6 Creating drafts in urban settings through coloured façades: Exploring a new climate adaptation measure based on thermal stratification [11]

In the previous chapter the effect of numerous adaptation measures is described in relation to thermal comfort. The results show that increasing wind speed can be an effective cooling measure. However, the cold winter climate and the prevailing wind direction during heat and cold waves make it difficult to actually use this principle. Moreover, proven adaptation measures such as, more vegetation or water, are not always possible because of a lack of space or undesired aesthetic effects. This chapter answers the sub question: How can ventilation be utilized in hot weather situations without deterioration of the wind conditions in winter?

An alternative option for more fresh and cool air in a street canyon is to make use of façade colours to accelerate wind speed. Differences in colour and materials already influence the air flow in street canyons, but in an uncontrolled manner. If we could employ this principle for the improvement of thermal comfort it potentially has a large impact on many cities in the world. This chapter gives the results of a first exploratory research based on measurements on scale models and at full scale. This pilot study shows that the principle works and advocates further research. For example, more research is required to examine if the cooling effect is significant in the perception of pedestrians.

§ 6.1 Introduction

In order to control the thermal comfort conditions in an urban setting there are four physical parameters that can be influenced: air temperature, radiant temperature, humidity and wind speed. There are quite some climate adaptation measures available

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[11] This chapter is published as Journal article: Kleerekoper, L., Dobbelsteen, A.A.J.F. v.d., Ham, E. v.d., Hordijk, T. and Martin, C. (2015), "Creating drafts in urban settings through coloured façades: Exploring a new climate adaptation measure based on thermal stratification". Urban Climate, Vol. 14, Part 2, pp. 290-300.

(Kleerekoper et al., 2014, Kikegawa et al., 2006, Carter, 2011, Mees & Driessen, 2011), these measures include protecting and enhancing urban vegetation and water bodies; decreasing the area of hard surfaces; the use of 'cool' materials and implementing sustainable drainage systems (SUDS).

There are many streets where additional vegetation or water is not an option because of a lack of space or technical difficulties. Options to reduce temperatures in these streets are to add coverings such as canvas sheets to provide shade; providing spraying nozzles to cool by evaporation; increasing the surface albedo of pavement or ventilating the streets to bring in cool air (Nishimura et al., 1998, Nikolopoulou & Steemers, 2003). The latter option could be done by orientating streets to the prevailing wind direction or using wind directing elements during hot summer periods.

For The Netherlands the prevailing wind direction during heat waves is North-East. Unfortunately this is also the prevailing wind direction during cold waves, and moreover, the strongest and year-round prevailing wind direction is exactly opposite: the South-West. Therefore, streets oriented from N-E to S-W will be less comfortable in especially winter and during stormy weather. In addition, the measure will not be that effective because wind speed is usually very low during heat waves, around 0.5-2.5 m/s (KNMI, 2011). Another way to bring cool air in a street canyon during sunny weather could be to accelerate the process of thermal stratification. On a larger scale this process is known from situations where cool airflow is generated from a park to a hot urban area adjacent to this park (Eliasson & Upmanis, 2000). On the smaller scale of a street the use of temperature differences could be used to accelerate airflows.

Therefore the hypothesis tested in this paper is as follows:

The colour and material of a façade influences the thermal stratification process in a street profile, so with a darker coloured façade the air will rise more rapidly along the façade's surface, increasing wind speed at street level and increase the mixture of air between the canopy layer and the city's boundary layer.

We know hot air rises: the stratification of air in a street canyon can have a strong influence on the circulation. With an ambient wind speed lower than 3-4 m/s, which is the case during heat waves, air flow processes are dominated by gravitational forces (Santamouris et al., 2001). A stable stratification can reduce the circulation of air, while convective stratification can intensify it (Bohnenstengel et al., 2004). We also know that dark colours absorb solar radiation and light colours reflect radiation. In Table 6.1 an overview is given of the effect of heated urban surfaces that has been studied by various scholars.

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	TYPE OF STUDY	MAIN CONCLUSION	REFERENCE
Numerical studies	A heated building wall by solar radiation	Thermal heating of the building wall modifies the local air flow around buildings significantly.	(Dimitrova et al., 2009)
	The effect of bottom heating on urban street canyon flows	Thermal heating of the ground plays a significant role in determining flow fields within street canyons. The upward flow induced by buoyancy force can either strengthen or weaken vortexes and modify the vortex structure.	(Kim & Baik, 2001)
	The effect of heated façade and ground surfaces on urban street canyon flows	The heating of surfaces leads to a strong buoyant force close to the solid boundaries that receive direct solar radiation. The effect of the façade heating strongly depends on the height/width (H/W) ratio of the street canyon.	(Xie et al., 2007)
Wind tunnel measurements	The effect of solar radiation on stratification and mixing of air in a street canyon	The mixing of air in a street canyon is higher in case of an unstable stratification. When the atmosphere is stable, wind speeds decrease and less mixing of air occurs between canyon and layers above the canyon.	(Uehara et al., 2000)
	The effect of heated facades	In case the heated façade is at the windward side, the buoyancy force might not be enough to turn around the direction of the airflow.	(Kovar-Panskus et al., 2002)
Water tank experiments	Investigation of the convection flow induced by street floor heating.	The fluid experiments show that, with calm ambient wind, the flows in a street canyon are completely driven by thermal force from the bottom heating, and that the convection can reach the upper atmosphere of the canyon.	(Huizhi et al., 2003)

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	TYPE OF STUDY	MAIN CONCLUSION	REFERENCE
Full-scale measurements	Investigate of urban canyon flow patterns in relation to air pollution by traffic	The solar radiation drives the thermal motions and triggers the photochemistry which has a significant impact on the evolution of pollutant distribution in time.	(Vachon et al., 1999)
	Differences in air temperature between air above and within the canyon	In an East-West oriented canyon in Japan differences in air temperature between air above and within the canyon only occurred within 0.5 m from the floor or façade surface. And there is a large surface-to-air temperature difference for facades that receive direct solar radiation.	(Nakamura & Oke, 1988)

TABLE 6.1 Prior studies into the effect of heated urban surfaces on air flow.

From the numerical and experimental studies mentioned above we can conclude that the heating of a façade has a strong influence on the movement of air within a street canopy when the prevailing wind speed is low. The studies indicate a change – strengthened or weakened – in the circulation pattern where vortexes change direction, and even additional vortexes appear with the increase of surface temperatures. The buoyancy effect of bottom heating in a scale model proved to be strong enough to reach the upper part of the street canyon. In combination with the numerical model result, which determined the strong buoyant force due to façade heating, the expectation is that the effect of heated facades is also strong enough to reach the upper part of the façade and therefore improves the mixing of air between the canyon and the upper layers.

This paper aims to answer the question whether we can make use of coloured façades to accelerate the rising of air in a street canyon in order to attract cooler air into the canyon. Differences in colour and materials already influence the air flow in street canyons, but in an uncontrolled manner. Different colours and materials were therefore studied for their effect on the air speed by means of an experimental test with a scale model. Full scale measurements were carried out on a warm day with low wind speed.

This study is a first step in the development of a new climate adaptation measure which could be applicable to many cities across the world that have to deal with heat stress or air pollution in their cities. An important connotation is the possible up-heating effect of the indoor environment when no precautionary measures are taken. Nevertheless, the proposed adaptation measure offers a new possibility for urban designers and policy makers to acclimatise urban areas where other measures are practically impossible.

§ 6.2 Research Methodology

In order to study the effect of façade colour and material on airflows two types of measurements were executed, those of wind speed and surface temperature. The measurements were first performed (with scale models) outside and inside on warm summer days. The results of these measurements are presented in detail by Kleerekoper et al. (2014) and are briefly summarized in this paper.

The scale model study indicates a significant difference in generated air speed by a black and a white surface. Air speed measurements at full scale were needed to confirm the principle at street scale. Therefore, two full-scale façades were studied on a moderate warm day with relatively low wind speeds.

§ 6.2.1 Air speed measurements on façade models

The air speed measurements are performed inside (Figure 6.1a) and the surface temperature measurements outside (Figure 6.1b). The weather conditions on the measurement days are given in Table 6.2 for De Bilt in The Netherlands with latitude 52° 7′ 0″ N and longitude 5° 11′ 0″ E.

FIGURE 6.1 a. The indoor laboratory set (left) and the anemometer measuring the speed of the vertical air flow (right) (27-08-2013); b. The surface temperature of black coated aluminium and bare aluminium (left) measured with a thermal camera (right) (05-09-2013).

DATE	TYPE OF MEASUREMENT	AVERAGE AIR TEMPERATURE IN °C	RELATIVE HUMIDITY	AVERAGE WIND SPEED IN M/S	PREVAILING WIND DIRECTION
23-08-2013	Surface temperature outdoor	20.2	72 %	2.2	77 ° (East)
27-08-2013	Air flow indoor laboratory	17.8	65 %	2.3	42 ° (North-East)
05-09-2013	Surface temperature outdoor	22.4	72 %	2.7	135 ° (South-East)
27-08-2014	Air flow and surface temperature outdoor	14.2	81 %	1.9	107 ° (East-South/East)

TABLE 6.2 Weather conditions on the days of measurement, De Bilt, The Netherlands.

The generation of air flow is tested in an experimental study with a scale model in two colours: black and white. The model consists of two flat panels representing a street canyon on a scale of 1:20. The size of the street canyon is 20*10*9 (100*50*45 cm) and has a height to width (H/W) ratio of 0.9.

For a first indication of the influence of colour on air speed the scale model was placed in a semi-enclosed, sunny space outside. In the outdoor environment the prevailing wind could have out ruled the effect of the different façade colours on upward air flow. Even so, the measurements show a difference between the black and white façade model in average and maximum airspeed. Because differences in airspeed are small all other airspeed measurements are done indoors to avoid the influence from the actual wind field.

The indoor experiment was executed in a non-isolated space. Before each measurement the airflow was measured to ensure there were no draughts in the space that could influence the wind speed measurements. The measurement equipment was an anemometer with a velocity range of 0 - 20 m/s, an accuracy of ± 0.25 m/s and a resolution of 0.01 m/s; see Figure 6.1a. The measurement point is directly above the middle of the panel that receives radiation. To measure the vertical wind direction generated due to the buoyancy effect, the anemometer is placed horizontally with the opening at a distance of 1 cm from the surface of the panel. A 1000W lamp was used to simulate the sun. As the lamp needed time to heat to full capacity, upwind speed measurements were conducted at the beginning, after 30 minutes and after one hour. The cooling time lag of the up heated surfaces was tested at least one hour after switching off the heat source following a period of up heating. After the heat source is switched off the wind speed was measured directly and about 5 and 10 minutes later. Each measurement was repeated at least three times to exclude occasional differences due to movements of for example the executers of the measurements. The anemometer used was not equipped with a data logger, therefore all measurements were performed with two persons: one reading the display and keeping the time schedule, the other noting down all measurements. Each air speed measurement lasts one minute, noting the maximum, minimum and average temperature displayed by the anemometer.

§ 6.2.2 Air speed measurements on full scale façade

The air speed measurements on two full scale facades were executed on the 27th of August 2014. The weather conditions on this measurement day are given in Table 6.2 for de Bilt in The Netherlands. The test location was the *Zonnebaan* in *the Lage Weide* neighbourhood of the city of *Utrecht*. It was chosen because the site has two eight-metre tall façades with a white and a black colour next to each other. The façades are facing South-West, which has the largest potential to heat up. There are no obstructions in the 16-metre wide street nor in front of the 10-metre tall façades (Figure 6.2).

FIGURE 6.2 A map of the measurement location and images of the measurement setup at the white (left) and black (right) façade (27-08-2014).

The measurements were performed with a single air speed measurement device along with a thermal camera and a thermocouple sensor. The airspeed measurement device was a hot wire thermo-anemometer with datalogger (Extech, model SDL350). The air speed measurement device has an accuracy of 0.1 m/s and a resolution of 0.01 within the range of 0.2-5.0 m/s. The thermal images were taken with the thermal camera Flir T440. In front of both facades 11 measurement points were chosen. Figure 6.3 gives the location of the measurement points. The thermo-anemometer measures the airflow in one direction only, the majority of the measurement points measured the vertical flow, while points 8, 9 and 10 measured the horizontal flow.

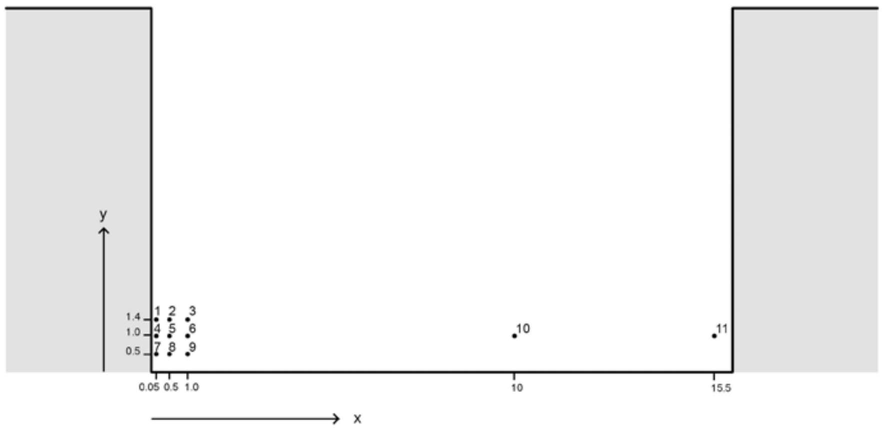

FIGURE 6.3 Street profile with the measurement points in a grid of 0.05, 0.5 and 1 m from the façade and a height of 0.5, 1.0 and 1.4 m. In addition a point in the middle and a point half a meter in front of the opposite façade were measured at a height of 1.0 m.

The measurement points were all measured twice for the black and white façade, see Table 6.3 for the time intervals. The air speed was stored every second during five continuous minutes. Due to a limit in time the last measurement set for both facades was shortened to 3 minutes. These measurement intervals are chosen to ensure a comparable solar angle for both facades with an orientation towards the South-West. With this orientation the sun is perpendicular to the façade at 14:00 h. The measurements with the thermal camera show a peak surface temperature at 14:30 h due to heat accumulation in time. The highest façade temperatures occur between 13:30 h and 15:30 h.

TIME INTERVAL	12:00-13:30 H	13:30-15:00 H	15:00-17:00 H	17:00-18:00 H
Façade	black	white	black	white

TABLE 6.3 Time intervals for the black and white facade.

§ 6.2.3 Surface temperature measurements

After measuring the airflows a control measurement was done to see whether the surface temperature indeed was the generating factor. To test the difference in temperature between materials and between colours, an infrared camera (FLIR T440) was used to measure surface temperatures. The surface temperature measurements at the façade models were taken each hour during the course of a whole day. The analysed façade model materials were brick, wood and aluminium (blank and with a black and white coating).

At the full scale façades the thermal images were taken before each measurement set to see the temperature development of the façades. An additional thermocouple was used once to check whether the thermal images reflect the same surface temperature.

§ 6.3 Results and Discussion

§ 6.3.1 Influence of colour on air speed at façade models

As explained in the introduction, the hypothesis tested in this study is whether a darker colour leads to a higher wind speed. Figure 6.4 shows the windspeed measurement results after measuring both, black and white panels, eight times. The average measured windspeed with a black panel was 0.37 m/s and with a white panel 0.28 m/s. The average difference in wind speed between the black and white panel was 0.09 m/s. This means an increase of 32% from white to black. The average error was 0.07 m/s, this minimises differences in wind speed. Nevertheless, the trend of higher wind speeds with dark colour compared to light still stands.

We need to place the difference in wind speed of 0.09 m/s in perspective to be able to give an indication of the effect at the full scale. However, scaling wind speed due to convection is very complicated because there is not a one to one relation. To be able to appoint scaling effects the test model can be constructed in a water tank. In this exploring study there was no possibility to do so. Therefore, the full scale measurements presented in the proceeding section are performed to see whether the difference in air speed is of similar significance. Another uncertainty in the results is caused by the accuracy range of the air speed measurement equipment. The uncertainty is minimized by repeating the same measurements at least three times.

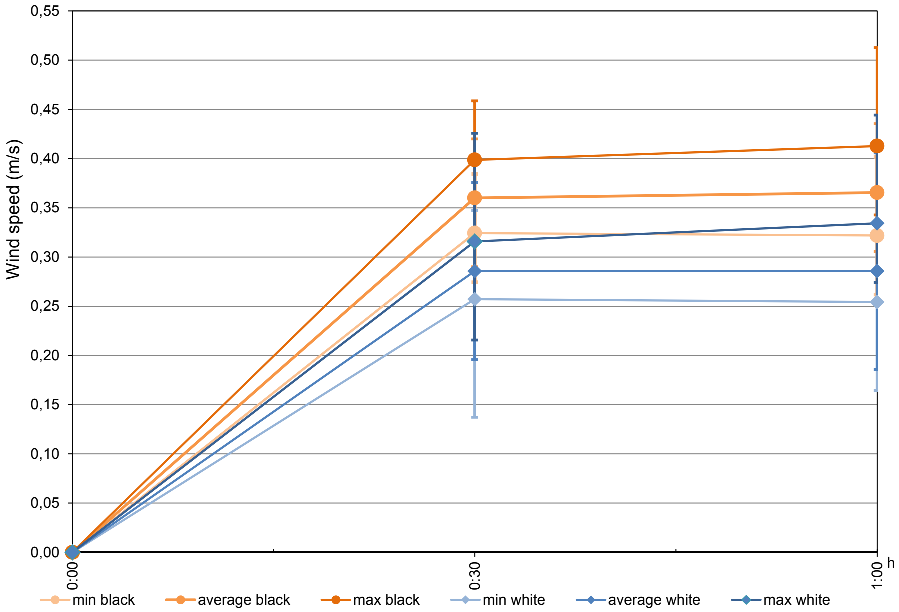

FIGURE 6.4 Wind speed measured after 0, 0:30 and 1:00 h for a black (orange colour in graph) and white (blue colour in graph) aluminium panel in an indoor space on the summer day 27-08-2013 (based on 8 measurements).

§ 6.3.2 Influence of colour on air speed at full scale façades

The measurement results from one day of measurements in front of alternately a white and a black façade are presented in the supplementary material section 5.3, Figure 6.10. The graphs show the wind speed distribution per measurement point. This distribution presents the frequency at which a certain wind speed occurs during equal time intervals. In points 1, 2, 3, 8, 9 and 10 there is a clear difference in air speed between the black and white façade, while the points 4, 5, 6, 7 and 11 do not reflect this clear difference. Another observation of the measurement results is that the measurement points 1, 4 and 7, which are close to the façade, and also point 2, 3 and 5, measure longer periods with very low (< 0.1 m/s) wind speed for the white façade than for the black façade. The low wind speed frequency varies from 100-180 for the white façade and 20-120 for the black façade.

In the points where we measure a clear difference in wind distribution between the black and the white façade the wind speed occurring most can be read as the top of the graph. Figure 6.5 shows these points in a larger resolution. In point 1, 2 and 3 the wind speed occurring most at the white façade is around 0.2 m/s and at the black façade

0.4 m/s, an increase by a factor of two. In point 8 and 9 at the white façade the peak is again around 0.2 m/s while the peak at the black façade is around 0.6 m/s. This is an increase by a factor of three. In the middle of the street point 10 shows a peak of 0.4 m/s at the white and 0.8 m/s at the black façade, which is again an increase by a factor two.

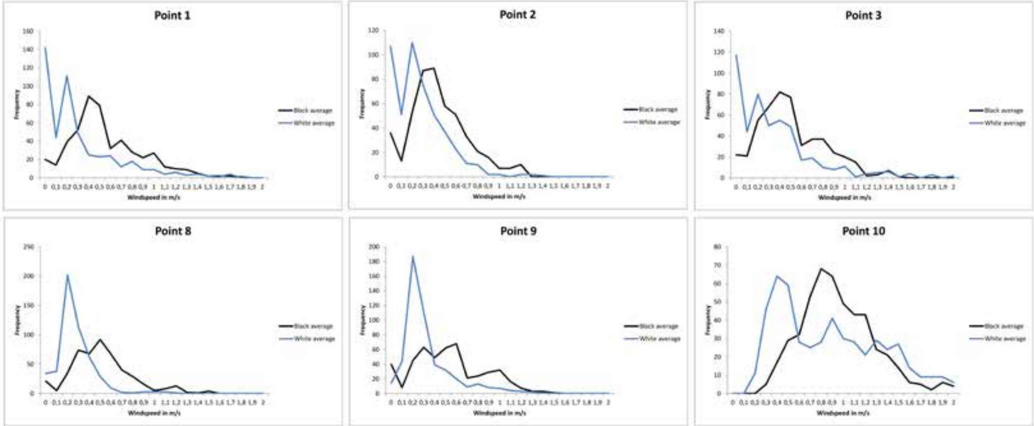

FIGURE 6.5 The frequency of airspeed occurrences over an interval of 8 minutes for the measurement points 1, 2, 3, 8, 9 and 10.

The measurement points that do not show a clear difference in wind speed at the black or white façade might be positioned within a rotating vortex where the air flow is generally lower or has another direction. At point 11, positioned close to the opposite façade on the shadow side, no influence is noticeable from the two different façade colours.

The distribution of wind speed follows a normal distribution in an open field. In an area with obstacles such as buildings the distribution of wind speed usually follows the so-called Weibull distribution (Voorden, 1982). All measurement points, except for number 10, have a wind distribution that is similar to the Weibull distribution. Number 10 is the only measurement point further than 1.5 metre from a façade and approximates an open field more than the other points. Therefore the distribution comes close to a normal distribution. Another difference is the larger influence of natural occurring wind gusts that are noticeable in front of both facades. The wind speed measurements are based on only two measurements of 5 minutes per measurement point. Therefore, further analyses looking into the mean standard

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deviation or a statistical test (in this case a Mann-Whitney test should be used) were not considered relevant.

Even though the measurement day does not represent a heatwave day and during this day quite some cloudy moments and wind gusts occurred, it was still possible to measure a significantly higher air speed at the black façade in comparison with the white façade. We expect a greater difference on days with more sunshine hours, a higher temperature and less wind gusts.

§ 6.3.3 Influence of colour on the surface temperature

The test panels indicate the difference between several materials. The surface temperatures measured at the panels are given in Figure 6.6. The maximum surface temperature difference between the black and white panel was 33°C. This is also the largest temperature difference that occurred, implying that the surface temperature difference between materials is smaller than between coloured aluminium. The three different materials brick, wood and bare aluminium show a maximum temperature difference of 17°C between aluminium and brick. Wood shows a slightly higher temperature compared to bare aluminium, with a maximum difference of 5°C. Brick is heating up much more, and shows a maximum difference of 16°C compared to bare aluminium. The same sequence as we see here in up heating is expected to appear with the wind speed measurements: from white aluminium to bare aluminium, wood, brick and finally to black aluminium.

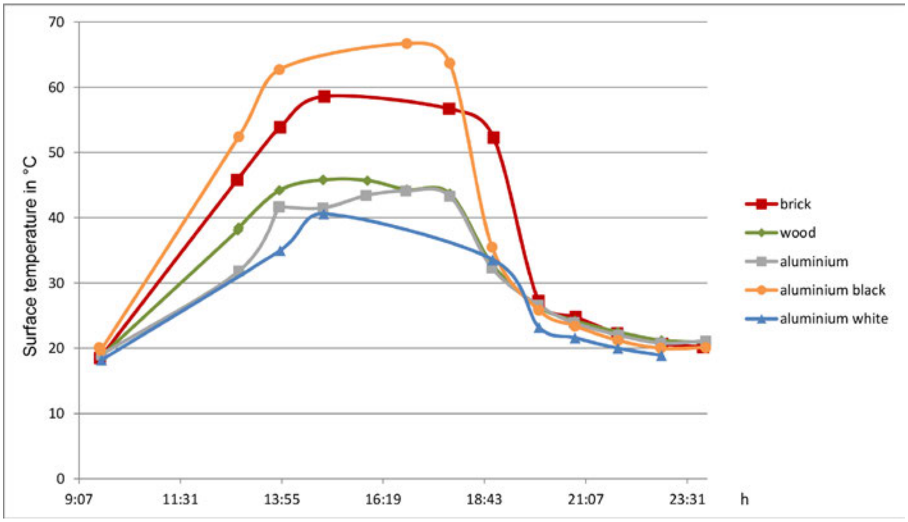

FIGURE 6.6 Surface temperature for the materials brick, wood, bare aluminium, black coated aluminium and white coated aluminium panel measured in the outdoor on the summer day 23-08-2013.

From the surface temperature measurements the time lag of the brick façade is clearly visible. The use of brick instead of aluminium in combination with façade colours will probably prolong the effect of the heat accumulation on air movements after sunset. This can be of value when the sky view factor of the street is low which prevents cooling down by radiating heat to the sky.

At the full scale façade the temperature difference between the white and the black façade was at its maximum around 16:30 h. At this time of the day the average difference was 15˚C. Figure 6.7 shows the thermal camera measurements around 16:30 h. The façade has a temperature gradient itself, where the top of the façade is 2 to 4˚C warmer than the bottom part.

The temperature difference between the black and white façade determine the difference in wind speed induced by the façade. Table 6.4 presents the differences between the two facades on the measurement day for the early afternoon and the late afternoon. The facades are facing South-West, which means they start to receive solar radiation only after midday. This is the moment a difference in temperature starts to evolve. Around 14:00 h the sun angle is perpendicular to the façade, but still high in the zenith. In the late afternoon, as the sun lowers, the impact of the solar radiance continues to be fierce when the air is clear. This is expressed in the much greater difference in temperature and airspeed for the black and white façade in the late afternoon compared to the early afternoon.

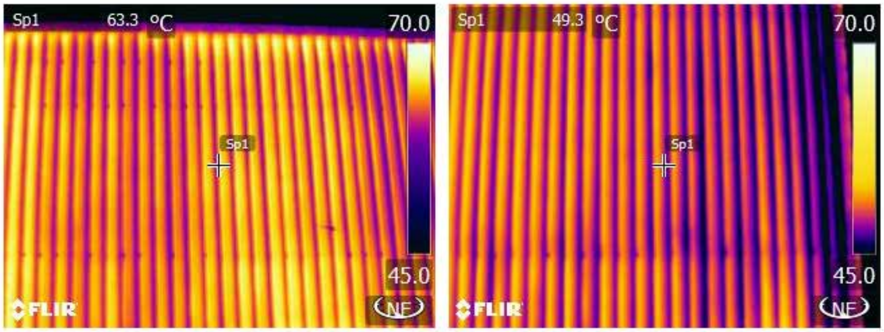

FIGURE 6.7 Thermal image of black (left) and white (right) façade around 16:30 h.

TIME PERIOD	TS BLACK-TS WHITE (˚C)	V BLACK-V WHITE IN POINT 1 (M/S)	V BLACK-V WHITE IN POINT 10 (M/S)	V BLACK-V WHITE IN POINT 11 (M/S)
12:00-15:00	2	0.09	-0.45	-0.03
15:00-18:00	14	0.38	0.63	0.09

TABLE 6.4 Difference in surface temperature (Ts black-Ts white) and the average wind speed (v black-v white) in measurement point 1, 10 and 11 between the black and white façade for two time periods.

§ 6.4 Additional Opportunities

Increasing façade temperatures for the benefit of outdoor thermal comfort also affects the indoor climate. The 'hot' façade needs extra attention to prevent extra up-heating of the indoor environment. Better thermal insulation and a heat-reflecting foil could mitigate these negative effects, as presented in Figure 6.8. The same picture also presents the opportunity to collect heat gained by the façade during the day: this can be achieved by means of a heat collector integrated into the outer wall, which is connected to a hot water tank or to seasonal storage. With this principle the air generation by the solar-heated façade is at its maximum at daytime and the accumulated heat is quickly absorbed when the seasonal storage is activated to minimize the nocturnal heat island effect. This is important for more climate-robust cities. In wintertime collected solar heat can serve functional purposes. In this case, climate adaptation meets climate mitigation. Both effects should be studied further to validate potential gains.

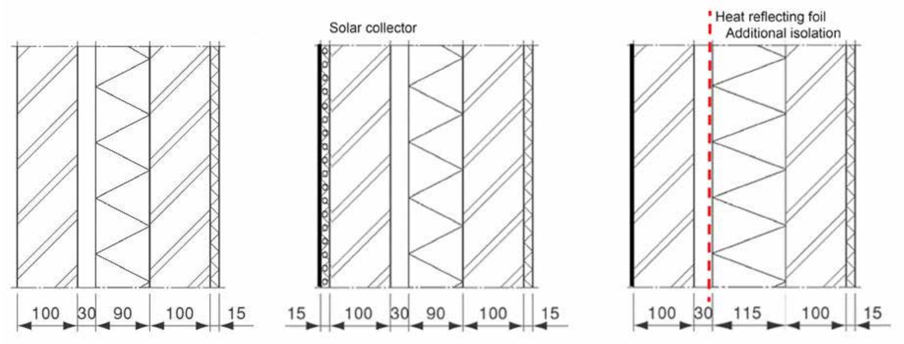

FIGURE 6.8 Left: common cavity wall. Middle: cavity wall with black façade colour and solar collector system to harvest heat. Right: cavity wall with heat reflective foil and additional isolation to prevent heating of the indoor spaces.

The two measurement tests presented in this paper both indicate a larger wind speed with a darker façade surface. To substantiate the findings, a next step would be to test the draft principle with a CFD model. This model can then test different options of façade colours, determining the strongest acceleration effect with a certain amount of painted surface, or with a glass panel to create an urban solar chimney. In addition, the so-called zebra-stripe effect can be tested: black and white stripes potentially contributing to the cooling effect by generating air flow from light to dark. See Figure 6.9 for illustrations of different painting options.

The solar chimney principle is used in passive climate design for buildings (Bronsema, 2013) and could improve the ventilation of a street canopy in addition to façade colouring. With a solar chimney wind gusts have a smaller impact on the airflow. A stronger and steadier air flow is expected from the technique. In addition, a solar chimney may increase the mix of cool air from the boundary layer above the roofs with the air from lower parts of the canopy. A dark facade without the chimney effect may cause more air circulation and a higher speed, but not necessarily a mix with air above. This leads to an increase of comfort due to a higher wind speed, but may not discharge the up-heated air from the canopy layer to the upper boundary layer above the urban area.

Building further on the results of this study, hot surfaces can also be combined with cool spots such as parks. Air flows are then guided from the cool spot to the hot spot.

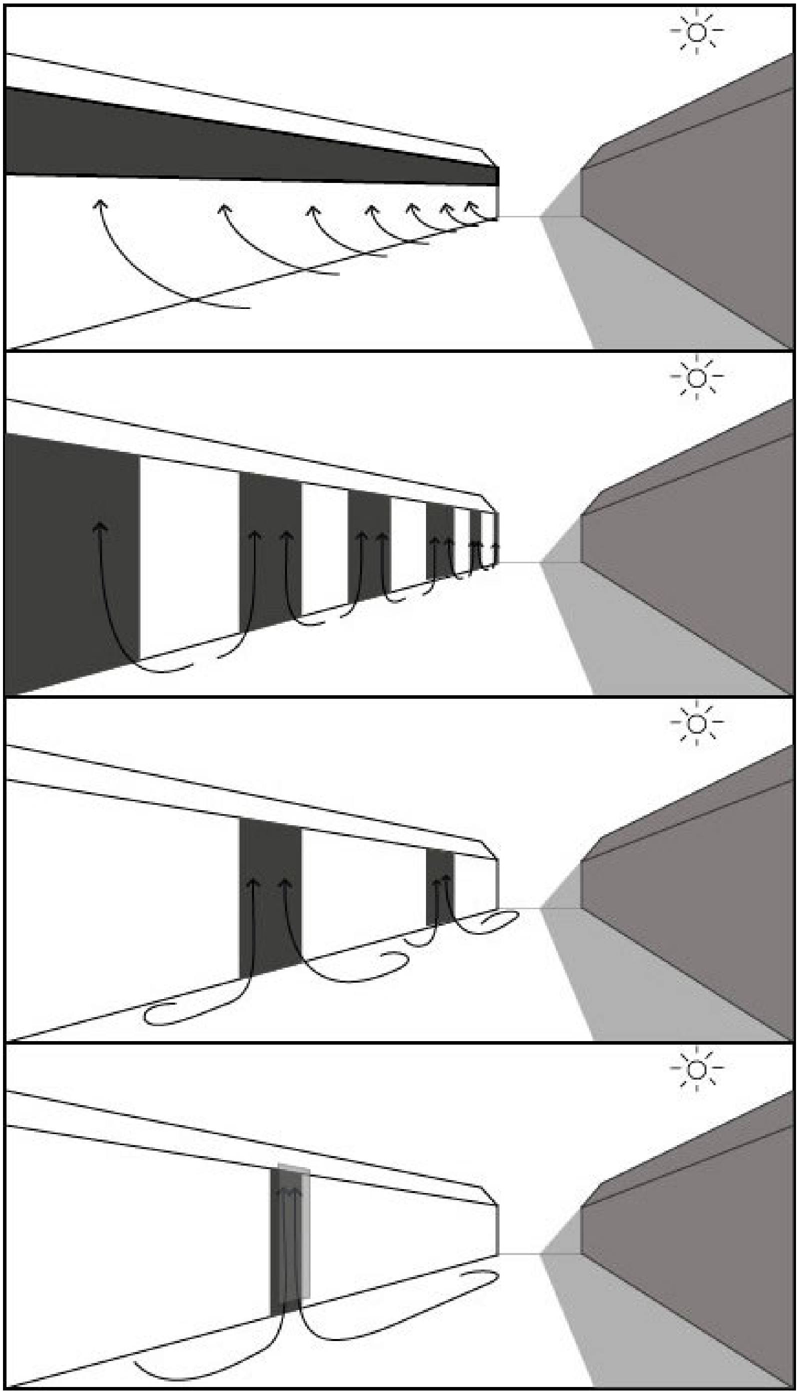

FIGURE 6.9 Painting options from top down: the upper part of the façade is painted dark, the façade of dwellings are painted dark alternately, only a few dwelling facades are painted dark and a small vertical strip is painted dark with a glass plate in front.

§ 6.5 Conclusions

This paper discusses exploratory research in the use of coloured façades to enhance an increase of wind speed to improve thermal comfort in urban spaces on hot days with a prevailing low wind speed. The initial hypothesis was that a cool draft can be generated by creating a local hot spot with an open connection (e.g. a street or a square) to a cool spot. In this paper the effect of a dark façade on air speed is compared to a light façade.

The two measurements of wind speed and surface temperature indicate a higher wind speed with a dark façade compared to a light façade. Also the material of the façade influences the surface temperature, hence the acceleration of the wind speed.

In the lab test using scale models the generated wind speed between 0 to 0.5 m/s was low due to the relatively small heated surfaces and the limited power of the alternative radiation source (construction light). The low wind speeds require a higher accuracy in measurement equipment than that available for this study (0.25 m/s). The scale model results also require a valid method to upscale the results from 1:20 to full scale.

With the full scale measurements inaccuracies are avoided. In this case the higher wind speed (between 0 to 2.5 m/s) was measured with a measurement device with a higher accuracy of 0.1 m/s. Nevertheless, in this set up, the weather (wind gusts and clouds) can have an influence on the measurement results: the measurement intervals are not parallel but consecutive. The intervals are chosen with comparable radiation loads regarding the solar angle. Follow-up measurements should include simultaneous measurements along the complete height of the façade.

Colouring facades to increase thermal comfort is a relatively low-cost strategy and its influence on occupation of public space is negligible. Both indicate a good feasibility. This however, depends on the influence on the aesthetic value of the building(s).

An important connotation is the negative effect that the darker façade might have on the indoor climate. Existing measures can be applied to prevent an increase of the indoor temperature and even make use of the additional heat captured in the façade. Some ideas for this were proposed in this paper. Further research into these solutions is recommended. This paper also advocates for further study on the perception of pedestrians. Further research is needed to confirm the significance of the increased wind speed in thermal comfort sensation.

§ 6.6 Acknowledgements

This study was funded by the governmental institute in the Netherlands, *Knowledge for Climate* and city stakeholders among which Rotterdam, The Hague, Amsterdam and Utrecht. The research projected is a sub research of the research program *Climate Proof Cities*.

We want to thank Huug Schuil for his assistance in constructing the laboratory set up, Cécile and Ria Kleerekoper for conducting the measurements, Ruud and Marjan Stroeve for facilitating the laboratory space, and Frans Baak and Eric Buitenhuis for their cooperation with the full-scale measurements.

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§ 6.8 Supplementary material

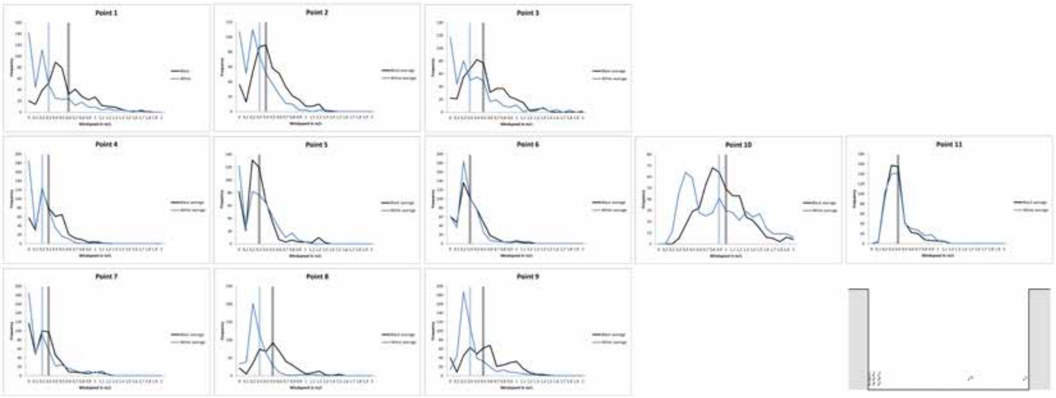

FIGURE 6.10 The frequency of airspeed occurrences over an interval of 8 minutes with an indication bar for the average wind speed for the measurement points 1 to 11 and the location of each measurement point.

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Heat mitigation guidelines

The design guidelines presented in this section originate from various studies described in the previous chapters 4, 5 and 6. Guidelines based on literature are presented concisely and originate from chapter 2 and 3. The guidelines go beyond specific locations, however, they are not applicable everywhere. Heat mitigation guidelines are contextual and related to other design interventions. The list of guidelines presented here does not aspire to collect guidelines from other studies nor to be new and innovative per se. As the guidelines evolve from the research within this project they can strengthen or question conclusions from other studies. In addition, they offer urban designers and policy makers grip on specific issues concerning heat mitigation and climate adaptation. Conclusions from parallel research projects that are part of the same research consortium Climate Proof Cities are used as input for mainly chapter 3.

Vegetation

Plant trees strategically

The simulated effect of trees on thermal comfort (PET) is larger than all other simulated measures in this study. Trees reduced the maximum PET with 20 °C in close proximity of the trees. This is for a large part related to the shadow casting of trees that prevents heating of urban surfaces. Also on a wider range from the trees the potential cooling effect in comfort sensation can be very significant. On the other hand trees can also have a slightly heating effect due to the obstruction of air flow. The cooling effect depends on the specific location, and time of the day. Important in placing trees is weighing where the cooling effect of a tree is most desired and does not obstruct too much light in buildings or on commercial terraces.

Do not combine trees with highly reflective facades

The more heat is reflected from the façade, the more heat is trapped under the tree crowns.

De-pave and grow grass and flowers

A ground cover of grass instead of pavement can decrease the average comfort temperature PET with 5.5 °C. The more area cover is vegetated, the larger is the cooling effect during warm weather. When only half of the area is covered with grass instead of pavement a cooling of 3.5°C above grass and 0.5°C above pavement can be achieved. A spread mix of grass and pavement will probably level out temperature differences. Depending on the use of the space cooler and hotter spaces can be created.

From literature

- Park Cool Islands (PCI) have a cooling effect up to 100 metres: with a park every 200 metres a complete urban area can be effected;
- The park breeze effect is working within 250 meters;
- Avoid artificial soccer fields: they heat up even more than the regular urban tissue during the day;
- Green roofs significantly lower the roof surface temperature. The measure is therefore effective on the indoor thermal comfort and, when applied on large scale, on the urban boundary layer. Irrigation is key in cooling factor;
- Green facades are effective for indoor comfort during daytime and they prevent heating of the façade. Especially in the late afternoon and evening façade greening reduces the re-radiation of heat to the outdoor space because the facades did not accumulate as much heat as would be the case without greening. Irrigation is key in cooling factor;
- Green facades have a large effect on thermal comfort because they influence the thermal perception of people (more visual-eye height).

Water

The simulations performed in this research are not accurate enough in the cooling potential of water to present new guidelines.

From literature

- Flexible water catchment and ground water serves flood prevention, infiltration and evaporation;
- Catch rain water with flexible water levels or underground storage to buffer water for dry periods and relief the sewage system and water treatment plants;
- Slowly infiltrate a part of the rainwater catchment to supplement the groundwater level and to provide space for new heavy rainfall;

- When groundwater levels lower during hot and dry periods the buffer should be employed to secure the cooling effect of evaporation;

- Irrigated landscapes provide cooling: therefore the amount of water and vegetation in new developments must be preserved;

- Spraying water on streets is a locally effective measure provided that the water supply is sufficient;

- Water has a large effect because it influences thermal perception of people;

- Large, especially flowing, water bodies have a cool potential during the day. Small water bodies heat up easily, after a longer warm period also large water bodies may increase temperatures in cities.

Built form

Compensate for additional buildings

In general additional buildings result in higher average and maximum temperatures. Locally shadow casts of buildings and the heat absorbing materials can result in lower temperatures, especially in the morning. When the new building surfaces mimic a natural surface or the surface is shaded the contribution of the building to heat accumulation can be decreased.

Additional building layers can result in both heating or cooling of the direct surroundings of the building

An additional building layer results in: more shade, less ventilation and more heat trapping. The magnitude depends on the orientation, H/W ratio, materials and objects in the street.

Do not create wind shelter without offering shading facilities

Wind plays a very significant role in thermal comfort sensation and should be considered in both warm and cold weather situations. In urban design wind is usually an element we want to block or deviate to increase comfort at street level whole year round. Be aware that during hot weather periods this can lead to extremely high temperatures. Make sure that (temporary) shading devices keep the sheltered space comfortable.

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Be careful with orienting on the prevailing wind direction if cold or strong winds come from the same or opposite direction

Increasing ventilation is very effective in subtropical climates with high temperatures year-round. Be careful with directing airflows in colder climates to avoid uncomfortable and dangerous situations.

From literature

- Height to width ratio: For countries in the temperate climate zone and a low sun angle, wide streets with a height to width ratio below 0.66 with seasonal shadow elements are preferable above narrow streets. This allows ventilation and space for green;
- Increasing street width is preferable to shadowing buildings with buildings in temperate climate zones: winter situation;
- E-W oriented streets have one (the south façade) side with an extreme radiation load. This can be effectively shaded with a single row of trees. N-S oriented streets have a higher radiation load over the whole day and provide more outdoor comfort in winter;
- A mix of building heights , slanted roofs and open urban blocks increase ventilation;
- A higher density generally leads to higher temperatures.

Material and colour

Avoid reflective facades
For countries in the temperate climate zone and a low sun angle, light and reflective facades can decrease thermal comfort at street and especially neighbourhood level. Thus do not increase albedo above 0.4 to avoid heat trapping in the canopy layer.

Encourage reflective roofs
Light roofs have a positive effect on the urban heat island when applied on a large scale. The effect on comfort at street level depends on the building height. On the even smaller building level it decreases up heating of the upper floor considerably.

Air flow
Orientation of streets and squares on the prevailing wind direction to cool Dutch cities during heatwaves is not effective. Instead, make use of locally generated air flows. This can be achieved by increasing differences in surface temperatures, placing solar chimneys or on a somewhat larger scale by combining PCI’s and hotspots (max 250 metres distance).

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Make use of smart facades for indoor and outdoor climate control

Thermal induced air flows generated by dark coloured (smart) facades or hot and cool spots are a means to create cooling when other options such as green or shadow devices are not appropriate or desirable.

General

T_{mrt} and wind speed have a large and local effect.

T_{air} and humidity have a small and wide spread effect.

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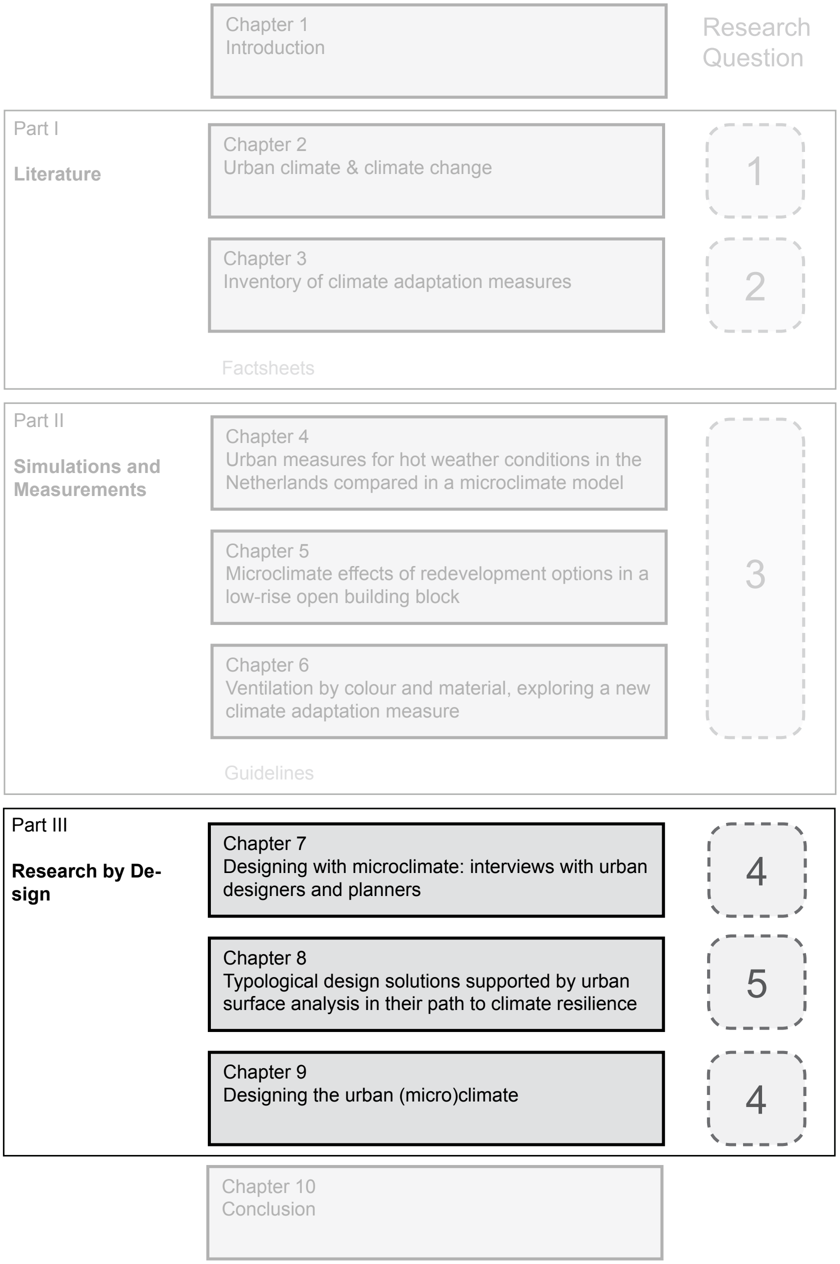
PART 3 Research by Design



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