer than deciduous trees. For acoustics, there are special species that absorb a lot of noise and can thus reduce noise level with around 5 dB. Most of the efficient species are deciduous but there are also some conifers that work quite efficiently (Kristinsson, 2002).

For the architectural design, the demands are less specific. In paragraph 6.3.1 the themes for each level of the building are explained. The accompanying image (*Figure 6.6: Ambition for the atmosphere on the different levels*) shows the ambition for the park. However, it is not realistic to think that exactly such a park can be realized underneath boarding platforms. What is essential is the recreational ambience the Vondelpark in Amsterdam vibrates. References of the Museum park in Amsterdam and the terminal in Yokohama show that it is possible to create such an ambience with other elements than just plants, trees and grass. For the park at the reception hall, from an aesthetic as well as a practical point of view, a combination of the different elements is desired.

The placement of trees is very difficult in this design for a transport terminal. The height of the reception hall is too low to grow large trees and it is not possible to provide sufficient soil at the floors. One of the most important aspects for a transport terminal, good overview, is compromised when trees are obstructing the line of view. The solution is to place trees at the tram level. That way the crown of the tree extends to the next level so that the park at the reception hall can profit from the niche the tree creates but does not experience problems with overview or day lighting. Furthermore, the trees can emphasize the continuation of the boulevard by extending the line of trees in the centre of the boulevard through the building and to the other site of the Utrechtsebaan. In the case of trees, temperature and lighting are the factors that are influenced the most. The large crowns take away a lot of sunlight and produce a lot of evaporation, reducing light and heat, while this small amount of trees has little effect on wind or air quality. Large crowns can also have quite large sound absorbing capacity. For these reasons, the choice for large leafed deciduous trees is made.

Plants and grass are a very different case. Their influence on lighting and temperature is much less as well as their influence on the overview in the transport terminal. They are also less demanding than trees; less soil and less sunlight is needed so there are a lot of possibilities. Ideal for both the architectural concept and the climate concept is to place as much green as possible. However, the function of a transport terminal demands clear alleys for large amounts of people to transfer from one transport type to the other and it implies large infrastructures taking away a lot of daylight. This is why in the final design plants and grass are tactically placed. To connect with the urban situation of parks at both ends of the building, grass is placed at both entrances of the reception hall. Hiking trails are engraved in the grass and covered by crushed shells. Inside the building, the grass is gradually replaced by wooden boarding. This provides the passenger with fast and practical walking routes and the problem of too little lighting for grass to grow is solved. With the wooden floors, a landscape is created. The direction of the laths distinguishes different routes and zones in the building (*Figure 6.10: Impression of boarding in reception hall*). These wooden floors are laid on top of a layer of soil that provides a lot of thermal capacity and pollution processing and allows plants to grow anywhere they can. At the places where sunlight can shine directly from the roof down to the reception hall through atria there is sufficient day light for larger plants to grow. For all the places where this opportunity is given, the boarding gives way for plant growth so that niches can be created and wind can be blocked. Specifically to combine the filtering of air by plants with an architectural function, a hedge of conifers is placed along the floor and around the atria. The large area and the placement at the fronts of the floors improve the air filtering performance of the plants and the hedge serves as a balustrade to avoid people from falling down.

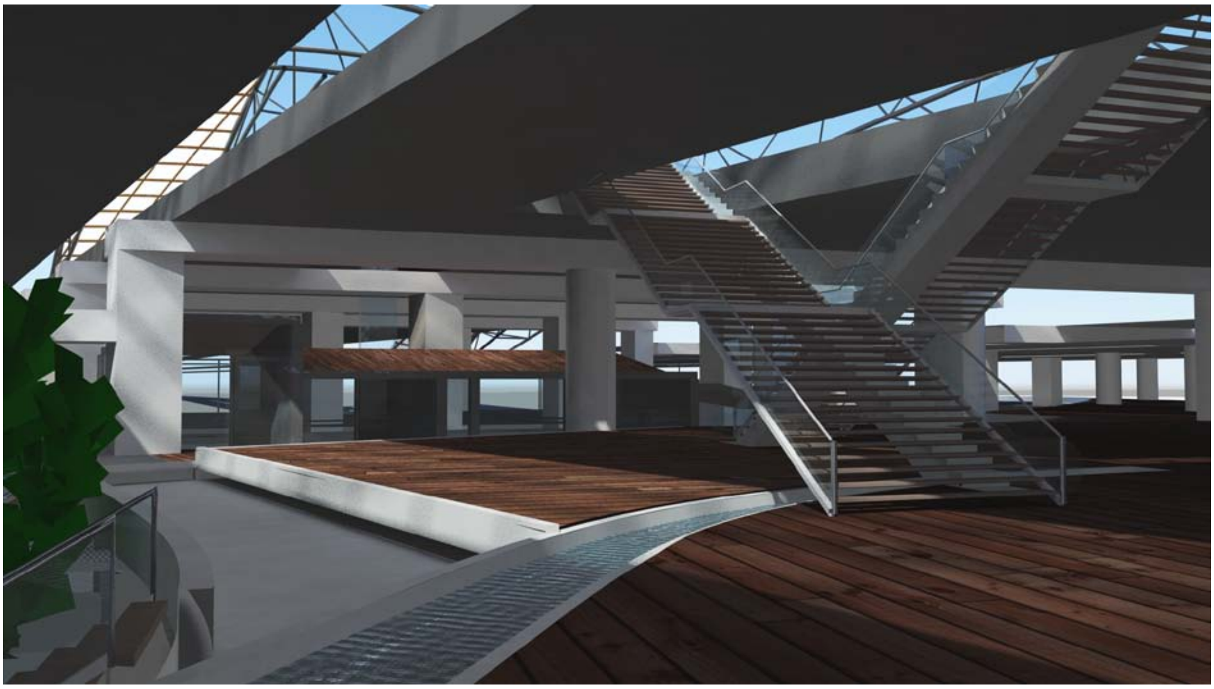


Figure 6.10: Impression of boarding in reception hall

Water is another quite important element in park design. Like green, water attracts live and activity. It also has a positive influence on the technical aspects of temperature, air quality, acoustics and lighting. Water has a large density which means it has a lot of weight to serve as a thermal buffer or to isolate noise. Besides isolating noise, streaming water can overpower noise as well. Evaporation of water when temperatures are high helps to cool down the building. The evaporation of water can also provide a natural air filter in which particles collide with small water drops which then condense so that air quality improves. The last but very important positive effect of water is caused by its reflective properties. The reflection of light on the water surface can help to light up darker places where no direct daylight is entering the building.

These reflective properties are important for the influence of water on architecture as well. Reflection of light in water causes a very lively atmosphere in buildings because a dynamic and moving pattern of light is produced. Streaming water only amplifies this effect of liveliness. Water can serve as an attraction on its own. It provides an interesting view and a place to play in summer. The use of open water inside a building not only enlivens the experience but it also provides opportunities to create a sustainable drainage and water regulating system. When natural filters of helophytes or other plants are applied, water can even be recycled or collected and used for other functions inside the building (Teeuw & Luising, 2005).

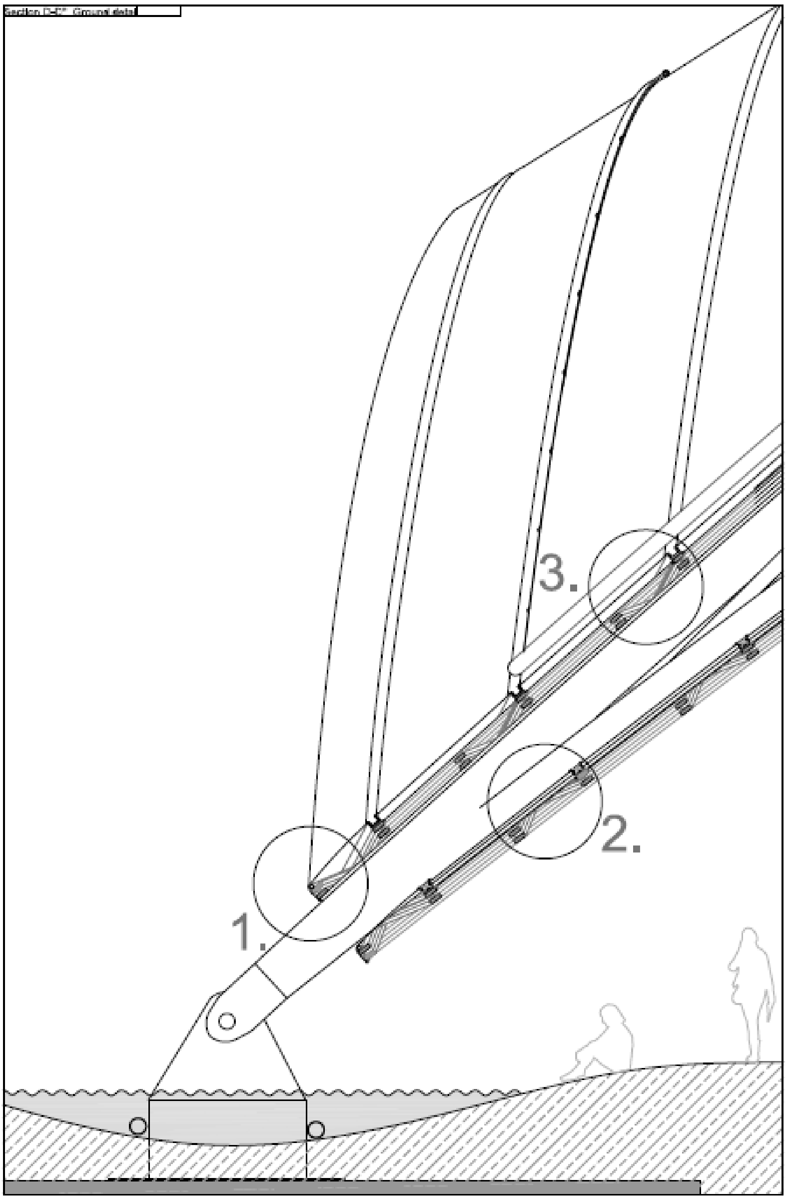


Figure 6.11: Detail of water basins at the foot of the girders

It is clear that water only has positive effects on comfort as well as architecture. However, a good implementation is very difficult and bad implementation can turn the positive effects into negative very fast. Therefore an integral approach is taken in which the total water regulating system of the building is designed at once. This system is built out of several different parts. The first part is the drainage system in the roof that transports rainwater via the roof construction to basins at the foot of each pillar (*Figure 6.11: Detail of water basins at the foot of the girders*).

In these basins, water is collected and filtered and then pumped up to either the water installations that provide the building or to the green roof, used for the park at the reception hall level. From the internal installations of the building, after use water is exported to the sewerage. Part of this water is used in a pump system to fill or refresh basins positioned on the floors of the boarding platforms and on top of the kiosks. The water that is pumped to the green roof is used to irrigate the plants. Excess water is pumped up to a pool at the reception level that also functions as a reservoir for rain water that is blown inside by the wind. When this reservoir is full, canals embedded in the floors of the reception hall transport the water back down to the basins at ground level. This loop is repeated continuously, this way the water keeps streaming so that it mixes with sufficient oxygen to keep it clean and odourless.

Water and green are integrated in the design, not only on the level of the reception hall but on all levels they play a function (as explained in the section about niches). However, at the reception hall, a park is created using trees, plants, grass, water and wooden boarding. Additional furniture and the use of boarding at different levels complete the recreational ambiance.

6.4 Routing

The routing design is crucial for the functioning of the transport terminal and the architecture. Whereas the program of the building relates to the urban activity, the routing inside the building relates to the infrastructure and the activity of transferring. The desire to integrate both means clever design of an efficient transfer while allowing space for other activities as well. Although the openings used for the infrastructure, the configuration of spaces and the placement of functions is of great influence on the comfort level, the actual routing design is not. Therefore, the emphasis in this paragraph is on the architectural design.

6.4.1 Fast and slow routing

To meet the demands for an efficient transfer but at the same time create opportunities for other activities, a division is made between fast and slow routing and the connection is made as direct as possible (*Figure 6.12: Concept of fast and slow routing*). The fast routing is meant for the passenger that regularly visits the terminal and knows exactly where he wants to go like for example the people who work at the centre of The Hague. The slow routing is meant for occasional visitors and tourists but also for people who live in the area and use the commercial and recreational functions in the transport terminal.

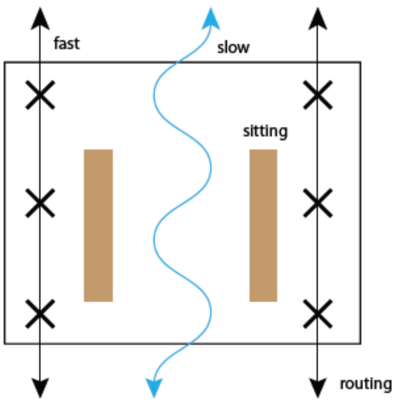


Figure 6.12: Concept of fast and slow routing

The fast routing is placed at the ends of the building. It is organized in such a way that the different transport types are connected as directly as possible. From the parking garage, the bus, the tram and the bikes are directly accessible. The trains can easily be reached by escalators or lifts located in the garage (*Figure 6.13: Fast and slow routing at tram level*).

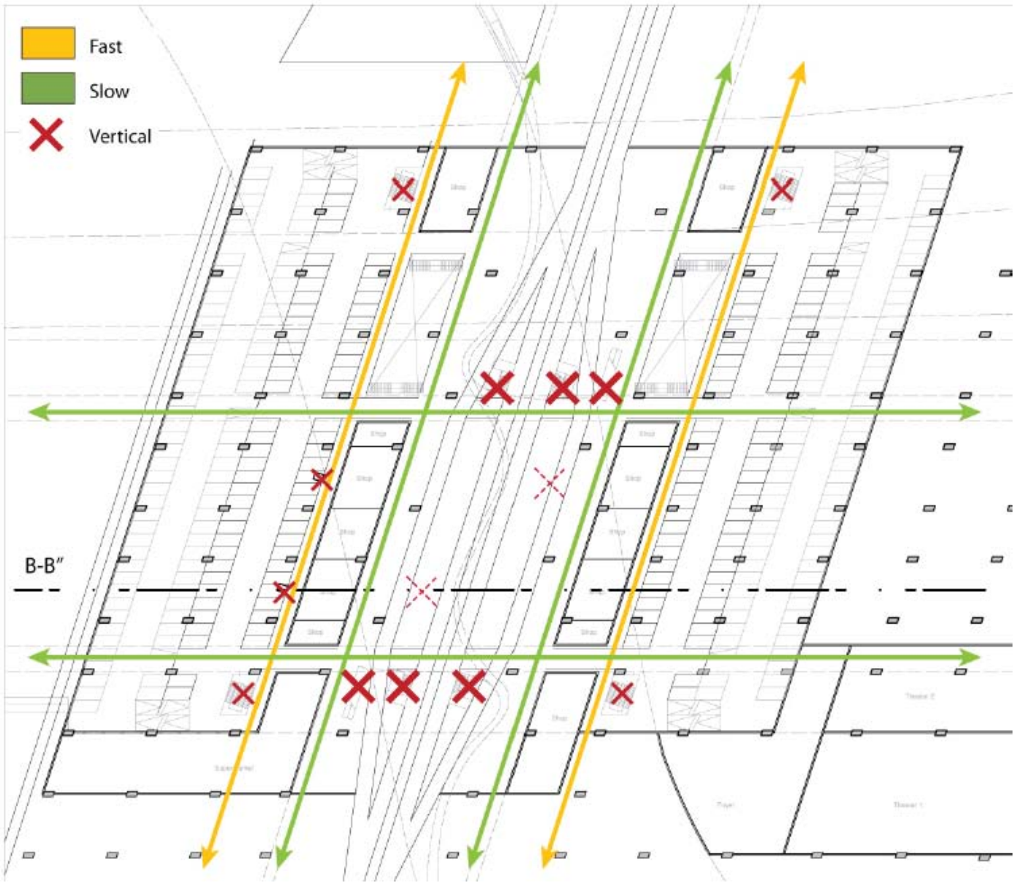


Figure 6.13: Fast and slow routing at tram level

To keep the routing understandable, the fast routing on each level is organized in approximately the same way.The link between trains and bikes is given extra attention to stimulate people to use the more sustainable transport types. Whereas in the current railway stations the parking spaces for bikes are outside the building, in the design for a transport terminal at the Prins Clausplein the bikes can be parked directly below the platforms and next to the reception hall.

The slow routing is organized around the central areas at tram level (level 0) and reception hall (level 1). The functions are located here and visibility of the different transport types and of the way to get there can be provided. At tram level, this route runs along the boulevard, providing the shops. At the reception hall, the slow routing follows the direction of the green link and provides access to the cinema and the tennis court but also to the ticket office. At this level, recreational and transfer functions are mixed and the routing is part of the park (*Figure 6.14: Fast (red) and slow (green) routing in the reception hall and the ticket office indicated in red*).

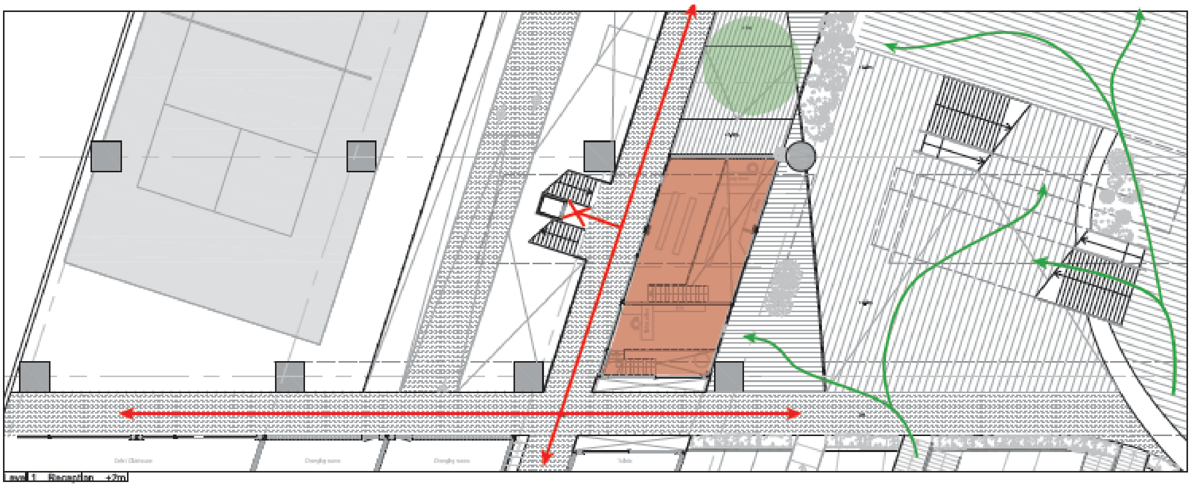


Figure 6.14: Fast (red) and slow (green) routing in the reception hall and the ticket office indicated in red

6.4.2 Overview and navigation

For a transport terminal, not only a well organized routing is important, people need to understand it as well. Navigation should be easy and naturally. Some architectural tools are applied to provide this clearness of routing the most important ones being overview, sight and rhythm (*Figure 6.15: Navigation concepts*).

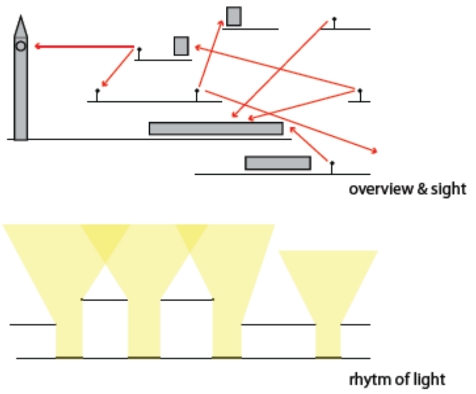


Figure 6.15: Navigation concepts

Overview and sightlines are created by placing the floors not perfectly on top of each other but shifted horizontally and vertically. Additionally, atria are placed in the reception hall and boarding platforms (the effect on comfort is explained in paragraph 6.2.2). This way, the different levels and transport types and the stairs, escalators and ramps towards them are visible from the entrances and from other important places in the building (*Figure 6.16: Impression of the overview at the tram level*). To create a sense of orientation for the passengers inside the terminal, a lot of views outwards are provided. Being able to see remarkable buildings and other objects in the skyline of The Hague simplifies the process of finding the direction, not only inside the building but also when leaving the building. Especially the view from the boarding platforms to the Utrechtsebaan and the other way around is important. Since an opening at that place would cause very much problems with wind and noise from the highway, the opening is filled with glass.

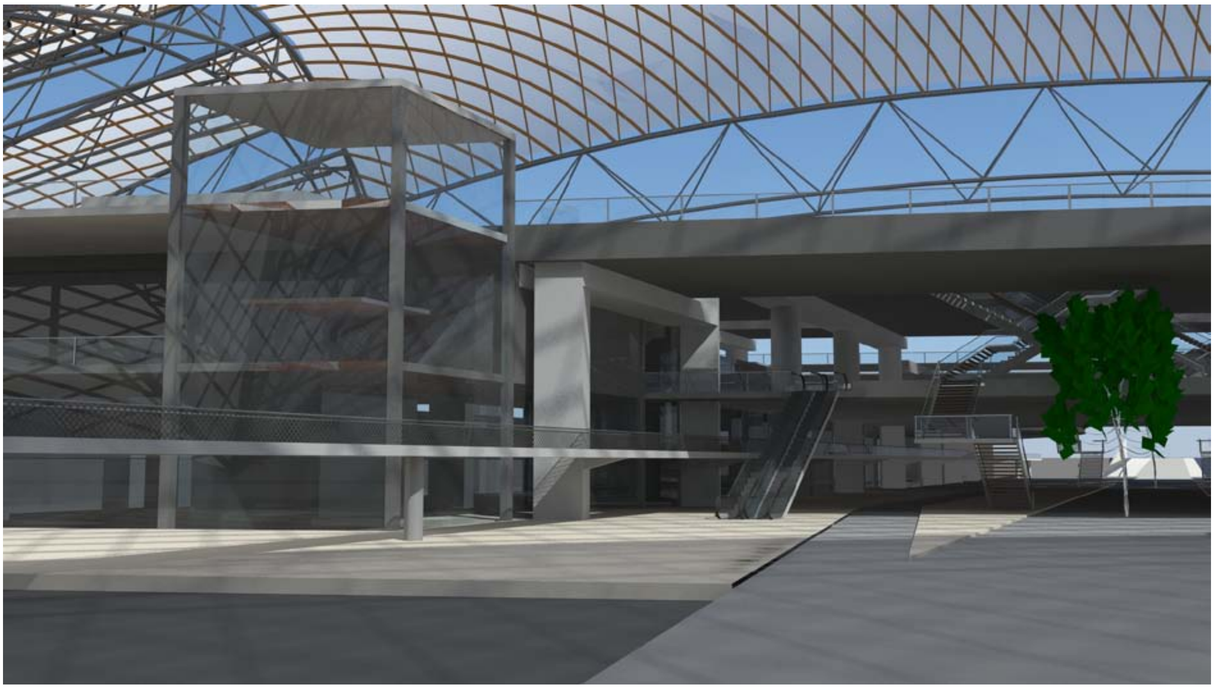


Figure 6.16: Impression of the overview at the tram level

The logic of the routing in the building is clarified by the gaps between the floors of the boarding platforms and the highway creating a rhythm of light (figure XX; rhythm of light in section). This rhythm is accompanied by the repetition of columns, alleys and vertical elements. As explained in the previous paragraph, the day light entering from the gaps between the floors is used to provide the plants and trees below the boarding platforms of light.

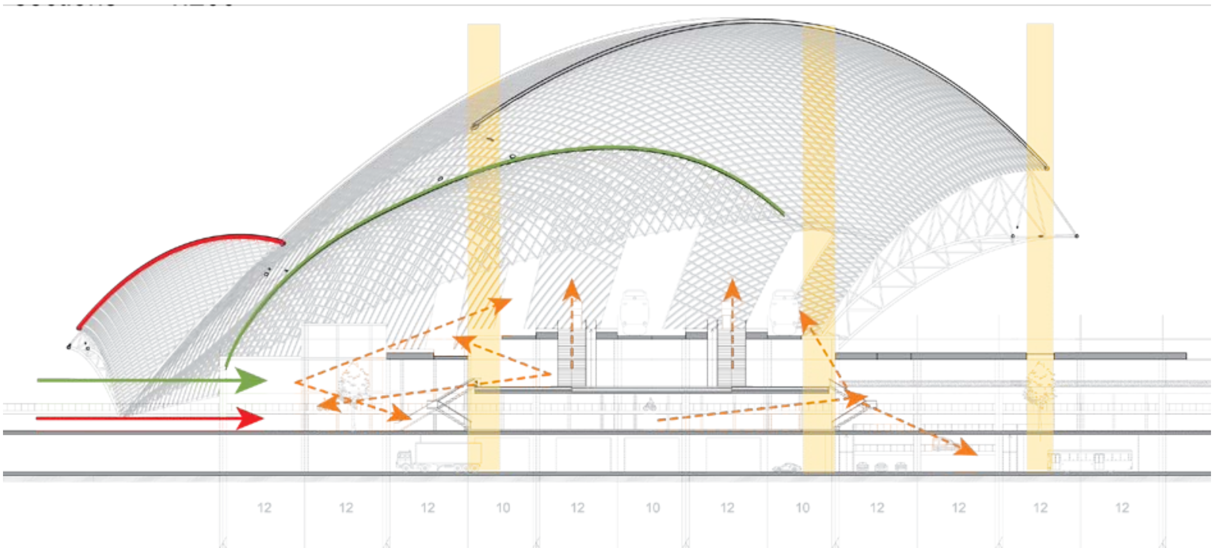


Figure 6.17: Rhytm of light (light yellow), overview (dotted yellow) and guidance by shape (green for reception level and red for tram level) in the final design

6.5 Materialization

One of the most influencing design parameters for comfort as well as architecture is the materialization of the building.

The choice of materials affects the aspects of temperature, air quality, acoustics and lighting each in their own way. On this scale, wind is not influenced by materials. The most important material properties for thermal comfort are mass (M) and transparency (ZTA) and consequently the amount of transparent area in the envelope is important (Atrans). The material mass is also important for sound isolation. Sound absorption is determined by the porosity of the material. For air quality there are certain specific materials that should be avoided, materials to be used are porous materials with a rough surface so particles can be captured inside the material. Material properties that effect lighting conditions are transparency, reflectivity and colour.

The influence that materialization has on architecture is strangely enough caused by the effect on the different aspects of comfort. Here, technical and architectural demands mix. For example the effect of the material properties on the reverberation time influences also the sense of orientation in a space and the way the different materials reflect the light determines the ambience. Furthermore, the architectural expression from the outside is very much determined by the tectonics of the materials but also by the shape that can be formed by a certain material. This is where the structure of the building also comes into play. Other material properties like strength and elasticity but also mass determine the type of structure and its dimensions and this affects the architecture again.

In this paragraph, the material choice in the final design is explained using the three basic parts of the building; the skin, the floors carrying the infrastructure and the volumes for the additional program.

6.5.1 Skin

For both architecture and comfort, the skin is the ultimate parameter for optimization. The architectural appearance and the experience inside the building are for a large part determined by the materials of the skin. Temperature and lighting conditions are very much dependent on the composition of the materials and their transparency. This means that both design demands and technical demands are important and a balance needs to be found.

Drawing from the architectural concept of a hovering roof and the architectural expression that is desired, light weighted and light transmitting materials are preferred. These can emphasize the idea of a city underneath a canopy. For the experience underneath the skin, a comfortable and peaceful atmosphere is demanded (as explained in the previous paragraph). A translucent material creates this atmosphere because of the diffusing effect on light. Natural materials like bamboo or wood can contribute to this atmosphere.

The technical demands for temperature in summer are explained extensively before; low transparency or little transparent areas and a low insulation value. However, for the winter situation, the demands are quite different. In most cases the heat of the sun is actually very welcome and the building can be comfortable without the necessity of extra heating so transparent areas are desired.

To provide day light inside the building, transparency or at least translucency is needed as well. However, too much transparent areas can also cause problems with glare from direct sunlight. This is why a careful balance is maintained while designing the skin and the composition of materials in it.

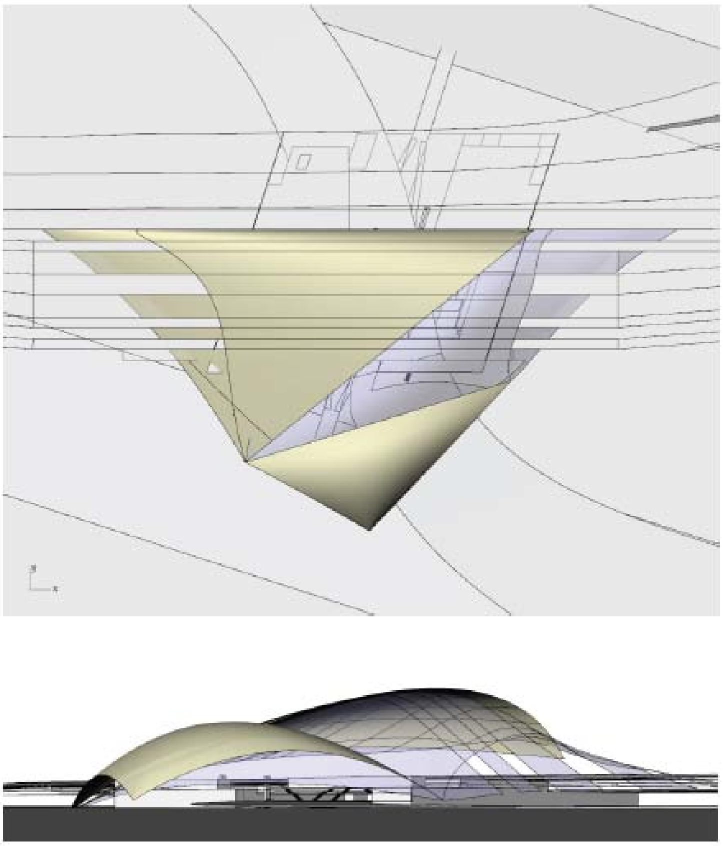


Figure 6.18: Composition of the facades in relation to the sun in summer (horizontal surface) and in winter (vertical south surface)

For the skin itself, fabric is chosen as the best material to fit the shape of the double curved surface defined in paragraph 2. The flexibility of the material allows for complex surfaces and the lightness and translucency of the material fit the architectonic demands very well. To create the desired balance for the climate system the different shells of the roof have different transparencies. On the two outer shells and their caps, a double layer of PTFE is applied resulting in a white coloured surface with a transparency of 20%. On the inner shell ETFE with a transparency of 80% is applied. The choice to give the inner shell the largest transparency is based on the path of the sun and on the lighting demands for the spaces below the shell. Namely, the inner shell is the one that has the smallest horizontal surface and the largest south oriented vertical surface. This means that in summer, when the sun is high, sun enters the building only through the smallest area while in winter, when the sun is low an optimal amount of sunlight can enter the building (*Figure 6.18: Composition of the facades in relation to the sun in summer (horizontal surface) and in winter (vertical south surface)*). Additionally, the inner shell is running in about the same direction as the green route at the reception level. So by giving the inner shell more transparency, trees, plants and grass are provided with sufficient day lighting.

A skin merely built out of fabric is not possible; a structure is needed to support the skin. For the skin in the final design, a widespan structure is chosen. A widespan structure allows for undisturbed movement and placement of building volumes. This confirms the identity of the building; a small city underneath a canopy. Large spans are bridged by the use of steel trusses in the shape of bows to transport the loads of the roof to the ground *(Figure 6.19: Static scheme of the construction elements of the widespan structure of the skin*).

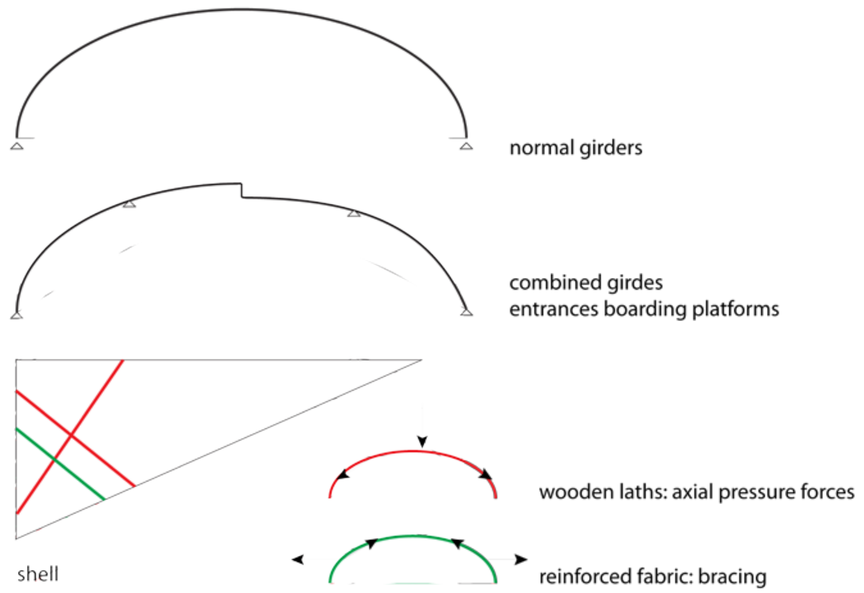


Figure 6.19: Static scheme of the construction elements of the widespan structure of the skin

On top of that, four layers of wooden laths are forming a lightweight compression shell taking only axial forces. The choice for wood is based on the desired atmosphere underneath the skin; comfortable and peaceful. The double curved shell is covered by fabric that stabilizes the whole structure and at the same time forms the waterproofing layer of the skin (*Figure 6.20: Detail of the construction of the skin*).

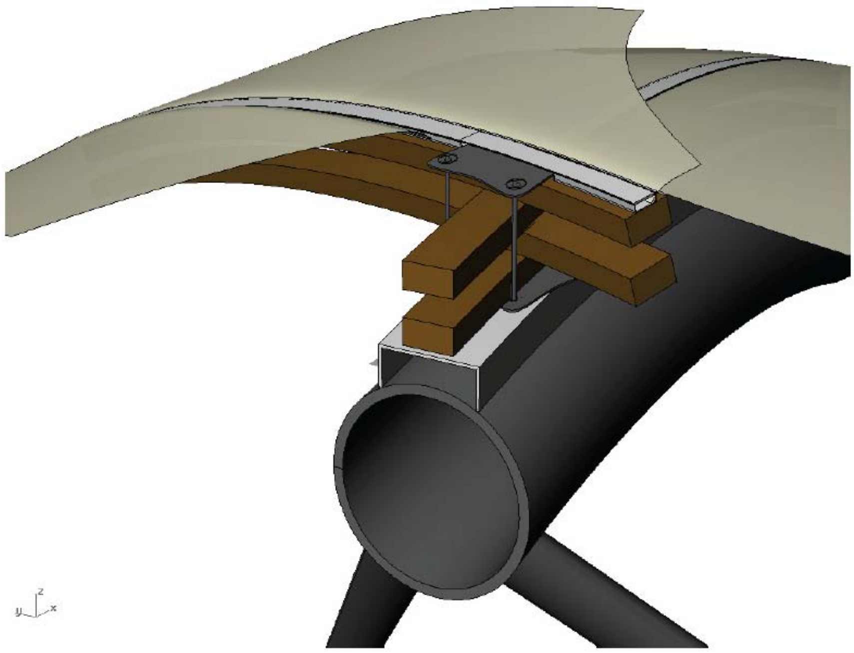


Figure 6.20: Detail of the construction of the skin

One of the additional methods, mentioned in chapter 3 is to use glow-in-the-dark or photoluminiscent material to enlighten the spaces at night. A small literature study shows that there are a lot of possibilities to mix the material with other ones like for example plastic or epoxy but also concrete (Dark Glow inc.). The study also shows that it is not efficient to place the material where it does not receive sufficient day lighting to load up. This means that placement on the roof would be ideal and since photoluminiscent powder can be processed with almost any material, it can be incorporated in the coating of the fabric. Although the light intensity is probably not high enough to provide enough lighting for the terminal at night, the glow can serve as background lighting. Looking from the outside, the photoluminiscent material will give the building a distinct glow that creates an extravagant architectural appearance at night.

6.5.2 Floors

The materialization of the floors in a transport terminal is very much dictated by the infrastructure that the floors have to carry. High strength and durability are pointing towards reinforced concrete. Since this heavy and sober material creates a great contrast with the light roof, this choice can be approved architecturally. Also technically concrete is a good choice; heavy floors create a large buffer to capture heat energy and noise can be isolated and absorbed. This means that concrete is used in the final design for the floors and their accompanying structure.

A rigid structure of prefab concrete columns and beams is supporting the floors of the tram level and the reception hall. The boarding platforms and the railways are also carried by this structure but are spanned in the other direction and the floors themselves are a large U-profile. Stability is provided by the rigid joints with the floors and by concrete walls (*Figure 6.21: Structure of the transport terminal*). The structure is diamond-shaped so that the directions of the different transport routes are followed according to the architectural ideas for shape.

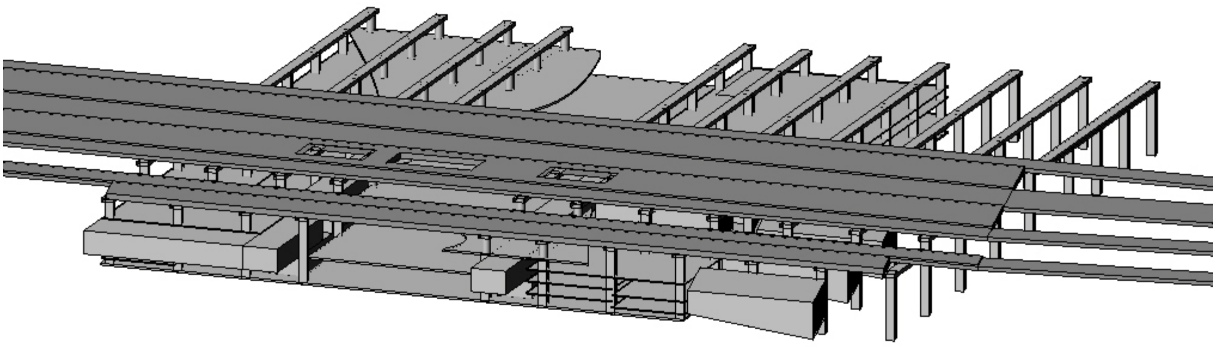


Figure 6.21: Structure of the transport terminal

What is more interesting for comfort as well as for architecture is the finish of the floors. The finishing materials on the floors are architecturally important, especially for transport terminals. Since a terminal is not a regular building with rooms, doors and windows, the materialization of the floors is used as a tool to distinguish and separate the spaces. For comfort, the finishing materials of the floors determine to what extend the thermal capacity is effective, noise is absorbed, particles are captured and light is reflected.

For the parking spaces, no finishing materials are used. The concrete of the structure is merely polished to protect it and to give it a bit more glamour. With the concrete left bare, the thermal mass is most effective and the sober expression reflects the functionalism of the spaces. The floors at the tram level running along the boulevard are covered with limestone tiles; they relate to the curbs in the surrounding areas and provide some sound absorption. Furthermore, the light colour of the stones assures optimal use of natural as well as artificial lighting. The floors at the reception hall are constructed as green roofs. A watertight layer, a root barrier and a drainage system are put on top of the concrete structure to provide a good basis for soil to grow plants (*Figure 6.22:Detail of the green roof and the boarding at reception level*). The technical and architectural merits of this configuration are explained in the paragraph about green and water. The floors of the boarding platforms are especially important for the distinction of the different zones on the platform as mentioned in paragraph 3.Relating to all the different spaces on the lower floors, the walking zone is marked by polished concrete floors, the standing zone by limestone tiles and the waiting zone by wooden boarding.

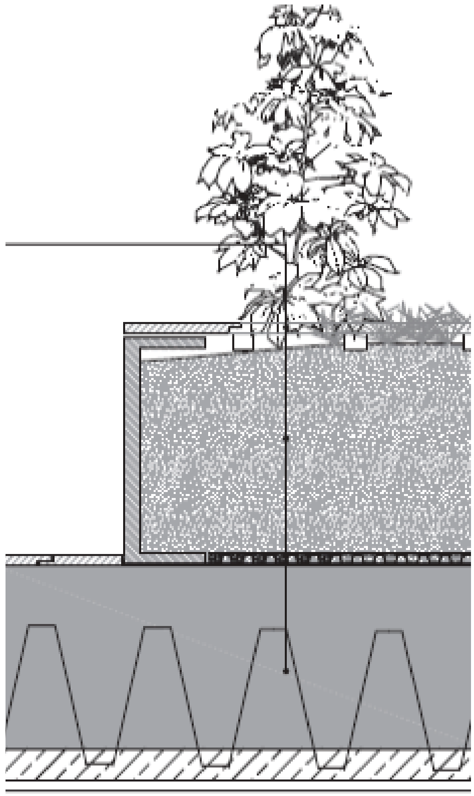


Figure 6.22:Detail of the green roof and the boarding at reception level

6.3.5 Volumes

The additional program in the terminal is housed in “volumes”. This term refers to the distinct character of the building blocks that are used for the additional functions. They are created separately from the main structure and the skin. They are literally buildings inside a building or, as the architectural concept prescribes; a city underneath a canopy. To allow the additional functions to develop separately from the transport terminal their structure is completely detached from the main structure. Flexibility is assured by using steel as the construction material; construction with steel is fast and demountable (*Figure 6.23: Section of the shops showing the use of materials*).

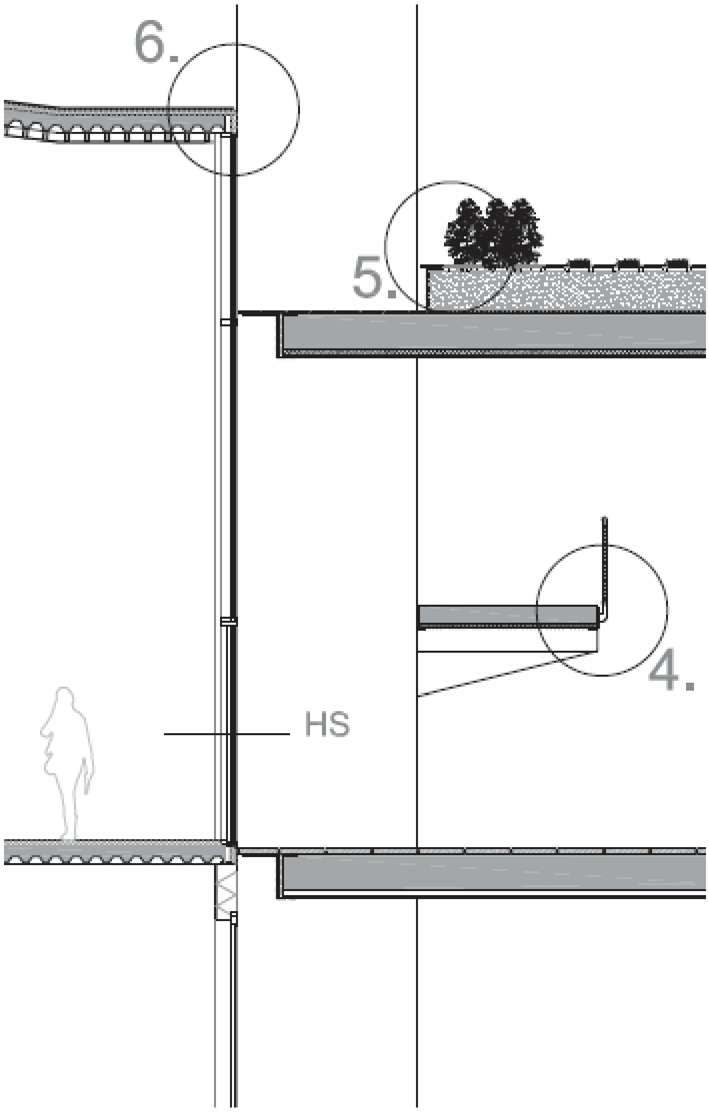


Figure 6.23: Section of the shops showing the use of materials

To complement this temporary character and to create transparency inside the terminal, glass windows in aluminum frames are used for the facades of the volumes. The commercial functions can display their products here and the facilities for food and drinks can use these windows to provide the important view on the boarding platforms. The facades also influence comfort; they form the watertight, wind tight and insulating layer of the volumes and create the boundary for active heating and cooling inside the transport terminal.

6.4 Conclusion

In the introduction of this chapter, the final design is defined as the integrated answer to the architectural and the research question. It is not the optimal design solution for one of the two but the best solution for both. The decision making in design is never completely scientific but in this chapter the considerations about the influence of different design decisions are described. This approach gives insight in the process of integrating research and design and argues why the solution used in the final design is the best one.

The analysis of the design parameters gives a clear overview of the overlapping parameters, involved in both research and design. The demands for openings and shape of the skin (Oskin), the use of building volumes (obstr), the transparency of the enveloping material (ZTA) and the area of this material (Atrans) are contradicting. The demands for openings in the floors (Ofloors) and in the top of the skin (Otop) as well as the parameters of volume (V), height (H), mass (M) and evaporation (E) are similar.

The parameters volume, height, shape and openings are determining for the architectural appearance of the building. The dimensions for height and volume taken in the sketch design proof to be quite positive for comfort so the solution for the final design is not much different from the sketch design; large volume but relatively low height (compared to the surrounding buildings). The contradicting demands for shape of the skin and the openings in it proof to be much more difficult to solve. A solution that gives the desired architectural expression but does not sacrifice on comfort is chosen. Large entrances are created but the actual openings remain small. As a result from the research, additional openings in the top of the skin are designed.

The program and the way it fits into the building are chosen entirely for architectural reasons. However, the program is developed using the concept of niches to create comfort. Dependent on the activity, a different climate is desired. Using physical boundaries in the form of an opening in the floor, a hedge, a piece of furniture or a building volume a comfortable space is created. The materialization of the surrounding walls and floors further improves the climate and emphasizes the boundaries of the niche. Green and water are described as a program on its own. Because the parameter evaporation is determined by the amount of green and water, the ambition is to implement as much as possible. The implementation of green and water in the design is done by tactical placement of the different elements; trees, plants, grass, water and boarding. All possible places where light enters the building are used to grow green; the rest is filled by a landscape of wooden boarding. The element water is cleverly integrated with the drainage system of the skin and the irrigation system of the green roof.

For the integration of transfer activities with urban activities, routing is very important. To accommodate both activities in the same building, a separation between fast and slow routing is made. To clarify this routing and to help the passenger navigating, the architectural tools of rhythm, repetition and overview are applied. The openings in the floor are placed in such a way that they create a large volume directly behind an opening in the skin to improve comfort in winter. The gaps between the floors are also used to improve lighting conditions.

When it comes to the choice of materials, not only demands for architecture and comfort but also for structure need to be evaluated. The chosen materialization in the final design is therefore dependent on the structure. Skin, floors and volumes are materialized differently because of their different architectural and structural nature. The materialization of especially the skin is important for both design and research. The translucent and transparent fabrics chosen for the skin comply with the architectural demands but also with the demands of lighting and temperature in winter. Comfort in summer is ensured by the balance created by the different transparencies of the materials and their configuration in the composition of the skin.

The final design is an integrated design that effectively combines technical and architectural demands in a coherent way. Good solutions to deal with the conflicts are found and most solutions contribute to both the architectural and the climate design resulting in an integrated comfortable transport terminal.

7. Conclusion and recommendations

Temple of Mobility is a project with very high ambitions. It includes not only an architectural design of a transport terminal but also a building technical research on comfort and moreover the integration of design and research in an integrated building. This chapter reflects on the architectural and building technical problems described in the introduction and on the process of dealing with such an ambitious project.

7.1 Conclusion

The architectural objective of this project is to create a design for a transport terminal at the Prins Clausplein that integrates infrastructure and urban structure. The building technical objective is to find methods to regulate climate in a transport terminal that can be integrated in the architectural design. The ultimate goal for the project is to combine the architectural design of a transport terminal with a good climate design so that research and design strengthen each other. Following the structure of the report, a conclusion of the findings in design, research and integration of the two is given.

The definition of comfort in semi-outdoor situations is formed by the interrelation of different factors that influence comfort. The factors that are involved are the same for indoor, outdoor and semi-outdoor situation, the relation between the factors and the importance of specific factors is what defines comfort in a certain situation. The most important factors for comfort in semi-outdoor situations are wind and temperature but air quality, acoustics and lighting also play a role. Psychological and architectural aspects are at least as important as well.

Passive and sustainable methods to regulate the climate in order to create comfort are numerous. The performance of the methods can only be evaluated when applied to a specific design. However, precedents indicate that the multifunctional methods of natural ventilation, placement of functions, use of material properties and use of green and water are the most promising ones.

From the development of both research and design the points of attention for both can be concluded. For the architectural design it is important to embed the building in the surroundings, relating it to infrastructure as well as urban structure. The architecture and the program need to express the ambition of the project to integrate them. The climate design must be suited for the location and the function of the building and in order to integrate it with the architectural design it needs to follow the architectural ideas. Using these criteria, the methods of natural ventilation, materialization, placement of functions and use of green and water are selected for the climate system. Additional methods are the use of volumes to create niches and the use of photoluminiscent material to provide lighting at night.

Research on the aspects of wind and temperature investigates the performance of the methods in the architectural design. For winter, the use of small openings and a large volume proofs to be most effective although comfort at the boarding platforms can still not be achieved. For summer there are more methods that can be effective. However, only a combination of the right choice of materials, a balanced composition of transparent materials in the skin, a large thermal capacity and large amounts of green and water can lead to total comfort in summer.

The integration of research and design in the final design is difficult to evaluate. However, the approach of explaining design solutions with respect to the architectural and building technical demands gives a good insight in the level of integration. The final design proofs that the simultaneous development of research and design results in a closely integrated design. In this final design for a comfortable transport terminal at the Prins Clausplein, architecture and building technology work together and strengthen each other.

7.2 Recommendations

As is the case with all projects, there is some space left for improvements of the process as well as the project.

Research and design were developed in a process of different phases. From the starting point of the Prins Clausplein a vision for the urban plan around the junction and the definition of the design assignment were developed. After that, a sketch design and a framework for the building technical research were made. With this basis, the building technical research was performed and the architectural design was developed further. Finally, the two specialties were integrated in the final design of the transport terminal. This process of developing a definition of the assignment and a framework for the research is a very slow one when boundaries are not clear yet as was the case in this project. It is important to do a structured analysis of the assignment as well as the research topics so that a clear decision for the most interesting subject can be made. Research and design considerations have to be evaluated separately in this first stage in order not to confuse design decisions with technical study. When the framework is set it is important to directly create the link between research and design in order to stimulate the influencing between them. It is clear that this link between research and design is fully present in the whole process of this project and it proofs to be as successful way of integrating the both disciplines in the design of a building. At the final stage of integration between the two, this project lacks a feedback loop that evaluates the decisions made in the integrated design. Especially a calculation of the building technical performance of the final design would have resulted in a more complete project although research on earlier models suggests a good performance of the final design.

The project itself is of such great ambition that it is difficult for both research and design to reach the desired level of detail. Besides a good framework, a realistic level of ambition for the time frame of the project is essential. For architecture, further design and investigation on the wide span structure of the skin and the detailing of the materials used in the skin but also in the rest of the building is recommended. Besides that, a better impression of what the building will look like, especially from the inside would be interesting.

The recommendations for the building technical research are more specific. As mentioned above, more calculations on the performance of the final design are needed to create an extra feedback loop. Not only the effect of the final design on wind and temperature but also on air quality, acoustics and lighting have to be explored in depth. Additionally it is interesting to see what the climate design does for temperature in winter. The working method used to calculate performance in winter and in summer can be broadened as well. A study in Computational Fluid Dynamics is interesting to get a better idea of the influence of shape and obstructions on the local wind climate. In summer, the one-zone model could be expanded to a multiple-zone model so that temperatures in different spaces and at different levels can be calculated precisely. To incorporate the air flow in summer more fluently, a fluent cooperation between Summertemp and Excel would speed up the process significantly. Finally, there are some additional researched that would be a good follow-up. Research on adaptable systems for summer and winter and on the possibilities of collecting energy for active sustainable systems are recommended.

Bibliography

Allen, R. G., Pereira, L. S., & Smith, D. R. (1998). *Crop Evapotranspiration - Guidelines for computing crop water requirements.* Rome: FAO - Food and Agriculture Organization of the Unites States.

Blocken, B. (2009). CFD in Building Engineering. *CFD in Building Engineering.* Eindhoven.

Dark Glow inc. (sd). *Dark Glow*. Opgeroepen op march 2010, van Photoluminiscent materials: www.dark-glow.nl

Dear, R. J., & Brager, G. S. (1998). Developing an Adaptive Model of Thermal Comfort and Preference. *ASHRAE Transactions* .

Dienst Stedelijke Ontwikkeling. (2006). *Vliet-A4/zone.* Den Haag: DSO.

Esch, M. v. (2009). *Wind in de bebouwde omgeving.* Delft: Delft University Press.

Fanger, P. (1972). *Thermal Comfort.* New York: McGraw Hill.

Freeman, K. (1995). *Plants in buildings*. Opgeroepen op Novembre 2009, van Plants and their acoustic benefits.

Gemeente Den Haag, Dienst stadsbeheer, milieu en vergunningen. (2008). *Actieplan .* Den Haag: Gemeente Den Haag.

Haartsen, T. J. (2005). Kennis over wind toegepast bij het ontwerpen van gebouwen. *Lezing Kennisdag Bouwfysica 2005.* Delft.

KNMI. (1979-2000). *Koninklijk Nederlands Meteorologisch Instituut.* Opgeroepen op 2010, van Klimatologie: www.knmi.nl

Kristinsson, p. i. (2002). *Vitale Architectuur Integraal ontwerpen.* Deventer: Kristinsson-Reitsema BV.

Linden, A. v., Boerstra, A., Raue, A., & Kurvers, S. (2004). Adaptieve Temperatuurgrenswaarden (ATG). *Bouwfysica* .

Marsh, A. (1990). *Healthy Heating*. Opgeroepen op September 2009, van Human physiology: http://www.healthyheating.com

Ministerie van Verkeer en Waterstaat. (2006). *Informatieanalyse Luchtkwaliteit.* Den Haag: Ministerie van Verkeer en Waterstaat.

Nikolopoulou, M., & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: Analysis across differen European countries. *Building and Environment* , 1455-1470.

Nikolopoulou, M., Lykoudis, S., & Kikira, M. (2003). *Thermal Comfort in Outdoor Spaces: Field Studies in Greece.* Athene: C.R.E.S.

Oliviera, S., & Andrade, H. (2007). An initial assessment of the bioclimatic comfort in an outdoor public space in Lisbon. *Climate and Perception* , 69-84.

Picot, X. (2004). Thermal comfort in urban spaces: impact of vegetation growth. Case study: Piazza della Scienza, Milan, Italy. *Energy and Buildings* , 329-334.

ProRail. (2007, June). Innovatieprogramma Geluid voor het spoor. *ProRail maakt het spoor stiller* . Utrecht: ProRail.

Scudo, G., & Dessi, V. (2006). Thermal comfort in urban space renewal. *The 23rd Conference on Passive and Low Energybn Architecture.* Geneva.

Stichting Kennisbank Bouwfysica. (1999, December). *Kennisbank Bouwfysica.* Opgeroepen op March 2010, van Kennisbank Bouwfysica: www.kennisbankbouwfysica.nl

Straube, J., & Acahyra, V. (1998). *Indoor Air Quality, Healthy Building and Breathing Walls.* Waterloo: Waterloo University Press.

Teeuw, P., & Luising, A. (2005). *Water duurzaam in het ontwerp.* Delft: SOM.

U.S. Environmental Protection Agency. (1995). *The Inside Story: A Guide to Indoor Air Quality.* Washington: NSCEP.

Westerberg, U., Knez, I., & Eliasson, I. (2004). *Urban Climate Spaces, A Multidisciplinary Research Project.* Göteborg: Göteborg University Press.

Wit, i. M., & Linden, i. A. (1999). *Evaluatie van prestatie-indicatoren voor thermische behaaglijkheid in gebouwen.* Rotterdam: TU Delft.

Appendices

Appendix I: Explorative research

Appendix II: Theory

Appendix III: Calculations

Appendix I: Explorative Research

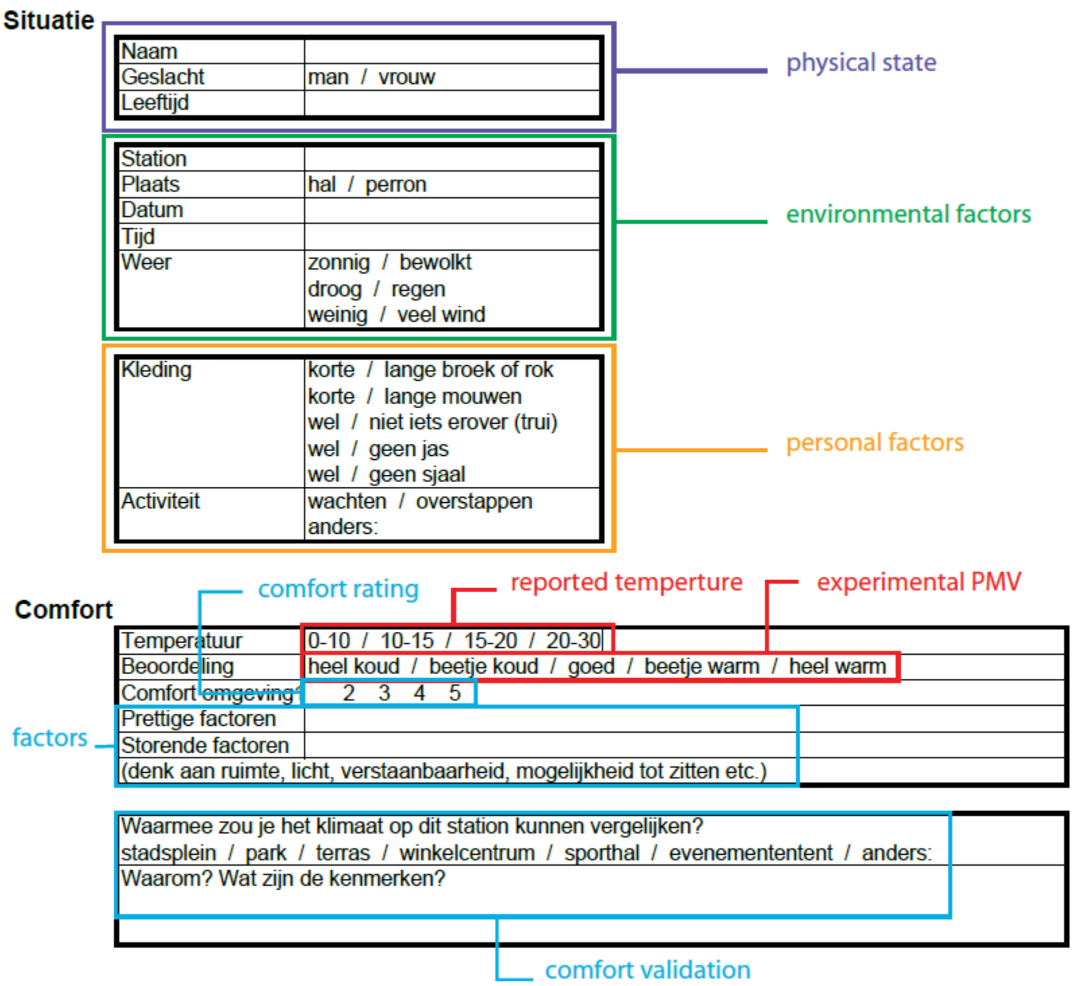
As explained in chapter 2, the explorative research is a qualitative research. Data of as much persons possible is collected in the shortest amount of time to create more insight in the interplay between the factors in the semi-outdoor situation.

I.I Research method

The research method is chosen based on the objective and time frame. The research is meant as an orientation on the factors that influence comfort in the semi-outdoor situation. The time frame is short so a fast research method that collects a lot of data in a short amount of time is needed. The will to cooperate is important for every research but especially when time is short.

To direct the research towards the objective of the project to create a comfortable transport terminal at the Prins Clausplein, comfort in different railway stations in the Netherlands is tested. Data is collected by sending a questionnaire by e-mail to friends and family asking about their last railway station experience. The advantages of this method are that the will to participate is large and the method of communication is fast so that a large amount of data can be collected in a short time. Additionally, little effort is demanded from the researcher so that the time can be used efficiently. An extra advantage is that a large variation of data is obtained; a lot of different railway stations are tested. A large disadvantage is that the method is not very precise because there is no possibility to take measurements or make observations at the place of questioning. Besides that, the target group might be limited; age, gender and cultural background are not randomly deviated in the selected group of friends and family. However, the objective is not to collect scientifically relevant data but to get an indication of the factors that are involved. The method is suited for this objective.

The questionnaire exists out of four parts (figure XX; explorative research questionnaire). The first part is containing questions that are used to determine the physical state of the person. The second part is used to determine the environmental factors specific for that area and date. The third part concerns the personal factors and the last part gives the participant´s evaluation of the comfort. This last part is divided into evaluation of the thermal comfort and of the overall comfort. The questions are remained abstract on purpose. The goal of this approach is to get an image of what the participant finds important without influencing the person with predetermined factors.



I.II Research question and hypotheses

With the research method defined, the objective can be clarified with a research question:

What are the factors that influence the feeling of comfort in railway stations for passengers and other users and how are they related to each other and to comfort?

To help answering the research question, a set of hypotheses is tested:

1. There exists a discrepancy between the predicted mean vote using the Fanger theory and the actual sensation vote reported by the participants.
2. The level of overall comfort has a strong correlation with the level of thermal comfort.
3. The most important factor that influences the feeling of comfort negatively is the amount of wind or draft.
4. Architectonic aspects are equally important as physical aspects to the feeling of comfort.
5. People who are transferring from one train to the other are easier satisfied with the environmental quality than people that are waiting.
6. The experimentally estimated temperature is the same as the determined air temperature.

I.III Data processing

The responses in the form of answers to the questionnaire cannot be used directly to test the hypotheses; they have to be processed first. Processing of the different parts of the questionnaire is done in the following way:

- The physical state is determined by age and gender; this information is only used to check the variation of physical state in the group of respondents.

- The environmental factors cannot be derived directly from the questionnaire. Date, time and location of the station are used to find the necessary hourly weather information of the nearest weather station in the online database of the KNMI (KNMI, 2009). The other questions are used as additional information to refine the environmental profile.

- The personal factors of clothing and metabolism are directly derived from the responses. The clothing level for each clothing option in the questionnaire is set to the average level of that type of clothing. The total clothing level is then determined by adding up the individual types of clothing used by the respondent. The metabolism is determined in the same way; the activities of waiting or transferring are set to the average value for sitting and walking fast.

- The comfort rating is divided into a rating for the thermal comfort, one for the overall comfort and a general rating of factors that are important for comfort to the participants. The thermal comfort rating can be related to the PMV, the validation of “very chilly” being -2 and the validation of “very hot” being +2. The overall level of comfort is calculated back to the scale of the PMV; a rating of 5 is a rating of 0 in PMV, a rating of 4 is -1 or +1 etc. From the last pair of questions, factors that influence comfort are extracted. The mentioning of specific factors and the frequency of positive or negative rating of the factor are the output of these questions.

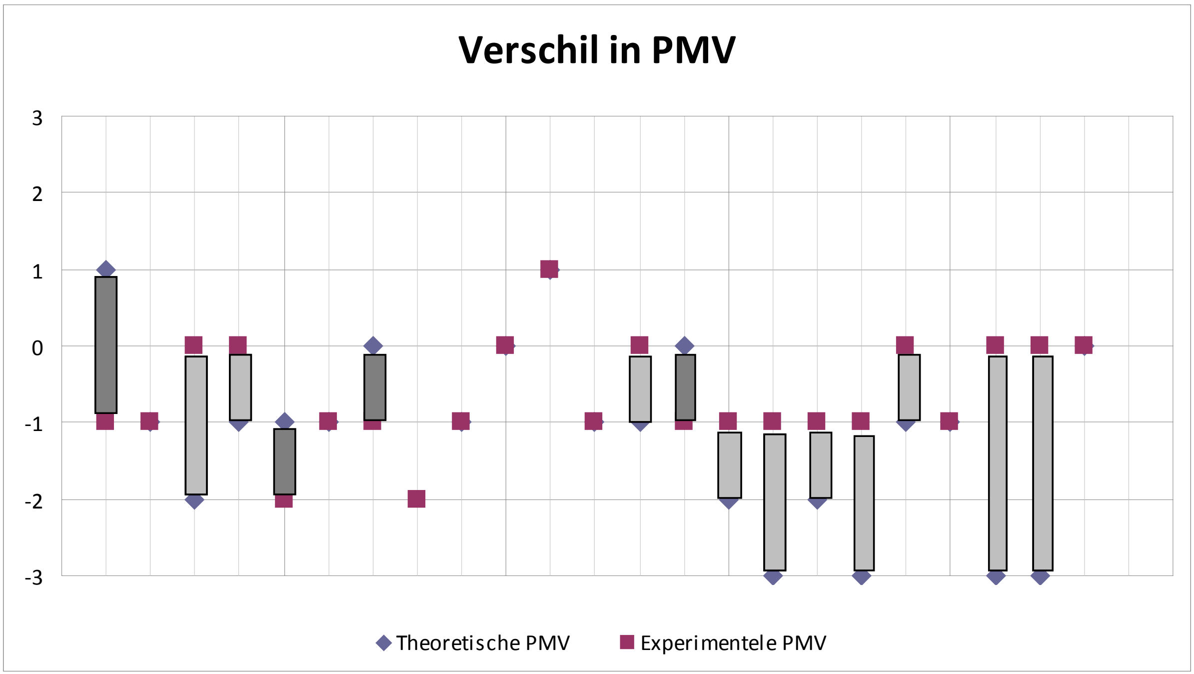
The environmental factors and the personal factors calculated for each participant are used to calculate the theoretical PMV. This is done using an Excel sheet in which the Fanger formula is incorporated, the variables of temperature (assuming that the air temperature and the radiant temperature are equal), air velocity, humidity, clothing level and metabolism are used as an input.

I.IV Results

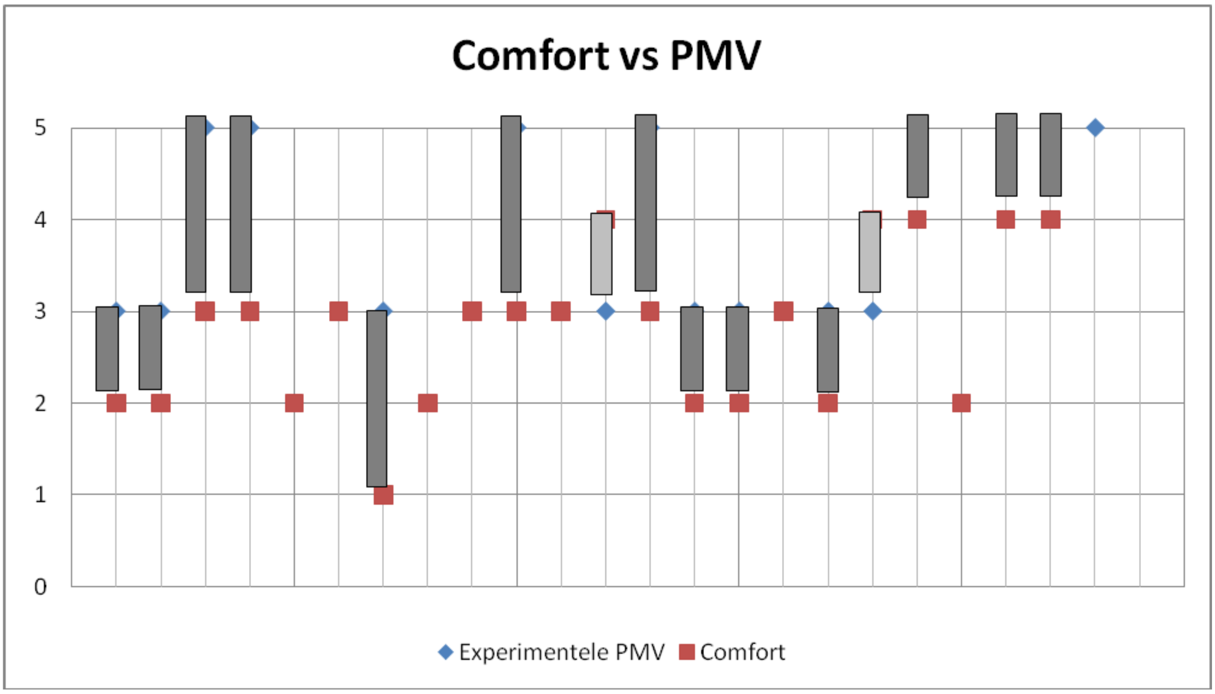
Using the hypotheses as a framework, the results are visualized.

The first set of results validates the PMV as a value to predict thermal comfort and overall comfort in semi-outdoor situations. The relation between the PMV and the ASV and the relation between the

ASV and the overall comfort are evaluated.

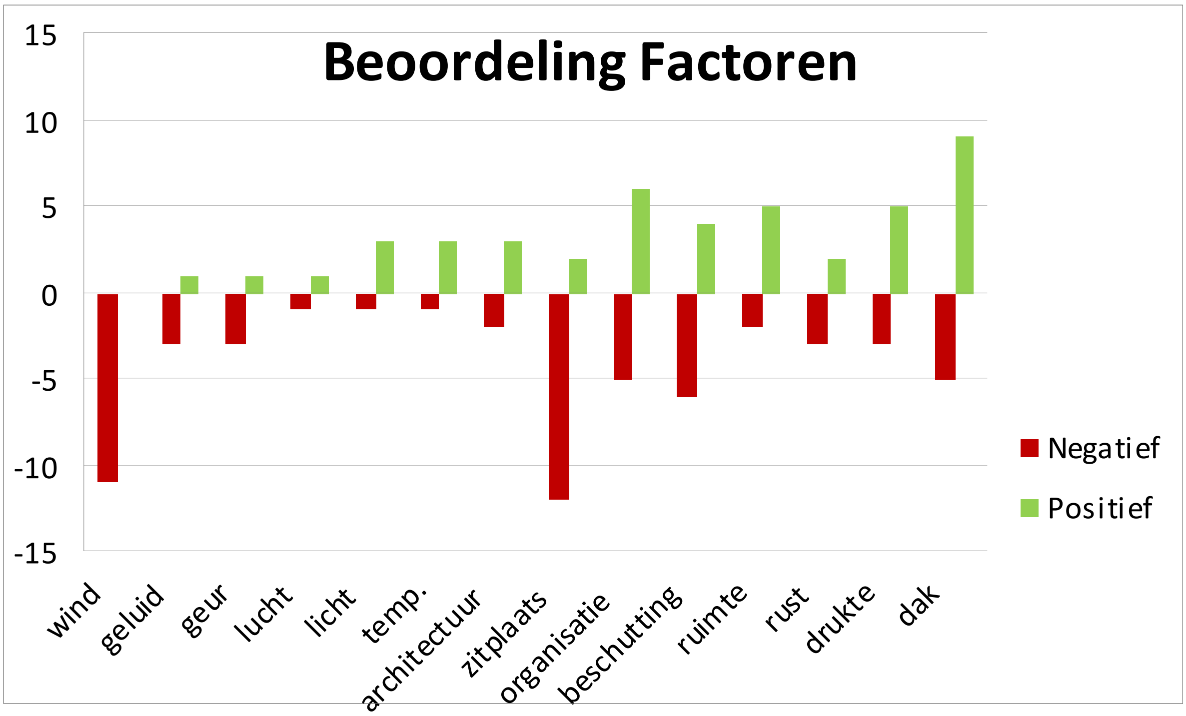


- most of the time the PMV is not equal to the ASV
- most of the time the PMV appears to be lower than the ASV
- the average difference is 1,022

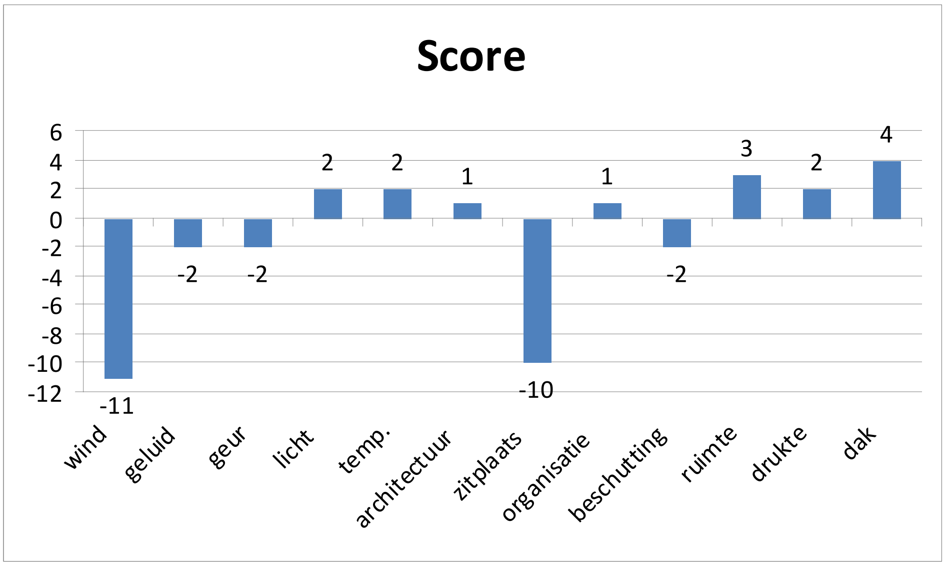


- most of the time the ASV is not equal to the overall comfort rating
- most of the time the thermal comfort is higher than the overall comfort
- the average difference is 0.87

The next set of results investigates the factors involved in comfort in railway stations, their importance and their effect on comfort. The graph below shows the reported values and the frequency with which they are reported negatively or positively. The next graph shows the score of the most frequently reported factors by adding positive ratings as +1 and negatives as -1.

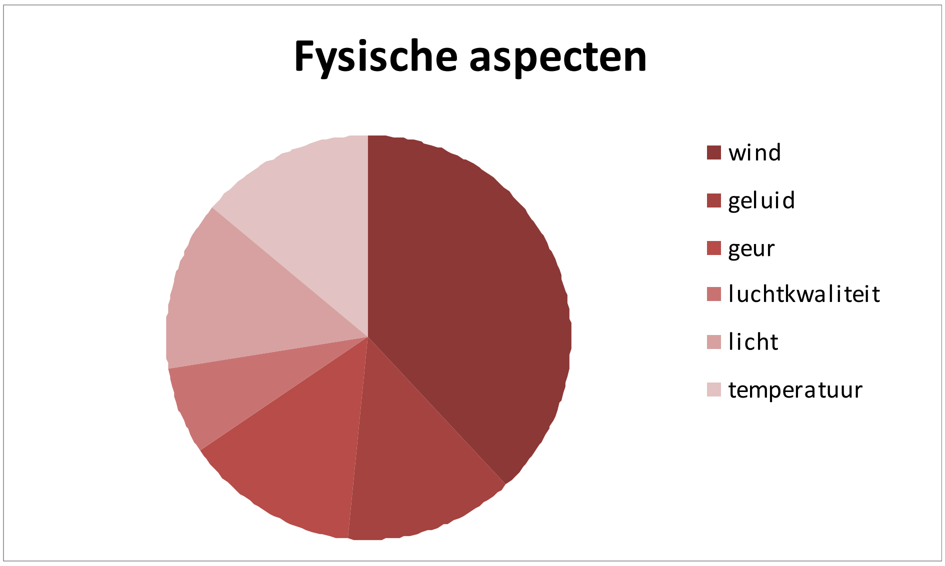


- wind and seats are very negatively valued, shelter and roof are very positively valued
- other factors are more in balance

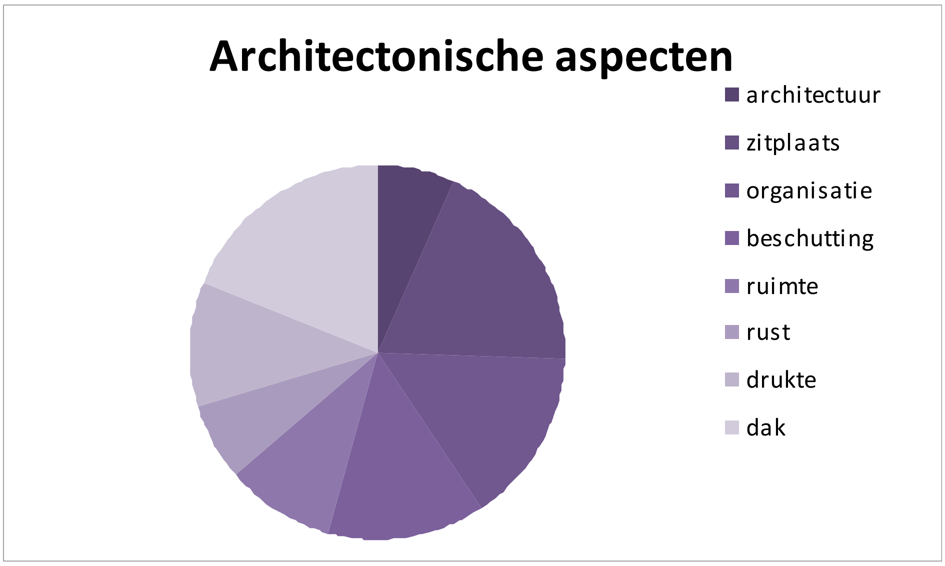


- wind and seats are most frequently and most negatively valued

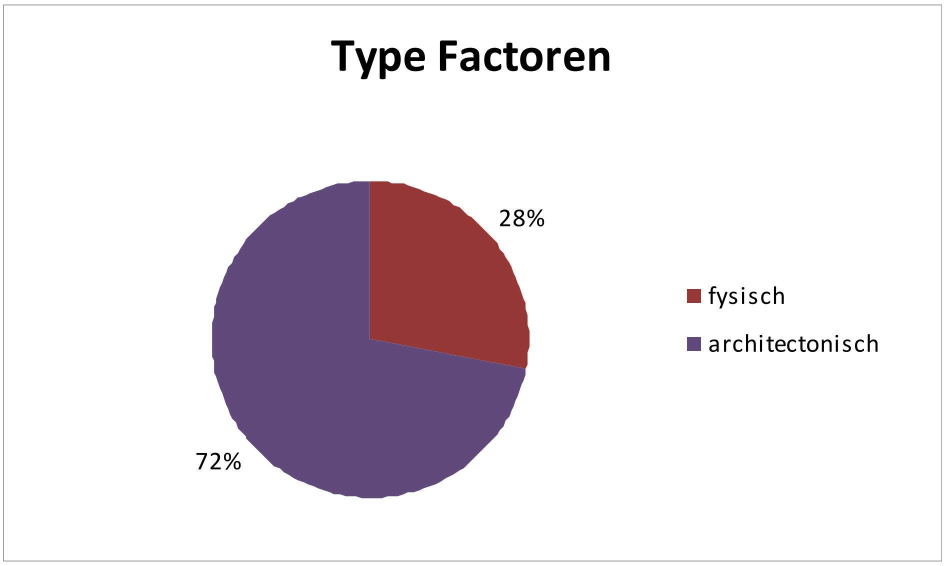
The reported factors can be separated in physical and building technical aspects. The pie diagrams show the percentage of the frequency with which a factor is reported and to the percentage of the two categories.



- all factors that determine the environmental quality, except vibrancy, are reported
- wind is the most important, after that noise, odor, light and temperature, after that air quality

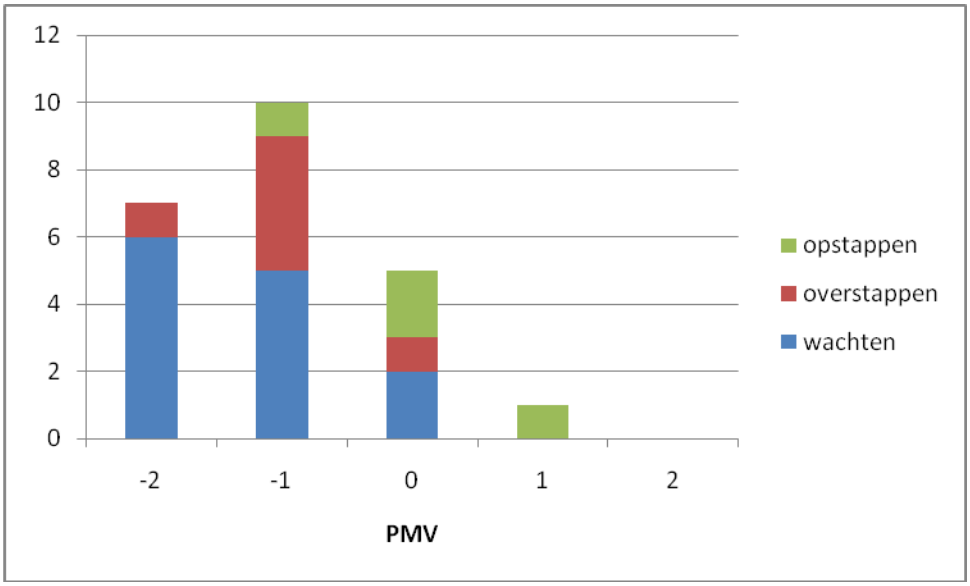


- pretty much all of the factors that determine architectural quality are reported
- roof and seats are the most important, after that organisation and shelter, after that busyness and space, after that the others



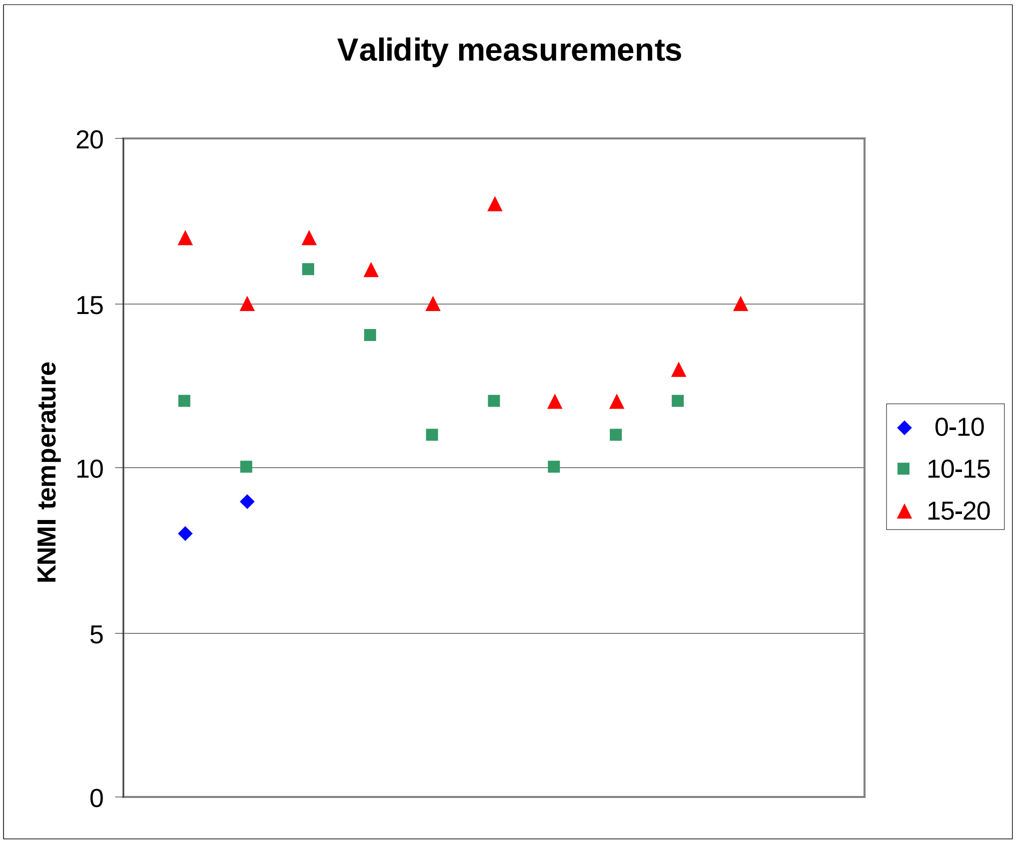
- Architectural are at least as important as physical aspects (warning type of questions!)

The relation between thermal comfort and activity is visualized in the next graph.



- the activity waiting gives the most negative (cold) ratings
- the activity transfer gives remarkably more -1 than other ratings
- the activity stepping on/off gives the most positive rating
- the activity stepping on/off gives a warmer rating than the other activities

To validate the method of obtaining the environmental factors via the weather station closest to the location, the reported estimated temperature is compared to the measure temperature at the weather station. This graph shows the values obtained with the weather stations, the colours indicate the estimated temperature. In the ideal situation, the blue points are between 0 and 10 °C on the vertical axis, the green between 10 and 15 °C and the red between 15 and 20 °C.



- The estimated temperatures seem to match the obtained temperatures quite well.
- A quarter of the estimated temperatures do not respond to the obtained ones.

I.V Conclusion

To conclude the research, the results are compared to the hypotheses.

1. There exists a discrepancy between the predicted mean vote using the Fanger theory and the actual sensation vote reported by the participants.

The results indicate that this might be true however the amount of data is too small to scientifically confirm this.

2. The level of overall comfort has a strong correlation with the level of thermal comfort.

Just as the one above, this hypothesis is difficult to test without further research on the subject but the results do indicate a relation although this might not be as strong as assumed.

3. The most important factor that influences the feeling of comfort negatively is the amount of wind or draft.

The factor wind is most definitely the one that has the lowest score of all factors and has thus been most frequently reported as a negative factor. Besides that, it's also one of the most important factors, apparent by the frequency of reporting it as a factor. However, the factor 'seats' is reported as negative as frequently as wind although it has a higher score overall. This could also be because 'seats' is given as an example of things that could influence comfort in one of the questions.

4. Architectonic aspects are equally important as physical aspects to the feeling of comfort.

It looks like the architectonic aspects play a very big role indeed; they are mentioned more frequently than physical aspects so they might even be more important to people than physical aspects. However, the line between physical aspects and architectonic aspects is not as clear as it looks in the graphs. For example, shelter will most likely have something to do with the physical aspects of wind and rain, the presence or absence of it is originated from an architectural choice though. Besides that, there is another remark about the way of questioning; the first part of the interview is focused on physical aspects (although in another way) which could cause the focus on architectural ones in the second part.

5. All factors involved in the environmental quality play a role in the feeling of comfort in railway stations.

The factors involved in the environmental quality are: thermal quality, acoustical quality, lighting quality, air quality, odor quality and vibrancy quality. Vibrancy is not reported in the research as positive nor as negative and therefore doesn't seem to play a role in people's experience of comfort in railway stations. Architectonic factors are not mentioned in the definition of environmental quality. Probably they are categorized under the psychological influences on comfort.

6. People who are transferring from one train to the other are easier satisfied with the environmental quality than people that are waiting.

The uncertainty of the results to test this hypothesis is very large because the definition of the different activities and the effort related to it is very sensitive to interpretation.
Besides, the largest part of the respondents was waiting, which makes the data very difficult to compare. However, a trend towards a lower rating from people that are waiting can be observed. The category step on/off seems to be more comfortable in general and rate a warmer ASV than the other categories which might indicate the relation to a higher level of effort.

7. The experimentally estimated temperature is the same as the determined air temperature.

This is true for some part of the responses. However almost a quarter of the responses doesn't seem to match the data given by the KNMI. This mismatch has probably to do with the method of using KNMI data from an observation point that is closest to the station but could be kilometres away (although some tiny estimated corrections have been made for the configuration of the station and with the help of the other information about the weather given by the respondent). Another error could have been caused by the quality of the estimation of the respondent although the given categories seem to be large enough to even out this effect

With the results of the reports factors and their importance, the answer to the research question can be given. The most valid conclusions can be drawn from that part of the research because no calculations or estimations are involved. It is important to note the architectural factors and their importance.
Seats are rated very negatively and are very critical for the feeling of comfort (Milan research). The presence of a roof is rated very high especially because of the shelter it gives. Shelters are present in most situations but they are not rated high, probably the presence of a shelter is valued but the way

they are designed is not up to standards. Organisation is obviously very important because it determines the difficulty of navigation. The factors business, peacefulness and space are related to each other. They are not rated purely positive or negative but their importance as a factor becomes clear by the frequency of reporting.

Appendix II: Theory

II.I Wind

Theory of wind is quite complex because there are a lot of different factors at play and the behaviour of the flow is dynamic. To give a full explanation of the theory of aerodynamics would go beyond the scope of this research and of the domain of building. The aim of this paragraph is to give a basic understanding of wind in the built environment so that it can be used as a tool for the design of the climate system.

Originating from pressure and temperature differences a continuous wind flow is generated around the earth, causing differences in climate and in weather from day to day from place to place. This wind flow is disturbed by the friction of the earth's surface and all the objects standing on it, causing differences in wind speed from fast to slow land inwards and from the sky downwards (reader windhinder, theory aerodynamics). In the Netherlands this means that at the coastal line wind speeds are much higher than in the east of the country. In general this also means that near cities, wind speeds are much lower at lower heights. Wind coming from a rural area, blowing in the direction of a city, will experience obstructions in the form of buildings. The friction of these buildings causes the layers of air above it to be disturbed and slowed down. This disturbed layer is called the urban Boundary Layer (UBL), above that is the layer where the wind goes undisturbed by the city and the velocity is as high as the velocity in rural areas called the Atmospheric Boundary Layer (ABL), below is the layer of air hanging in between the buildings called the Urban Canopy (UC) (figure XX; layers above city, Oke 1978).

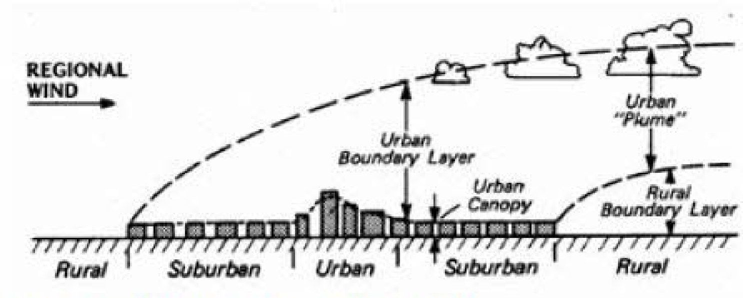


fig 1 lagen boven de stad (Oke, 1978)

Depending on the roughness of the obstructions varying from the earth's surface to plants to small buildings to high rise buildings (roughness length), the wind speed at a certain height can be described by a logarithmic graph (windhinder). This graph is different for each type of location and is called the wind profile of a location (windhinder, figure XX).

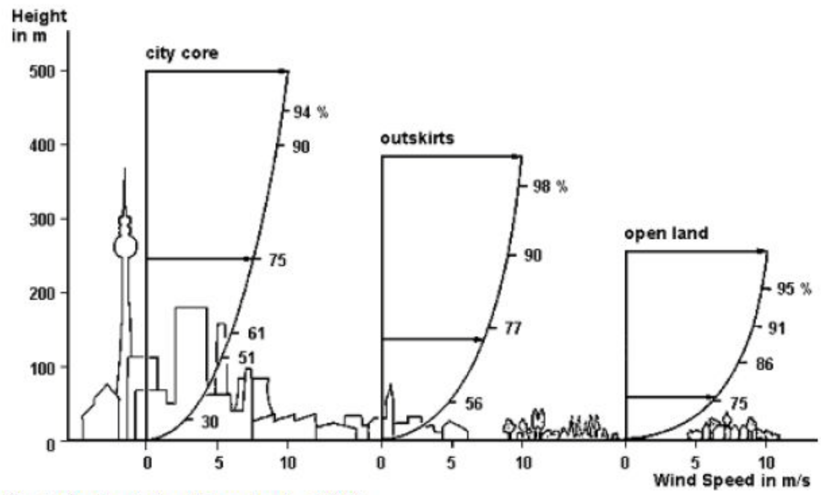
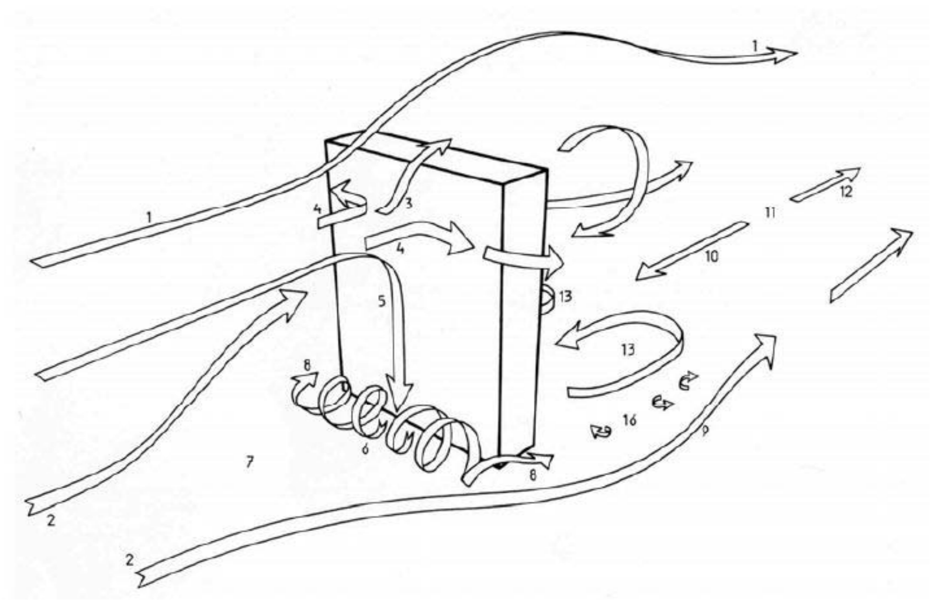


fig 2 windprofielen (Baumbach, 1991)

For cities, the lower part of the wind profile is that of the Urban Canopy layer, for calculations of wind around buildings however, this value is not representative. It indicates the mean velocity of the wind at that height but the actual wind speed at one point is very different because of the complicated air flows around buildings (windhinder). Wind speeds at lower heights vary a lot; high wind speeds occur around edges while directly behind buildings, a calm area occurs (figure XX; flow around building).



Looking closer at a building, keeping the wind profile of a city in mind, this is understandable. Wind coming from a certain direction is blocked by a building so that it needs to go around it; more air needs to flow at one place, creating higher wind speeds at the edges (1, 2, 3, 4, 9). Directly behind the building on the downwind side there's no wind at all because it has been blocked. Now looking at the wind profile with its higher wind speeds at higher levels the other air flows can be explained. The low wind speeds at the foot of the building cause an under pressure which causes the wind from upstream that is obstructed by the building not only to flow around the building but also downward (5). This air flows along the building downward and is changed in direction, pointing in the opposite direction of the original wind flow. Air from this flow is turned around again by the upwind stream creating a vortex at the foot of the building (6). Downwind, at the back of the building, something similar happens; low wind speeds there cause an under pressure that pulls air from the flow around the edges towards the building (10, 13, 14). This flow is again obstructed by the building causing the flow to be directed upwards and to merge in the upstream wind again (15) The normal flow pattern is recovered only after around 16 times the height of the building downstream. (figure XX; flow around building section and plan) (literatuurstudie M.M.E. van Esch).

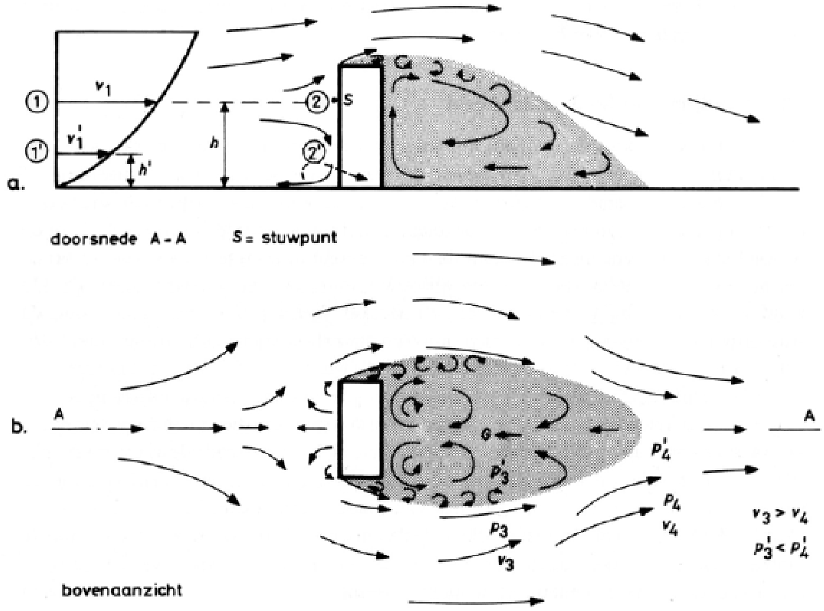
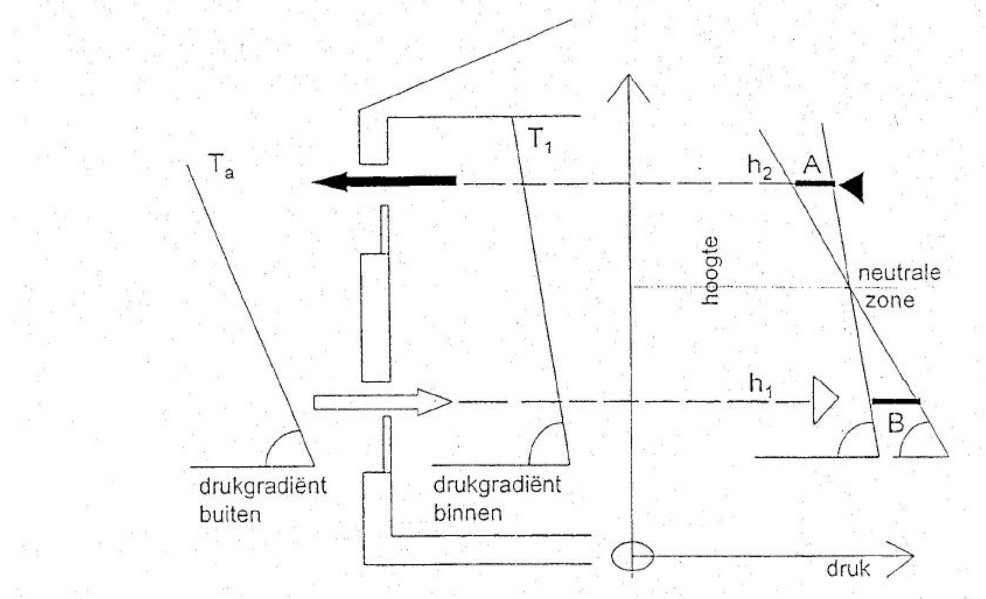


fig 9 Stroming rond een enkel gebouw, doorsnede en bovenaanzicht. In grijs het zoggebied (Beranek, 1979)

The effect on the small scale of the building is that all these different wind flows cause over or under pressure on the facade. Depending on the orientation of the building towards the wind direction pressure differences occur; not only between the facades but also between the facades and the inside of the building. Since wind is driven by pressure differences air flow occurs inside the building when there are openings in the facade or when a window is opened (figure XX; push & pull of wind on facade, reader draagconstructies).

Air flow inside buildings can also result from temperature differences. Hot air is lighter than cold air which causes hot air to flow upwards; when kept inside a building an over pressure occurs at the top. The effect is even strengthened when there's a temperature difference between outside and inside and there are openings in the building. If the indoor temperature is higher than the outdoor temperature, cold air from outside is pulled inside at the bottom of the building, the place where under pressure is created by ascending hot air. At the top of the building, an over pressure occurs and the hot air is pulled outside again. This principle of creating an airflow using temperature difference and building height is called the heat stack effect (figure XX; pressure gradient,



figuur 6. schematische weergave van het principe van thermische trek

Kennisbank Bouwfysica Drukverschillen scheidingsconstructie). In most cases, the air movement in a building is defined by pressure differences from both wind and temperature difference. The velocity with which the air moves through the building relates directly to the difference between pressures. This velocity is only limited by the resistance of the volume of the air inside the building and by the resistances of the openings as is described in the formula below (Kennisbank Bouwfysica, ventilatie & infiltratie):

$$\Delta P = \frac{1}{2}\zeta_i \rho v_i^{\,2} + \frac{1}{2}\left(\mu \frac{L}{D} + \xi_a\right)\rho v_a^2$$

Pressure difference resulting from wind on the facade and pressure difference resulting from difference in temperature can be added using the flow rate through the openings in the facade (Kennisbank Bouwfysica, ventilatie & infiltratie).

$$\Delta P_w + \Delta P_T = \left(\frac{\dot{V}_i}{C_d A_i}\right)^2 \frac{\rho}{2} + \left(\frac{\dot{V}_a}{C_d A_A}\right)^2 \frac{\rho}{2}$$

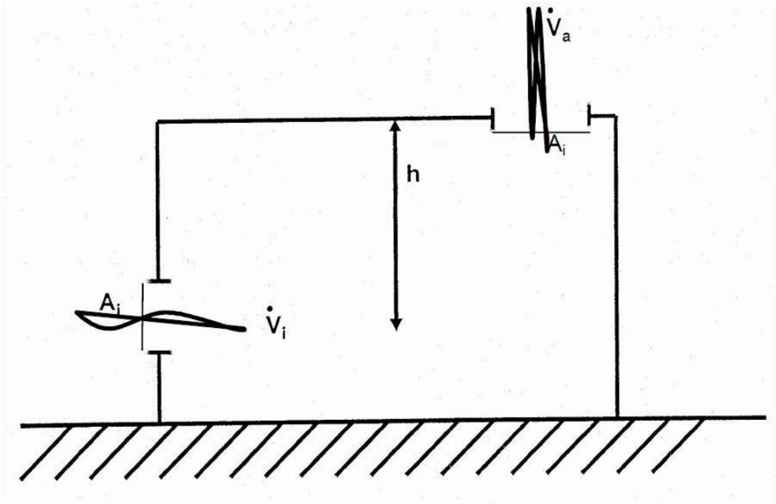
With:

$$P_{Wp} = P_o + C_P .\ ½\, \rho v^2$$

and

$$\Delta P_T(h) = \rho_i g h \frac{(T_i - T_a)}{T_a}$$

Together they define the air velocity inside (m/s) or the ventilation rate (m3/s) through the building. These are measures for the nuisance from the wind but also for the refreshment of air and thus for air quality and partly for temperature (figure XX; berekening natuurlijke ventilatie, ventilatie en infiltratie).



figuur 3. eenzonemodel voor berekening van de natuurlijke ventilatie

Global location

Local location

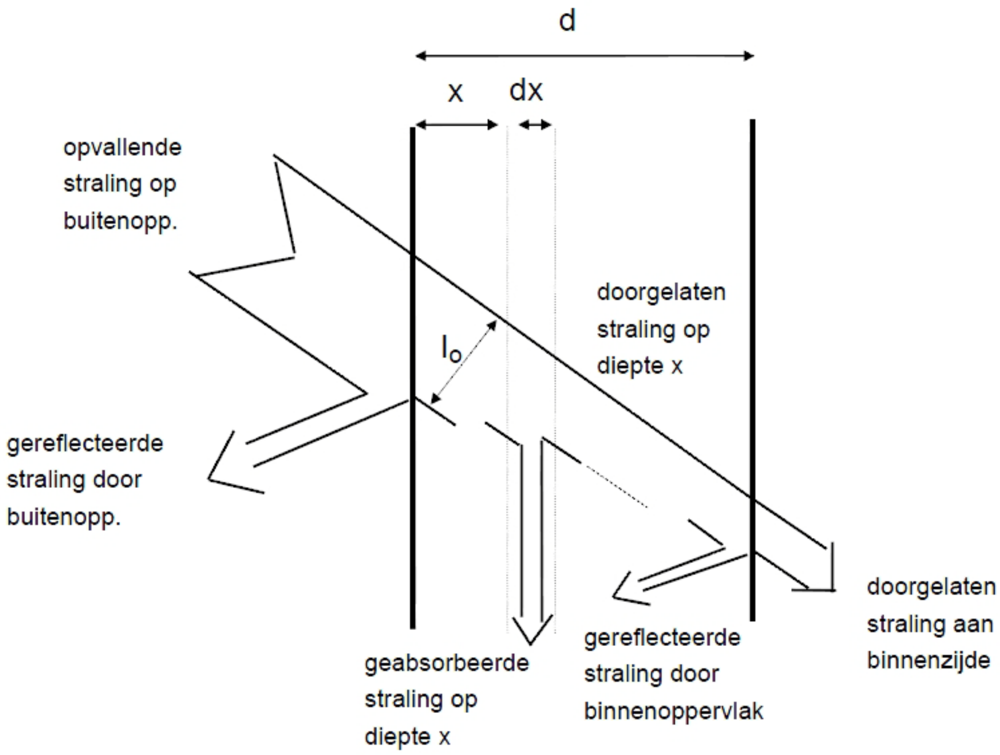
Boundary layers etc

Wind profile

II.II Temperature

Temperature is a very broad term; it can be split up in air temperature and radiant temperature. Together they are a measure for the heat of a certain object or place on earth. The temperature on a certain place on earth is ultimately determined by the heat of the sun. The hottest areas on earth are the ones that are closest to the sun lying along the equator while the furthest places, the poles, are the coldest. Above and below the equator, the amount of sun is varying due to the inclined axis of the earth, causing the difference in temperature in the seasons each year. Difference in temperature also occurs in the daily rhythm of the sun, originating from the earth turning around its axis. These two patterns together define the amount of sun shining at a surface on a certain time on a certain place on earth.

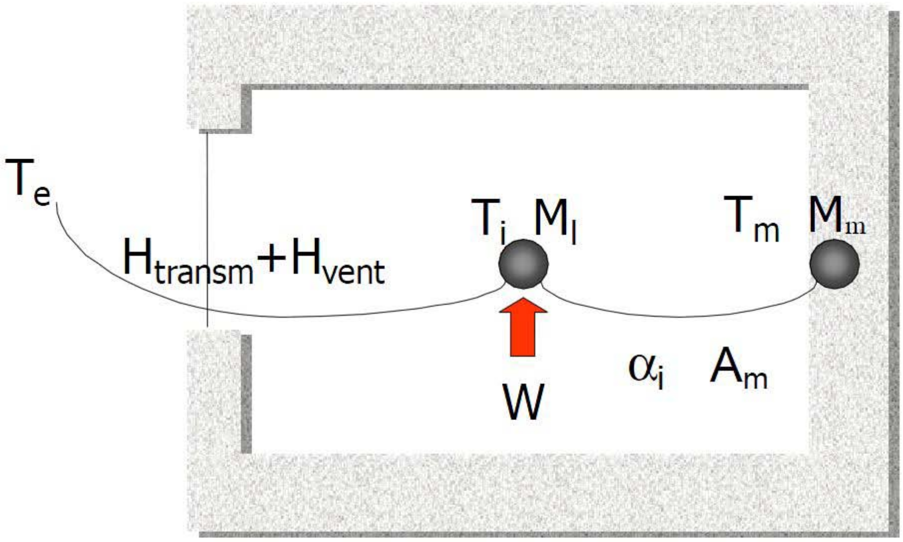
Sun shining directly or indirectly on a building causes heat inside the building. When short wave radiation from the sun shines on a transparent surface the waves are reflected, absorbed or transmitted, dependent on the angle of incidence and the material of the surface (Kennisbank bouwfysica, zonbestraling, figure XX; radiance on surface).



figuur 2. straling door een transparant materiaal

Reflection prevents heat from coming in. Absorption causes the surface of the material itself to radiate long heat waves towards colder objects inside or outside the building. Transmittance results in the heating up of objects inside the building. These objects will radiate long heat waves to colder objects but since most transparent materials don't transmit long waves, the heat is kept inside. In summer, this phenomenon can cause overheating, depending on the other factors that play a role in the heat balance of a room.

Other factors that play a role are the materials of the building, the building envelope and the openings in it. Together with the air temperature in- and outside, they determine the absorption of heat inside building materials, the transmission through the envelope and the convection through air movement. Additional mechanical heating and cooling and heat production by humans or machines can be added up in the heat balance of the building (Kennisbank bouwfysica; eenzonemodel, figure XX; eerste orde model).



figuur 1. eerste-ordemodel van een vertrek

Altogether this results in the following (simplified) formula:

$$T_i = \frac{W + HT_e}{i\omega M_l + H + i\omega M_m}$$

The air temperature inside the building is determined by all these different variables and is one of the most important factors for thermal comfort in summer.

Appendix III: Calculations

III.I Contam

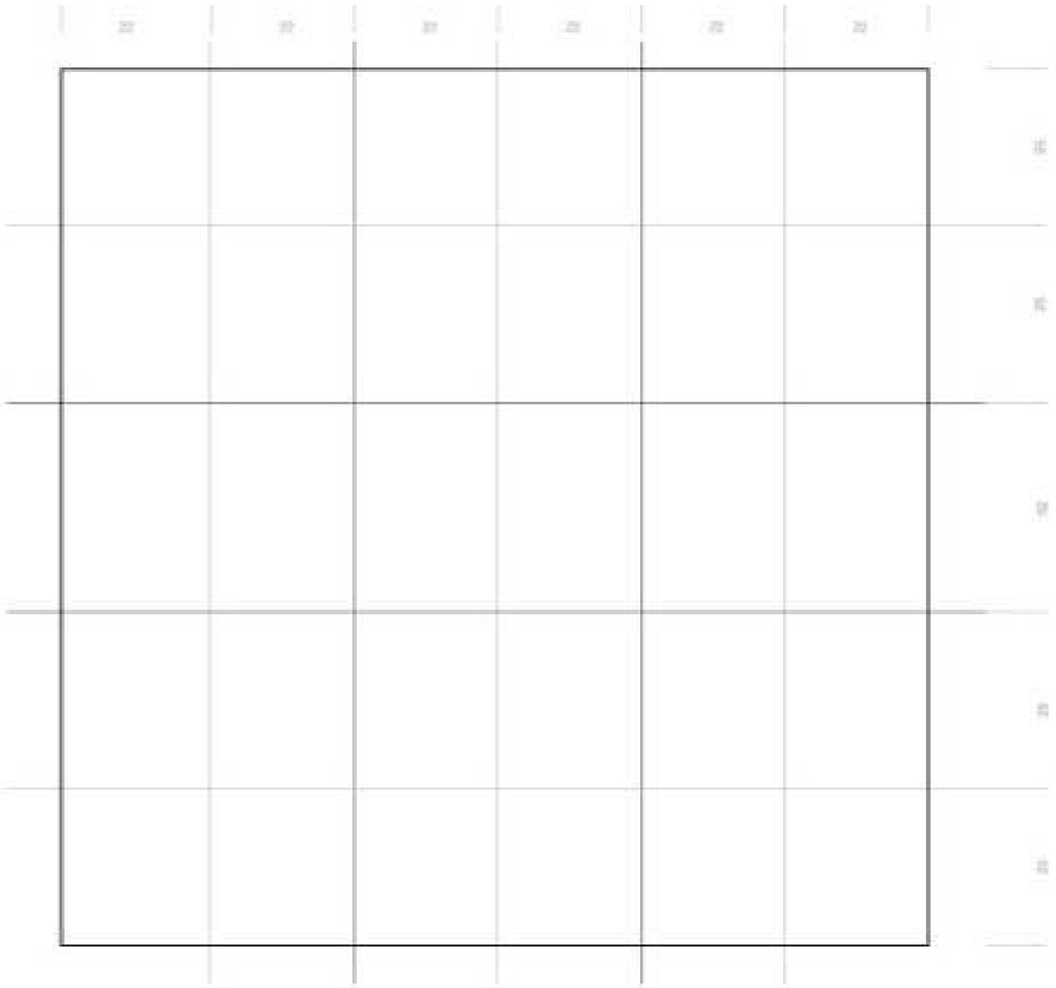
The computer program Contam is used. Contam is based on a simple physical model that calculates air flow through difference in pressure caused by temperature difference or wind pressure difference. The model is based on the gridlines of the preliminary design.

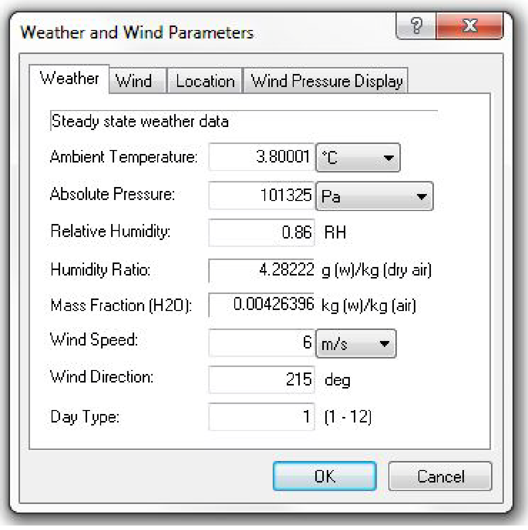
Pressure resulting from temperature difference and wind are calculated for each zone in the building and then translated to a flow rate through openings.

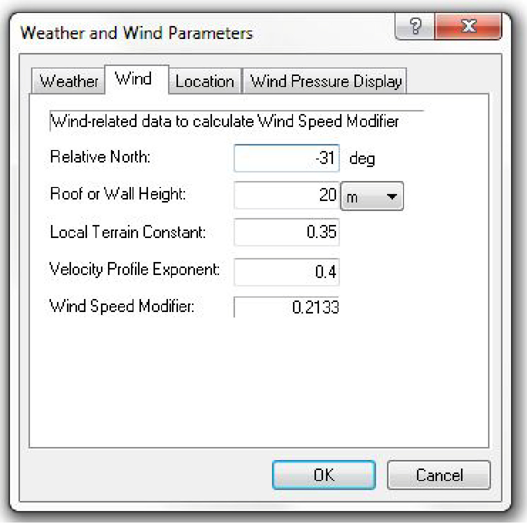
Contam is a very abstract program in which the only input to define the configuration of the building is:

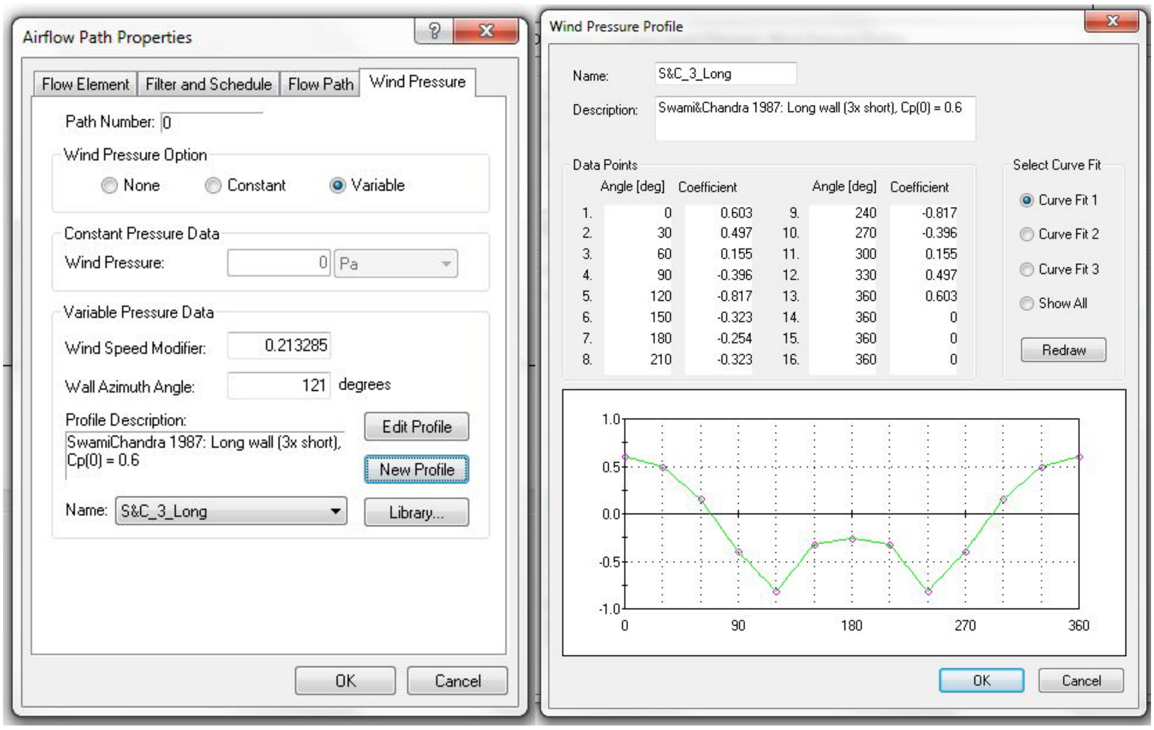
- Volume of a zone (the space for which flow rates are calculated)
- Orientation towards the wind and towards other zones (sloped angles not possible!?)
- Area of openings in the zone
- Wind pressure on the openings of a zone (which can be calculated by the program itself) using the input for the environmental conditions).

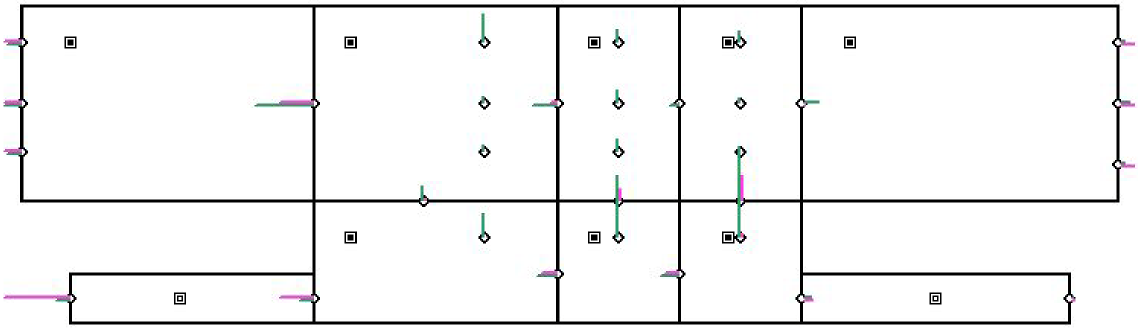
Output data of Contam is flow rate through a certain zone. This has to be calculated to a wind speed in a certain zone by dividing the flow rate by the area of the opening in that zone.




Weather and Wind Parameters
Weather
Wind
Location
Wind Pressure Display
Steady state weather data
Ambient Temperature: 3.80001 °C
Absolute Pressure: 101325 Pa
Relative Humidity: 0.86 RH
Humidity Ratio: 4.28222 g (w)/kg (dry air)
Mass Fraction (H2O): 0.00426396 kg (w)/kg (air)
Wind Speed: 6 m/s
Wind Direction: 215 deg
Day Type: 1 (1 - 12)
OK
Cancel


Weather and Wind Parameters
Weather
Wind
Location
Wind Pressure Display
Wind-related data to calculate Wind Speed Modifier
Relative North: -31 deg
Roof or Wall Height: 20 m
Local Terrain Constant: 0.35
Velocity Profile Exponent: 0.4
Wind Speed Modifier: 0.2133
OK
Cancel


Airflow Path Properties
Flow Element
Filter and Schedule
Flow Path
Wind Pressure
Path Number: 0
Wind Pressure Option
None
Constant
Variable
Constant Pressure Data
Wind Pressure: 0 Pa
Variable Pressure Data
Wind Speed Modifier: 0.213285
Wall Azimuth Angle: 121 degrees
Profile Description:
SwamiChandra 1987: Long wall (3x short), Cp(0) = 0.6
Edit Profile
New Profile
Name: S&C_3_Long
Library...
OK
Cancel
Wind Pressure Profile
Name: S&C_3_Long
Description: Swami&Chandra 1987: Long wall (3x short), Cp(0) = 0.6
Data Points
Angle [deg] Coefficient Angle [deg] Coefficient
1. 0 0.603 9. 240 -0.817
2. 30 0.497 10. 270 -0.396
3. 60 0.155 11. 300 0.155
4. 90 -0.396 12. 330 0.497
5. 120 -0.817 13. 360 0.603
6. 150 -0.323 14. 360 0
7. 180 -0.254 15. 360 0
8. 210 -0.323 16. 360 0
Select Curve Fit
Curve Fit 1
Curve Fit 2
Curve Fit 3
Show All
Redraw
1.0
0.5
0.0
-0.5
-1.0
0
90
180
270
360
OK
Cancel



Powerlaw Model: Orifice Area

This airflow element allows you to input the description of an orifice.

Name: Enter the name you want to use to identify the airflow element. The airflow element will be saved within the current project and can be associated with multiple airflow paths.

Cross-sectional Area: This refers to the observable area of the opening.

Flow Exponent (n): Flow exponents vary from 0.5 for large openings where the flow is dominated by dynamic effects, and 1.0 for narrow openings dominated by viscous effects. Measurements usually indicate a flow exponent of 0.6 to 0.7 for typical infiltration openings.

Discharge Coefficient: The discharge coefficient, C, is related to the dynamic effects and is typically close to 0.6 for a sharp-edged orifice and slightly higher for other openings in buildings.

Hydraulic Diameter: The hydraulic diameter is equal to (4 · Area / Perimeter). For square openings this equals the square root of the area, and for long thin openings it is two times the width.

Reynolds Number: The transition from laminar flow to turbulent flow occurs over a very broad range of Reynolds numbers with the flow being fully laminar approximately below 100.

Note: The hydraulic diameter and Reynolds number have little impact on the calculations. Generally you should use the default values except for special circumstances where you need them to be modified. The parameters above describe the flow characteristics of an orifice in typical operation. At extremely low pressure drops the use of the powerlaw model leads to a division by zero during the network solution process. ContamX avoids this problem by changing to a linear model in this region. The model is based conceptually on the flow changing from turbulent to laminar at very low pressures. The Hydraulic diameter and Reynolds number are used to determine a point where the model changes from the powerlaw to linear.

Description: Field for entering a more detailed description of the specific airflow element.

Icon: Choose either the small or large opening icon as appropriate for the specific airflow element. The icon has no effect on the simulations.

III.II Excel

The formula for heat balance is attached to the hourly values of the sun load for all different orientations of surface, obtained from sun diagrams for a typical hot summer day in The Netherlands.

Like Contam, Summertemp is abstract too and purely works with the variables of the function. This means that the building can be defined by:

- Area of the enveloping surfaces and their U-value and ZTA-value (for transparent surfaces)
- Weight of the total effective thermal mass of the building
- Ventilation rate
- Hourly cooling capacity

Again, the effect of the shape can't be calculated directly, it can only be simulated by using the different surface orientations. What is important too is that unlike Contam, Summertemp does not work with volume nor area of openings but only with a ventilation rate. The whole building volume and the total amount of fresh air coming in are the only variables included in the ventilation rate. To calculate the effect of natural ventilation on the temperature inside the building, Contam is used. Calculated temperatures in Summertemp are used as in input in Contam and then the heat stack effect is calculated using the rule of thumb of 0,5 degrees/m height. Than iterations are made until the intersection is found. This indicates the final temperature in the building.

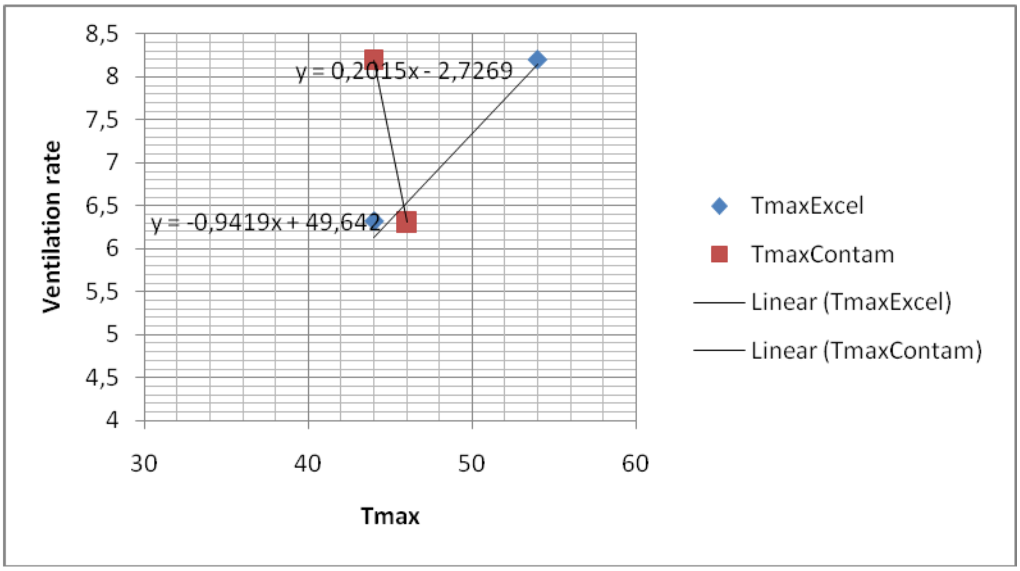


Table used to test the effect of different parameters.

ZTA	0,8	0,6	0,4	0,2	0
Tmax	60	50	41	31	21
dT	17	7	-2	-12	-22
Atransph	26000	19500	9750	2437,5	0
Tmax	43	38	31	26	24
dT	0	-5	-12	-17	-19
Utransp	0	2,5	5	7,5	10
Tmax	1378	65	46	40	37
dT	1335	22	3	-3	-6
G	0,00E+00	7,00E+06	1,40E+07	2,10E+07	2,80E+07
Tmax	66	49	43	41	40
dT	23	6	0	-2	-3
V	0	2,5	5	7,5	10
Tmax	43	34	31	30	29
	0	367505,325	735010,65	1102516	1470021
dT	0	-9	-12	-13	-14
Uontrans	0	2,5	5	7,5	10
Tmax	43	42	41	41	40
dT	0	-1	-2	-2	-3
Water	0	5000	10000	15000	20000
Tmax	43	41	38	36	34
dT	0	-2	-5	-7	-9

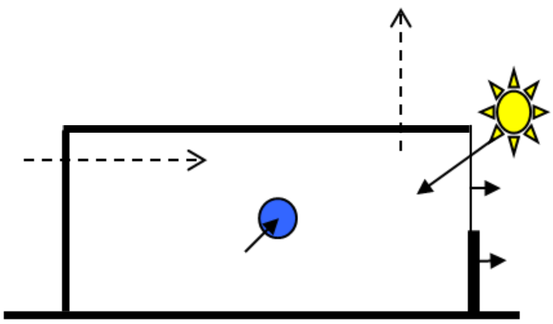
For the cooling by evaporation, only an hourly cooling capacity can be given as an input. The most important limitation, not as much of the program itself but of the formula incorporated in the macro, is that the building as a whole is only seen as one zone, one volume. Thus, differences in temperature for different rooms or different levels are not calculated. As a result, only the building volume as a whole with its surrounding surfaces can serve as an input. Evaporation is calculated with a constant hourly cooling capacity of 2,5 W/m2 (Vela roof).

Edit yellow fields only					
glas (facade and roof)	m2	######	U-value	6,00	W/m2K
non-transparent 1	m2	5918,0	U-value	0,33	W/m2K
non-transparent 2	m2	0,0	U-value	6,00	W/m2K

G =	14000000

C=	840	alph.	3,06E-07

Tmax	30,53
Tavg	23,05



G=thermal active maas in kg

Hv=qv*rho* c = 0,33* n * Volume

variant 1 skin	basis								
9	8	7	6	5	4	3	2	1	Hv
58,5	57	55,5	54	52,5	51	43,5	34,5	25,5	158300
48,5	47	45,5	44	42,5	41	33,5	24,5	15,5	122100
50,5	49	47,5	46	44,5	43	35,5	26,5	17,5	121700
final building									
35	33,5	32	30,5	29	27,5	20	11	2	955513,9
38	36,5	35	33,5	32	30,5	29	20	23	corrected

variant 2 skin	wind optim								
9	8	7	6	5	4	3	2	1	Hv
58,5	57	55,5	54	52,5	51	43,5	34,5	25,5	141453
49,5	48	46,5	45	43,5	42	34,5	25,5	16,5	106026
51	49,5	48	46,5	45	43,5	36	27	18	105012
final building									
35,5	34	32,5	31	29,5	28	20,5	11,5	2,5	837912,1
38,5	37	35,5	34	32,5	31	29,5	20,5	23	corrected

variant 3 skin	vent optim								
9	8	7	6	5	4	3	2	1	Hv
58,5	57	55,5	54	52,5	51	43,5	34,5	25,5	433920
41,5	40	38,5	37	35,5	34	26,5	17,5	8,5	304910
44,5	43	41,5	40	38,5	37	29,5	20,5	11,5	301470
final building									
32,5	31	29,5	28	26,5	25	17,5	8,5	-0,5	2381435
35,5	34	32,5	31	29,5	28	26,5	17,5	23	corrected