WATER-SMART URBAN DESIGN: CONSERVING POTENTIAL IN SWIMMING POOLS

by

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THESIS ABSTRACT

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Dry weather dominates several U.S. states, and some of them experience even long-term droughts. Yet, more than 10.6 million swimming pools exist in the U.S., and over 43,000 of them are in greater Los Angeles. Since roughly 100% of their water evaporates on a yearly basis, pool water evaporation accounts for a significant amount of water being wasted every day. Several studies have been conducted to create a proper equation for the evaporation rate on a pool surface, based on the wind speed, water temperature, and relative humidity. This thesis will address a research gap that was found in exploring the way the surroundings of the pool can affect its evaporation rate. In particular, this study examines the relation of the urban design to the evaporation rate of outdoor swimming pools by studying the way the housing type of a neighborhood affects the wind speed over the neighborhood's pool surfaces.

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To my parents and siblings

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CHAPTER I

INTRODUCTION

During the past thirteen months, since the journey to my M.Sc. started, I was genuinely concerned with water consumption patterns and local water resources in drought-hit areas. What I always found interesting is that, even in areas that experience long-term droughts, activities and uses that consume a great amount of water are still taking place. One of them is the use of swimming pools, which requires vast amounts of water. The fact that pools are abundant and very water intensive renders them worth studying more when it comes to water scarcity. Besides, the various uses of pools, either for swimming, or just for relaxation are part of our contemporary culture. Thus, it seems advisable to examine ways to minimize their negative impact on water resources.

Background & Literature Review

Current freshwater resources in California are in stress (Hancock et al. 2004). At the same time, the number of swimming pools across the nation has already reached 10.6 million (Center for Disease Control and Prevention). California is an area of hot and arid climate that meets its water needs with water travelling from as far as Colorado and Wyoming (Fig. 1). Just four years ago, in 2012, California was only experiencing abnormal to severe drought (Fig. 2). In 2015, almost half of the state of California is exceptionally dry. Besides, during the first half of 2015, the Governor of California mandated a 25% reduction in the overall water consumption of the state of California (State of California Executive Department 2015).

However, even there, an abundancy of swimming pools can be noticed. The reason for that is can be found in the history of the pools in the United States. It all started on 1887, when the first public pool was built in Massachusetts. After a series of innovations in the pool construction methods by the construction and manufacturing industry, it is in the early ‘20s that Southern Californians started building their own swimming pools. On average, twenty (20) new swimming pools were built each year. On 1936, Philip Ilsley, landscape architect in Southern California, started designing pools for his new residential projects (Pool & Spa News 2013). After World War II, the pool business flourished once the American soldiers returned home (Heeger 2004). In Nathanael West's The Day of the Locust (1982), the cultural aspect of the swimming pools in Los Angeles is shown. The swimming pool, at least for some people, was a way to make an impression and display their status quo. By the early ‘50s we can see the first pool boom, with the pool being part and parcel of the ideal Los Angeles lifestyle (Tim Street-Porter 1995). Since then, Los Angeles alone accounts for more than 43.000 swimming pools (Gross & Lee 2013).

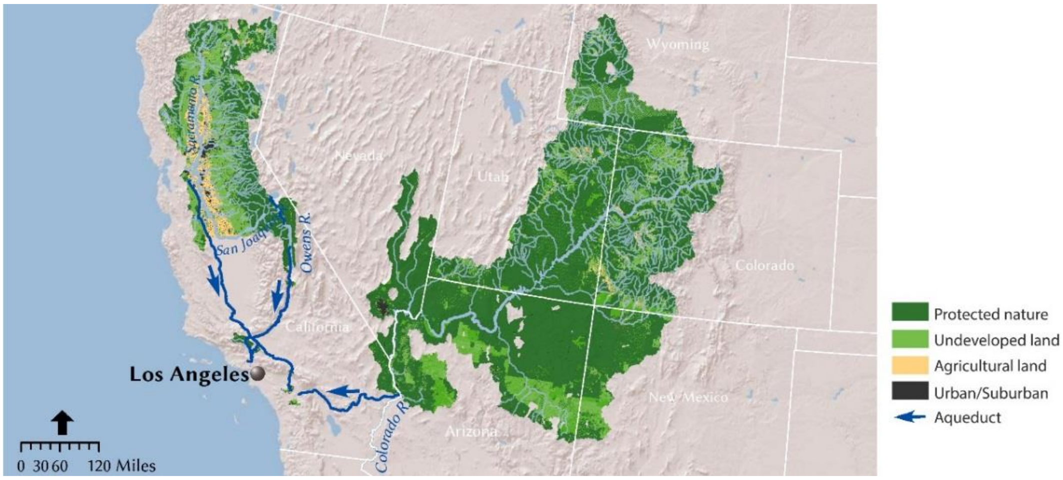


Fig. 1. Surface Drinking Water Sources for Los Angeles, CA courtesy of The Nature Conservancy www.nature.org (adapted). Map produced for The Nature Conservancy (TNC) 2012. TNC uses the most current and complete data available. GIS data and product accuracy may vary. Areas delineated as having "No known protection" may include water district lands and easements on private lands. Using GIS products for purposes other than those for which they were intended may yield inaccurate or misleading results. Sources: Protected Areas Database of the U.S. 2010, USGS National Hydrography Dataset, National Land Cover Database 2006, and the website(s) of the utilities provider(s).

Nowadays, the California Code of Regulations (CCR n.d.) allows only potable water to be used in the swimming pools. As a result, the amount of water used in the swimming pools highly affects the overall potable water consumption. Furthermore, if we take into account the water that is wasted due to evaporation from uncovered pools (Hof & Wolf 2014) cannot be overlooked,. According to Forrest & Williams (2010), who compared the water consumption of various U.S. cities, the average swimming pool of Los Angeles consumes 22,000 gal/year (Fig. 3), so, in total, the swimming pools of Los Angeles consume 946,000,000 gal/year. This amount of water is not used to just fill up the pool, but is consumed in a number of ways. More specifically, this quantity of water can be divided in the amount of water needed to refill the pool and make up for water losses caused by splashes and overflow, the amount of water needed to backwash the filters, the amount of water needed to provide the required electricity through hydropower, and the amount of water that evaporates through the pool's surface. Of these amounts, the one associated with the evaporation of pool water is the most significant one, accounting for roughly 40% of the overall water consumption of each pool in Los Angeles.

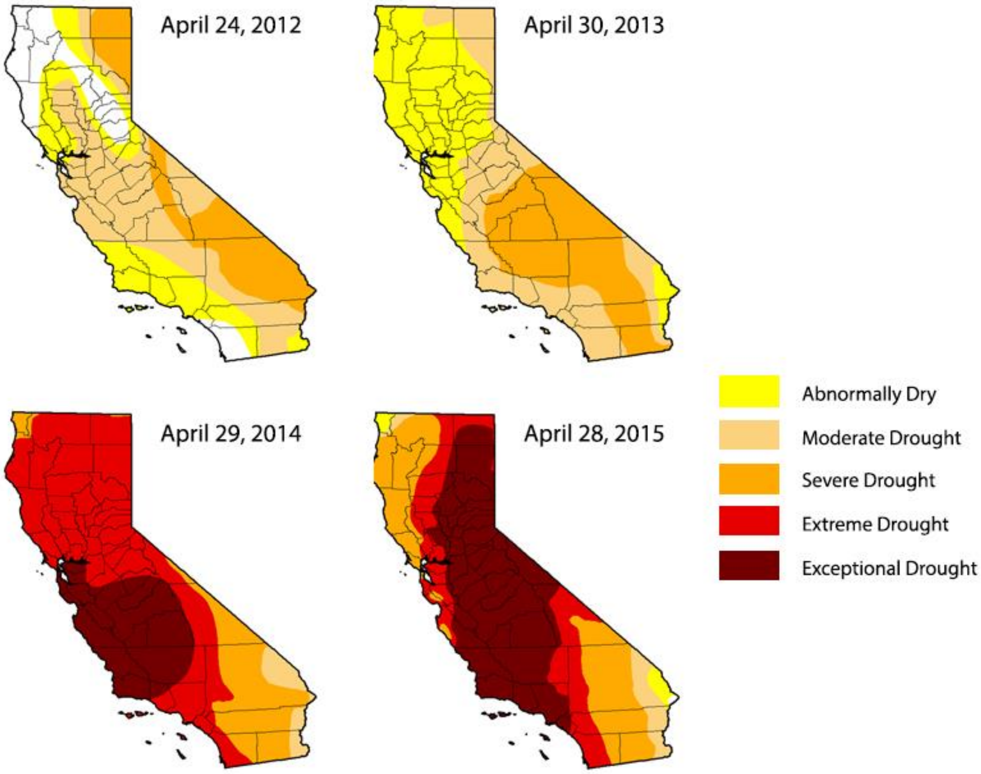


Fig. 2. Intensity of California's water resources, adapted by U.S. Drought Monitor, which is jointly produced by the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. Maps adapted, courtesy of NDMC-UNL. (http://droughtmonitor.unl.edu)

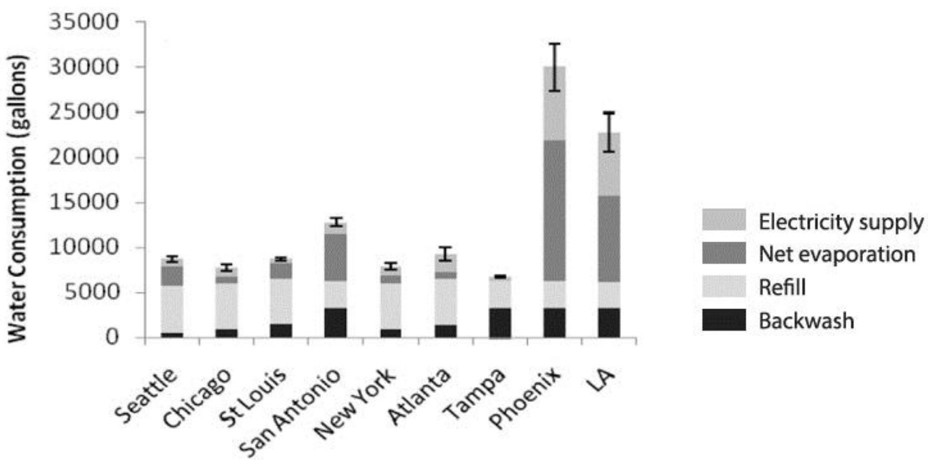


Fig. 3. City comparison for pool water consumption, adapted with permission by Forrest & Williams, 2010. © 2010 American Chemical Society.

According to the ASHRAE (1999) equation (Equation 1) for the calculation of the water evaporation rate of the pool surface, wind speed plays an important role, affecting positively the evaporation rate. However, wind speed is not constant over the surface, and is a function of many factors. One very important factor affecting the wind speed over a pool surface seems to be the surrounding space of the pool, i.e. buildings, vegetation, fences, furniture, topography, which block the winds. The rest of the factors remain constant for every pool with the same environmental conditions such as the saturation pressure at room air dew point and at surface water temperature (U.S. Department of Agriculture Forest Service 1992).

$$w_P = \frac{A}{Y}(p_w - p_a)(0.089 + 0.0782V)$$

Equation 1 Pool water evaporation rate

where:

$w_P =$ evaporation of water, kg/s

$A =$ area of pool surface, m^2

$V =$ air velocity over water surface, m/s

$Y =$ latent heat required to change water to vapor at surface water temperature, kJ/kg

$p_a =$ saturation pressure at room air dew point, kPa

$p_w =$ saturation vapor pressure taken at surface water temperature, kPa

The relation between the wind currents and temperature change, due to climate change, with the evaporation of open water surfaces is also the subject of some important studies (Helfer et al. 2012; House-Peters & Chang 2011). Research provides an accurate equation for the water evaporation rate (Shah 2011; Shah 2013; Shah 2014; Shah 2008; Asdrubali 2009; Vinnichenko et al. 2011; Warnaka & Pochop 1988; Sartori 2000), or an estimation of the evaporation from open water mass (Vardavas et al. 1997). Little research exists, though, on the way that pools are affected by their immediate urban context (Siebrits 2012).

Many researchers have studied the way that wind speed in urban context is affected by the geometry of the urban street canyons (Setaih et al. 2013; Li et al. 2003; Memon et al. 2010; Afiq et al. 2012) using either Computational Fluid Dynamics simulation (CFD), or experiments on models and on-site. Other scholars have used CFD to examine the effect of the wind speed and the urban street geometry to the microclimate of the street (Kishi & Yoshida 2009; Chung & Choo 2011;

Saneinejad et al. 2014) in terms of wind and thermal comfort. However, studies do not exist that examine the way the urban context of the swimming pool affects its performance regarding the amount of water consumed.

Research Question

This study will address this research gap. In particular, the present study will examine the way that the urban context of a pool affects the evaporation rate of the pool water. The buildings surrounding a pool (Fig. 4) can block, slow down or let the wind flow above the pool's surface. Thus, the surroundings affect the wind speed over each pool, which, in turn, affects the rate of water being evaporated from its open surface, as it is evident from Equation 1 (ASHRAE 1999). Therefore, this study attempts to identify and present the impact of various versions of urban context of an outdoor pool on the pool water evaporation rate.

The urban context that surrounds each pool is translated in types of housing. The arrangement and geometry of the residential buildings along with the ancillary buildings and the backyards are some of the main characteristics that define each housing type and affect the way wind flows through the residence.

The research hypothesis of the present study is that pool-water evaporation rate of in-ground outdoor swimming pools is highly affected by the housing type surrounding them, which act as windbreaks. Thus, housing types of varying densities will give different evaporation values.

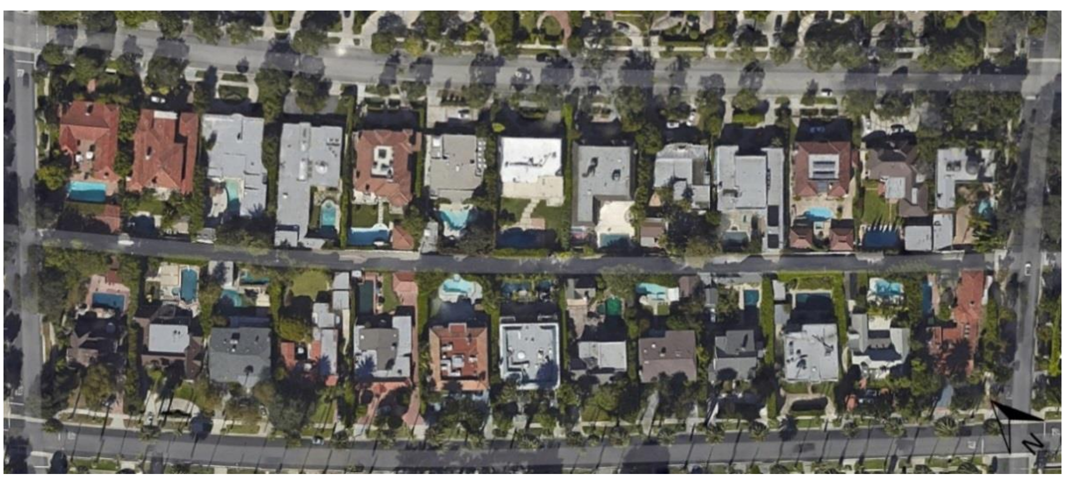


Fig. 4. Neighborhood with many swimming pools in Beverly Hills, CA, adapted by Google Maps, Map Data: ©2015 Google, Imagery: Digital Globe, U.S. Geological Survey

The underlying hypothesis is that housing types where residences are spaced more densely, will give evaporation rates that are lower than those of housing types with less dense residences. Besides, another sub-hypothesis is that the difference in the evaporation rates over the swimming pools will depend on the incoming wind velocity and speed, meaning that some housing types may perform better for lower and some other housing types may perform better for higher wind speeds.

All in all, this is not a quantitative study that tries to quantify the exact percentages of the change in the evaporation rate between each case studied. Instead, it is a qualitative study aiming to identify house types and design solutions that have the potential to perform better in terms of evaporation and thus, minimizing water consumption. The results of this study could be useful for planners and policy makers, when it comes to designing masterplans for water-smart residential projects and communities. Besides, it could be useful for projects of retrofitting existing residential complexes with swimming pools.

Overall Anticipated Results

The simulations are expected to indicate which neighborhoods perform better in terms of wind speed and, thus, pool water evaporation. The anticipated outcomes are that the density of the housing type affects negatively the water evaporation rate. In other words, it is expected that the denser the housing type of the neighborhood, the lower the evaporation rate, as well as that the less dense the housing type, the higher the evaporation rate. That is because the dense spacing of the residences is expected to more effectively protect the pools from high speed wind currents compared to pools surrounded by less dense residences. All blocks studied are expected to give varying results based on the wind direction. Each housing type will not perform the same way for all tested wind directions as proven in experiments of existing studies (Afiq et al. 2012).

The simulations are also expected to show greater speeds over the pools that are close to the edges of the blocks. Besides, different rates of change in the evaporation rate are expected to be measured depending on the wind direction, as well as the location of the garages. This is because, when the pools are successfully protected from a specific wind direction, then their evaporation rate is expected not to vary a lot for the various wind speeds.

The change in the evaporation rate is anticipated to depend on the location of the swimming pool in relation to the wind direction (leeward, windward side). Wind speed is expected to be greater in the windward side of the buildings, and, thus, the evaporation rate of the pools as well. The rate of evaporation rate change is also expected to be lower on the swimming pools close to intersections, regardless of the wind direction.

What is more, water evaporation rate is anticipated to be higher in housing types that have wide passages or side alleys between the buildings, and lower in those with buildings tightly spaced. In fact, more dramatic results are anticipated in the pools that are less protected, e.g. in wider backyards and unprotected from garages. Besides, the higher the incoming wind speed, it is expected that the higher the resulting wind speed will be for all swimming pools, since the wind currents blowing over and through the block will be higher resulting in higher evaporation rates.

CHAPTER II

METHODOLOGY

Site Selection

The very first part of the research is to select the larger area to be studied. It seems of high priority to study water related issues in California instead of anywhere else in the U.S, since California is experiencing the nation's most severe drought (Hess & Frohlich 2014). Furthermore, Southern California experiences even more extreme water issues (Reisner 1993), and this is why this study will focus on some neighborhoods within the greater Los Angeles area. What's more, a series of criteria have to be met in order to pick the neighborhoods to study. First of all, the neighborhoods have to be in flat areas, otherwise the surrounding topography will significantly alter the wind speed and direction flowing through the buildings and over the pools. Besides, the neighborhoods need to have residences of mainly one housing typology, in order to produce results that are directly related to the typology itself. Moreover, the neighborhoods need to have a sufficient number of swimming pools, so that more swimming pools can be tested without having to study many/larger neighborhoods. Last but not least, the neighborhoods have to be on an orthogonal grid to achieve homogeneous flow of the wind over and through the neighborhoods.

Case Studies Selection

The next part of the research is to identify the various urban contexts that already exist in Los Angeles and pick some characteristic ones to study. To identify different urban contexts, as mentioned earlier, the housing types are considered, since the various layouts of the residential types in the lots result in an overall different urban fabric. Several studies are focused on the housing typology of U.S. cities in general (Ellis 2004; Roseland et al. 1998), and Los Angeles in particular (Polyzoides et al. 1992). The house typologies of Los Angeles that were selected from the mentioned references and are going to be studied are:

1. single family detached residences with detached garage and side alley (1-2 story)
2. single family detached residences front loaded (1-2 story)
3. semi-detached residences with in-law unit in detached garage (2-3 story)
4. front loaded row houses
5. courtyard housing (1-3 story)

According to Roseland et al. (1998), there are three ways to measure density, the so-called "density-indicators": 1) measuring the density of users per land area, 2) measuring the density of dwellings per residential land area, and 3) measuring the floor space ratio. The second one is the most appropriate for this study since it measures the ratio of the built space to the land area covered. In many studies the housing types are categorized based on this factor. The unit that measures this factor is the ratio of the number of residences to the net residential area DU/AC (Dwelling Units/Net Acre). This indicator is used in order to identify and rank the five main types of housing to be studied. What's more, the various ranges of this ratio can signify attached, detached, or semi-detached houses.

1) The least dense of the studied residential types is the *detached single-family residence with detached garage and side alley*. This is because the alleys that are located between two neighboring alley-loaded residences form a gap that, if unprotected, lets wind currents flow through. This house type has a density of 10-15 DU/AC (Ellis 2004).

2) The next house type is the *detached front loaded single-family residence with attached garage* and no side alleys, 1-2 story high. This is one of the most common residential types in Los Angeles, with a density varying from 10-15 DU/AC as well (Ellis 2004).

3) The semi-detached house (1-2 story) with in-law unit in garage is the next denser residential type, with a density factor of 15 DU/AC (Ellis 2004).

4) An even more dense residential type is the *rowhouse*, complexes with residences attached to each other, forming a row. With a 20-25 DU/AC density indicator (Ellis 2004), this is one of the most affordable housing options, since the residences are attached to each other allowing for less privacy and outdoor space.

5) Last but not least, the most dense residential type that will be studied is the *courtyard* house. Based on Polyzoides et al. (1992), the courtyard houses of Los Angeles are found to have five (5) main categories, each with different density indicator. The two densest categories of those are the U Parti, and the Completed Courtyard Parti. They have a 35-40 DU/AC density indicator (Ellis 2004), and, thus, these are the ones that will be examined in the present study.

Case Studies Modeling

The next step is to digitize the built space, both the buildings, and the in-ground swimming pools. The digitization will be made using Revit® (Figs. 5-7) since in this way one can import the site image (Fig. 5), model the architectural elements as conceptual masses (Figs. 6,7) and run the simulations using the same software with a plug-in, minimizing errors from file conversions. The number of stories of the buildings will be taken from ©2015 Google Street View. The current situation for each neighborhood will be modeled (Fig. 7) and analyzed in order to measure the wind velocity over each pool, and thus each pool's current evaporation rate.

The neighborhoods that will be modeled and simulated consist of one block with one or two (2) facing rows of residences of the same, when possible, house type. In each side of the block, at least one (1) of the neighboring buildings in each direction will be modeled too, since those buildings alter the direction and speed of the wind flowing over and through the neighborhood. In this way, the results of this study will be realistic for the entire area of the studied neighborhoods.

Wind Simulations

Afterwards, the resulting models of each one of these iterations will be used to run horizontal 3D wind simulations using Autodesk® Flow Design as a plugin in Revit®. This particular program can run CFD simulations quickly, is freely available, and has a series of options regarding the wind velocity, wind direction input, the plane at which the analysis will be made, as well as the wanted results, either wind velocity, or wind pressure on a given surface or point. What's more, prior research has shown that the direction of the wind blowing over an urban street canyon affects the wind flow at the ground level (Afiq et al. 2012). Thus, for each of the five (5) models, three wind directions will be examined in relation to the x axis of the studied neighborhood: parallel, perpendicular, and oblique (Fig. 8), However, the actual orientation of the studied neighborhoods is not taken into account, nor is the direction of the prevailing winds, because this study attempts to extract general results for the housing types, not site-specific ones. Instead, the wind directions will have as reference the main axis of each neighborhood so that the results can be applicable to blocks of various orientations. Besides, two wind velocities will be tested, the annual average high and annual mean wind velocities of each neighborhood, in order to test how the blocks perform under a variety of wind conditions.

With the results from the CFD simulation, for each of the swimming pools the wind velocity will be measured using the "prone" option of Flow Design to extract the velocity of the wind on the centroid of each pool surface 1 foot above the water level (Jodat et al. 2013) and calculate the water evaporation rate for every modeled pool based on the equation by ASHRAE (1999). In this way, only the wind direction and housing type will be considered as variables of the simulation tests, and, thus, the impact of the housing type on the evaporation will be more effectively detected.

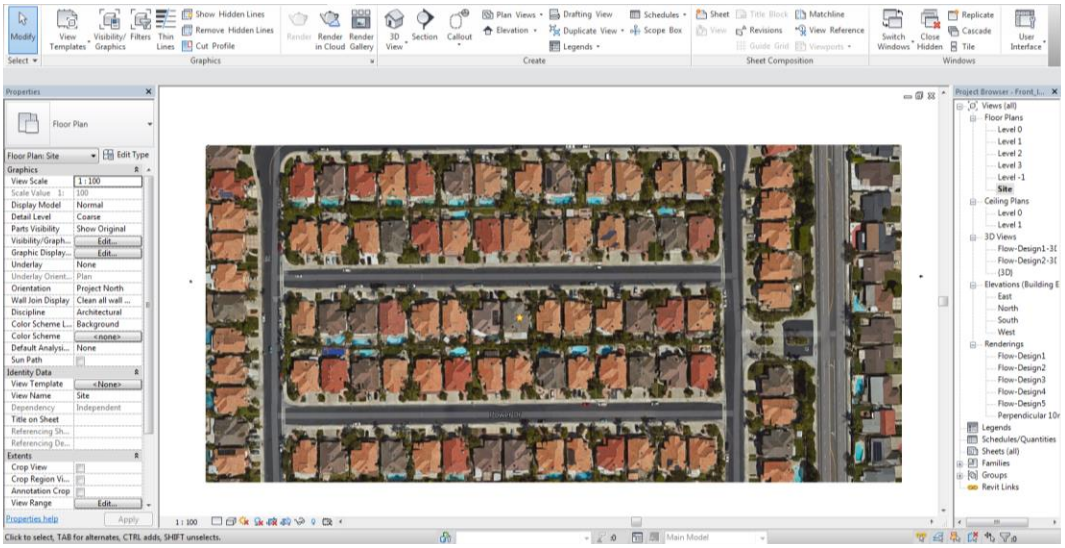


Fig. 5. Imported site image in Revit, Autodesk screen shot reprinted courtesy of Autodesk, Inc., site image adapted by Google Maps, Imagery and Map Data: ©2015 Google

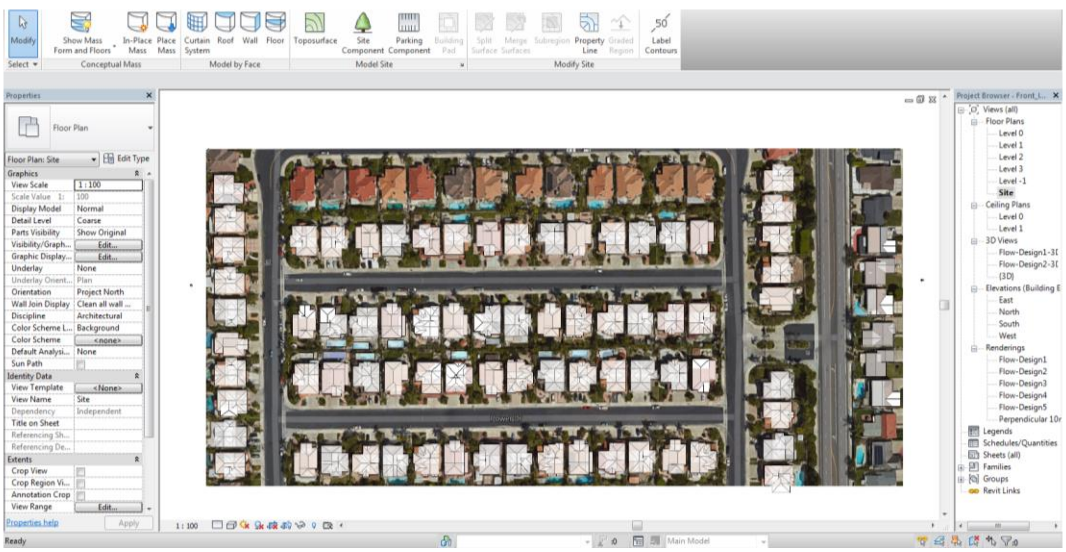


Fig. 6. Modeling with conceptual masses in Revit, Autodesk screen shot reprinted courtesy of Autodesk, Inc., site image adapted by Google Maps, Imagery and Map Data: ©2015 Google

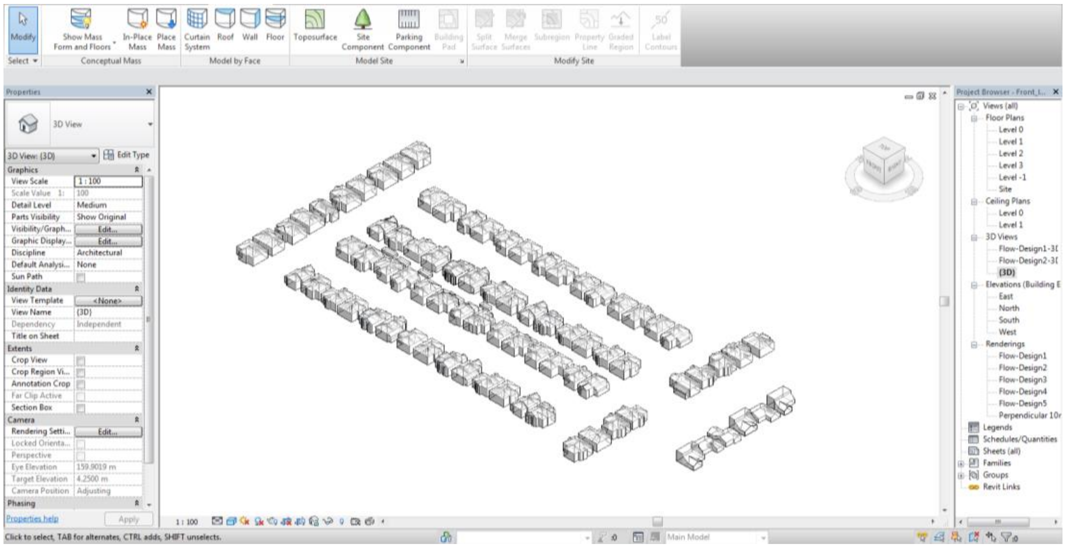


Fig. 7. 3D conceptual masses modeled in Revit, Autodesk screen shot reprinted courtesy of Autodesk, Inc.

Evaporation Rate Calculation

In order to be able to compare the evaporation taking place on the surface of every swimming pool, regardless of their size, we need the ratio of the evaporation rate on the water surface to the area of the water surface. Thus, we do not need the area of each pool surface. Taking a look at Equation 1 by ASHRAE (1999), there is a number of factors that are unknown so far: the *latent heat* to change the water of surface water temperature to vapor (Y), the *saturation pressure* at air dew point (p_w), and the *saturation vapor pressure* at surface water temperature (p_s).All these three factors are dependent on the surface water temperature, and the last two are also dependent on the relative humidity.

The three mentioned factors (Y, p_w, p_s) that are needed to measure the evaporation are calculated based on the annual average relative humidity and annual average surface temperature as follows:

First, the latent heat of water evaporation at the surface water temperature is calculated based on the equation by Rogers & Yau (1989):

$$Y(T) = \left(2500.8 - 2.36T + 0.0016T^2 - 0.00006T^3\right) {}^{KJ}\!/_{Kg}$$

Equation 2 Latent heat of water evaporation at surface water temperature

where T is the water temperature in ^{o}C.

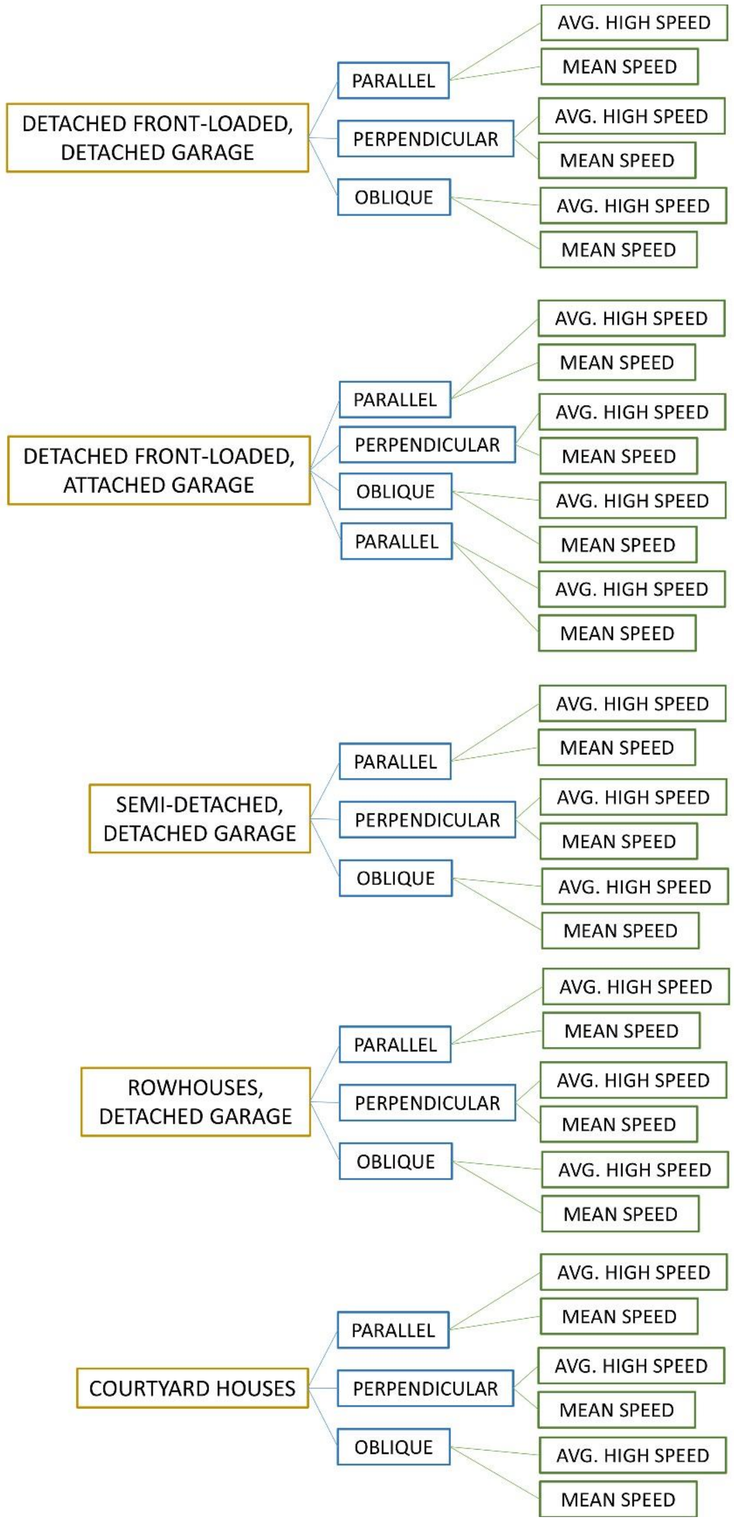


Fig. 8. Diagram of simulations

Second, the saturation pressure at air dew point (p_w) as well as the saturation vapor pressure at surface water temperature can be calculated using the equation provided by Tetens (1930) and the National Oceanic and Atmospheric Administration (2014) respectively:

$$p_a = 0.611 \times 10^{\left(\frac{7.5 \times T_a}{237.3 + T_a}\right)} kPa$$

Equation 3 Saturation pressure at air dew point

where T_a is the dewpoint temperature in ^oC.

For T_w the annual average dewpoint temperature will be used, based on Climate Consultant's database (5.5 version, developed by the UCLA Energy Design Tools Group, ©2014 Regents of the University of California) for each neighborhood's climate zone.

$$p_w = 0.611 \times 10^{\left(\frac{7.5 \times T_w}{237.3 + T_w}\right)} kPa$$

Equation 4 Saturation pressure at surface water temperature

where T_S is the surface water temperature in ^oC.

As will be explained later in the assumptions, it is assumed that, for outdoor pools, the surface annual average water temperature matches the annual average surface air temperature. Therefore, for T_s the annual average of T_S will be used, based on the weather data of each neighborhood's climate zone provided by the U.S. Department of Energy (2015).

Besides, the air velocities which will be used in the simulations are the annual mean and annual average high air velocity. The air velocity, annual surface temperature and annual relative humidity data are taken from Climate Consultant's 5.5 version database for the California climate zone of each studied neighborhood.

Finally, with all the above factors, the ratio of water evaporation rate to the surface (e_r) will be calculated based on the ASHRAE (1999) equation.

$$e_r = \frac{w_p}{A} = \frac{A}{Y}\frac{(p_w - p_a)(0.089 + 0.0782V)}{A} \Rightarrow$$

$$\Rightarrow e_r = \frac{(p_w - p_a)(0.089 + 0.0782V)}{Y} Kg / s \times m^2$$

Equation 5 Ratio of evaporation rate to surface (e_r).

Consequently, through the described process, it will be possible to compare each pool's ratio of water evaporation rate per surface unit to that of the rest of the pools. In this way, we will be able to conclude on whether the evaporation is affected by the housing type, according to the research hypothesis, and whether this effect is negative or positive, that is if the wind speed is reduced or increased.

Assumptions - Limitations

The wind direction taken into account in this study will be in relation to the main axis of the neighborhoods and blocks, and not the global north. In this way, we can have results applicable to blocks of every single orientation, and not site specific.

It is assumed that the wind velocity on the centroid of the pool surface is the average wind velocity above the swimming pool's surface. Thus, only one point, "prone", will be needed for each examined swimming pool in order to extract the average wind velocity above their surface.

As this present study focuses on outdoor swimming pools that are not heated, and not indoor heated ones, the pool water temperature is not mechanically controlled. Consequently, the annual average water temperature is assumed to be equal to the annual average air temperature. Besides, the presence of fences and other means of landscaping is not taken into account since these features are not considered to have significant impact on the wind speed of large surfaces as those of swimming pools. This is because they tend to be small in height and depth, and can be easily penetrated by the wind currents.

The urban context will be modeled taking into account the roof geometry. The shape of the roof is considered to affect the wind speed of points surrounding the building on the ground level, since the residences are low-rise. Besides, for the purpose of this study the vegetation is not taken into account in the modeling and CFD analysis since it can be added or removed more easily than buildings can be added or removed. Instead, vegetation of various heights and types could be a possible solution to block the unwanted winds coming from points in the block without wind protection.

In the following chapters, many times you will encounter the phrase wind or evaporation performance. This phrase will be used from now on to indicate the potential, of a neighborhood or housing type, to achieve low wind speed or evaporation rate respectively. Another underlying assumption, therefore, is that low wind speed and low evaporation rates are to be preferred, and, thus, signify better wind or evaporation performance respectively.

In order to identify cases of housing types with pools that have the potential to conserve water, all the studied wind conditions will be taken account. This means that a given pool will have to demonstrate low evaporation rates for the majority of wind conditions and not just for specific wind directions and/or speed. Otherwise, the results cannot be generalized, instead we would only speak for specific conditions under which a pool is effectively protected by its surroundings.

CHAPTER III

CASE STUDIES AND ANTICIPATED RESULTS

Front-loaded Residences with Detached Garage

Based on the previously mentioned criteria, the first neighborhood that will be studied is the one with the housing type of single-family detached residence with detached garage, where the access to the garage is through side drives. The selected neighborhood is an entire block located in Sherman Oaks, California (Fig. 9).

Fig. 9. Neighborhood with single-family detached houses with detached garage and side alley in Sherman Oaks, CA, adapted by Google Maps, Imagery and Map Data: ©2015 Google

The block consists of two facing rows of houses of the same type, with the swimming pools and garages in the backyards. The residences are 1-2 story high and have one side drive separating them from their neighboring residences. Besides, the swimming pools in the backyards are placed with their long axis perpendicular to the block's main axis. The existence of the side alley signifies a minimum distance between the buildings that allows wind to flow through, when the drives are left unprotected, and reach the backyard zone.

This case study is the most sparse one since each residence is detached from each other, and the side drives put them in greater distance from each other. This, in turn, means that the open water surface of the swimming pools at such residences is highly vulnerable to the wind currents. It is, thus, anticipated that pools of this residential type will have some of the highest evaporation rates/square footage.

What's more, it is expected that the evaporation rate will vary for the three different wind directions, since the swimming pools, located in the zone between the two rows of residences, with no wind blocking on either ends, are not protected from all four sides. Thus, the evaporation rate is expected be higher for wind parallel to the axis of the neighborhood. Additionally, higher evaporation rates are expected in swimming pools that are close to intersections, since the wind velocity there is expected to increase.

Front-loaded Residences with Attached Garage

The next studied case is a neighborhood that consists of front loaded single-family detached residences with swimming pools, where the garages are attached to the residences. The specific neighborhood that will be modeled and studied is located in Huntington Beach, CA and is part of a gated community (Fig. 10), Similar to the first studied house type, the block consists of two facing rows of residences, 1-2 story high, with swimming pools in their backyards. The swimming pools of this residential type are placed with their longer axis parallel to the block's main axis since the backyard zone is narrower than in the neighborhood of the first housing type.

For this particular block, the immediate surroundings of the block are almost symmetrical, with the gate of the community being the main element breaking this symmetry. In fact, the gate on the east of the block is aligned with the backyards, where the swimming pools are located. Thus, by simulating both the east, and the west parallel wind we can see how significantly, if at all, the presence of a building/windbreak at the end of the backyards' zone could make a difference in the evaporation rate of the pools located there. As a result, in this particular neighborhood, four (4) wind directions will be tested, east and west (parallel to axis), north (perpendicular to axis), and oblique (Fig. 8).

It is anticipated that this neighborhood will be one of the best among the studied ones based on the evaporation rate. The fact that the residences are very close to each other, with only narrow passages in between them, is expected to result in adequate wind protection of the pools in the backyard zone, especially when the incoming wind is not parallel to the neighborhood's main axis. Despite that, the pools located close to the open sides of the block, the two ends of the main axis of the block, are expected to have higher evaporation rates since they are not very well protected by the incoming winds. However, this difference in the evaporation rates of the pool in the ends, is expected to depend on the wind direction of the incoming wind, meaning that for each wind direction, the least protected pool will be at a different location.

Fig. 10. Neighborhood with front loaded single-family detached houses with attached garage in Huntington Beach, CA, adapted by Google Maps, Imagery and Map Data: ©2015 Google

Semi-detached Residences with Detached Garage

The following housing type consists of one row of residences that are semidetached, 1-2 story high, with rear garages (Fig. 11). There is also a zone of backyards between the row of residences and the row of garages. The backyard depth ranges from 4,0-4,5 m. Besides, most of the residences are not connected to their garage, except for two residences, which break the uniformity. Each block has only one row of residences and the entrance for the cars is from the rear street that acts like an alley too.

This type of housing is not very common in Los Angeles and actually tends to be more affordable. Thus, no block of this housing type was found to have swimming pools. To overcome that restriction, the points in the backyards where theoretically the swimming pools could be placed are tested in this case study. In this way, the simulations of the theoretical pools will be used to calculate what the evaporation rate would be if they had pools in the backyards, and compare the results with those of the rest of the studied house types. Additionally, the existing community pool with its surroundings will also be modeled and studied, in order to compare its evaporation rates with those of the rest of the studied pools.

Fig. 11. Neighborhood with semi-detached single-family residences with detached garage in Huntington Beach, CA, adapted by Google Maps, Imagery and Map Data: ©2015 Google

It is expected that this residential type will give fairly good results in terms of evaporation rates. The fact that the backyard zone is narrow enough to ensure that the swimming pools are sufficiently protected from winds of almost every direction. However, since the sides of the block are open, the swimming pools will have higher evaporation rates when the wind is blowing parallel to the main axis of the block.

Row Houses

The next house type that will be studied is the row house where both sides of each residence are attached to neighboring residences, thus, creating a row. The neighborhood of row houses that will be studied is located in Huntington Beach, CA. This block consists of two (2) facing rows of rear loaded row houses and one community swimming pool for the entire community (Fig. 12). Due to the nature of the row houses, and the income level of the people they are usually occupied by, no row houses were found in Los Angeles that had private swimming pools for each one of the residences. For this reason, hypothetical swimming pools will be designed for this housing type as well. The simulations will be used to calculate what the evaporation rate would be for these hypothetical pools in the backyards, and to compare the results with the results of the rest of the housing types.

Fig. 12. Neighborhood with row houses with detached garage in Huntington Beach, CA, adapted by Google Maps, Imagery and Map Data: ©2015 Google

It is expected that the existing swimming pool will have the highest evaporation rate among all the pools of this block, since it is not adequately protected from the wind. Besides, since the pools are on the outer parts of the studied block, while the residences are in the inner part of it, the pools are expected to show great variations in the evaporation rates, depending on the incoming wind speed and direction.

Courtyard Houses

The last housing type that will be studied is the courtyard house, and the selected neighborhood that will be modeled is located in West Hollywood, CA. This housing type is tied to Los Angeles' history (Polyzoides et al. 1992). The selected neighborhood consists mainly of courtyard houses with swimming pools inside their courtyards (Fig. 13). In this particular block, U-shaped or U-parti courtyard houses are found, as well as Complete courtyard (Polyzoides et al. 1992) ones. These are the courtyard house types that are expected to provide the higher wind protection to the swimming pool in the courtyard, since the swimming pools are inside the courtyards and surrounded on three to four sides by the building itself. Thus, these types of the courtyard house are more meaningful to study for the present research. We can notice that there are two facing rows of courtyard houses, and each swimming pool is located inside a courtyard.

Fig. 13. Neighborhood with courtyard houses with pools in West Hollywood, CA, adapted by Google Maps, Imagery and Map Data: ©2015 Google

It is expected that this housing type will have the lowest evaporation rates, since the pools in the courtyards are surrounded by the courtyard houses, which are anticipated to protect them from the wind. Especially when it comes to Complete Courtyards, where the pools are protected by the houses on all four sides, it is anticipated to find the lowest wind velocities and evaporation rates. Besides, as observed by Reynolds (2002), it is expected that the depth of the courtyards will affect the wind velocity over the pools, with the deeper courtyards providing better wind protection and thus giving lower evaporation rates. Similarly, when the courtyards are shallow, the wind protection will not be sufficient, and the evaporation rates will be higher.

CHAPTER IV

RESULTS AND ANALYSIS

Front-loaded Residences with Detached Garage

The selected neighborhood of this housing type is within the boundaries of California Climate Zone 9 (California Energy Commission 2015) (Figs. A 1-2, see Appendix B for all A figures), so the wind speeds that will be studied are 2.5m/s and 5.5 m/s (Tables A 1-2, see Appendix B for all tables). Below are the results of the simulations for the two (2) different wind speeds and three (3) different wind directions. The swimming pools are highlighted and named in Fig. 14. Since the wind speed over each pool is inherently connected to the specific pool's evaporation rate, only the wind speeds will be mentioned, in order to avoid using too much numerical data. However, the tables of Appendix B include both the wind speed and the evaporation rates, as well as a diurnal water consumption.

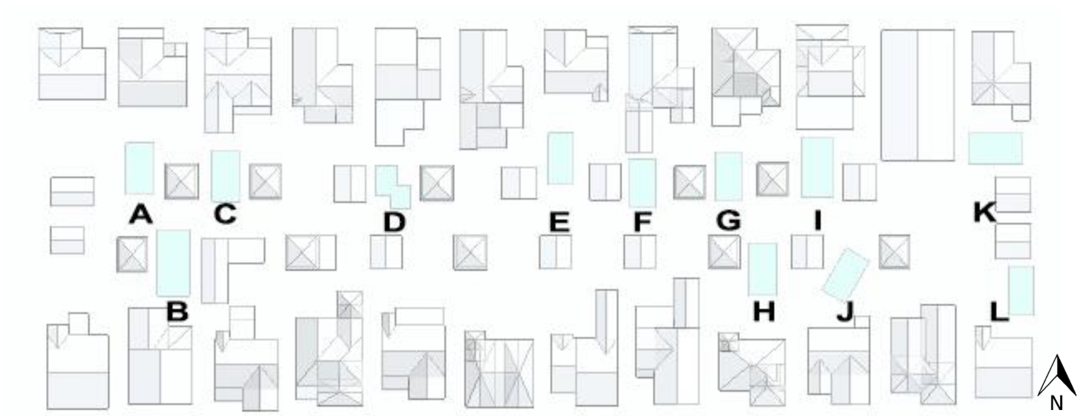


Fig. 14. Studied block of front loaded houses with detached garages, pools are named and highlighted in cyan. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When wind is parallel to the main axis of the block with a wind speed of 2.5 m/s we can notice that the wind over the swimming pools is slowing down as it gets towards the leeward side of the block (Fig. 15). For incoming wind speed of 2.5 m/s the average resulting wind speed over the swimming pools is 0.3 m/s. This is caused by the existence of the detached garages that are scattered in the backyards and provide some wind blocking. However, there are two points of interest where wind speed is still higher. These points are close to the edges of the block and, thus, are not very well protected. In particular, point B has a wind speed of 1.0 m/s and evaporation ratio 4.38 Kg/s sq. m. despite being sheltered behind the garage, since the wind current finds its way around the garage and over the pool. Regarding point L, the fact that it is located between the garage and the residence, and not on the leeward side of the garage, makes it vulnerable to the wind current. This led to a high evaporation ratio of 3.97 Kg/s sq. m.

Besides, evaporation is higher in the zone between the two rows of garages since there are no obstacles there, except for the garages at the two ends of the block, and, thus, wind is flowing freely. At the same time, the the garages at the very end succeed to reduce evaporation in the pools right next to them, however, since the rest of the passage between the garages is empty, wind speed is higher there and penetrates the backyards in between the garages as in pools B and F. In the studied case, since only one block is studied, having a higher speed between the rows of garages might have no consequences in the overall wind conditions and water consumption. Nevertheless, when the bigger picture is taken into account, for example, when it comes to planning for a community spanning over more than one block, this could compromise the wind and evaporation conditions in the surrounding blocks.

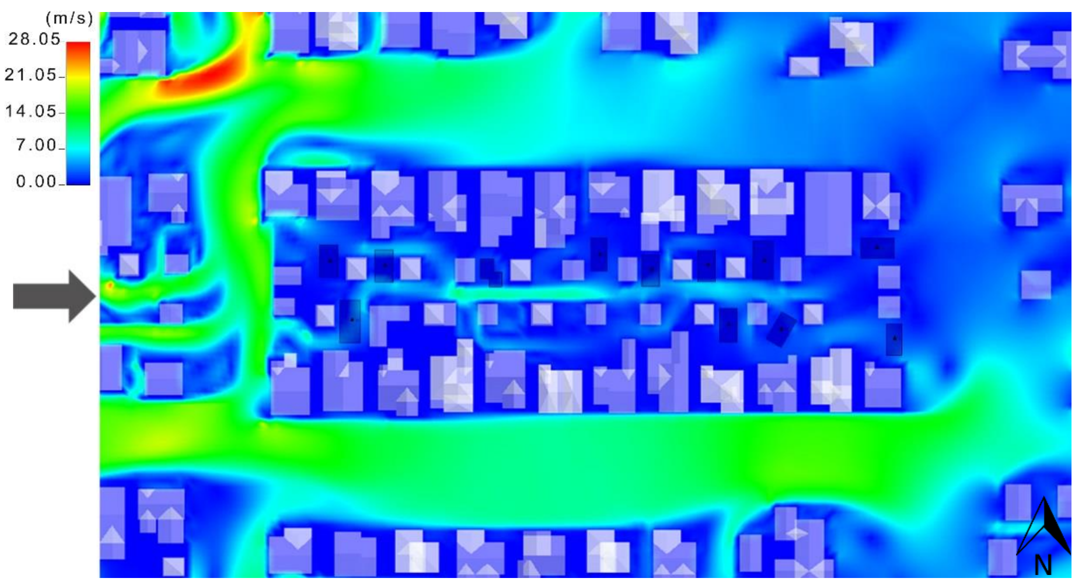


Fig. 15. Front loaded residences with detached garages, simulation for parallel wind of 2.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

Even when the incoming wind speed is 5.5 m/s (Fig. 16), the two garages on the west side slow wind down and lead higher speed currents around them. This creates a bypass of high speed to the corridor between the garages. This highly affects the pools located close to the west side of the block, since the wind of high speed is flowing over them instead of the corridor. Additionally, wind flows with a high speed on the sides of the two garages on the east side increasing the speed of the wind flowing over the swimming pools K, and L. As a result swimming pool K has a high wind speed of 3.1 m/s and pool B has an even higher speed of 4.5 m/s.

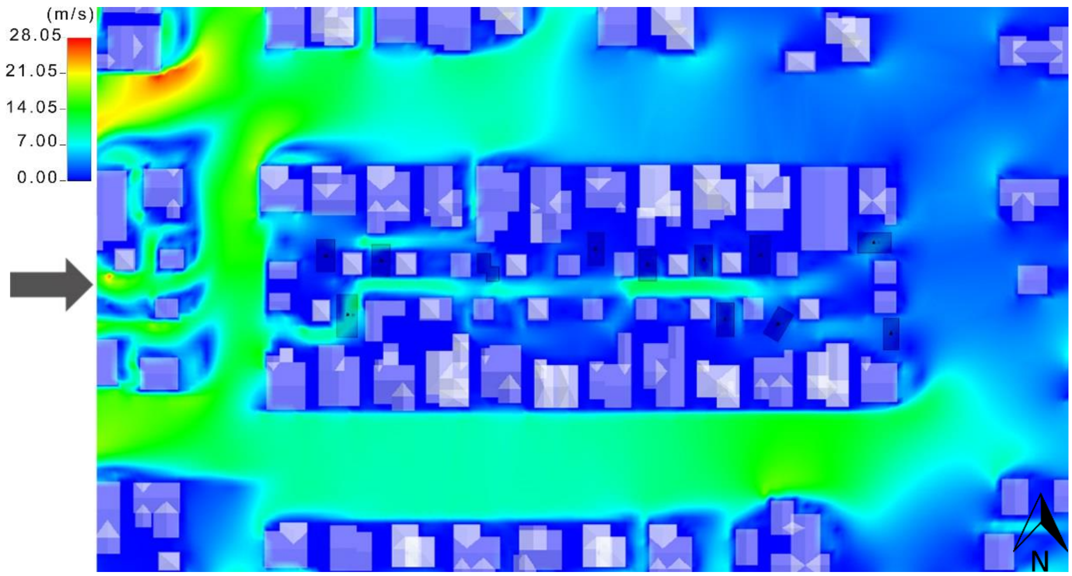


Fig. 16. Front loaded residences with detached garages, simulation for parallel wind of 5.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When the wind is flowing perpendicular to the main neighborhood axis, we can notice some “corridors” of relatively high wind speed that are associated with gaps or alleys in the opposite block (Figs. 17-18). Thus, it is safe to say that the immediate surroundings of each block highly affect the wind and evaporation conditions in the block that is studied. Besides, the swimming pools at the east side of the block, being unprotected from the wind, since they are not aligned with the garages, have higher wind speeds (points J, K) since wind is flowing unrestrained out of the wind tunnel of the backyards.

With an average high wind speed, 5.5 m/s, of the same direction (Fig. 18) the corridor between the garages is still noticeable but not as much as with slower incoming wing. The perpendicular street and the gaps between the buildings north of the studied block leads to a penetration of high speed wind through an alley that hits a garage and continues flowing through its two sides and partially over a few swimming pools. As a result, for both wind speeds wind protection at the edges of the blocks is essential. However, equally essential is the wind protection of the leeward surroundings of the block, to minimize the wind speed flowing towards the block.

When the wind is oblique, with an angle of 45 degrees NE, there still is a corridor in between the two rows of garages in the backyards, where wind speed is higher (Fig. 19). Point K on the east side of the block, which in this case is the windward side if the block, is unprotected and has a higher wind speed than point K, which is again on the east side, but is protected by a garage. Point E has a relatively higher wind speed since it is not aligned with the garage.

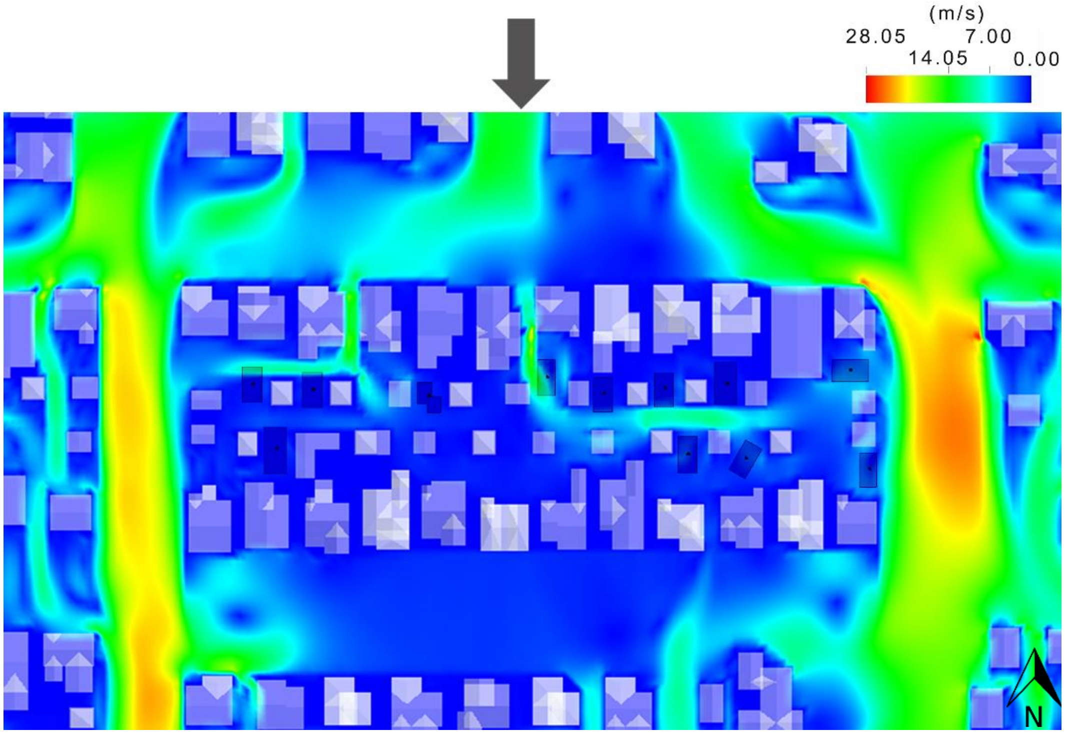


Fig. 17. Front loaded residences with detached garages, simulation for perpendicular wind of 2.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

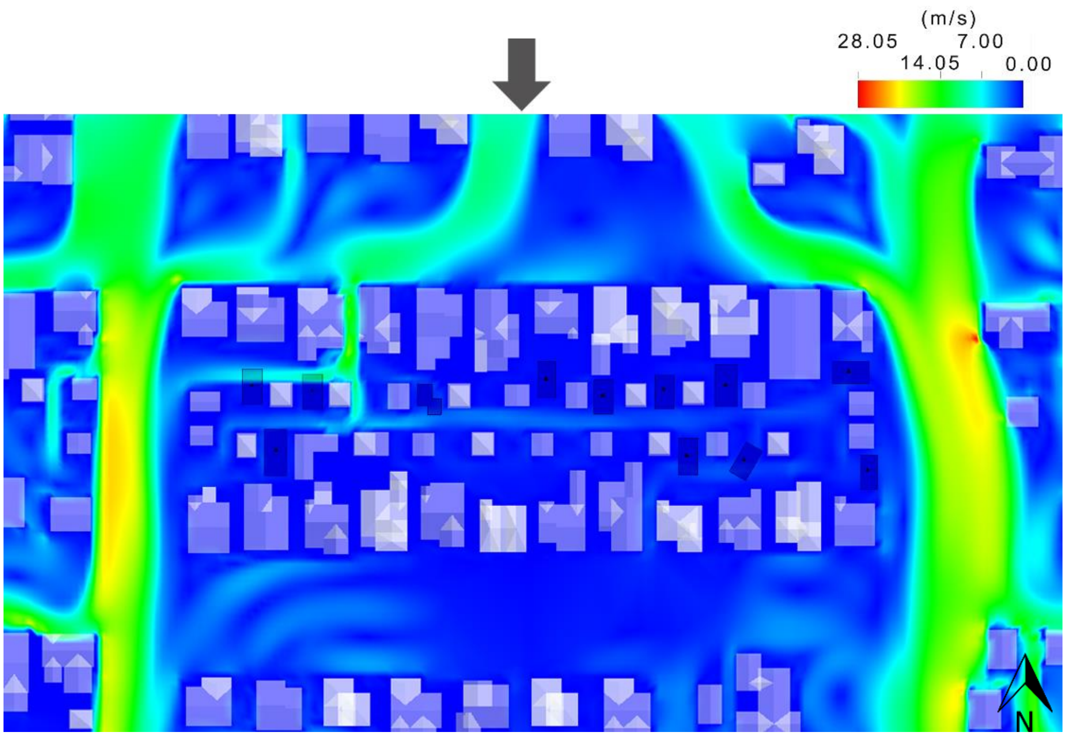


Fig. 18. Front loaded residences with detached garages, simulation for perpendicular wind of 5.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

We can notice that since wind is oblique in relation to the main axis of the block, it enters through some of the side alleys and flows around the garages as in point E. Again, the perpendicular street and the gap in between the buildings on the windward side of the street directly affect the wind performance of the studied block. This is the reason why wind flows through the alleys next to points C, and E. The wind has no obstacles flowing through the adjacent block, and continues unblocked to flow through these side alleys. Besides, the residences in the northwest part of the block have no protrusions towards the backyards, letting wind flow rapidly through their backyards. However, since their swimming pools are in the leeward side of the garages, they are not affected. If the residence on the northwest side had a swimming pool, its evaporation rate would be extremely high.

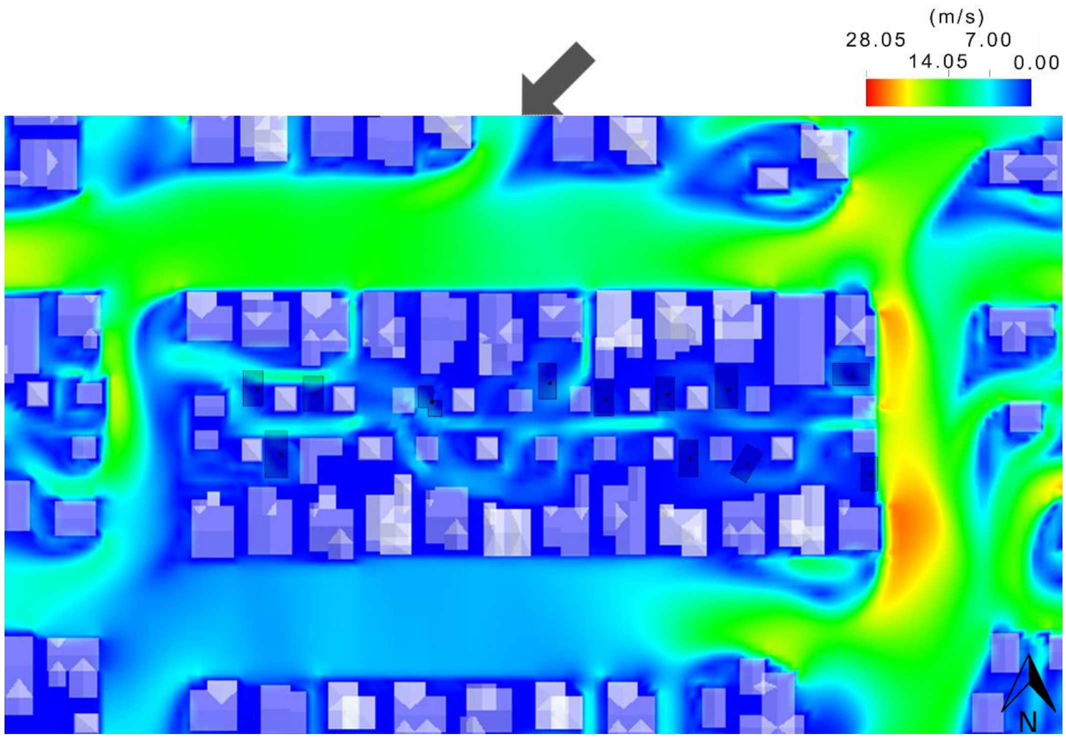


Fig. 19. Front loaded residences with detached garages, simulation for oblique wind of 2.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When the incoming wind is 5.5 m/s (Fig. 20), the corridor that is formed in between the garages has high wind speed throughout its length. The displaced garages at both ends of the block break this corridor. Especially the garages at the west side of the block lead wind to their sides, increasing the wind speed over the backyards on the west side of the block. Besides, there is still a higher wind speed in the alleys mentioned before, even though the differences is significantly smaller.

All in all, the garages provide enough wind protection when swimming pools are properly aligned with them. In addition, wind protection, or density of the buildings in the immediate surroundings should be also considered, in order to avoid anomalies and need for extra wind protection as in the mentioned side alleys.

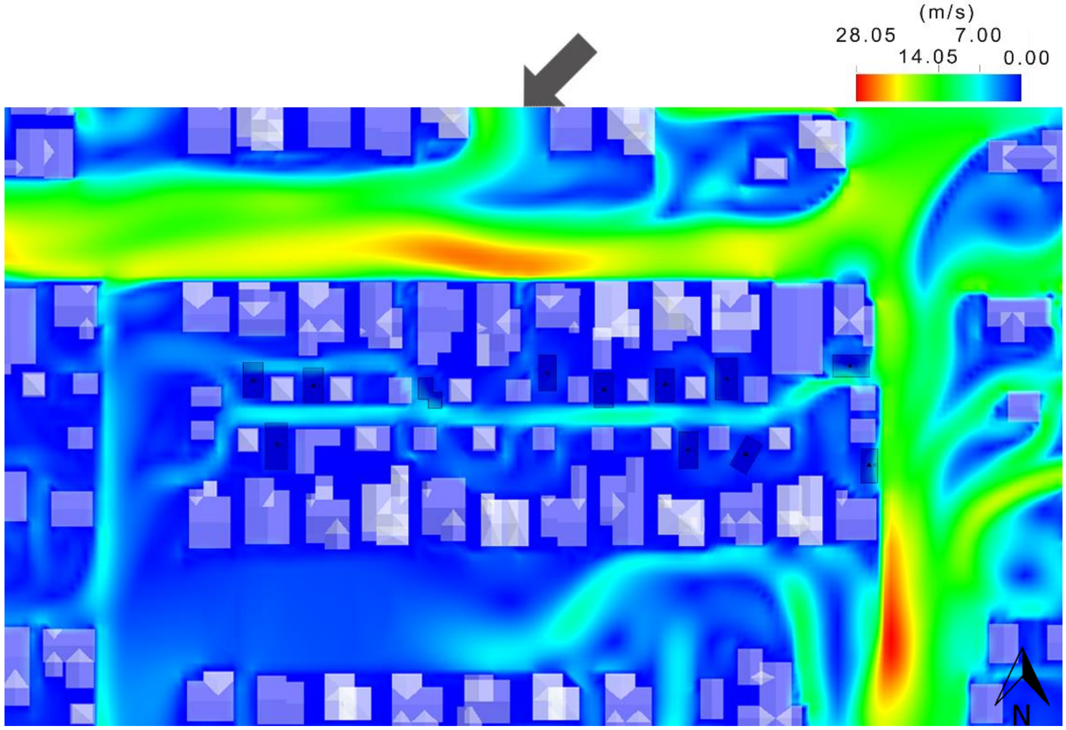


Fig. 20. Front loaded residences with detached garages, simulation for oblique wind of 5.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

Front-loaded Residences with Attached Garage

The selected neighborhood of this type is located in the California Climate Zone 6 (Table A 1), so the wind speeds that will be studied are 3.25 m/s and 6.25 m/s. In this case four (4) different wind directions will be tested, instead of just three, since the relative symmetry of the block in contrast with the asymmetry of the surroundings, and especially the gate on the east side can give us more solid results on the effect the surroundings have on the wind speed and pool water evaporation. Below are the results of the simulations for the two (2) different wind speeds and four (4) different wind directions (Table A 3). The swimming pools are highlighted and named (Fig. 21).

For the mean average wind speed of 3.25 m/s, when the incoming wind is parallel to the main axis of the block and flowing from the west (Fig. 22), wind is blocked by the residences surrounding the studied block. However, wind of higher speed enters from the sides of the backyard zone and through the wider gaps between the residences, increasing wind speed over some of the pools. This is why pools A-F have wind speeds, 0.8-1.9 m/s, that are higher than those of pools I-K, whose wind speeds range from 0.5-0.6 m/s.

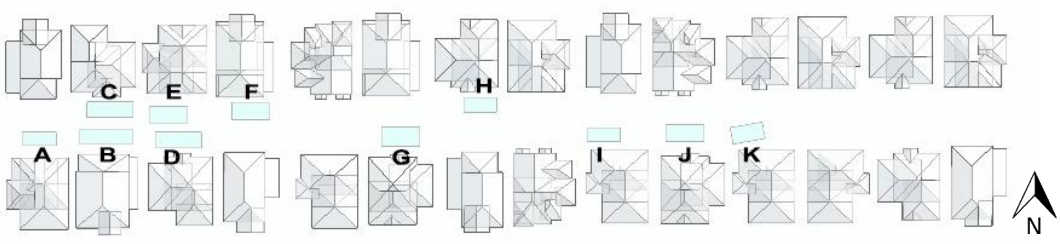


Fig. 21. Studied block of front loaded houses with attached garages, pools are named and highlighted in cyan. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

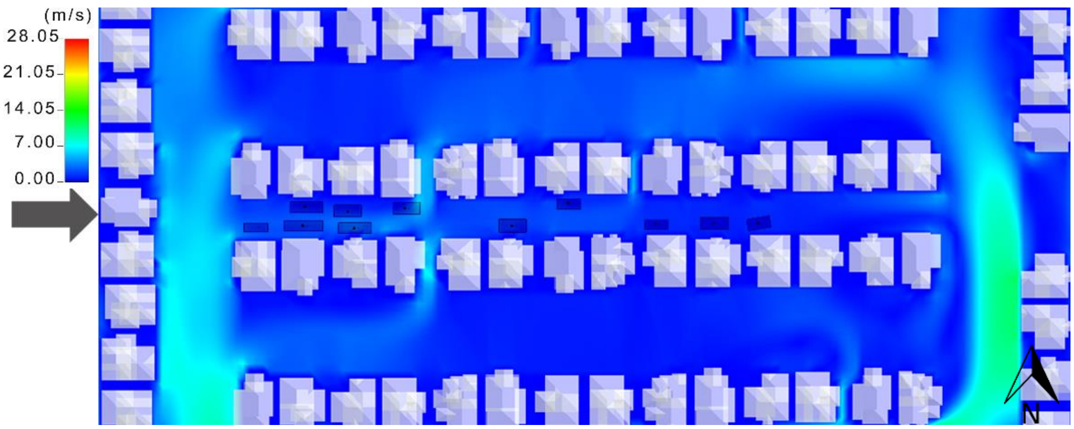


Fig. 22. Front loaded residences with attached garages, simulation for west parallel wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

With the same wind direction, and the wind speed at its high average, 6.25 m/s (Fig. 23), the resulting wind speeds over the swimming pools are significantly higher. Wind flowing over the street has a very high speed that flows along the entire backyard zone. The wind speed reaches its peak at roughly the middle of the block, with wind speed over pools I-K being 5-5.1 m/s.

For the mean average wind speed of 3.25 m/s, when the incoming wind is parallel to the main axis of the block and flowing from the east (Fig. 24), wind is flowing through the gate which is in line with the backyards of the studied block. However, since the surroundings do not have a similar gap, the wind is blocked. As a result, wind is not flowing parallel to the main, long axis of the block, leading to a decrease in the wind speed.

In the row of residences south of the block, every time two neighboring residences have long flat facades facing each other, without protrusions such as bay windows or porches, creating an alley, this alley acts as a wind tunnel that lets wind flow unobstructed. When two or more of these alleys are aligned to each other they create a path a long which wind speed is higher as in the alley between pools I and J.

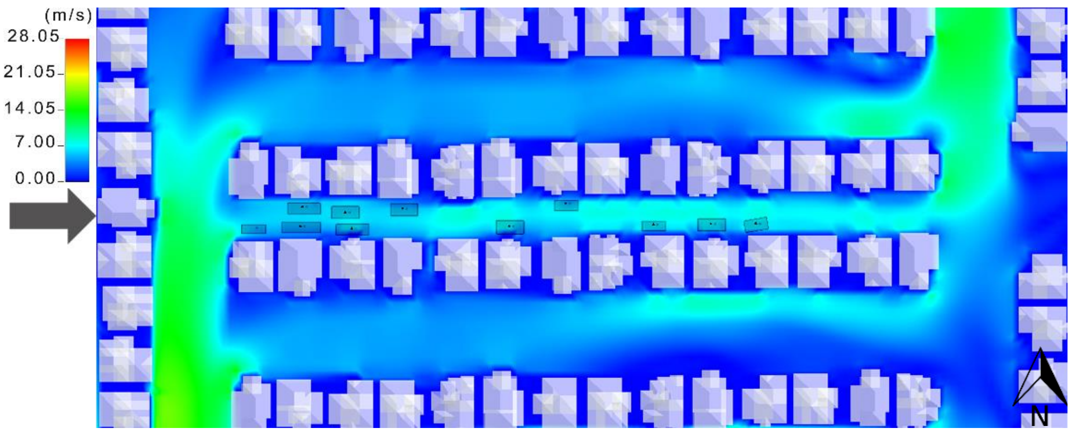


Fig. 23. Front loaded residences with attached garages, simulation for west parallel wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

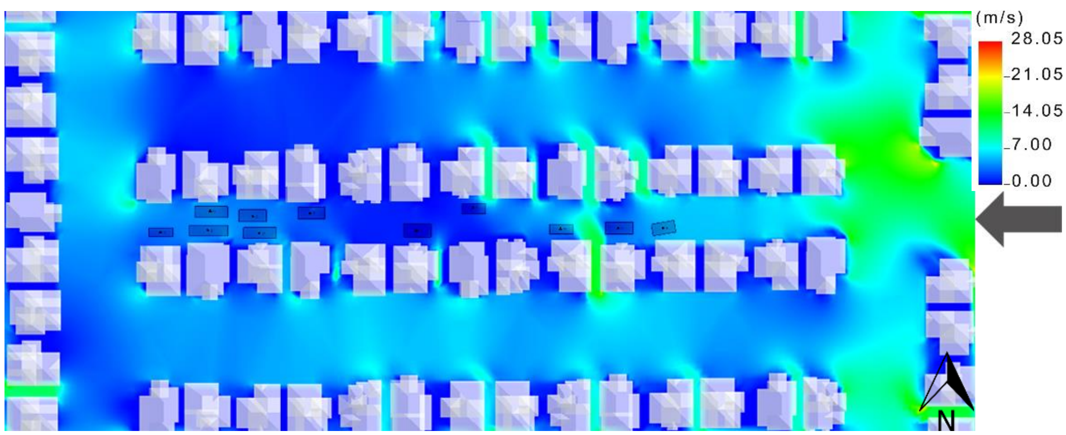


Fig. 24. Front loaded residences with attached garages, simulation for east parallel wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

All in all, even though the zone of the backyard at first seemed unprotected, the further surroundings of the block managed to alter the wind speed and direction before the wind flowed over the studied block. It seems that the way wind speed is increasing or decreasing between the residences depends on the geometry of the gap-either long, flat surfaces, or facades with protrusions. Of these geometries, those of narrow gaps work better in keeping wind speed lower.

When the wind speed is at its high average (Fig. 25), then the wind flowing through the gaps in between the residences is slower. However, the gap of the gate east of the block lets wind easily flow through the backyards. As a result the wind speed over the pools is significantly more rapid compared to when the incoming wind speed is the average mean one. This confirms what was anticipated, the fact that the presence of a row of buildings that is aligned with the open end of the backyard zone will block the wind and result in lower wind speeds and evaporation rates over the pools. Furthermore, a path of higher wind speed is noticed flowing through one of the wider gaps in the north part of the block, resulting in a decrease on the wind speed over the rest part of the block. Consequently, the pools on the leeward part of this gap, A-H, have a lower wind speed.

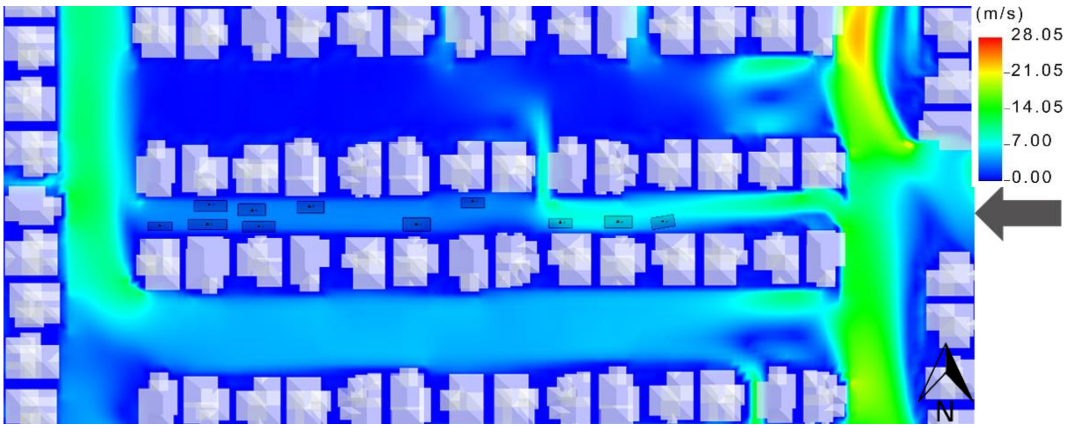


Fig. 25. Front loaded residences with attached garages, simulation for east parallel wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When wind of 3.25 m/s is blowing from the north, the backyards are adequately protected (Fig. 26). High speed currents can penetrate between some of the residences of the surrounding blocks, however, this does not directly affect the wind speed in the backyards. The edges are still vulnerable, with pool A having the highest wind speed, 1.0 m/s, under these particular wind conditions.

For the high average wind speed of 6.25 m/s, wind still flows in between some buildings in the north of the studied block with a higher speed (Fig. 27). Even so, the high speed current does not affect the backyards of the studied block. Additionally, wind flows with a higher speed entering from the west edge of the backyard zone causing high wind speeds over pools A through F, resulting in an average of 4 m/s air velocity over them.

For oblique NE incoming wind of the mean speed (Fig. 28), wind is flowing with a higher speed through some of the gaps of the row of residences north of the block. In particular, wind manages to flow quickly through relatively wider gaps. This affects the studied block as well, pools A-F are a higher speed current that comes from one of those gaps. Once more, it is evident how important it is to take into account at least the immediate surroundings when studying a neighborhood and providing wind protection solutions. In general the gaps in between the residences in the studied block are narrow enough so as to slow the wind down. As a result the wind speeds over the pools range from 0.4 m/s to 0.6 m/s. The gap for the gate on the east side of the block did have impact on the wind speed in the backyards, increasing the wind speed up to 1.7 m/s.

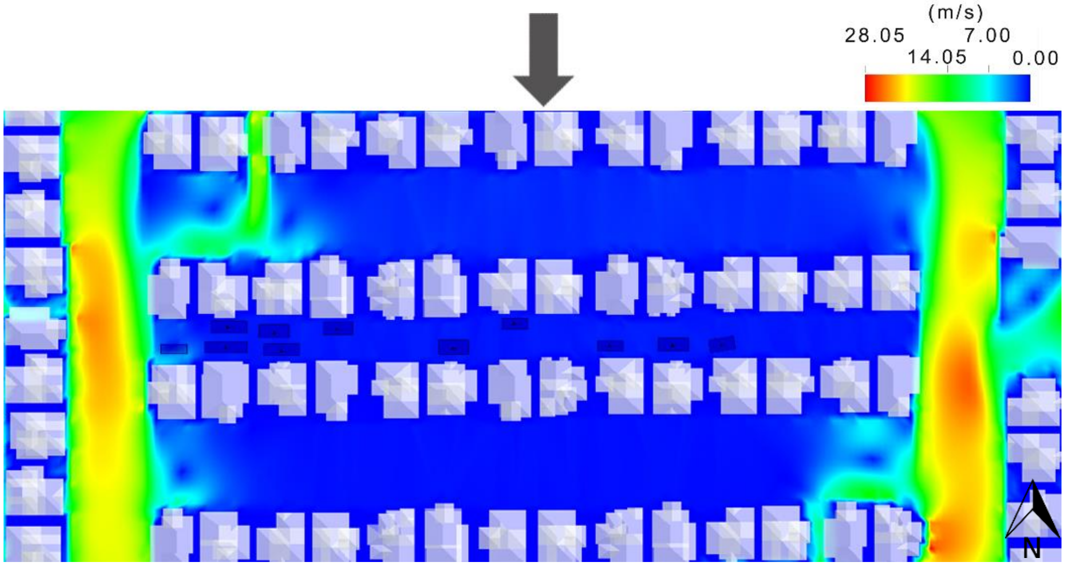


Fig. 26. Front loaded residences with attached garages, simulation for perpendicular wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

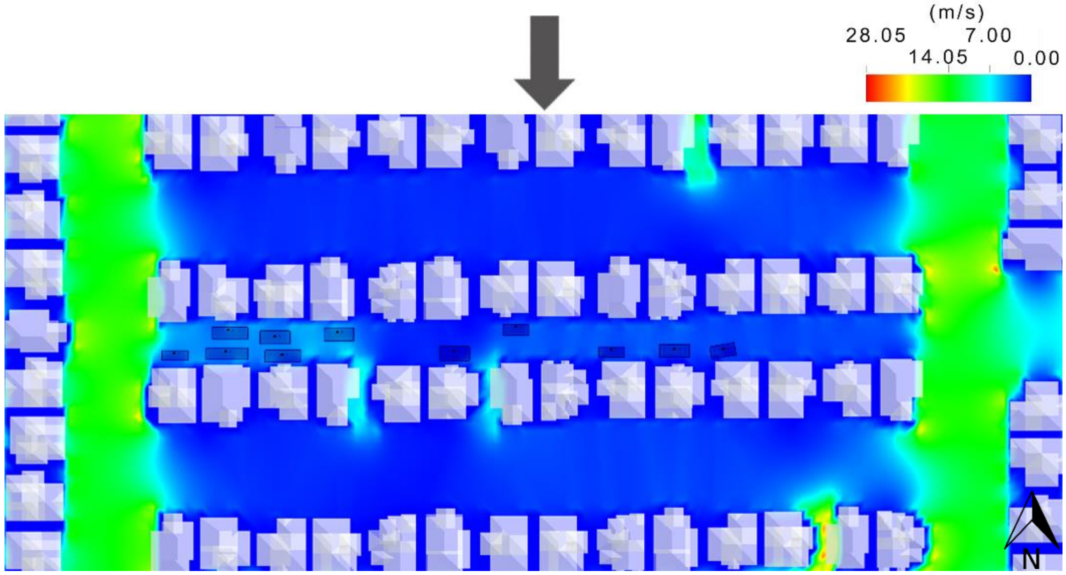


Fig. 27. Front loaded residences with attached garages, simulation for perpendicular wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When wind speed has its highest studied value, 6.25 m/s (Fig. 29), the highest wind speed over the pools is found over pool G, since there wind of high speed is flowing perpendicularly between the residences, through the wider gaps in the block. The fact that the east side of the backyard zone is unprotected, coupled with the gate gap result in an even higher wind speed on the east side of the block.

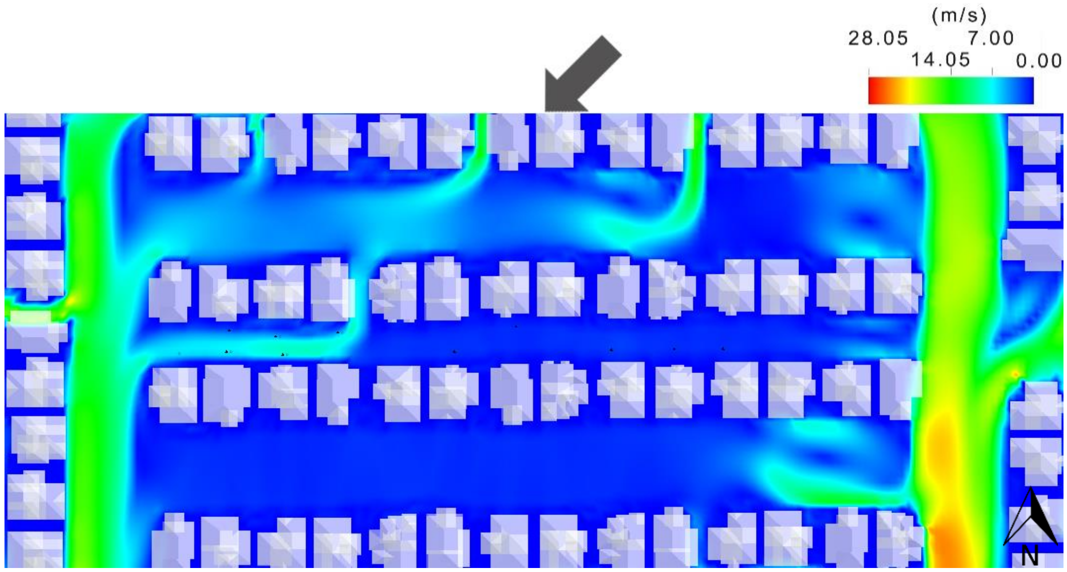


Fig. 28. Front loaded residences with attached garages, simulation for oblique wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

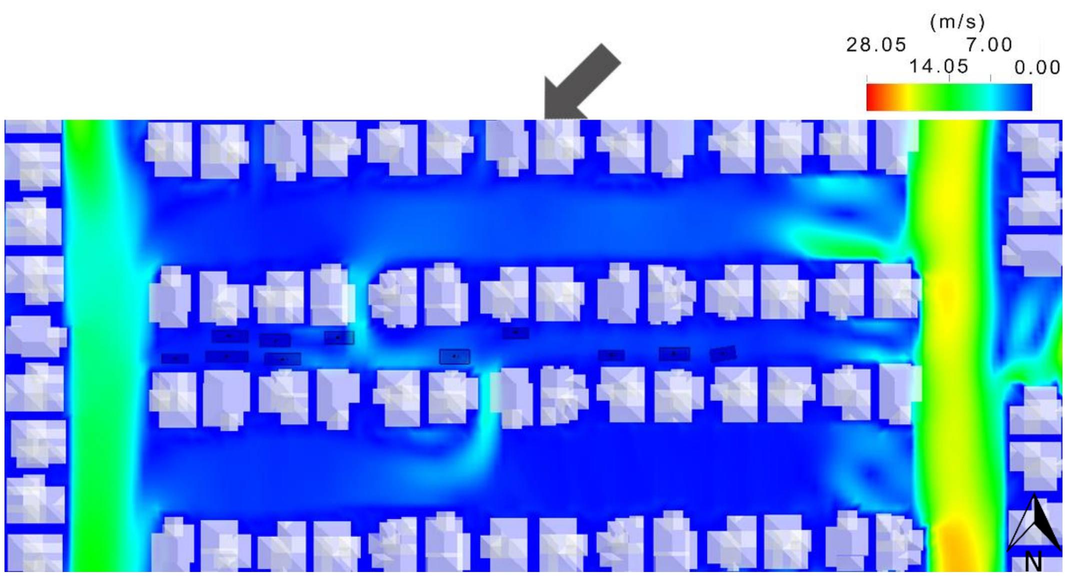


Fig. 29. Front loaded residences with attached garages, simulation for oblique wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

Semi-detached Residences with Detached Garage

The selected neighborhood of the semi-detached houses is also located in the California Climate Zone 6 (Table A 1, Figs. A 1,2), so the wind speeds that will be studied are 3.25 m/s and 6.25 m/s. Below are the results of the simulations for the two (2) different wind speeds and three (3) different wind directions (Table A 4). The swimming pools are highlighted and named (Fig. 30).

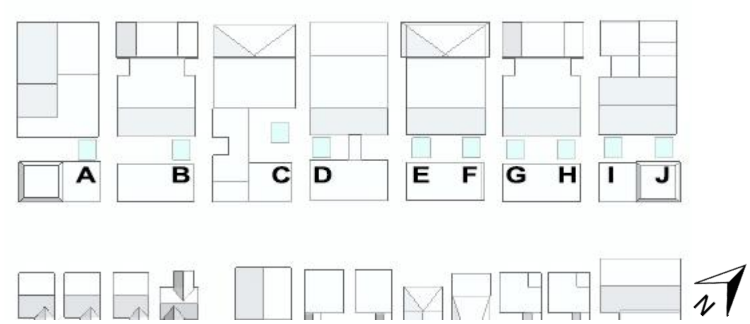


Fig. 30. Studied block of semi-detached houses, pools are named and highlighted with cyan. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When the incoming wind is 3.25 m/s and parallel to the main axis of the block, then wind of high speed flows over the backyards, between the residences and their garages (Fig. 31). Pool A, which is next to one end of the block, has the highest wind speed, 2.3 m/s, since it is unprotected. The first of the two residences that are connected to their garages, the one next to pool B, is 2-story high and does not affect the wind speed over the backyards next to it. However, since pool C is further inside the backyards, is protected from three sides and, thus, has the minimum wind speed of the entire block. Furthermore, the second residence that is connected to its garage, has only a narrow 1-story high corridor connecting the main residence with the garage. It is worth noticing that the wind speed on the leeward side of this corridor is more uniform over the backyards leading to lower wind speed on the swimming pools of the leeward side. On the other hand, the 2-story part of the previous residence, which connects it to its garage, does not affect the wind speed neither in its windward, nor in its leeward side.

When the incoming wind reaches is high average of 6.25 m/s and is parallel to the main axis of the block (Fig. 32), then wind of high speed flows over the backyards, between the residences and their garages. Even though the zone of the backyards is protected through the buildings across the street, since the distance is great, wind currents still finds its way around the corner and over the backyards increasing the evaporation in the swimming pools. As mentioned before, there are two residences that are connected to their associated garages with spaces that cross the backyard zone. The part of the residence next to pool B that crosses the backyard zone is 2-story high and provides wind protection to pools B and C. Interesting enough is that since this corridor blocks wind from flowing through, wind speed decreases in both its leeward, and its windward side. Besides, the fact that pool C is protected from three sides plays an important role in ensuring wind is of lower speed at this point. The second building that crosses the backyard zone has a 1-story high corridor-like part, which does not provide enough wind protection. Consequently, the geometry, and in particular the dimensions, of the wind obstacles are crucial in determining their performance is the desired one.

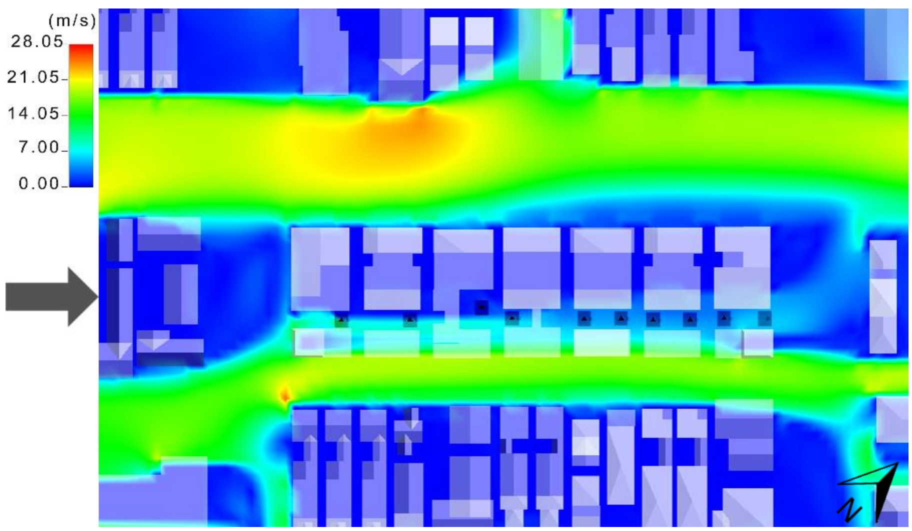


Fig. 31. Semi-detached residences with detached garages, simulation for parallel wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

Comparing the results of both wind speeds for the same wind direction, it is evident that the two wind obstacles in the backyards act in different ways for each wind speed. The higher obstacle performs better in higher incoming wind speed, while the lower wind obstacle performs better when the speed of the incoming wind was lower. Consequently, wind obstacles of varying geometry affect wind currents in different ways depending on the incoming wind's speed.

When wind is blowing perpendicular to the main, long axis of the block, with a wind speed of 3.25 m/s this housing type performs very well (Fig. 33). The 2 story residences block and slow down the wind as it flows over the backyards. Wind flows with low speed through the narrow gaps between the residences keeping the wind speed in the backyards low. The backyards and pools next to the sides of the block are still less protected in comparison to the rest of the block. The wind speed for the rest of the pools is ranging from 0.2 up to 0.7 m/s.

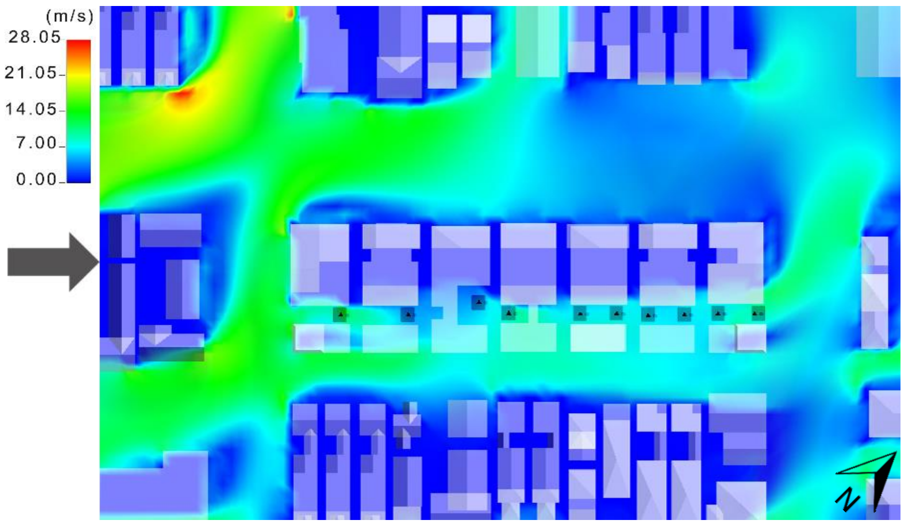


Fig. 32. Semi-detached residences with detached garages, simulation for parallel wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When wind flows with the same direction but with the high average speed, 6.25 m/s, this housing type still performs very well (Fig. 34). Wind flowing through the gaps between the residences is slow. Wind flows over the 2-story buildings and then over the backyards, keeping the wind speed over the swimming pools very low for the most part, 0.1-0.7 m/s. The only exception is pool A which is exposed to high speed wind through the side of the block. In this case, wind barrier of proper size should increase performance.

Finally, when wind is oblique, and 3, 25 m/s, the results are entirely different (Fig. 35). High speed wind flows through the windward side of the block, with the wind speed over pool A being 2.7 m/s, almost the same as the incoming speed. Wind currents of high speed flow through the

For oblique, 6.25 m/s wind the situation is very similar, with higher resulting wind speeds (Fig. 36). The first pool on the windward side of the block has a record high evaporation and wind speed, 6.2 m/s, almost the same as the incoming wind's speed. Wind hits the front of the opposite block bouncing back, with slower speed. If the front of the block across the street was not uniform, had a different angle, or had protrusions, then wind would be slower over the pools on the leeward side of the block.

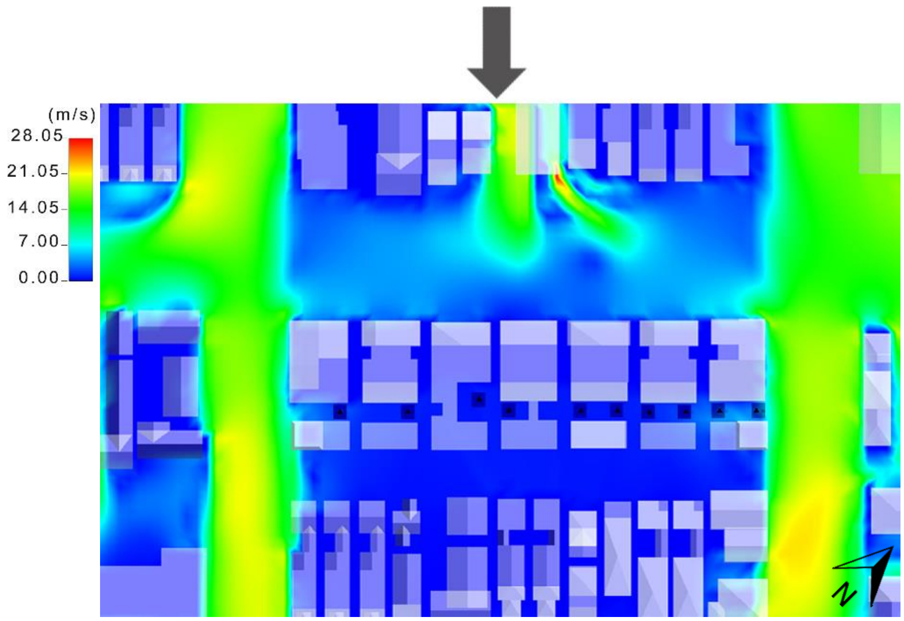


Fig. 33. Semi-detached residences with detached garages, simulation for perpendicular wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

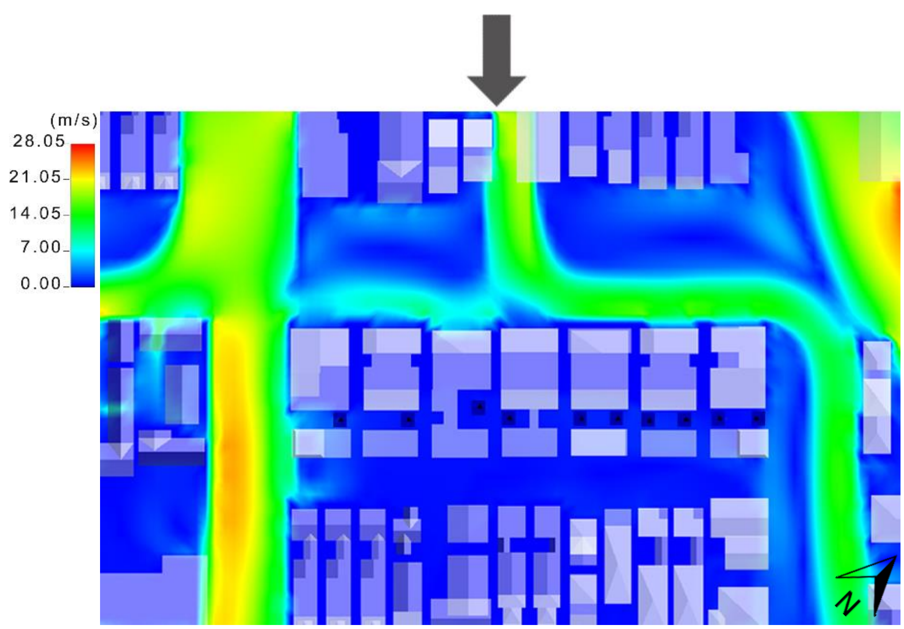


Fig. 34. Semi-detached residences with detached garages, simulation for perpendicular wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

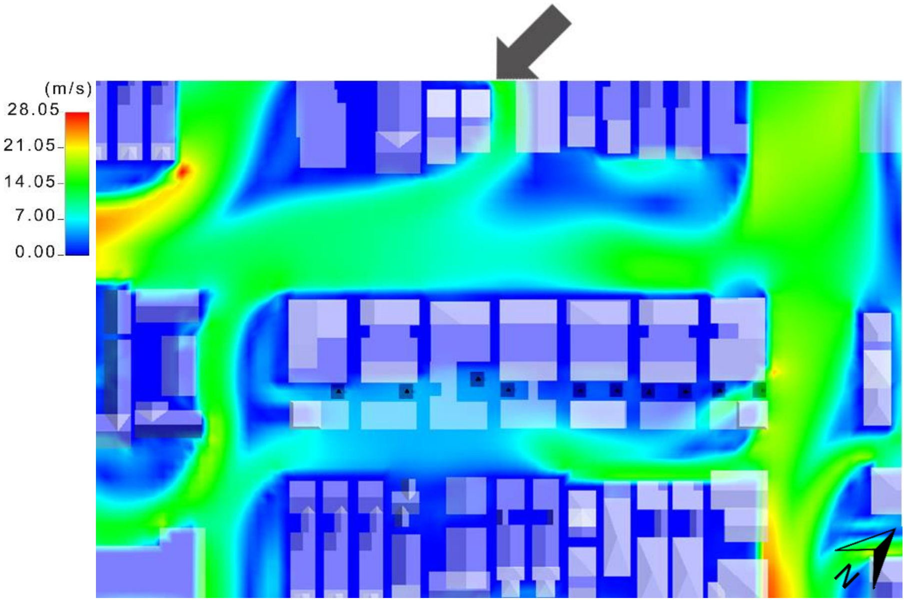


Fig. 35. Semi-detached residences with detached garages, simulation for oblique wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

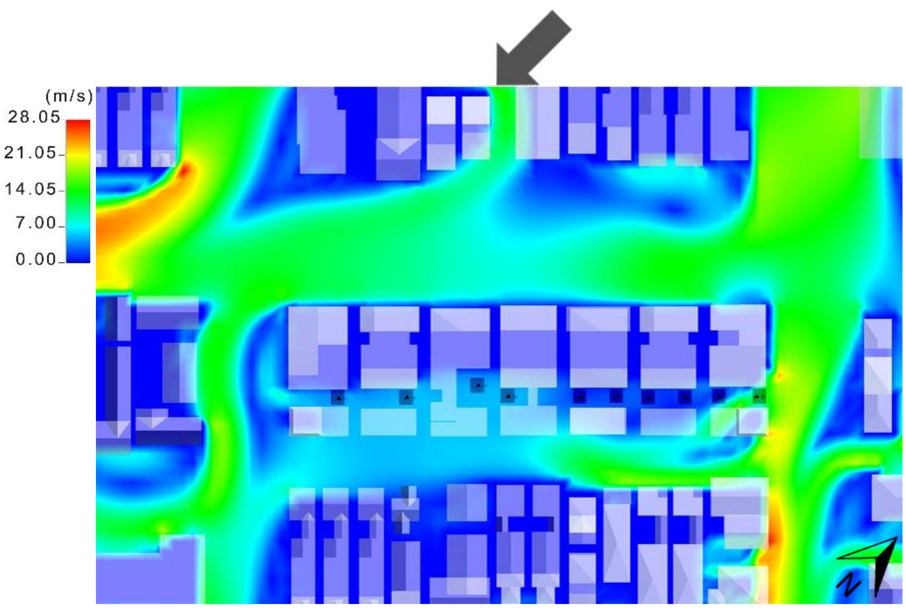


Fig. 36. Semi-detached residences with detached garages, simulation for oblique wind of 6.25m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

Row Houses

The selected neighborhood of row houses is, again, located in the California Climate Zone 6 (Table A 1, Figs. A 1,2), so the wind speeds that will be studied are 3.25 m/s and 6.25 m/s (Table A 5). Below are the results of the simulations for the two (2) different wind speeds and three (3) different wind directions. Swimming pools have been designed in the backyards of the row houses, to test how they would perform in case row houses indeed had pools. The swimming pools are highlighted and named (Fig. 37). Besides, the existing community pool is tested in the simulations as well, in order to compare the performance of a relatively unprotected pool, with the hypothetical pools that are placed in the backyards of the row houses just for testing purposes.

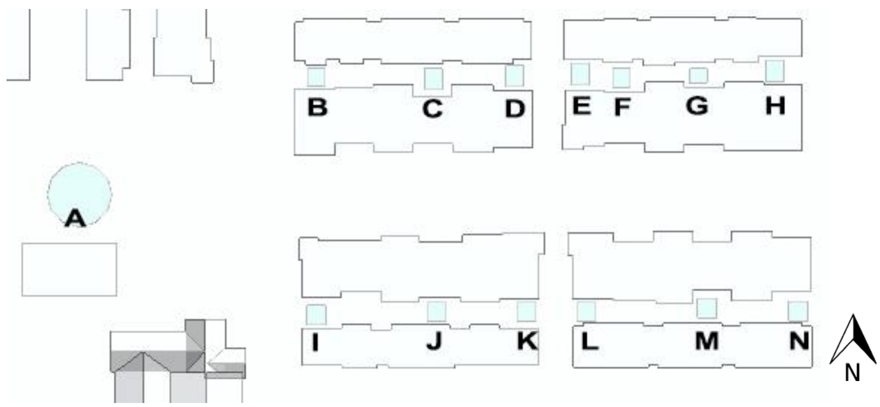


Fig. 37. Studied block of row houses, pools are named and highlighted in cyan. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When wind is parallel to the neighborhood's main axis, flowing from the west with a wind 3.25 m/s, then wind is flowing with high speed through the main street of the block, as well as over the backyards of the row houses (Fig. 38). However, the depressions in the row houses create spots of lower wind speed. Besides, since the two south rows of the studied neighborhood are aligned with the street on the leeward side of the block wind is flowing without any obstacles over the pools of those two rows of residences. On the other hand, in the north part of the neighborhood, the zone of the backyards is not aligned with any streets, instead, the buildings on both sides are blocking the wind from flowing freely, and slow it down. In particular, the northeast row of residences is effectively protected by the northwest residences that redirect wind to flow north, which results in wind speeds over pools E-H as low as 0.0-0.4 m/s. Consequently, even though most backyards are exposed to high speed wind currents, the depressions where the hypothetical pools are located provide adequate wind protection. Additionally, the wind speed of the existing community swimming pool wind speed, 4.0 m/s, is higher than the speed of the incoming wind leaving a lot of room for improvement in terms of water consumption.

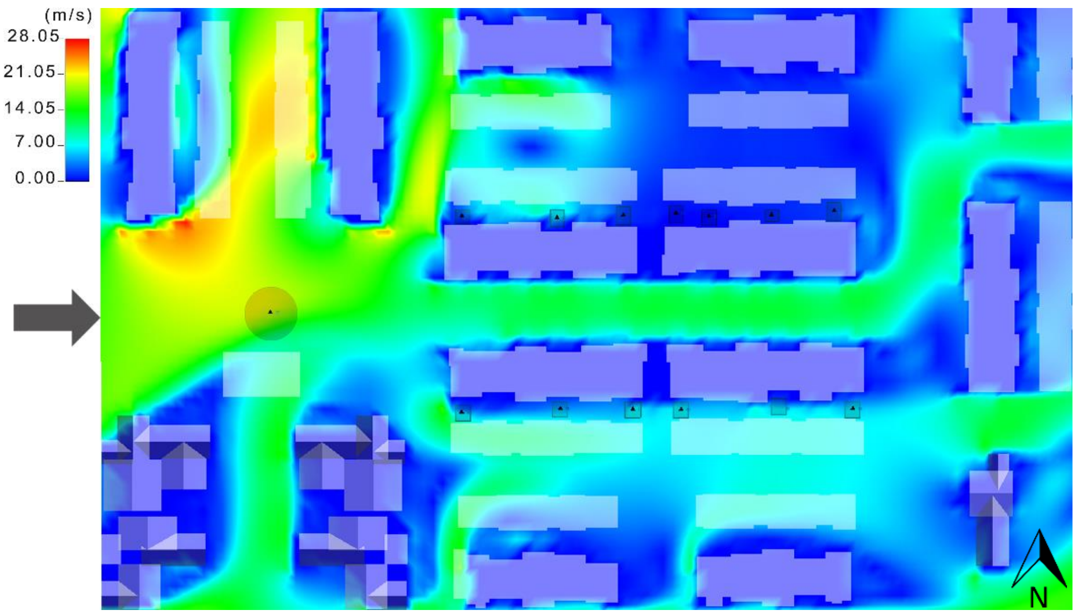


Fig. 38. Row houses, simulation for parallel wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When the parallel incoming wind has 6.25 m/s speed, the community pool has an even higher wind speed flowing over it, 7.2 m/s which, again, exceeds the incoming wind speed (Fig. 39). The performance of the backyards of the row houses is similar to the lower wind speed. The depressions in the backyards block effectively the wind, keeping low wind speeds flowing over the pools. The maximum wind speed over the hypothetical pools is over pool I, since it is located right at the corner where wind is flowing through. The northeast row houses is still the most protected one, which explains why pools E-H have low wind speeds (0.4-0.8 m/s).

Perpendicular wind gives slightly different results. When the incoming wind is 3.25 m/s, the wind speed over the community pool is the highest in the neighborhood, 4.8 m/s, since wind is funneled between the buildings north of the community pool and its speed increases exceeding the incoming wind speed (Fig 40). Regarding the hypothetical pools in the backyards, the northwest row of residences is blocked by the buildings on its windward side. Thus, the wind speeds over pools B and C are low, 0.3-0.4 m/s. Pool D and E, being at the very end of their respective rows of residences are partially exposed to the wind current flowing through the street at its windward side. Similarly, the northeast row of residences is exposed to the same wind current, and the wind speeds for pools F-H are higher than those of pools D, and E, since the current has reached its full speed. The southwest row of row houses is exposed to the current that hits the 2-story building in the south and bounces back. As a result, even though the neighboring buildings and the residences themselves could have protected the pools from high wind speeds, the building on the leeward side altered the overall performance. Furthermore, the southeast row of residences has low wind speeds, pool L has a 0.0 m/s wind speed.

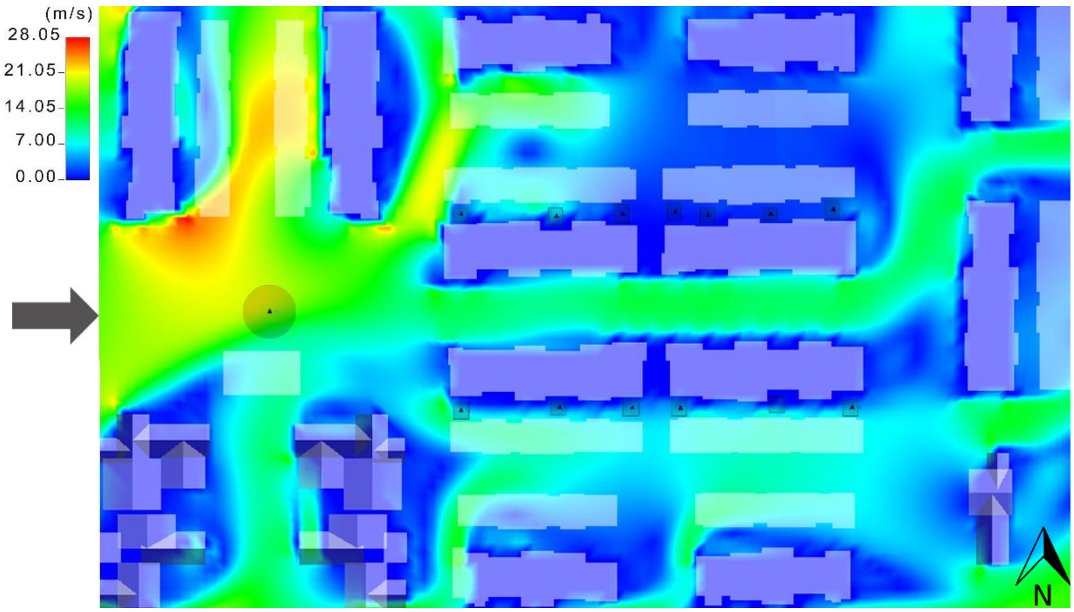


Fig. 39. Row houses, simulation for parallel wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When the perpendicular incoming wind has 6.25 m/s speed, the wind conditions are relatively similar, with a few exceptions (Fig. 41). The wind speed over the existing community pool reaches a record high of 9.8 m/s. This, again, is due to the funneling of the wind caused by the buildings on the pool's windward side. The northwest row of row houses has some points that are well protected, centroids of pools B and C, while the backyards next to its east side feature higher wind speeds. The backyards of the northeast row have the highest wind speeds observed in all backyard pools for these conditions. In particular, pool H, located on the edge of the row, is right on the spot where changes direction and increases its speed, leading to a speed of 6.6 m/s, higher than the incoming one. The lowest wind speed is found over pool N, 0.4 m/s, being protected by the 2-story row of residences in its windward side.

When the wind is NE, 3.25 m/s, each compact building of row houses performs differently (Fig. 42). First of all, the northeast row of houses of the block is protected by another block of row houses on its windward side which slow down the wind over the pools resulting in wind speeds ranging from 0,2 to 0,8 m/s. The minimum 0.2 m/s is for the pool in the middle of the backyard zone. This is not the case, though, for the northwest row of row houses. This row is exposed to the wind flowing through the street on its windward side. For this reason, the wind speeds are higher, ranging from 0.5 to 1.4 m/s. The southwest row of row houses is protected from the wind by the mentioned row of houses. Thus, the wind speeds are significantly lower, in fact, the lowest among all rows, being 0.0 -0.3 m/s. The southeast row of row houses, is partially protected by the northeast row of row houses, but its side is still unprotected. This is the reason why there is a current of higher wind speed over the backyard zone of this row of residences. It is worth mention the fact that the garages are not aligned with each other, rather they create depressions. These depressions, in turn, make wind slow down at such points. Besides, the free standing community pool has the maximum wind speed compared to the pools in the backyards.

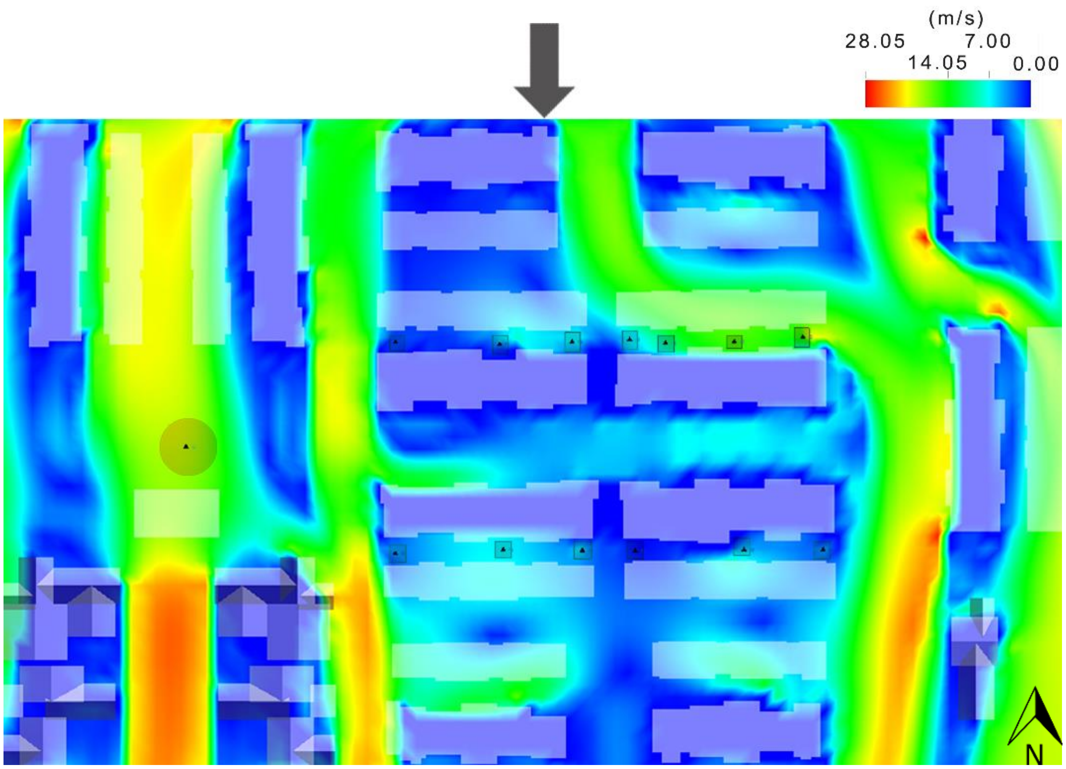


Fig. 40. Row houses, simulation for perpendicular wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

For oblique incoming wind with a wind speed of 6.25 m/s, the results are different at some points (Fig. 43). We can notice that a high speed wind current flows through the street between the north and the south part of this neighborhood. Additionally, regarding the backyards and the pools, the northeast row of row houses is again protected by another row of residences on its windward side. For this reason, the wind speeds for pools E-G are exactly the same as the ones for incoming wind of 3.25 m/s. This means that these pools are effectively protected, and are not easily affected by the wind speed for the given oblique wind direction. Pool H, however, since it is exposed to the wind current blowing from the street, has a higher wind speed this time, 2.2 m/s. The northwest part of the neighborhood is exposed to the wind coming through the street, and, for this, pool B and D have high wind speeds, 3.1 and 1.9 m/s respectively. Interestingly enough, pool C has low wind speed, since it is located in a small depression as mentioned earlier. The backyards of the southwest row of residences seem to be protected by the surrounding rows of residences, as well as from the 2-story residences themselves. However, a look at the wind simulation and the resulting wind speeds shows that, since rapid wind currents flow around the southeast row of residences, these backyards and pools experience higher wind speeds, 0.6-1.6 m/s. Furthermore, the southeast row of residences is exposed to higher speed wind, and this leads to the maximum observed wind speed for these wind conditions, 3.9 m/s, over pool N. The existing community pool's wind speed is 3.6 m/s, close to the maximum of 3.9 m/s. Pools L, M, however, have lower wind speeds, since they are partially protected by the row of 2-story residences on their windward side.

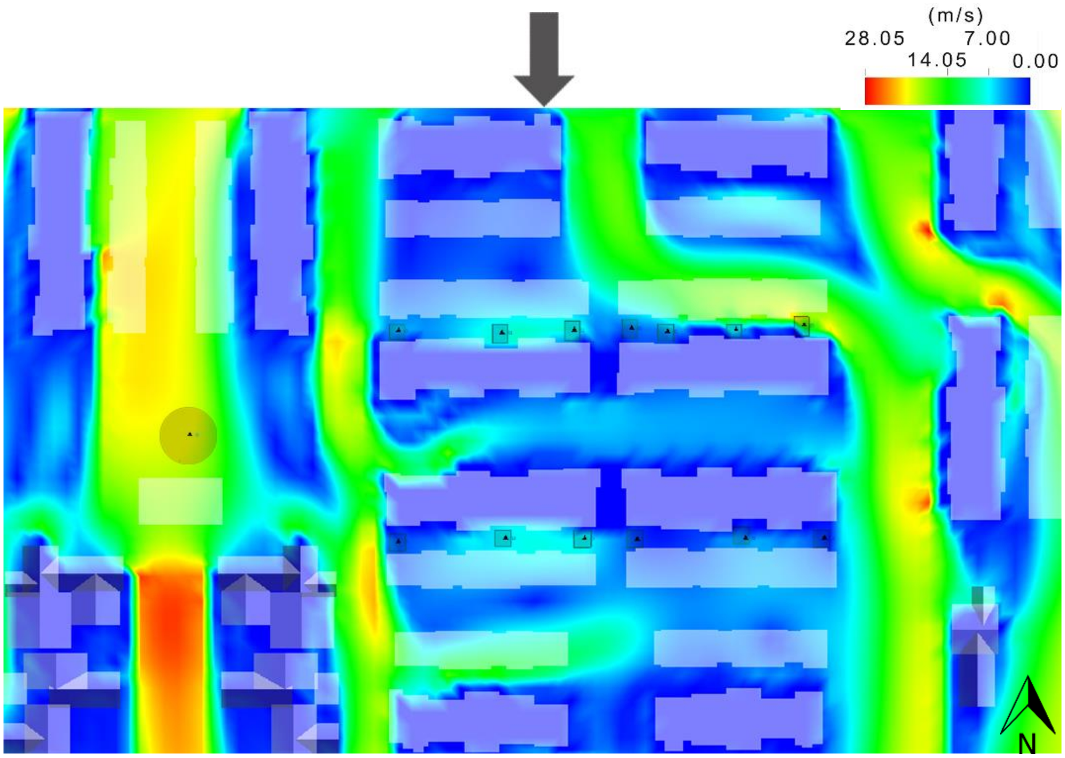


Fig. 41. Row houses, simulation for perpendicular wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

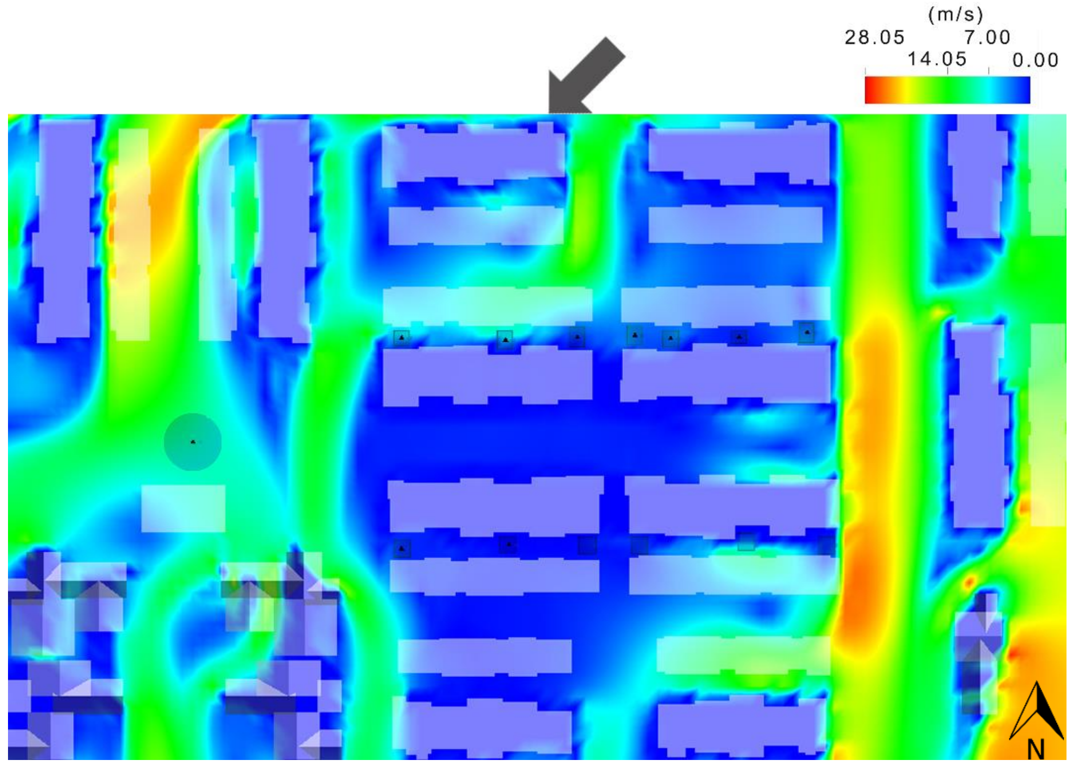


Fig. 42. Row houses, simulation for oblique wind of 3.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

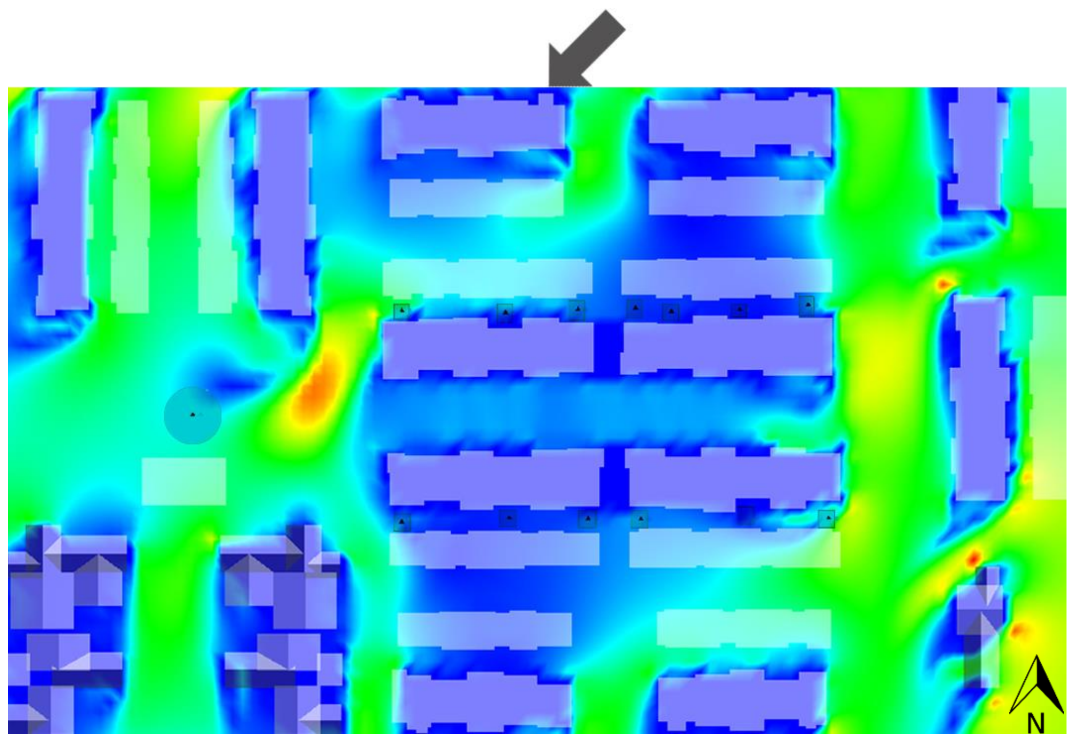


Fig. 43. Row houses, simulation for oblique wind of 6.25 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

Courtyard Houses

The selected neighborhood of courtyard houses is located in the California Climate Zone 9 (Table A 1, Figs. A 1,2), so the wind speeds that will be studied are 2.5m/s and 5.5 m/s (Table A6). Below are the results of the simulations for the two (2) different wind speeds and three (3) different wind directions. The swimming pools are highlighted and named (Fig. 44).

When wind is parallel to the block's main axis with a speed of 2.5 m/s, the wind is blowing through the neighborhood over the shorter of the buildings (Fig. 45). The complex around courtyard A is taller than the buildings on its windward side, and, thus, blocks the wind from penetrating its courtyard resulting in 0.0 m/s over its pool. Similarly, pools B, D and E have low wind speeds, 0.4, 0.0 and 0.0 m/s respectively. The rest of the pools of this block, however, fall inside stronger wind currents and their wind speeds are higher, ranging from 0.6-1.5 m/s. it is worth mentioning that the complete courtyard of pool H, even though it was expected to provide sufficient wind protection, does not perform very well for low incoming wind speed.

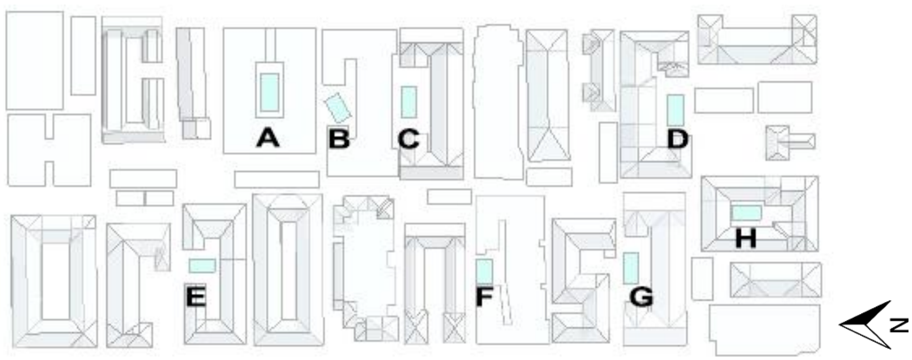


Fig. 44. Studied block of courtyard houses, pools are named and highlighted with cyan. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

For wind that is parallel to the main axis, but with a speed of 5.5 m/s the results are very different (Fig. 46). Due to the higher speed of the incoming wind, wind cannot penetrate the block with a high speed. Thus, the overall wind speed over the block is slower. Regarding the wind speed over the pools, the complete courtyards with pools A and H perform very well, with 0.0 m/s wind over their pools. Besides, the U-parti courtyards with pools B and E perform very well too, with a wind speed of 0.1 m/s above their pools. Even though the opening of the U-shapes of these courtyards is in their windward side, the surrounding buildings manage to protect them effectively since their surroundings are one story taller than the complex of the courtyard. The U-parti courtyards of pools C and F have their openings in their windward side, and are not protected from their surroundings since their surroundings are shorter than the complexes of courtyards C and F.

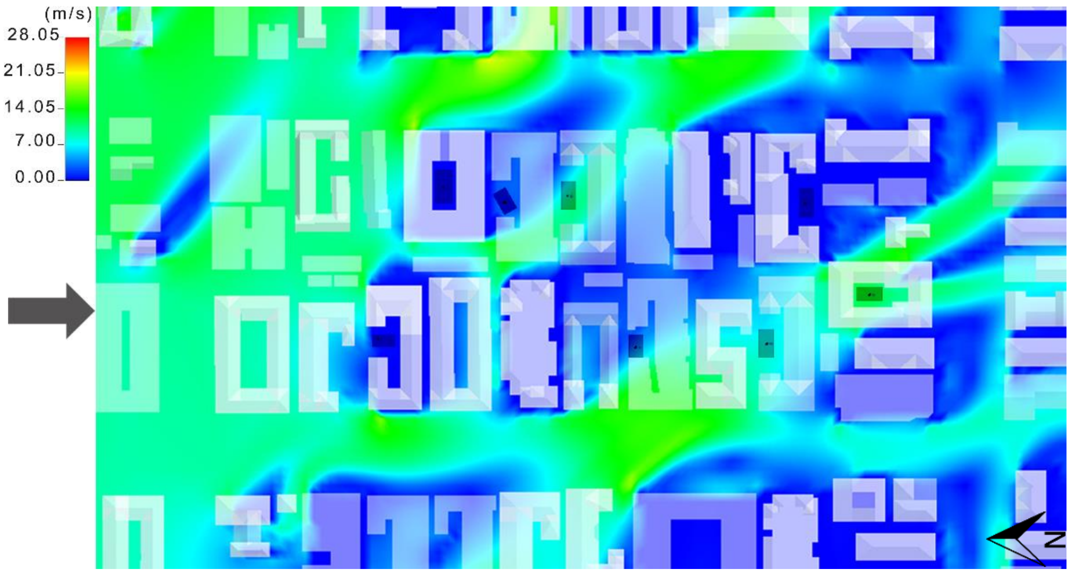


Fig. 45. Courtyard houses, simulation for parallel wind of 2.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

Fig. 46. Courtyard houses, simulation for parallel wind of 5.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When the incoming wind is perpendicular to the main, long axis of the block with a speed of 2.5 m/s (Fig. 47), there is a number of swimming pools that are successfully protected, with no wind blowing over their surfaces, 0.0 m/s wind speed, while others can reach up to 4.9 m/s, exceeding the incoming speed. The wind flows over the buildings east of the block and higher speed currents flow over the shorter of those buildings (opposite to pools B and D). It is worth mentioning that the difference in the height of the buildings is that of one floor with a gabled roof.

For this reason, wind reaching the courtyard complex with pool B is of higher speed resulting in a very high wind speed over the pool itself, 4.5 m/s. However, pools A and H, being surrounded by the houses all around the courtyard, are fully protected and feature 0.0 m/s wind speed above their surfaces. Similarly, pool C has very low wind speed, 0.4 m/s, which is explained by the fact that the courtyard is slightly taller than its adjacent ones, keeping away high speed currents. Yet, the only height difference is in the roof, since the courtyard with pool C has a roof that extends above the level of courtyard B's rooftop. It is worth noticing that the high speed current is blocked at the very edge of courtyard C's roof. Courtyards D and E have low incoming speeds and since their pools are protected from their respective windward sides by their courtyard, the speed above these pools is zero. Furthermore, the high speed wind current that flows over the complete courtyard opposite to the courtyard with pool D flows over some lower buildings of the studied block. Despite that, pools F and G have relatively low wind speeds, wince they are surrounded by buildings in a very short distance.

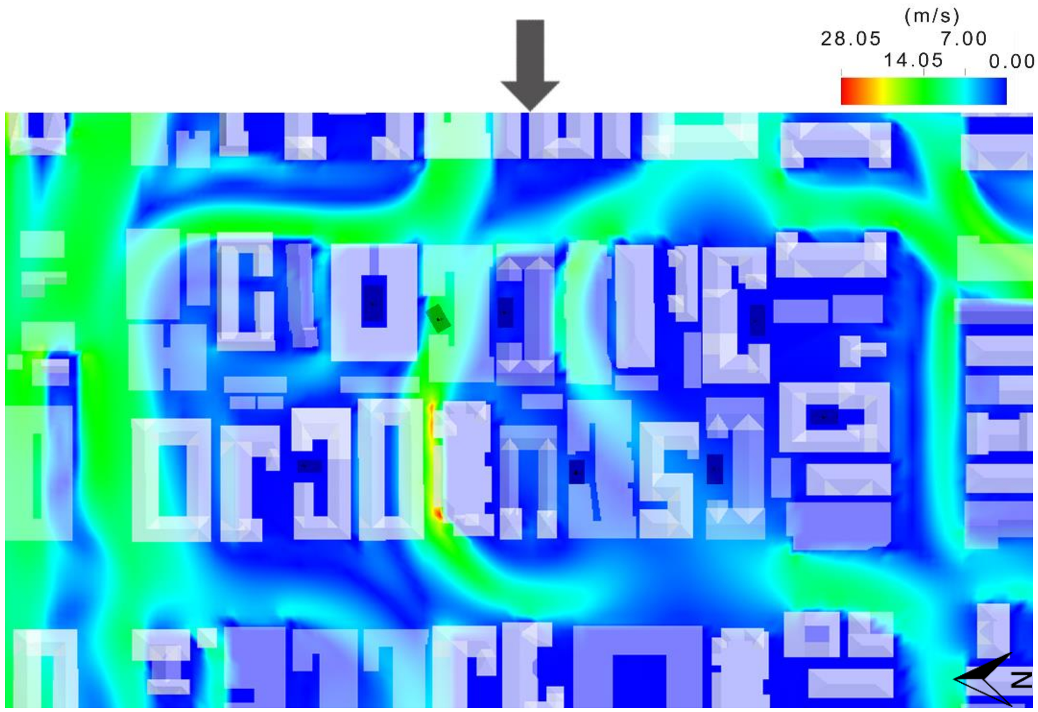


Fig. 47. Courtyard houses, simulation for perpendicular wind of 2.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

When wind is still perpendicular but has a speed of 5.5 m/s (Fig. 48), pools A and H are again successfully protected since they are inside complete courtyard houses that are higher than the surrounding buildings and, for this reason, effectively block the wind. This is why the swimming pools in those complete courtyards have a wind speed of 0.0 m/s above their surfaces. Yet, even pool D has 0.0 m/s wind speed, even though it's not protected from all four sides. This is because the three parts of the courtyard house of pool D, as well as the building right next to it are higher than their surrounding buildings, thus blocking the wind and keeping the surface wind conditions unaltered. For the same reason, the wind currents flowing over the lower buildings opposite to the studied block have higher speed, so pools B and F have higher wind speeds than for a lower incoming wind, 11.3 and 3.6 m/s instead of 4.5 and 0.8 m/s respectively. Pool E is right on the edge of being exposed to stronger wind due to the passage between its courtyard houses and the building next to it that funnels strong winds. Interestingly enough, pool G has lower wind speed when incoming wind is stronger. This is probably because the courtyard is elongated on the axis parallel to the direction of the incoming wind. In this way, when the wind is slow, it manages to create turbulence below the roof level and in the courtyard, whereas when the wind is blowing more quickly over the courtyard, it cannot manage to affect the surface wind speed so much. Additionally, the complete courtyard next to the courtyard of pool E, even though it is a complete one, it does not provide sufficient wind protection to its courtyard because it is one story shorter than the buildings next to it, letting strong wind that is blocked by the taller surroundings blow inside the courtyard. In general, though, the complete courtyards can perform very well for this wind direction, for both wind speeds, when they are not shorter than their surrounding buildings. The U-parti courtyards can be more vulnerable to the wind variations, especially when they are lower than their surroundings.

When wind is blowing oblique, 45º (Fig. 49), to the main axis of the block, and with a speed of 2.5 m/s, the resulting wind speeds are similar to the ones for perpendicular wind of the same speed. The taller buildings inside and around the studied neighborhood block the wind, which in turn blows above shorter buildings only, this time, stronger. For this, pool A and H feature 0.0 m/s wind speed even this time. It is interesting to see how all the U-shape courtyard houses of the same orientation, like the courtyard houses with pools B, C, E, and F perform differently depending on their height, surroundings, speed and direction of wind. Taller courtyard houses can efficiently block wind, but this also depends on the speed of the incoming wind.

For oblique wind of a 5.5 m/s speed, the edges of the strong wind currents are better defined (Fig. 50). In particular, the strong incoming wind blows through the passages of the buildings on the windward side of the studied block and continue through another passage over a short building in the block, complex of courtyard houses with pool B. From there, strong wind hits the corner of a tall building and breaks into two branches following the corner’s two sides. This way, the strong wind does not penetrate a lot of courtyards. In particular, the maximum wind speed is over pool B, which happens to be where the strong wind current blows through. Another pool that experiences high surface wind speed is pool C which is on the path of a relatively strong wind current, less strong than the first one, though, with the resulting speed being 2.1 m/s. The rest of the pools however, have surface wind speeds of 0.0 -0.8 m/s. This is caused by the fact that the spacing between the complexes of courtyard houses is successful in keeping strong winds away, and creating milder wind conditions.

All in all, the courtyard houses have the potential to perform very well, managing to achieve 0.0 m/s winds over their pools. However, a lot of factors could lead to higher wind velocities and evaporation rates. Some of them are the height of the courtyard houses, the dimensions of the courtyard, the heights of all the block’s buildings, as well as the orientation of each courtyard in relation to the incoming wind.

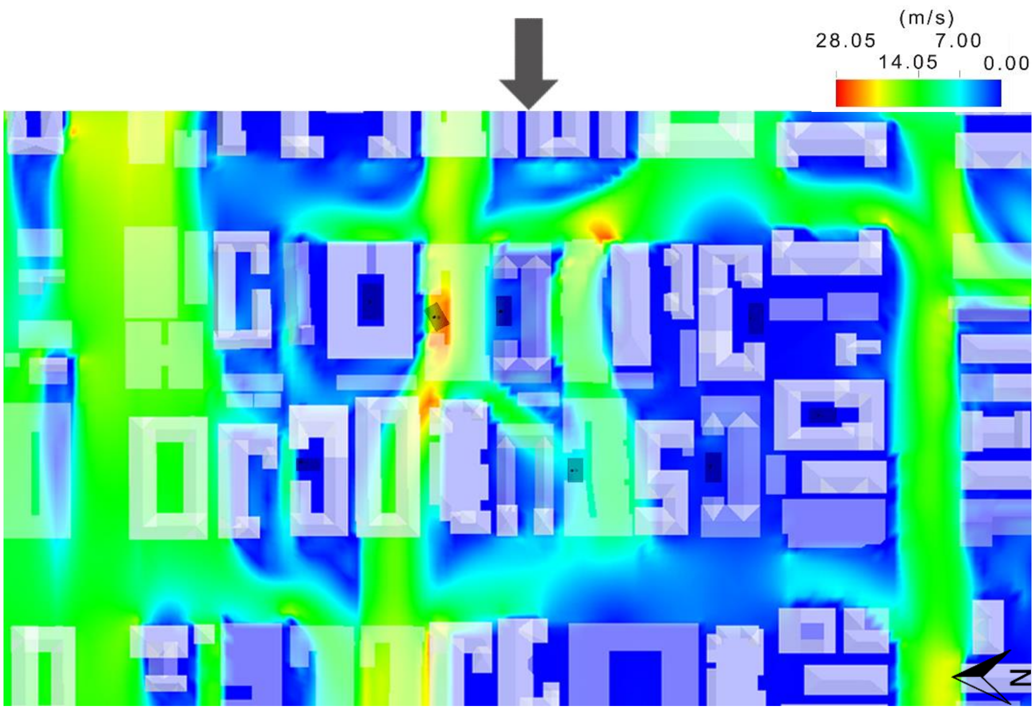


Fig. 48. Courtyard houses, simulation for perpendicular wind of 5.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

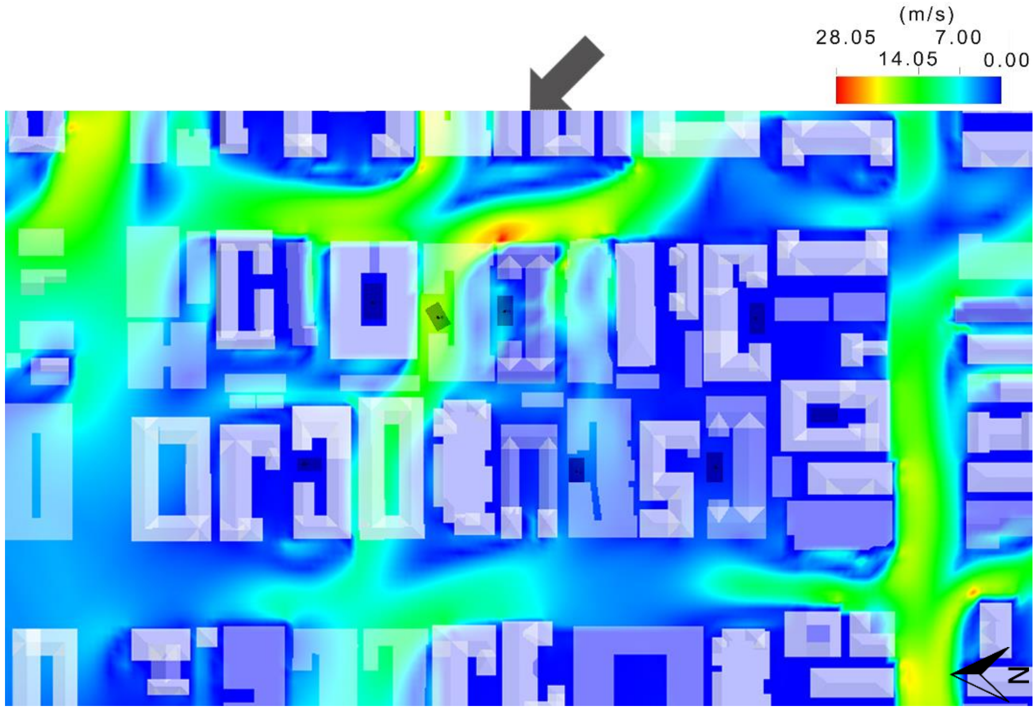


Fig. 49. Courtyard houses, simulation for oblique wind of 2.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

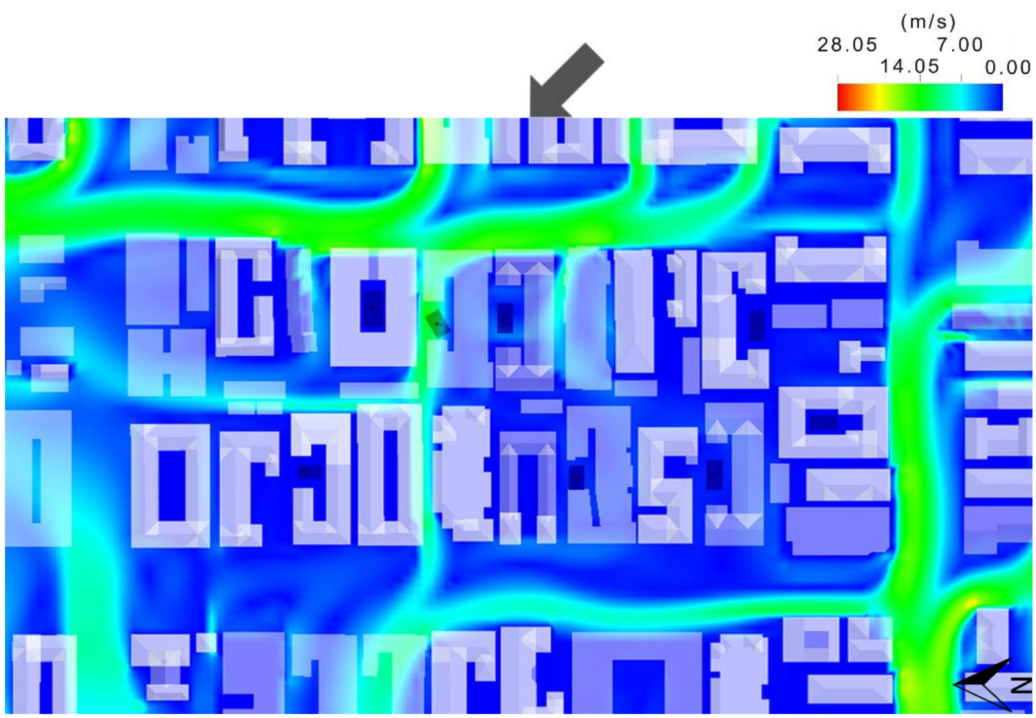


Fig. 50. Courtyard houses, simulation for oblique wind of 5.5 m/s. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

CHAPTER V

DISCUSSION AND FURTHER RESEARCH

Discussion

Looking back to the results of all the cases studies and their simulations, as well as the initial anticipated results associated with them, it is shown that the evaporation rate of the studied residential swimming pools is, indeed, affected by the type of residences surrounding it. Yet, not all of the initial anticipated results regarding the evaporation performance of the specific neighborhoods that were studied were proven right. In fact, the ranking of the neighborhoods based on their expected evaporation ratios is very different from the respective ranking based on the final results, as shown in Fig. 51.

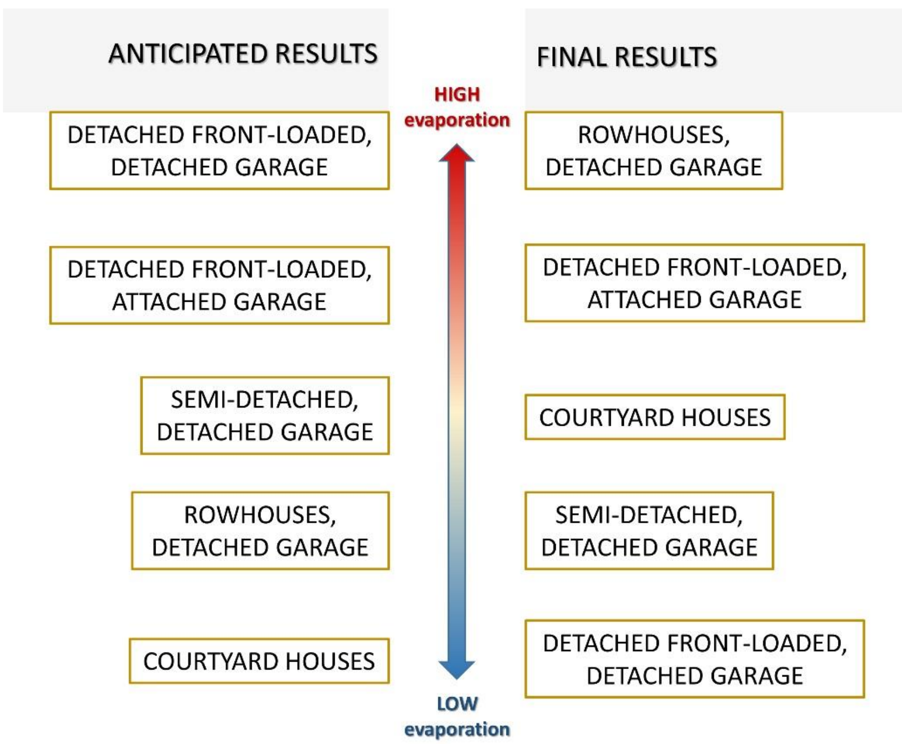


Fig. 51. Ranking of the housing types according to the anticipated and the final results.

More important than ranking the neighborhoods are the circumstances under which the resulting evaporation ratios tend to be lower or higher, indicating that we have identified a solution or a problem, respectively. Below, a review and explanation of the evaporation results is attempted.

First of all, regarding the overall performance of each housing type, the front loaded residences with detached garage performed better than expected, and, surprisingly enough, even better than the front loaded residences with attached garage (Table A 2, Fig. A 7-11). Even though the spacing between neighboring houses in the former type was greater than in the latter, the results show that the garages in the backyards of the residences with detached garage slowed down the wind and lowered the evaporation rate. The anticipated results were, thus, proven wrong, since the detached garages performed better. However, there are still points in the neighborhood of the front loaded houses with the detached garages that do not have low wind speeds and, thus, their pools have higher evaporation rates. Such points are close to the unprotected sides of the block or aligned with gaps in the surrounding blocks. Consequently, careful planning is needed to minimize the large unprotected gaps in both the blocks that are studied, and their neighboring ones.

The next housing type according to the evaporation performance, is the semi-detached residence with detached garages (Table A 4, Figs. A 17-21). Contrary to what was expected, the semi-detached residences performed better than the front loaded with attached garages. Of course, the swimming pools were hypothetical in the neighborhood of this housing type, but with careful design and planning this could be realized. The fact that the backyard zone, between the garages and their associated residences, in the semi-detached type is greater than the backyard zone, between two facing residences, in the front-loaded with attached garage, led to better wind protection, and lower evaporation rates in the pools of the semi-detached houses. Even though each residence is taller than the garage itself, it turned out that the garages, being placed close to the pools, managed to protect them from the wind effectively. Thus, the dimensions of the outdoor space where the pools are located are highly important, since they affect the microclimate, in terms of wind conditions, around and over the swimming pools.

The housing type that is next, based on the evaporation performance, is the courtyard house (Table A 6, Figs. A 27-31). Even though this type of housing was expected to give the lowest evaporation rates out of all the studied types (Fig. 46), and did in some of its pools, spikes of high resulting wind speeds were found in the performance of the pools of the studied neighborhood of courtyard houses. This means that the courtyard housing has the potential of achieving a very low evaporation rates under specific circumstances, since there were indeed many pools that reached the minimum of 0,0 m/s. However, in the studied neighborhood, there were specific courtyard houses that performed very poorly and should be avoided. These mainly were courtyard houses where the courtyard's main axis was aligned with the direction of the wind blowing over it. This means that along the direction of the wind the dimension of the courtyard was greater, and let wind currents penetrate it. Therefore, careful planning is needed in order to avoid high evaporation rates caused in such cases. When it comes to designing a masterplan for a particular area, taking into account the wind data would prove very helpful. What's more, the height of the courtyards in terms of in comparison to the rest of the courtyard houses' dimensions as well as in comparison to the heights of the surrounding buildings is highly important. Besides, the shape of the courtyards, U-shape or Complete, seems to play an important role in determining the evaporation performance of their swimming pools.

Right next in order of the evaporation performance, from high to low, is the detached front-loaded residence with attached garage (Table A 3, Figs. A 12-16). This residential type gives low evaporation rates for some of the tested wind conditions. There are a few pools that performed well, especially for the mean incoming wind speed, indicating that their location was effectively protected from the wind. However, the wind speeds over the pools were highly affected by the wind direction for the average high wind speed, meaning that the wind blocking was not efficient for such an incoming wind speed. In such cases, where the pools cannot be easily protected from all sides, the frequency of the various wind directions and speeds for the studied location, should be taken into account, in order to determine which sides are more prone to letting wind blow rapidly over the pool and increase pool water evaporation.

The last type in terms of evaporation performance is the row house with detached garage (Table A 5, Figs. A 22-26). This residential type has the least desired evaporation performance. Some of the pools have spikes of extremely high evaporation rate. In particular, the wind speed over those pools is higher than the incoming wind speed meaning that the surroundings of those pools not only fail to provide wind protection, but they also make it increase. Besides, it is worth noticing that the backyards and garages are in the outer part of the studied block. At the same time the backyard zone is unprotected from both its open sides. The above reasons seem to make the neighborhood prone to wind currents penetrating through those open ends. However, the rows of row houses that were in the leeward side of the block, depending on the wind direction of each simulation, had very low wind speeds, which means that effective wind protection from the windward side of the block, and not just the windward side of the pool, makes a difference in the pools' evaporation rates.

What's more, the evaporation rates of the existing community swimming pool are of particular interest when compared to the rates of the pools in the backyards. It is evident that letting a swimming pool unprotected from all sides leads to an extremely high water consumption. This, again, proves the research hypothesis that the surroundings of the buildings, in this case regardless of the housing types, directly affect the evaporation of the pool water. However, a community pool means that there will be less private pools in the entire community. Decreasing the number of swimming pools should always be considered, while, at the same time, increasing the number of occupants these swimming pools can be used by. Consequently, a balance should achieved between the number of pools in a community and their level of wind protection.

In general, it is worth noticing that protrusions of volumes in the facades can alter the wind current and create islands of lower or higher wind speed. Similarly, depressions create areas protected by the wind, so swimming pools placed there can be less affected by the changes in the wind speed, as specifically noticed in the depressions of the row houses. Besides, in many of the studied cases, the passages and gaps between the buildings across the street, as well as the heights of buildings of the surrounding blocks directly affected the wind conditions over the block and, thus, even the pools. So, with proper planning we could slow down wind at the lower levels before it even reaches the area with the swimming pools, creating a "cloud" of slower winds in the area surrounding the swimming pools.

Additionally, regarding the neighborhoods that had backyard zones in their inner part, when the incoming wind was parallel to the axis of this backyard zone, the presence of relatively large volumes, like garages or residences, either inside the zone of the backyards (Figs. 15,16), or even further outside of the block (Figs. 22,24) can significantly reduce the wind speed over the pools. Besides, as noticed in the row houses (Fig. 38) wind obstacles can protect the open sides of the blocks by leading wind to another direction and not necessarily slowing it down.

On the other hand, it is interesting to see (Figs. 31,32) that even with a corridor perpendicular to the wind speed crossing the backyard zone, the wind speed over the pools in its leeward side were only partially affected. In fact, the wind speed over the pools was not affected for the lowest of the tested incoming speeds. Thus, it is proven that even fences, which are significantly smaller in size, and often times are easily penetrated by the wind, should not be considered to have significant impact on the wind speed over their neighboring pools.

When it comes to strategically planning for a specific area, prevailing winds in terms of direction and speed, should be considered. Only in cases of housing types or particular residences where wind protection cannot be provided from all sides, wind protection for the direction and speed of prevailing winds should be chosen and the suggested design should aim to minimize evaporation for those at first. Similarly, when it comes to determining the proper dimensions and proportions of the residences in a neighborhood with pools, the most common wind speeds should be taken into account as well, since residences of a given proportion feature entirely different performances for different incoming wind speeds.

As noticed in the first housing type as well as the courtyard houses, the fact that there is a form of wind protection in all four sides of the pools does not necessarily mean that the evaporation is reduced for every wind direction and speed. Instead, as the simulations of the semi-detached houses showed, the geometry of the wind breaks, as well as their distance to the pool(s) they are protecting highly affects the evaporation of the pool water. In particular, regarding the backyard zones with swimming pools, regular wind breaks of proper sizing could ameliorate the performance of the neighborhoods, slowing wind down over the pools, for every wind direction. Those breaks would act the same way as the detached garages in the first case study in order to minimize the wind speed.

At the same time, we can achieve low wind speeds even for high incoming wind speeds, though, careful design and placement of the pools on strategic points is required. Among the case studies of the present study, only the front-loaded with detached garages and the courtyard houses achieved low wind speeds for every wind direction, when the incoming wind speed was the average high. This means, that these types have the highest potential to have low evaporation rates for every wind direction and speed. In the rest of the studied housing types, only a few pools were found to have zero evaporation. And even those pools had zero evaporation rate only for specific wind conditions, meaning that we cannot conclude that they are effectively protected.

The fact that planners should aim for low wind speeds and evaporation rates does not mean that the wind speed should be low all over the designed area. Instead, it is a matter of strategy to pick regions where pools will be located at and protect only those from the wind. At the same time, other regions could be used to exhaust wind of higher speed. These can be areas where no pools are located. As in the case of the front loaded houses with detached garages, if the pools were protected from the wind blowing through the passage between the garages, i.e. with wind obstacles parallel to the passage, then the evaporation rates in the block's pools would be low despite the high wind speeds in the core of the block.

Last but not least, if we take a look at Equation 5 as well as the resulting diurnal water loss tables, we will notice that even for 0,0 m/s wind over the pools, there is still a minimum amount of water that evaporates. This makes the need to minimize the wind speed over the pools even more important, since there is no way we can entirely eliminate evaporation water losses.

Further Research

This present study managed to simulate a few of the many housing types that are found in Los Angeles, and in United States in general. Regarding the size of the sample, more housing types could be tested. In this way, we could see if more of the existing housing types perform well, or to just look out for particular cases that have good performance, which when systemically implemented can have an impact on the water consumption of large communities.

The roof geometry and the way it affects the wind currents needs to be examined. In other words, the aerodynamics of the surroundings of the pools and the way it affects the ground wind speed need to be studied further. It is possible that proper roof planning could provide a level of wind protection above the swimming pools, reducing the need for extra wind protection by other means, like fencing and vegetation.

Similarly, variations in the geometry of the residences of a given housing type should be studied, in order to examine how these variations affect the overall evaporation in the pools, not just of their own backyard, but all around the block. Changes in the width, height, and length of the residences in a given block, with the surroundings remaining the same, could shed light on the residential forms that ensure evaporation in pools is kept low.

Nonetheless, the goal of this present study was the minimization of water consumption in swimming pools, and one of the assumptions was that loss of water through evaporation is a waste to be avoided. However, when not in extreme rates, water evaporation from the pools could be useful to control indoor air temperature and quality through increasing relative humidity, in non-humid climates. With careful planning, the moist air with water vapor from the pools could be directed inside the residences for natural ventilation, reducing the need for mechanical air-conditioning.

What's more, it is interesting to see what individual owners could achieve in order to minimize their pool's evaporative losses. When studying existing residences, and no masterplans of new residential projects, then the building and backyard's microscale gets ever more important. Water-smart design then should focus on the building's scale and not the urban one. In this case, the surrounding vegetation, small-scale structures that affect the backyard's microclimate, like shading of the pool, could make a difference.

Besides, in terms of methodology, simulating the wind pressure, as well as the wind direction, on various residential types could enrich the results. In this way, one could trace the detailed route of the wind currents and, thus, identify possible solutions to alter this route by strategically blocking or letting wind blow through given points. Thus, specific design suggestions can be made to improve the evaporation performance of the swimming pools.

Furthermore, the fact that swimming pools in California are required by law to use only potable water and not water of lower quality is something that needs further study. Given that the potable water sources are decreasing, the government could allow for water of high quality to be used instead of potable water. To this end, purified rainwater or reclaimed water seem to be good alternatives to potable water provided that their purification process will meet specific criteria set by scientists and the government.

To conclude, with this study, an attempt was made to address a gap in the literature concerning water consumption in outdoor swimming pools caused by evaporation. No other studies were found to deal with the relation of the pools to their surroundings, and, this study proved that indeed the pool water evaporation is affected by the buildings surrounding the pool. Hopefully, this research will succeed in engaging more researchers or designers with this important contemporary environmental issue.

APPENDIX A

DEFINITIONS

Densification: increasing the numbers of housing units or commercial facilities build per acre of land, with the goals of increasing the efficiency of land use and reducing the overall impact of growth (Roseland et al. 1998).

DU/AC (Dwelling Units/Net Acre): density indicator that calculates the density of dwellings per residential land area (Ellis 2004).

Evaporation: a dynamic process which represents the net difference between the number of water molecules leaving a surface and the number returning to the surface during some unit of time (Anderson 2015).

Vapor Pressure Deficit (VPD): the difference between the saturation water vapor pressure and the ambient water vapor pressure at the same temperature: $VPD = p_w - p_s$. (U.S. Department of Agriculture Forest Service 1992).

Water Vapor Pressure: a measure of the quantity of present water vapor, expressed in units of pressure, or in units of weight (Anderson 2015).

APPENDIX B

TABLES AND SUPPLEMENTARY FIGURES

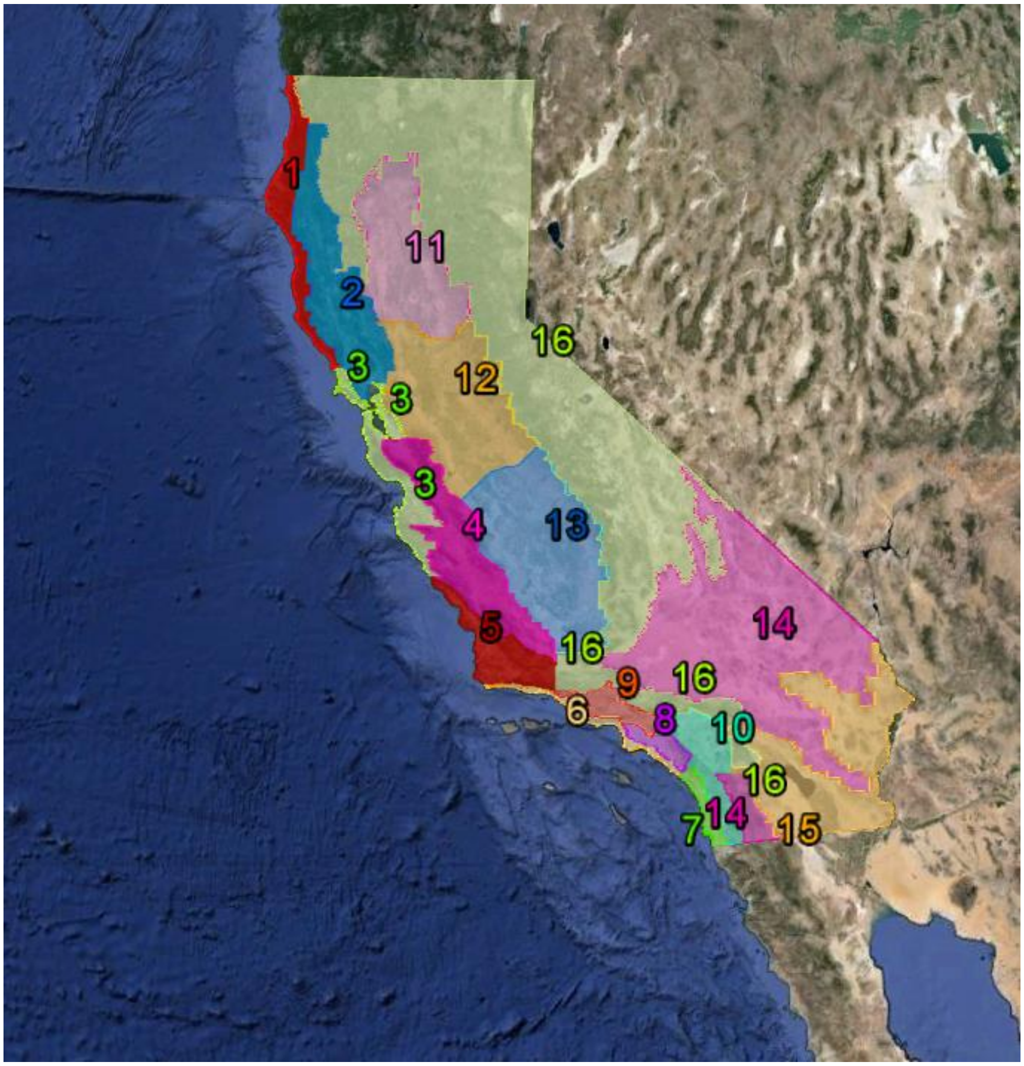


Fig. A 1. California Building Climate Zone Areas, adapted by Google Maps, Imagery and Map Data: ©2015 Google, SIO, NOAA, U.S. Navy, NGA, GEBCO, Landsat, and California Energy Commission

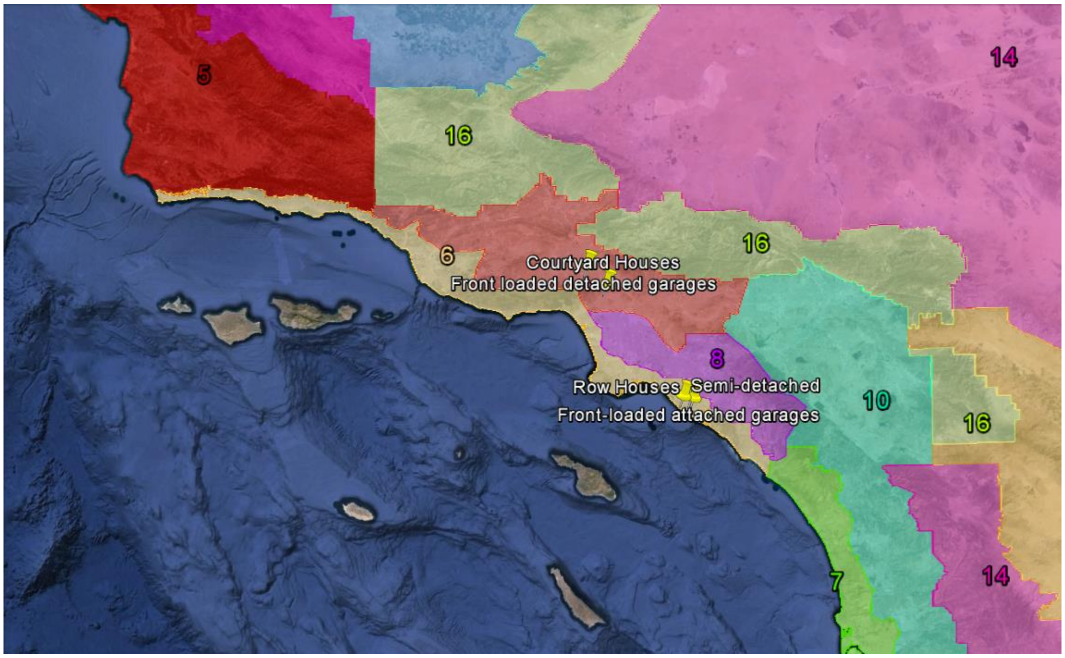
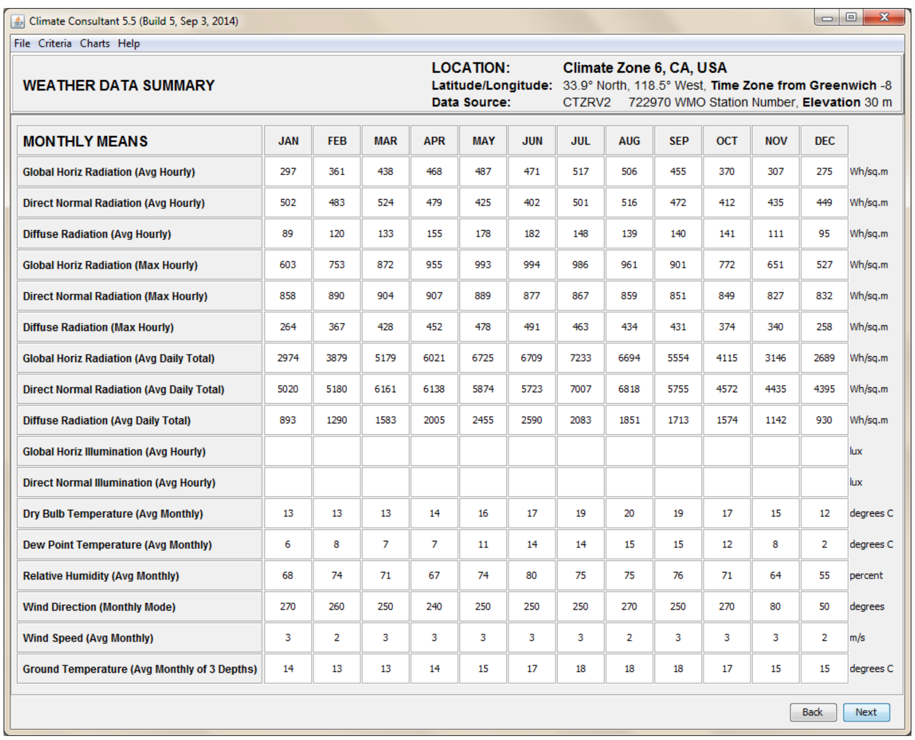


Fig. A 2. Case studies and California Climate Zones, adapted by Google Maps, Imagery and Map Data: ©2015 Google, LDEO-Columbia, NSF, NOAA, U.S. Navy, MBARI, SIO, NGA, GEBCO, Landsat, and California Energy Commission



MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	297	361	438	468	487	471	517	506	455	370	307	275	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	502	483	524	479	425	402	501	516	472	412	435	449	Wh/sq.m
Diffuse Radiation (Avg Hourly)	89	120	133	155	178	182	148	139	140	141	111	95	Wh/sq.m
Global Horiz Radiation (Max Hourly)	603	753	872	955	993	994	986	961	901	772	651	527	Wh/sq.m
Direct Normal Radiation (Max Hourly)	858	890	904	907	889	877	867	859	851	849	827	832	Wh/sq.m
Diffuse Radiation (Max Hourly)	264	367	428	452	478	491	463	434	431	374	340	258	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	2974	3879	5179	6021	6725	6709	7233	6694	5554	4115	3146	2689	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	5020	5180	6161	6138	5874	5723	7007	6818	5755	4572	4435	4395	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	893	1290	1583	2005	2455	2590	2083	1851	1713	1574	1142	930	Wh/sq.m
Global Horiz Illumination (Avg Hourly)													lux
Direct Normal Illumination (Avg Hourly)													lux
Dry Bulb Temperature (Avg Monthly)	13	13	13	14	16	17	19	20	19	17	15	12	degrees C
Dew Point Temperature (Avg Monthly)	6	8	7	7	11	14	14	15	15	12	8	2	degrees C
Relative Humidity (Avg Monthly)	68	74	71	67	74	80	75	75	76	71	64	55	percent
Wind Direction (Monthly Mode)	270	260	250	240	250	250	250	270	250	270	80	50	degrees
Wind Speed (Avg Monthly)	3	2	3	3	3	3	3	2	3	3	3	2	m/s
Ground Temperature (Avg Monthly of 3 Depths)	14	13	13	14	15	17	18	18	18	17	15	15	degrees C

Fig. A 3. Weather Data for California Climate Zone 6, still from Climate Consultant 5.5 developed by the UCLA Energy Design Tools Group, used with permission by the UCLA Energy Design Tools Group, ©2014 Regents of the University of California

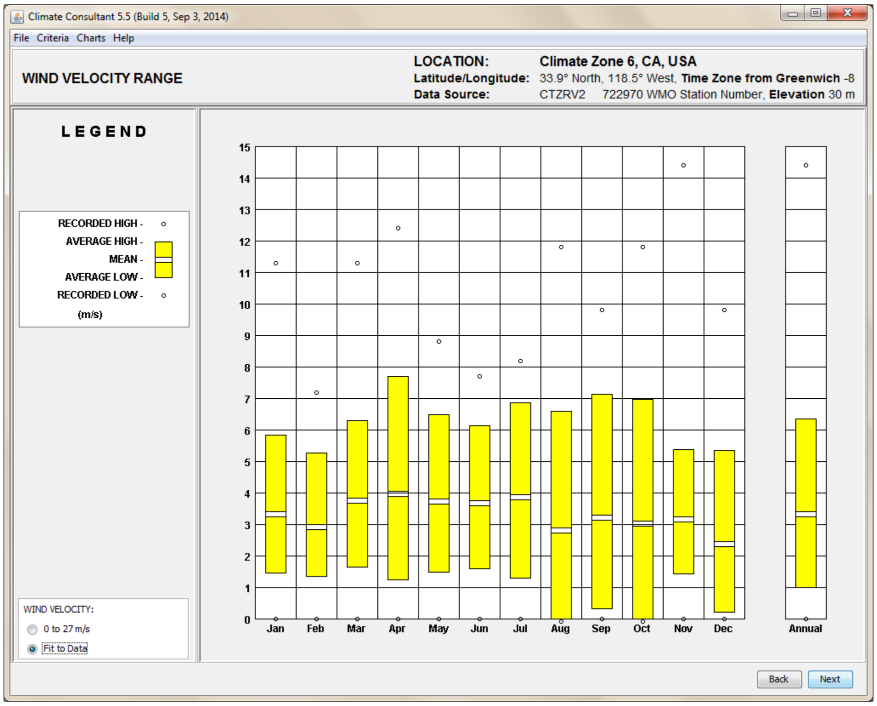
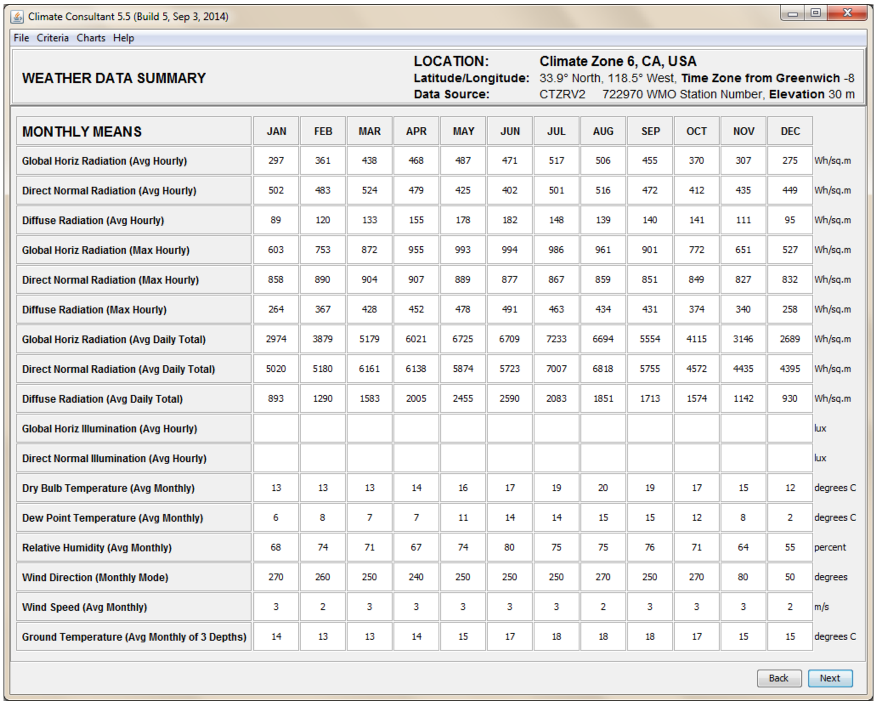


Fig. A 4. Wind velocity range for California Climate Zone 6, still from Climate Consultant 5.5 developed by the UCLA Energy Design Tools Group, used with permission by the UCLA Energy Design Tools Group, ©2014 Regents of the University of California



Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

WEATHER DATA SUMMARY

LOCATION: Climate Zone 6, CA, USA
Latitude/Longitude: 33.9° North, 118.5° West, **Time Zone from Greenwich** -8
Data Source: CTZRV2 722970 WMO Station Number, **Elevation** 30 m

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	297	361	438	468	487	471	517	506	455	370	307	275	Wh/sq.m
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Diffuse Radiation (Max Hourly)	264	367	428	452	478	491	463	434	431	374	340	258	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	2974	3879	5179	6021	6725	6709	7233	6694	5554	4115	3146	2689	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	5020	5180	6161	6138	5874	5723	7007	6818	5755	4572	4435	4395	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	893	1290	1583	2005	2455	2590	2083	1851	1713	1574	1142	930	Wh/sq.m
Global Horiz Illumination (Avg Hourly)													lux
Direct Normal Illumination (Avg Hourly)													lux
Dry Bulb Temperature (Avg Monthly)	13	13	13	14	16	17	19	20	19	17	15	12	degrees C
Dew Point Temperature (Avg Monthly)	6	8	7	7	11	14	14	15	15	12	8	2	degrees C
Relative Humidity (Avg Monthly)	68	74	71	67	74	80	75	75	76	71	64	55	percent
Wind Direction (Monthly Mode)	270	260	250	240	250	250	250	270	250	270	80	50	degrees
Wind Speed (Avg Monthly)	3	2	3	3	3	3	3	2	3	3	3	2	m/s
Ground Temperature (Avg Monthly of 3 Depths)	14	13	13	14	15	17	18	18	18	17	15	15	degrees C

Back Next

Fig. A 5. Weather Data for California Climate Zone 9, still from Climate Consultant 5.5 developed by the UCLA Energy Design Tools Group, used with permission by the UCLA Energy Design Tools Group, ©2014 Regents of the University of California

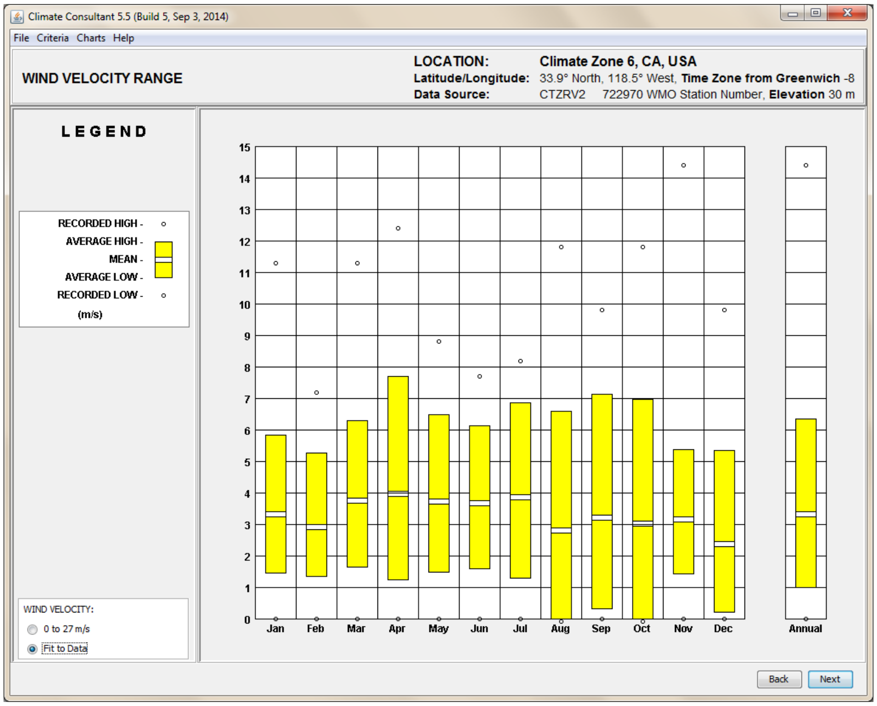

Fig. A 6. Wind velocity range for California Climate Zone 9, still from Climate Consultant 5.5 developed by the UCLA Energy Design Tools Group, used with permission by the UCLA Energy Design Tools Group, ©2014 Regents of the University of California

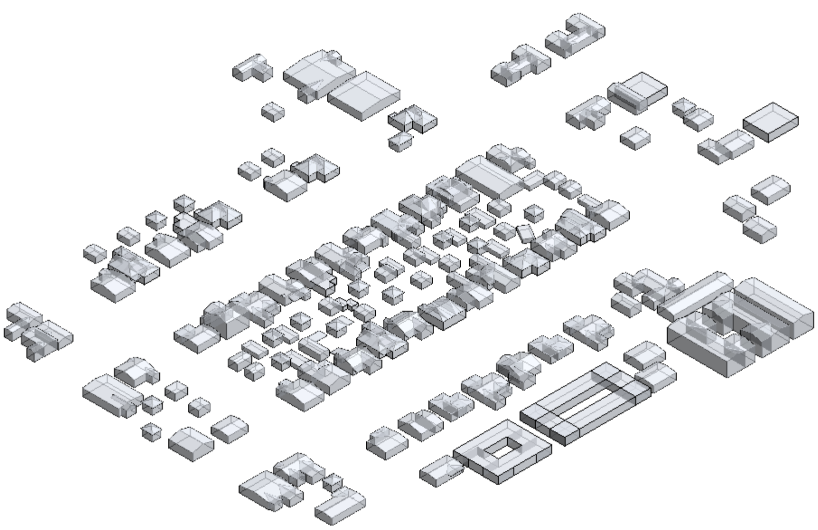

Fig. A 7. Front loaded residences with detached garages, axon. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

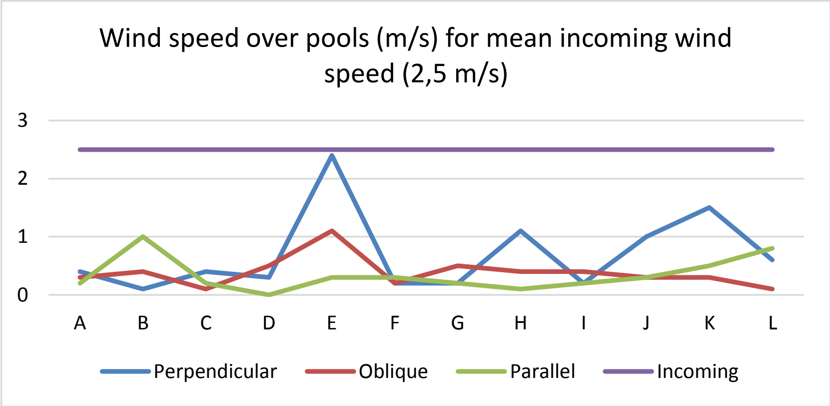

Fig. A 8. Front loaded residences with detached garages, diagram of wind speeds over pools for mean incoming wind speed.

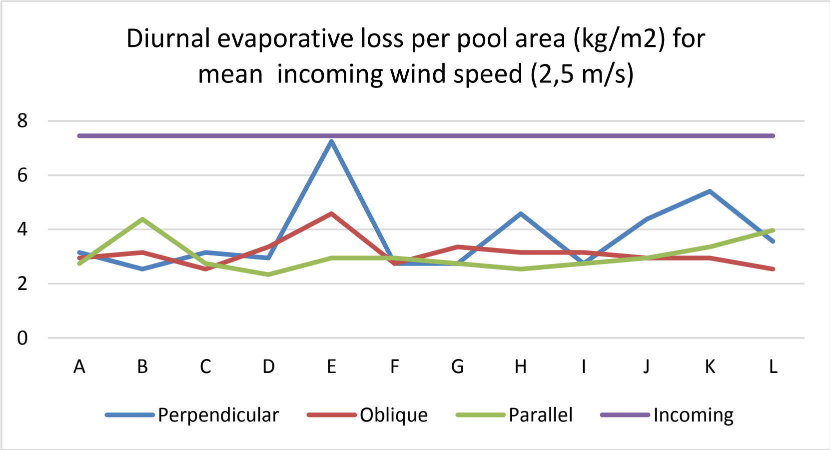

Fig. A 9. Front loaded residences with detached garages, diagram of diurnal evaporative loss for mean incoming wind speed.

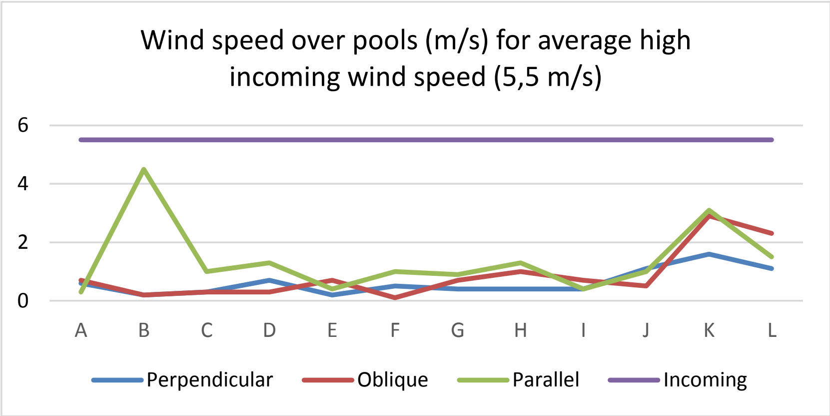

Fig. A 10. Front loaded residences with detached garages, diagram of wind speeds over pools for average high incoming wind speed.

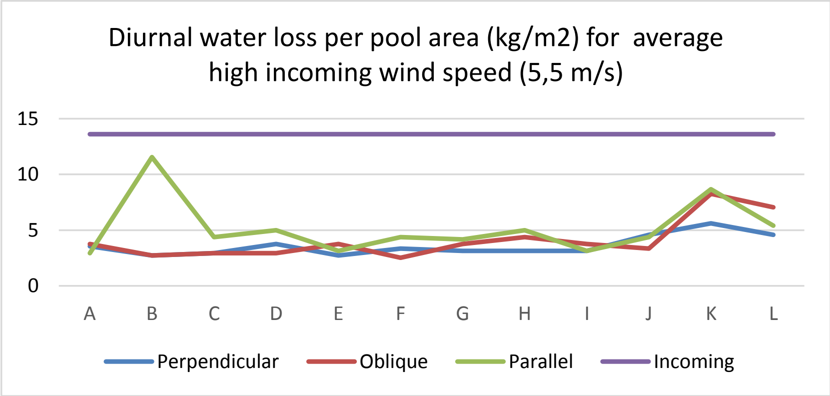

Fig. A 11. Front loaded residences with detached garages, diagram of diurnal evaporative loss over pools for average high incoming wind speed.

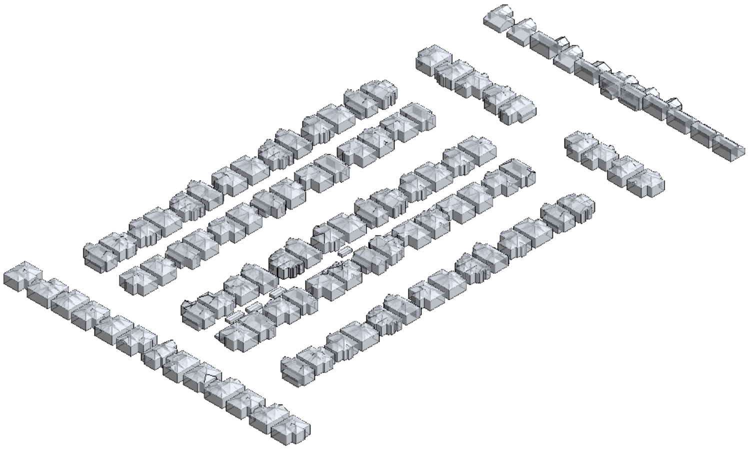

Fig. A 12. Front loaded residences with attached garages, axon. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

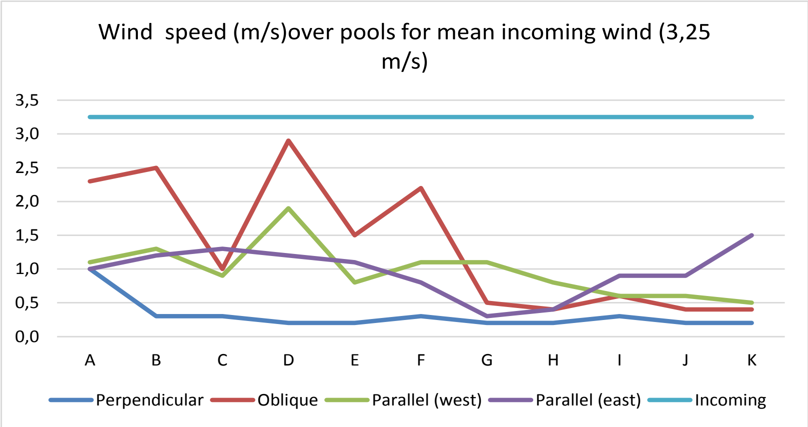

Fig. A 13. Front loaded residences with attached garages, diagram of wind speeds over pools for mean incoming wind speed.

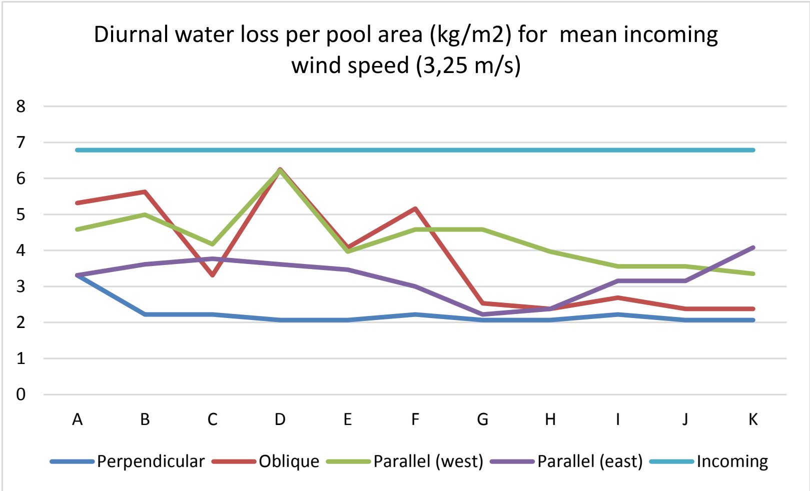

Fig. A 14. Front loaded residences with attached garages, diagram of diurnal evaporative loss over pools for mean incoming wind speed.

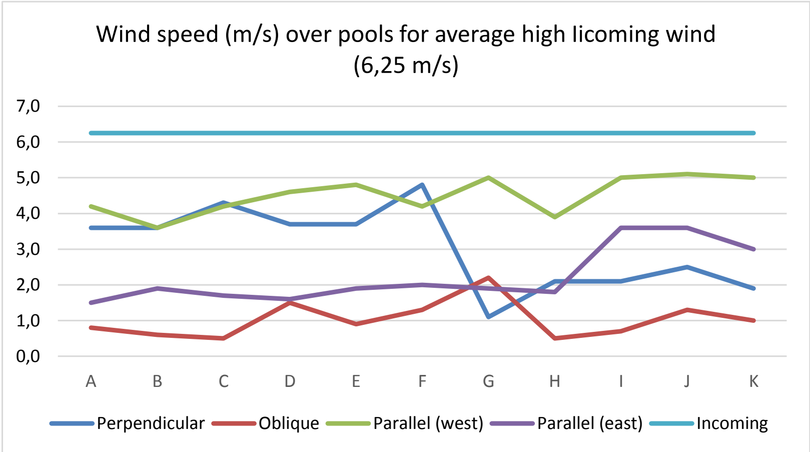

Fig. A 15. Front loaded residences with attached garages, diagram of wind speeds over pools for average high incoming wind speed.

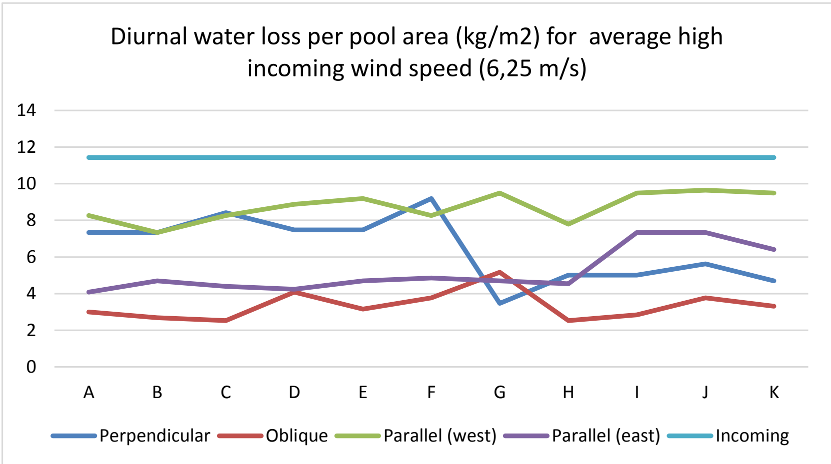

Fig. A 16. Front loaded residences with attached garages, diagram of diurnal evaporative loss over pools for average high incoming wind speed.

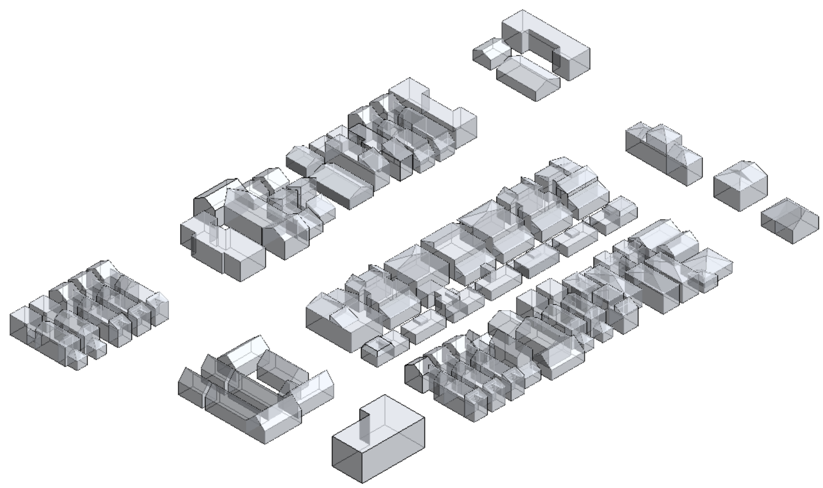

Fig. A 17. Semi-detached houses with detached garages, axon. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

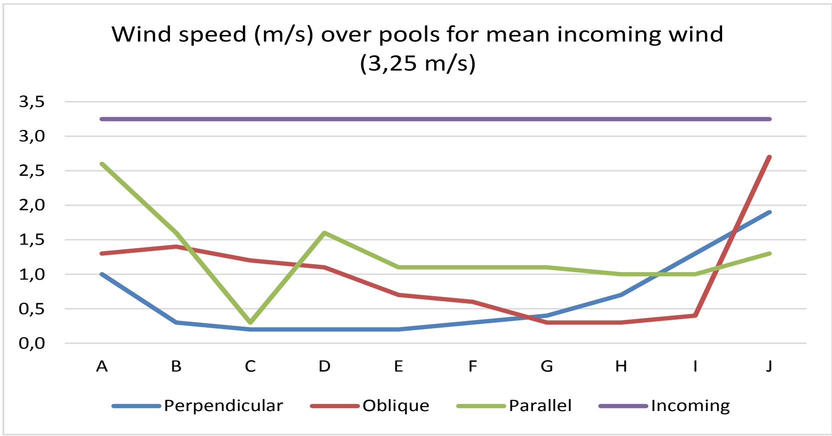

Fig. A 18. Semi-detached residences with detached garages, diagram of wind speeds over pools for mean incoming wind speed.

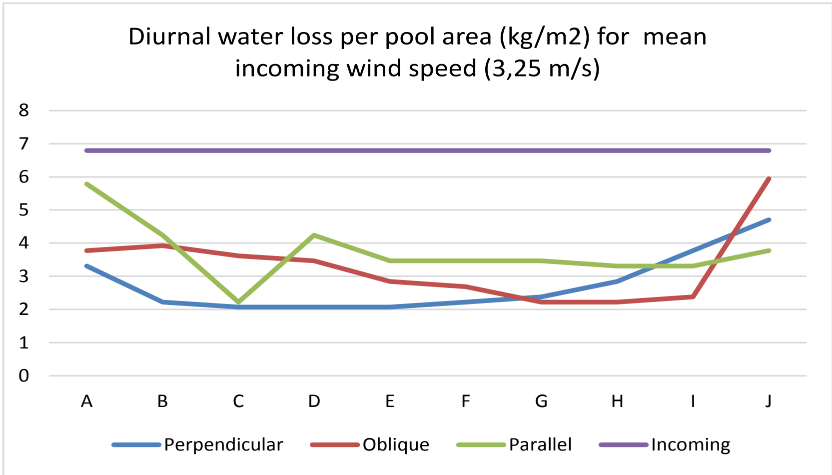

Fig. A 19. Semi-detached residences with detached garages, diagram of diurnal evaporative loss for mean incoming wind speed.

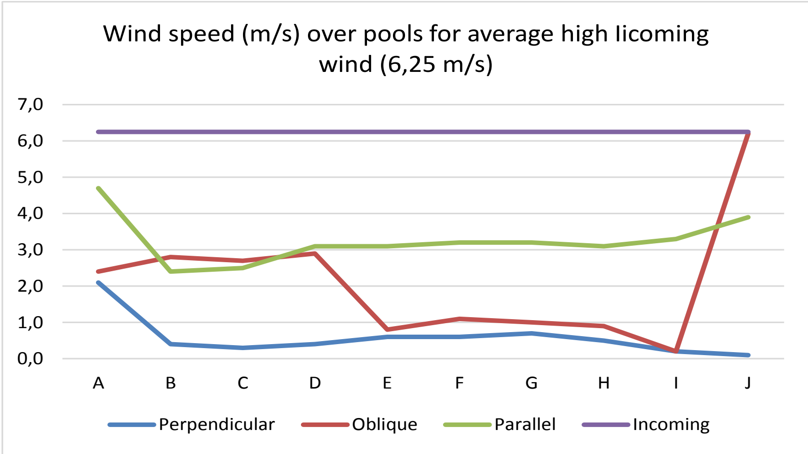

Fig. A 20. Semi-detached residences with detached garages, diagram of wind speeds over pools for average high incoming wind speed.

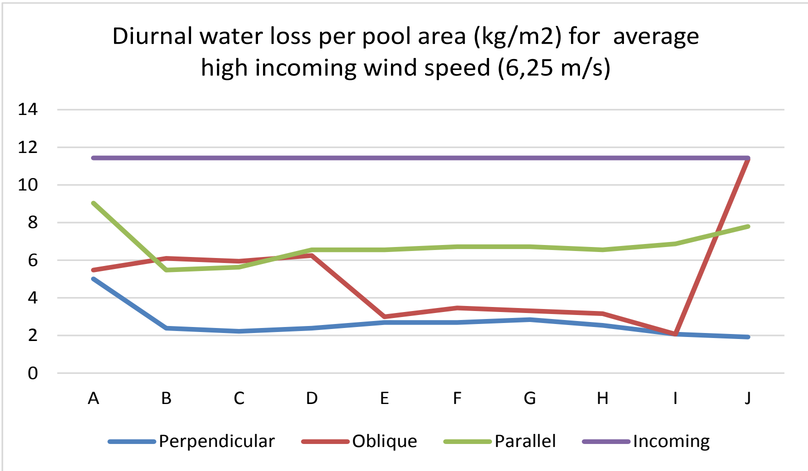

Fig. A 21. Semi-detached residences with detached garages, diagram of diurnal evaporative loss over pools for average high incoming wind speed.

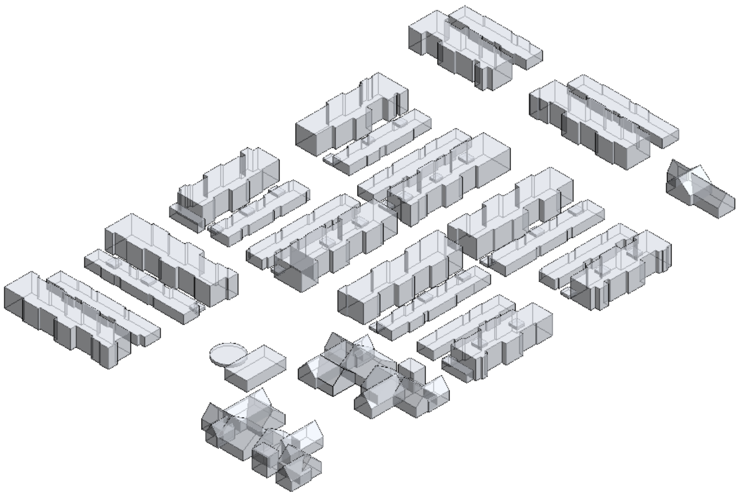

Fig. A 22. Row houses, axon. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

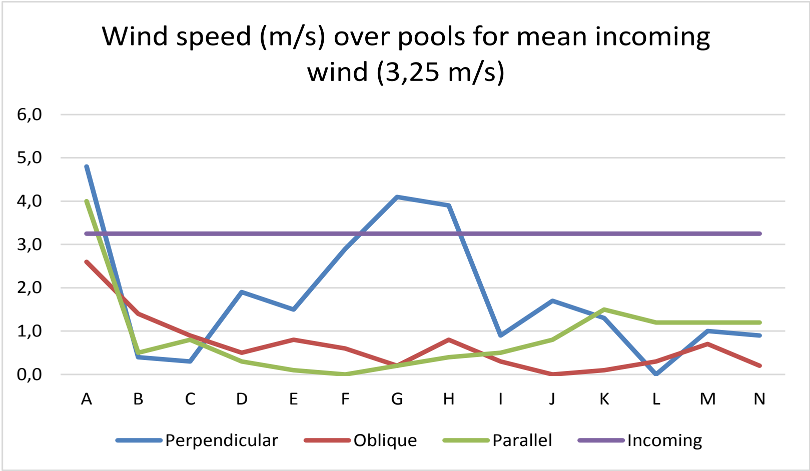

Fig. A 23. Row houses, diagram of wind speeds over pools for mean incoming wind speed.

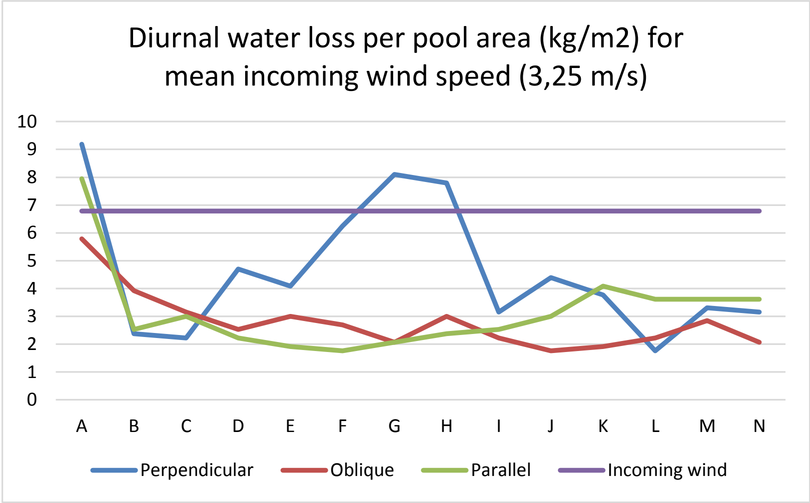

Fig. A 24. Row houses, diagram of diurnal evaporative loss for mean incoming wind speed.

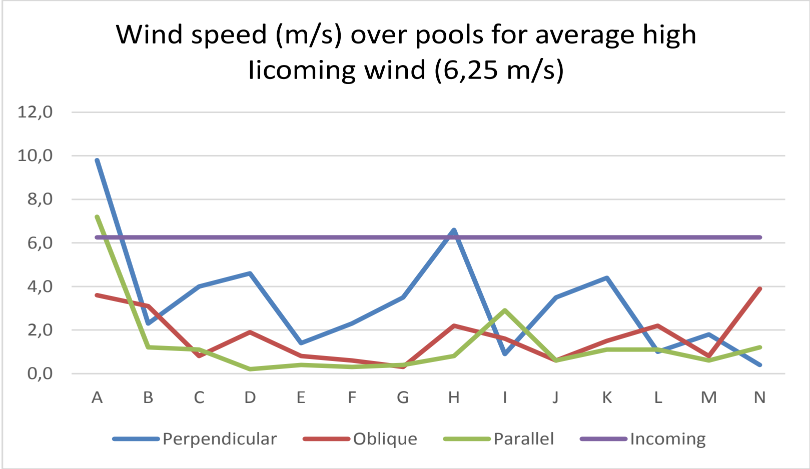

Fig. A 25. Row houses, diagram of wind speeds over pools for average high incoming wind speed.

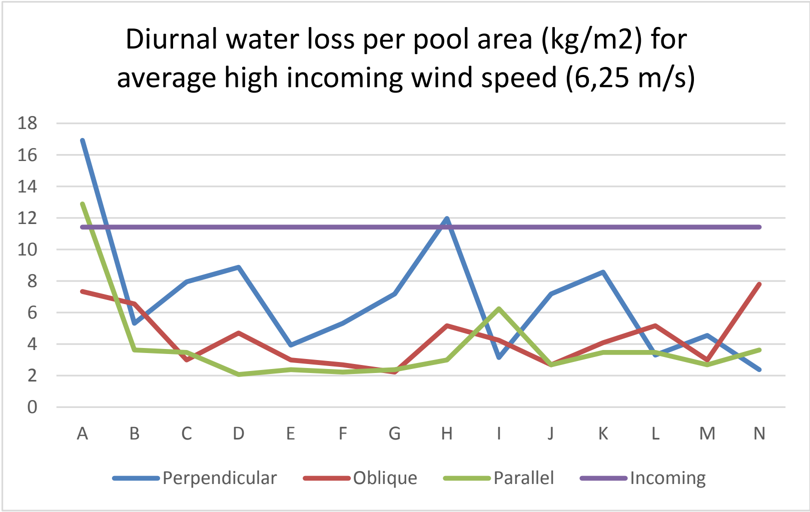

Fig. A 26. Row houses, diagram of diurnal evaporative loss over pools for average high incoming wind speed.

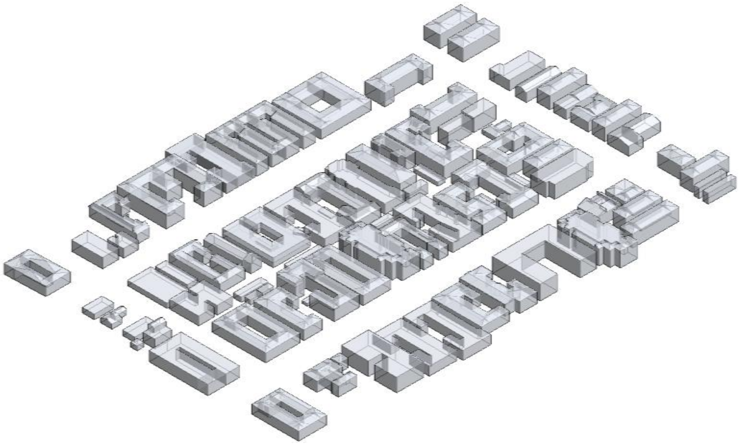

Fig. A 27. Courtyard houses, axon. Autodesk screen shot reprinted courtesy of Autodesk, Inc.

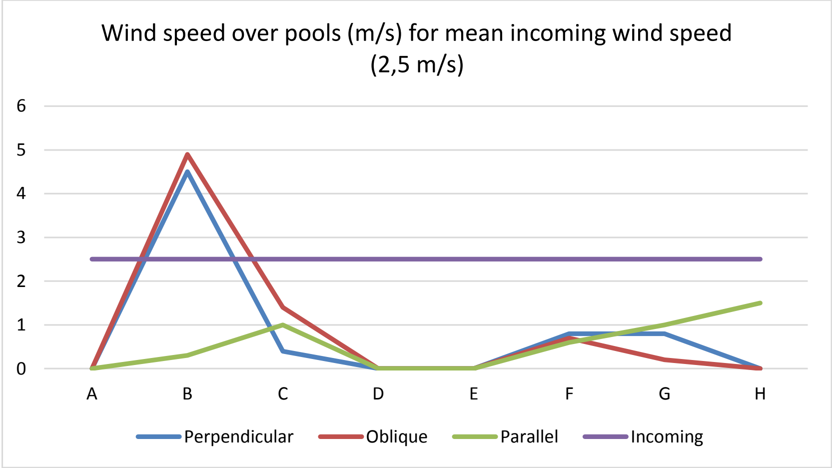

Fig. A 28. Courtyard houses, diagram of wind speeds over pools for mean incoming wind speed.

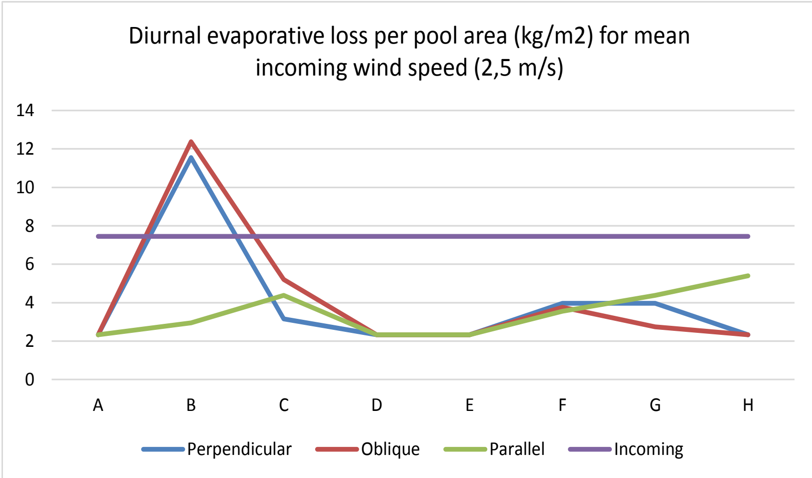

Fig. A 29. Courtyard houses, diagram of diurnal evaporative loss for mean incoming wind speed.

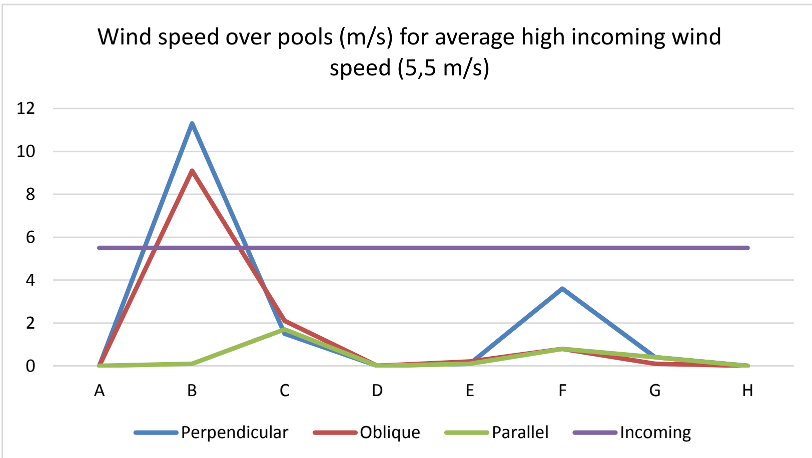

Fig. A 30. Courtyard houses, diagram of wind speeds over pools for average high incoming wind speed.

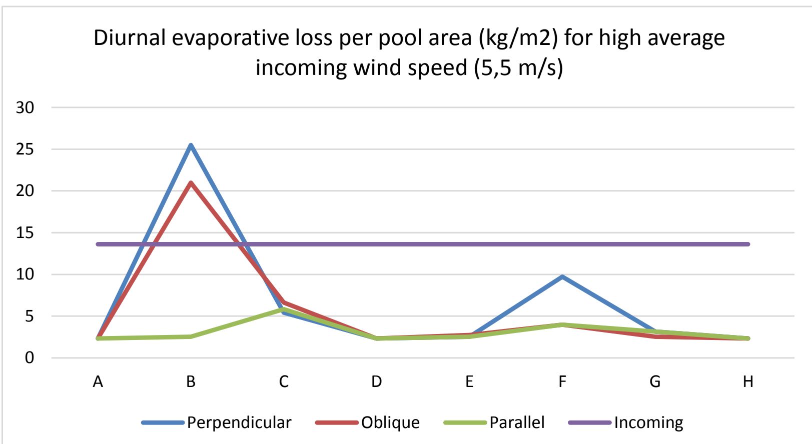

Fig. A 31. Courtyard houses, diagram of diurnal evaporative loss over pools for average high incoming wind speed.

Table A 1. California Climate Zones Weather Data (U.S. Department of Energy 2015; *calculated based on equation by Rogers & Yau 1989)

	Climate Zone 6	**Climate Zone 9**
Annual Average Relative Humidity (%)	71	61
Annual Average Ground Temperature (0.5m underground) (ºC)	16	17,5
Annual Average High Air Velocity (m/s)	6,25	5,5
Annual Mean Air Velocity (m/s)	3,25	2,5
Latent Heat for evaporation at Annual Average Ground Temperature (kJ/Kg) *	2463	2460
P_W vapor pressure at surface water temperature (kPa)	1,784	1,819
P_a vapor pressure at air dew point (kPa)	1,22	1,073
P_W-P_a vapor pressure deficit	0,564	0,746

Table A 2. Front loaded residences with detached garages: resulting wind speeds, evaporation ratios, and evaporative losses.

FRONT-LOADED DETACHED GARAGE Mean Incoming wind 2.5 m/s									
Pool	Perpendicular			Oblique			Parallel		
	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	0,4	0,036	3,151	0,3	0,034	2,947	0,2	0,032	2,742
B	0,1	0,029	2,537	0,4	0,036	3,151	1,0	0,051	4,381
C	0,4	0,036	3,151	0,1	0,029	2,537	0,2	0,032	2,742
D	0,3	0,034	2,947	0,5	0,039	3,356	0,0	0,027	2,332
E	2,4	0,084	7,249	1,1	0,053	4,586	0,3	0,034	2,947
F	0,2	0,032	2,742	0,2	0,032	2,742	0,3	0,034	2,947
G	0,2	0,032	2,742	0,5	0,039	3,356	0,2	0,032	2,742
H	1,1	0,053	4,586	0,4	0,036	3,151	0,1	0,029	2,537
I	0,2	0,032	2,742	0,4	0,036	3,151	0,2	0,032	2,742
J	1,0	0,051	4,381	0,3	0,034	2,947	0,3	0,034	2,947
K	1,5	0,063	5,405	0,3	0,034	2,947	0,5	0,039	3,356
L	0,6	0,041	3,561	0,1	0,029	2,537	0,8	0,046	3,971
AVG:	0,7	0,044	3,766	0,4	0,036	3,117	0,3	0,035	3,032
Average High Incoming wind 5.5 m/s									
Pool	Perpendicular			Oblique			Parallel		
	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	0,6	0,041	3,561	0,7	0,044	3,766	0,3	0,034	2,947
B	0,2	0,032	2,742	0,2	0,032	2,742	4,5	0,134	11,552
C	0,3	0,034	2,947	0,3	0,034	2,947	1,0	0,051	4,381
D	0,7	0,044	3,766	0,3	0,034	2,947	1,3	0,058	4,995
E	0,2	0,032	2,742	0,7	0,044	3,766	0,4	0,036	3,151
F	0,5	0,039	3,356	0,1	0,029	2,537	1,0	0,051	4,381
G	0,4	0,036	3,151	0,7	0,044	3,766	0,9	0,048	4,176
H	0,4	0,036	3,151	1,0	0,051	4,381	1,3	0,058	4,995
I	0,4	0,036	3,151	0,7	0,044	3,766	0,4	0,036	3,151
J	1,1	0,053	4,586	0,5	0,039	3,356	1,0	0,051	4,381
K	1,6	0,065	5,610	2,9	0,096	8,274	3,1	0,101	8,684
L	1,1	0,053	4,586	2,3	0,082	7,044	1,5	0,063	5,405
AVG:	0,6	0,042	3,612	0,9	0,048	4,108	1,4	0,060	5,183

Table A 3. Front loaded residences with attached garages: resulting wind speeds, evaporation ratios, and evaporative losses.

FRONT-LOADED ATTACHED GARAGE												
Mean Incoming wind 3.25 m/s												
	Perpendicular			Oblique			Parallel (west)			Parallel (east)		
Pool	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	1,0	0,038	3,308	2,3	0,062	5,319	1,1	0,053	4,586	1,0	0,038	3,308
B	0,3	0,026	2,225	2,5	0,065	5,629	1,3	0,058	4,995	1,2	0,042	3,617
C	0,3	0,026	2,225	1,0	0,038	3,308	0,9	0,048	4,176	1,3	0,044	3,772
D	0,2	0,024	2,070	2,9	0,072	6,248	1,9	0,072	6,225	1,2	0,042	3,617
E	0,2	0,024	2,070	1,5	0,047	4,082	0,8	0,046	3,971	1,1	0,040	3,463
F	0,3	0,026	2,225	2,2	0,060	5,165	1,1	0,053	4,586	0,8	0,035	2,999
G	0,2	0,024	2,070	0,5	0,029	2,534	1,1	0,053	4,586	0,3	0,026	2,225
H	0,2	0,024	2,070	0,4	0,028	2,380	0,8	0,046	3,971	0,4	0,028	2,380
I	0,3	0,026	2,225	0,6	0,031	2,689	0,6	0,041	3,561	0,9	0,036	3,153
J	0,2	0,024	2,070	0,4	0,028	2,380	0,6	0,041	3,561	0,9	0,036	3,153
K	0,2	0,024	2,070	0,4	0,028	2,380	0,5	0,039	3,356	1,5	0,047	4,082
AVG:	0,3	0,026	2,239	1,3	0,044	3,828	1,0	0,038	3,266	1,0	0,038	3,252
Average High Incoming wind 6.25 m/s												
	Perpendicular			Oblique			Parallel (west)			Parallel (east)		
Pool	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	3,6	0,085	7,331	0,8	0,035	2,999	4,2	0,096	8,259	1,5	0,047	4,082
B	3,6	0,085	7,331	0,6	0,031	2,689	3,6	0,085	7,331	1,9	0,054	4,700
C	4,3	0,097	8,414	0,5	0,029	2,534	4,2	0,096	8,259	1,7	0,051	4,391
D	3,7	0,087	7,485	1,5	0,047	4,082	4,6	0,103	8,878	1,6	0,049	4,236
E	3,7	0,087	7,485	0,9	0,036	3,153	4,8	0,106	9,187	1,9	0,054	4,700
F	4,8	0,106	9,187	1,3	0,044	3,772	4,2	0,096	8,259	2,0	0,056	4,855
G	1,1	0,040	3,463	2,2	0,060	5,165	5,0	0,110	9,497	1,9	0,054	4,700
H	2,1	0,058	5,010	0,5	0,029	2,534	3,9	0,090	7,795	1,8	0,053	4,546
I	2,1	0,058	5,010	0,7	0,033	2,844	5,0	0,110	9,497	3,6	0,085	7,331
J	2,5	0,065	5,629	1,3	0,044	3,772	5,1	0,112	9,651	3,6	0,085	7,331
K	1,9	0,054	4,700	1,0	0,038	3,308	5,0	0,110	9,497	3,0	0,074	6,402
AVG:	3,0	0,075	6,459	1,0	0,039	3,350	4,5	0,101	8,737	2,2	0,060	5,207

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Table A 4. Semi-detached residences with detached garages: resulting wind speeds, evaporation ratios, and evaporative losses.

SEMI-DETACHED DETACHED GARAGE Mean Incoming wind 3.25 m/s									
Pool	Perpendicular			Oblique			Parallel		
	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	1,0	0,038	3,308	1,3	0,044	3,772	2,6	0,067	5,783
B	0,3	0,026	2,225	1,4	0,045	3,927	1,6	0,049	4,236
C	0,2	0,024	2,070	1,2	0,042	3,617	0,3	0,026	2,225
D	0,2	0,024	2,070	1,1	0,040	3,463	1,6	0,049	4,236
E	0,2	0,024	2,070	0,7	0,033	2,844	1,1	0,040	3,463
F	0,3	0,026	2,225	0,6	0,031	2,689	1,1	0,040	3,463
G	0,4	0,028	2,380	0,3	0,026	2,225	1,1	0,040	3,463
H	0,7	0,033	2,844	0,3	0,026	2,225	1,0	0,038	3,308
I	1,3	0,044	3,772	0,4	0,028	2,380	1,0	0,038	3,308
J	1,9	0,054	4,700	2,7	0,069	5,938	1,3	0,044	3,772
AVG:	0,7	0,032	2,766	1,0	0,038	3,308	1,3	0,043	3,726
Average High Incoming wind 6.25 m/s									
Pool	Perpendicular			Oblique			Parallel		
	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	2,1	0,058	5,010	2,4	0,063	5,474	4,7	0,105	9,032
B	0,4	0,028	2,380	2,8	0,071	6,093	2,4	0,063	5,474
C	0,3	0,026	2,225	2,7	0,069	5,938	2,5	0,065	5,629
D	0,4	0,028	2,380	2,9	0,072	6,248	3,1	0,076	6,557
E	0,6	0,031	2,689	0,8	0,035	2,999	3,1	0,076	6,557
F	0,6	0,031	2,689	1,1	0,040	3,463	3,2	0,078	6,712
G	0,7	0,033	2,844	1,0	0,038	3,308	3,2	0,078	6,712
H	0,5	0,029	2,534	0,9	0,036	3,153	3,1	0,076	6,557
I	0,2	0,024	2,070	0,2	0,024	2,070	3,3	0,079	6,866
J	0,1	0,022	1,916	6,2	0,131	11,353	3,9	0,090	7,795
AVG:	0,6	0,031	3,612	0,9	0,031	4,108	1,4	0,031	5,183

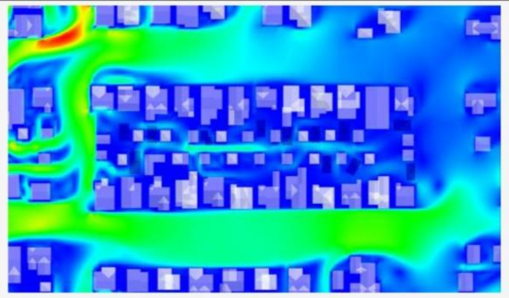
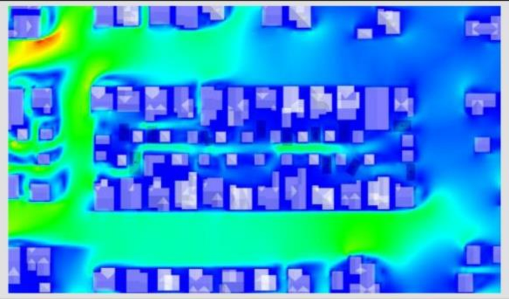
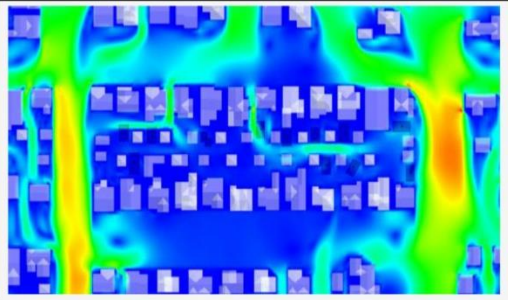
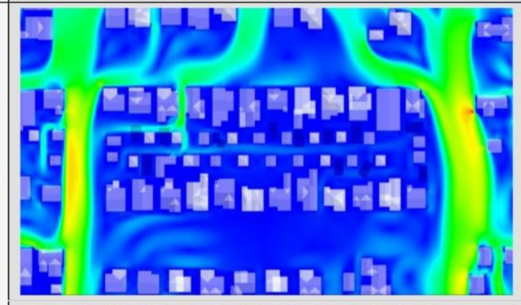
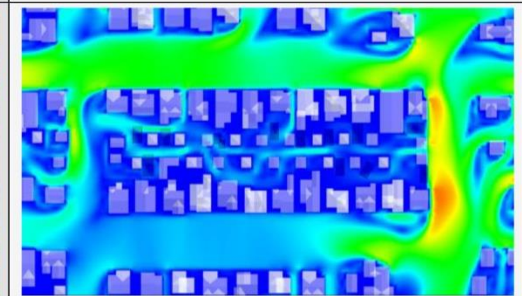
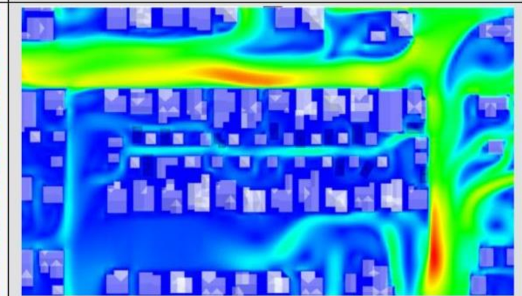
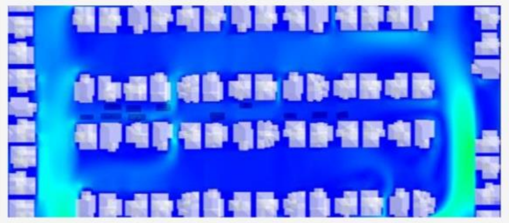
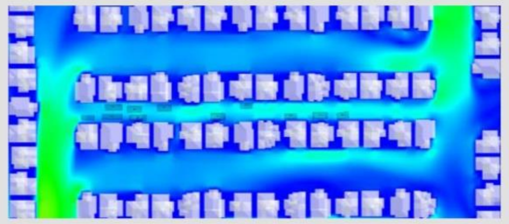
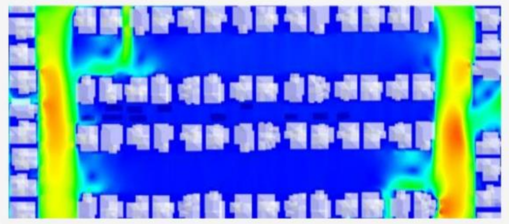
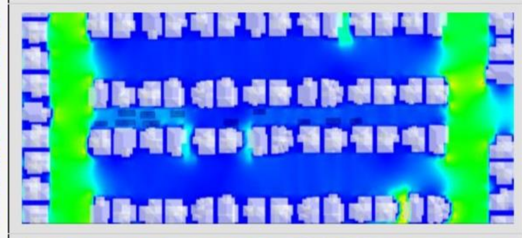
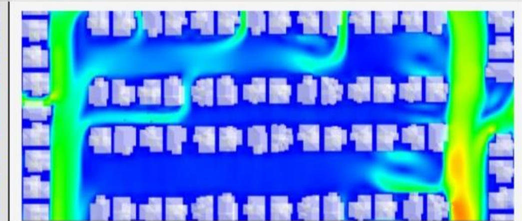
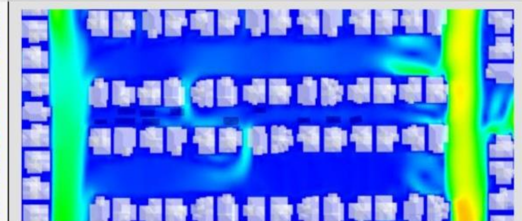
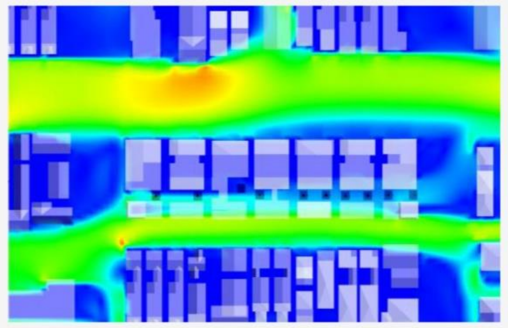
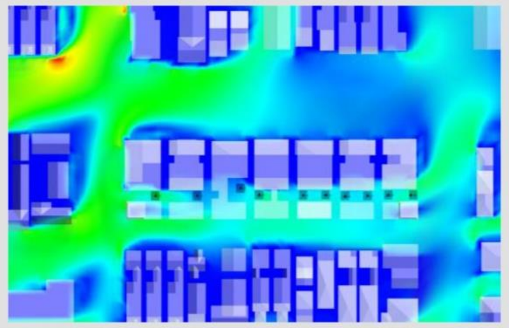
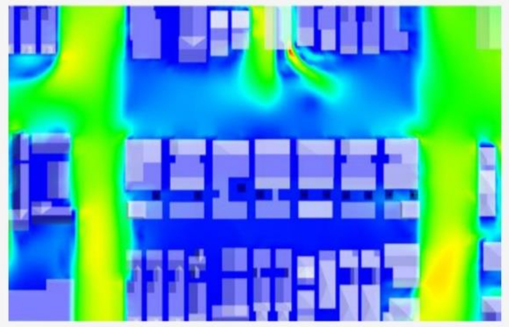
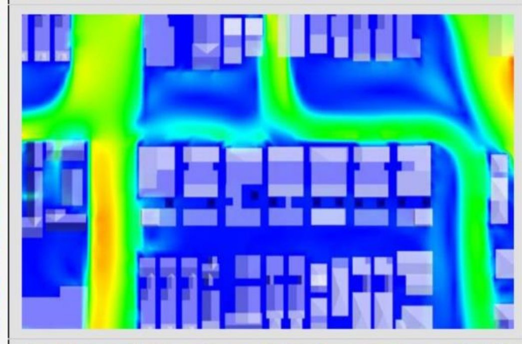
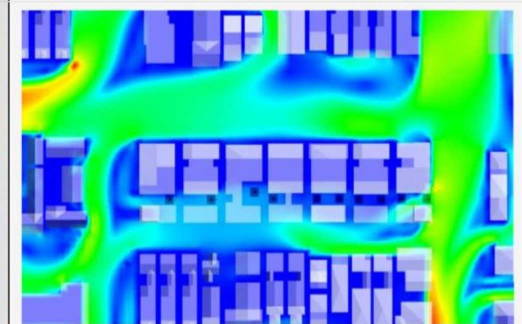
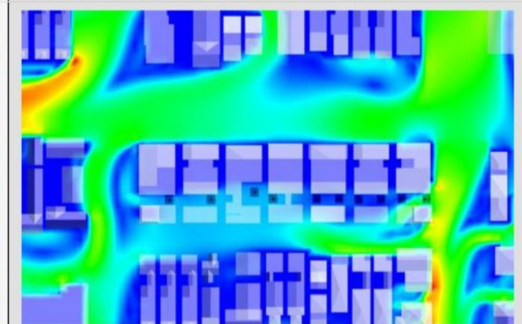
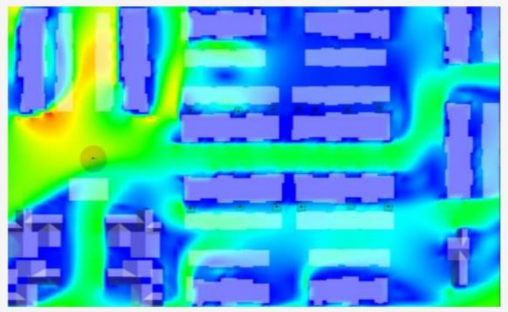
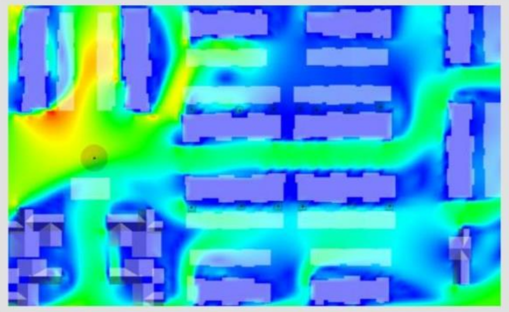
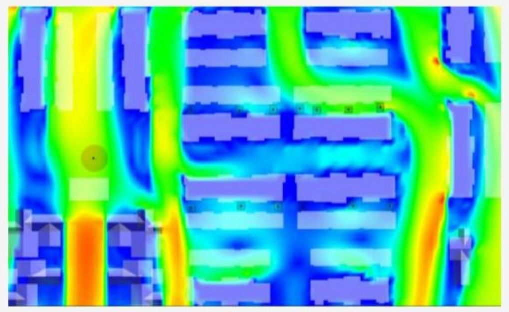
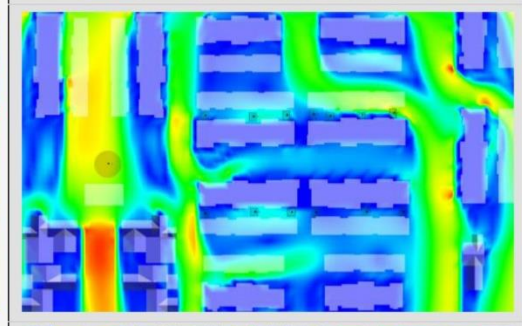
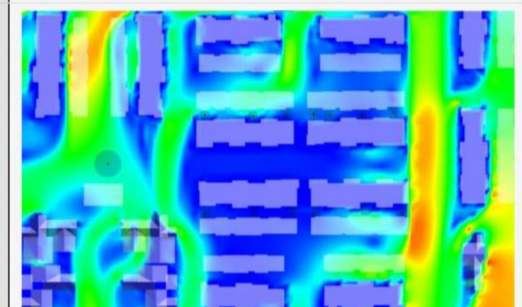
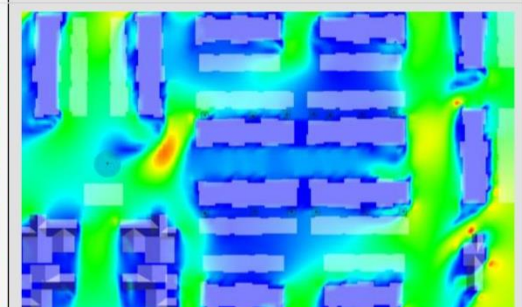
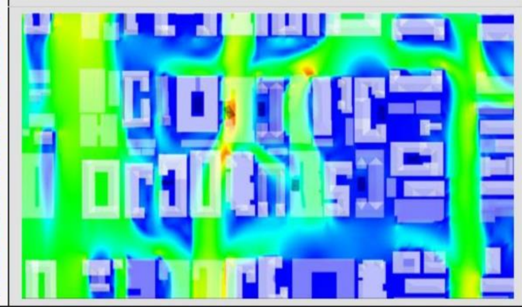
Table A 5. Row houses: resulting wind speeds, evaporation ratios, and evaporative losses.

ROW HOUSES Mean Incoming wind 3.25 m/s									
	Perpendicular			Oblique			Parallel		
Pool	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	4,8	0,106	9,187	2,6	0,067	5,783	4,0	0,092	7,949
B	0,4	0,028	2,380	1,4	0,045	3,927	0,5	0,029	2,534
C	0,3	0,026	2,225	0,9	0,036	3,153	0,8	0,035	2,999
D	1,9	0,054	4,700	0,5	0,029	2,534	0,3	0,026	2,225
E	1,5	0,047	4,082	0,8	0,035	2,999	0,1	0,022	1,916
F	2,9	0,072	6,248	0,6	0,031	2,689	0,0	0,020	1,761
G	4,1	0,094	8,104	0,2	0,024	2,070	0,2	0,024	2,070
H	3,9	0,090	7,795	0,8	0,035	2,999	0,4	0,028	2,380
I	0,9	0,036	3,153	0,3	0,026	2,225	0,5	0,029	2,534
J	1,7	0,051	4,391	0,0	0,020	1,761	0,8	0,035	2,999
K	1,3	0,044	3,772	0,1	0,022	1,916	1,5	0,047	4,082
L	0,0	0,020	1,761	0,3	0,026	2,225	1,2	0,042	3,617
M	1,0	0,038	3,308	0,7	0,033	2,844	1,2	0,042	3,617
N	0,9	0,036	3,153	0,2	0,024	2,070	1,2	0,042	3,617
AVG:	2,2	0,060	5,226	0,8	0,035	3,014	0,8	0,034	2,937
Average High Incoming wind 6.25 m/s									
	Perpendicular			Oblique			Parallel		
Pool	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	9,8	0,196	16,923	3,6	0,085	7,331	7,2	0,149	12,900
B	2,3	0,062	5,319	3,1	0,076	6,557	1,2	0,042	3,617
C	4,0	0,092	7,949	0,8	0,035	2,999	1,1	0,040	3,463
D	4,6	0,103	8,878	1,9	0,054	4,700	0,2	0,024	2,070
E	1,4	0,045	3,927	0,8	0,035	2,999	0,4	0,028	2,380
F	2,3	0,062	5,319	0,6	0,031	2,689	0,3	0,026	2,225
G	3,5	0,083	7,176	0,3	0,026	2,225	0,4	0,028	2,380
H	6,6	0,139	11,972	2,2	0,060	5,165	0,8	0,035	2,999
I	0,9	0,036	3,153	1,6	0,049	4,236	2,9	0,072	6,248
J	3,5	0,083	7,176	0,6	0,031	2,689	0,6	0,031	2,689
K	4,4	0,099	8,568	1,5	0,047	4,082	1,1	0,040	3,463
L	1,0	0,038	3,308	2,2	0,060	5,165	1,1	0,040	3,463
M	1,8	0,053	4,546	0,8	0,035	2,999	0,6	0,031	2,689
N	0,4	0,028	2,380	3,9	0,090	7,795	1,2	0,042	3,617
AVG:	3,9	0,090	7,779	1,6	0,048	4,159	1,5	0,047	4,097

Table A 6. Courtyard houses: resulting wind speeds, evaporation ratios, and evaporative losses.

COURTYARD HOUSES Mean Incoming wind 2.5 m/s									
Pool	Perpendicular			Oblique			Parallel		
	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	0,0	0,027	2,332	0,0	0,027	2,332	0,0	0,027	2,332
B	4,5	0,134	11,552	4,9	0,143	12,372	0,3	0,034	2,947
C	0,4	0,036	3,151	1,4	0,060	5,200	1,0	0,051	4,381
D	0,0	0,027	2,332	0,0	0,027	2,332	0,0	0,027	2,332
E	0,0	0,027	2,332	0,0	0,027	2,332	0,0	0,027	2,332
F	0,8	0,046	3,971	0,7	0,044	3,766	0,6	0,041	3,561
G	0,8	0,046	3,971	0,2	0,032	2,742	1,0	0,051	4,381
H	0,0	0,027	2,332	0,0	0,027	2,332	1,5	0,063	5,405
AVG:	0,8	0,046	3,997	0,9	0,048	4,176	0,6	0,040	3,459
Average High Incoming wind 5.5 m/s									
Pool	Perpendicular			Oblique			Parallel		
	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)	Wind Speed (m/s)	Evaporation ratio (g/s m2)	Water loss in 24h (Kg)
A	0,0	0,027	2,332	0,0	0,027	2,332	0,0	0,027	2,332
B	11,3	0,295	25,485	9,1	0,243	20,977	0,1	0,029	2,537
C	1,5	0,063	5,405	2,1	0,077	6,635	1,7	0,067	5,815
D	0,0	0,027	2,332	0,0	0,027	2,332	0,0	0,027	2,332
E	0,1	0,029	2,537	0,2	0,032	2,742	0,1	0,029	2,537
F	3,6	0,112	9,708	0,8	0,046	3,971	0,8	0,046	3,971
G	0,4	0,036	3,151	0,1	0,029	2,537	0,4	0,036	3,151
H	0,0	0,027	2,332	0,0	0,027	2,332	0,0	0,027	2,332
AVG:	2,1	0,077	6,660	1,5	0,063	5,482	0,4	0,036	3,126

Table A 7. Overview of simulations

DIRECTION	PARALLEL		PERPENDICULAR		OBLIQUE	
SPEED	MEAN	AVERAGE HIGH	MEAN	AVERAGE HIGH	MEAN	AVERAGE HIGH
FRONT-LOADED DETACHED GAR.						
FRONT-LOADED ATTACHED GAR.						
SEMI-DETACHED DETACHED GAR.						
ROW HOUSES						
COURTYARD HOUSES						

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