Assessment of Wind Driven Rain Under Open Shelters

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Abstract

This paper presents a discussion of the problem of wind .driven rain in terms of its impact and impingement under free standing open roof structures. Some aerodynamic consideration of falling rain drops is discussed and then some methods of assessment are presented. Finally, a method of determining the acceptability of rain fall rates under covered spaces is examined.

The Problem of Wind Driven Rain

With the increasing use of open-air structures, open roofs, outdoor cafes and tall open forms of architecture the problem of wind driven rain becomes an increasing design consideration. Wind driven rain theory may also be applied to architectural water features exposed to the wind in order to determine the extent of splashing. Understanding the way rain falls during wind events is also important in assessing wetting and weathering of buildings as well as rainfall infiltration under eaves, or into air vents and other permeable parts of a building envelope. Assessment of wind driven rain is made difficult by the number of variables involved in the assessment and by the interrelationships between the occurrence of wind and the occurrence of rain at a site. Some of the variables to consider in wind driven rain assessments include the following:

- both wind and rain are driven by temperature differences these vary with time of day and time of year.
- rainfall can occur by three different mechanisms involving the elevation and subsequent condensation of warm moist air
- the wind is gusty
- rainfall can be localized
- rainfall can affect the wind velocity profile
- rainfall can be a response to a previous wind movement and the two events are not necessarily simultaneous
- rainfall can vary in intensity
- drop size distributions vary with rain fall intensity
- the wind carries smaller drop sizes more easily

It is the purpose of this paper to investigate some ways of predicting the impact of wind driven rain on the pedestrian comfort and amenity under freestanding roofs. Some of the physics of wind driven rain are considered but this investigation aims to determine the key factors to consider and the relative magnitudes of importance of the many variables involved.

Some previous research

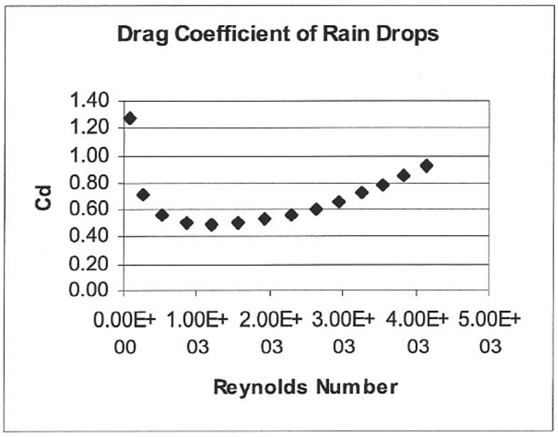
Studies of wind driven rain are not uncommon, in 1972 a Symposium was held by CSIRO on "Wind Driven Rain and the Multistory Building". Obviously many studies have been carried out in the field of meteorology relating to storm fronts and large scale occurrences of both wind and rain. Ample information exists on the physics of rain drops relating to drop size distributions and fall speeds. In relation to buildings some studies have been carried out on wetting of building facades, on computational modelling of wind driven rain. Few practical studies exist on the problem of wind blown rain impinging under open roofs and in particular on the design events for such occurrences and criteria for acceptability for such events

Aerodynamics of Rain Drops

The shape and size of rain drops is generally shown in literature to be governed by the balance of surface tension, hydrostatic pressure and surface pressure induced by airflow. As a large rain drop falls it tends to flatten out at the leading edge. As the skin friction and form drag increases during the fall the droplet breaks up when the water tension is no longer able to support the form of the drop. The ratio of gravitational force to surface tension force is known as the Bond number. It has been found by numerous sources that droplets of water tend towards a maximum drop size of around 7mm and tend towards a spherical shape this makes drag calculations a little simpler. For differing rates of rainfall the drop size distributions are also well documented. Empirical data and fitted formulae have been determined by Marshal and Palmer which determine the volumetric distribution of drops by drop diameter (ϕ) for varying rain intensities (R). These may be used in an assessment of the dispersion of different drop sizes .

$$\text{Cumulative Probability Distribution} = \exp\left[-\left(\frac{\phi}{R^{0.232}}\right)^{2.25}\right]$$

For a given drop size, a terminal velocity exists where gravity forces balance the drag forces, therefore it is possible to determine a drag coefficient for various drop sizes travelling at terminal velocity. Assuming a spherical drop size it is possible to use the same drag coefficient data to predict the drag on a given raindrop due to horizontal winds.



Rain Fall acceptability Criteria

Wind driven rain impact may be assessed in terms of the percentage reduction in dry area under a roof and by the volume of rainfall blown under the roof. There is little information available regarding human tolerance to rain and on the extent to which a shelter is considered to be adequately sheltering. Criteria for these events can to devised on a case by case basis with consideration to the usage of the shelter.

Design guidelines for achieving human comfort specified by AIRAH (The Australian Institute of Refrigeration Air-conditioning and Heating) indicates that a location is unacceptable if the design criterion is exceeded at the daily measurement time on more than 10 occasions per annum. From this criterion we may conclude that a once per month condition is likely to be the governing acceptability timeframe.

By analogy with AIRAH and to the once per year criterion of peak annual gust derived by Melbourne for pedestrian wind comfort, it is suggested to determine both a once per year and once per month design event for wind driven rain occurrences. As the rain fall often varies with season it is suggested to determine 12 design events based on the predicted maximum wind and rain event for each month of the year.

By further analogy to traditional wind environment studies it is suggested to use both an absolute and a relative criteria for wind driven rain assessment. The relative criteria would define some percentage of rain fall rate under the shelter compared with the unsheltered rainfall rate. An absolute criteria would define some maximum rain fall rate which may cause a surface to become slippery or may impact on mechanical equipment not designed for rain

Some research into footstep instability and surface friction on floors shows that a surface becomes slippery when the depth of water over the surface exceeds the roughness of the various surface asperities, therefore a smooth tiled floor becomes slippery at very low water depths while wetting of a concrete floor may require a greater depth of water to make the surface lubricated.

Some suggested criteria used by this author in the past tends to seek to maintain comfort over at least half the with of the shelter and includes:

- ❖ annual rain fall equal to the outside rain fall rate shall not be blown a distance of more than 40% of the width of the shelter.
- ❖ annual rain impact shall not exceed 30% of the outside rain fall rate at a distance of 50% of the width of the shelter.
- ❖ virtually no rain during monthly occurrence events shall be blown on to sensitive mechanical

components or sensitive pedestrian areas such as outdoor dinning areas.
- ❖ rainfall shall not exceed 3mm/h on potentially slippery surfaces such as concrete.
- ❖ rainfall shall not exceed 1mm/h on potentially slippery surfaces such as tiling.

For assessment of the carry of big rain drops (which carry most of the volume of the rain) the important parameter is an accurate prediction of the mean wind speed. For assessing wetting of sensitive areas of the building the important parameter is the rain fall rate because this determines the quantity of small drop sizes which are most easily transported under the shelter.

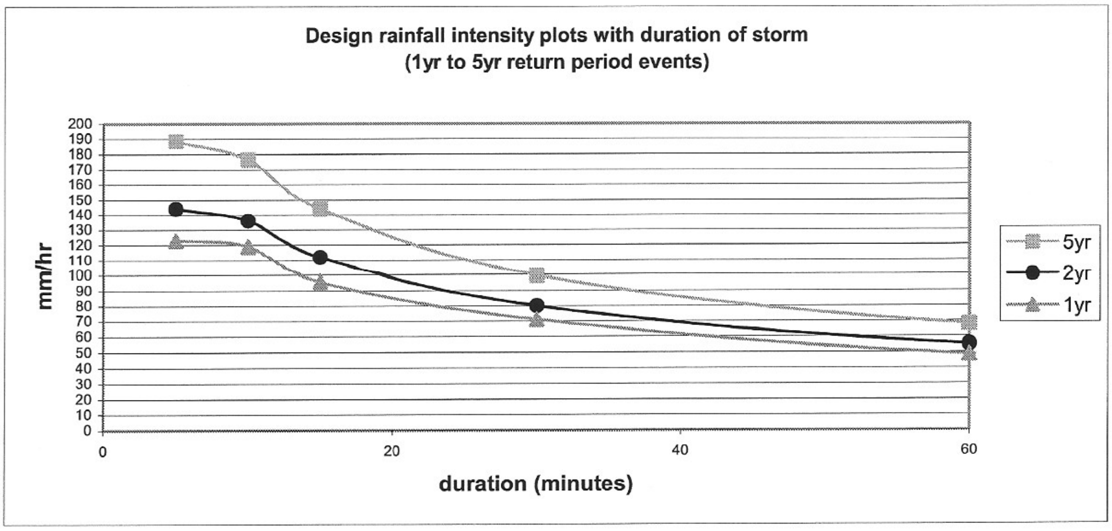
Meteorological Data and Design Events

Some consideration of the mechanisms through which rain occurs can shed light on the dual incidence of wind and rain. Rain occurs by three main mechanisms Convectional, Frontal and Orographic or relief rain. Some consideration of each of the processes can indicate the likely wind direction and magnitude during the rain events as well as the localization of the rain. All three mechanisms produce rainfall when specific thermal and wind incidences occur over time frames which can span a few days, and the actual surface wind speed during a specific period of rain may vary broadly from the average wind speed on that day. Importantly for most cities the overall annual distribution of wind velocities and directions (during all times) is not the same as the wind distribution during rain events.

As an example, the annual maximum hourly wind speeds in Melbourne throughout the year are strongest from the north through west to south and the characteristic hot northerlies can govern the wind comfort condition as annual basic wind speeds (gust at 10m cat 2) reach around 20m/s. During rain however the winds are far more likely to arrive from the southwest especially for stronger winds with the arrival of cold fronts. During such rain events the basic wind speeds are more like 11m/s.

Ultimately an assessment of wind driven rain requires meteorological data of the combined incidence of wind and rain. To determine the impact of wind driven rain under a free standing roof or large overhang it is necessary to know the rain fall rate at the site and the mean surface wind speed at building height along with the wind direction predicted during the time of rain fall. Wind tunnel studies of building wind effects may be modified to examine the wind flow patterns during known wind and rain events. Depending on the nature of the wind driven rain assessment it may be appropriate to separate the heavy thunderstorm activity from the data set of wind and rain (ie assessing impact on partially sheltered café dwellers during a thunderstorm may be inappropriate). It is suggested to use the maximum mean hourly wind speed during rain events and analyse the rain trajectories for a range of flow rates over 10min periods to 1hour periods which obviously do not exceed the measured total flow rate.

Meteorology departments typically measure rainfall by daily total (mm) and peak hourly rate (mm/h). If it is not easy to obtain data of the dual incidence of wind and rain over smaller time scales it may be necessary to take a worst case and assume that the daily total rainfall occurred with the daily maximum mean wind speed. Some data is available of the peak rain fall rates over various return periods and as an example a typical design hourly rainfall rate for Kuala Lumpur shows that over an annual return period, the peak rain fall over one hour can be sustained at a rate of almost 50mm/hr. Curves such as that below would apply to different cities and may be derived by direct measurement or obtained from flood and guttering designers.



In considering wind driven rain events it is important to realize that the peak annual rain fall is not necessarily the worst design case because storms with a lower flow rate contain smaller rain drops which carry further in the wind. Therefore it is necessary to assess a range of flow rate cases.

Wind Driven rain Analysis

In order to simplify the analysis of wind driven rain it is suggested to conservatively ignore some effects. The suggested assumptions are that the ground surface beneath the freestanding roof falls towards the edge (no surface wetting due to drainage), adequate guttering is assumed at the edge of the roof meaning that the predominant water source is the incoming rain, no evaporation occurs, rain drops fall at terminal velocity.

From the charts above showing drag on raindrops it is possible to determine a fall velocity and a horizontal velocity during various wind speeds. Melbourne has shown that in public spaces which are unsheltered from the rain, the rain pattern will tend to follow the mean airflow path of strong winds and only the smaller drops are affected by gusts and eddies which change in direction around a building. For consideration of wetting of sensitive surfaces it is suggested to account for turbulence in the wind flow and assume that small drops up to 2mm in size may be carried by turbulent effects. For the overall rain flow dominated by large drops it is suggested here to use the mean site wind speed during rain and include some overall dispersion factor to account for the turbulent fluctuations in the mean wind affecting all drops but to lesser degrees. Some guidance from particle inertia theory and turbulent eddy scales can assist in determining dispersion due to gusts.

To determine the impact of wind driven rain it is suggested to calculate the horizontal trajectory under a shelter for each rain drop size. A size distribution for the applicable rainfall rate will allow the calculation of rain fall rate vs distance from the edge of the shelter.

The distance travelled by the largest drops indicates the extent to which rain fall rate under the roof will be the same as that of the outside condition any area inside that limit will only be effected by smaller drops and therefore diminished drop rates. The fall distance may be calculated based on the terminal velocity of the largest drops and the drag coefficient used with the design horizontal wind flow. The smallest drops carry the furthest and may be considered in regard to impact on sensitive areas of the building which are least tolerant to moisture. Finally by calculating the trajectory of all rain drop sizes and integrating these with their volumetric proportion in the rain flow it is possible to determine the rain flow rate at any distance from the edge of the overhang and decide on its acceptability.

Conclusions and Discussion

Rain impact on buildings is a well studied physical process however human tolerance to rain fall is not so well known. In order to make an assessment of the effects of wind driven rain on a building it is relatively straightforward to calculate where the raindrops go but less straight forward to decide if ameliorative action needs to be taken. The accuracy of a wind driven rain assessment relies primarily on sourcing accurate data of the combined incidence of wind and rain events. Further analysis of various wind/rain data sets for a range of climates would yield some correlation coefficients which would allow the annual wind data set (all events) to be combined with the annual rain data set to predict a combined wind and rain design event. this may remove some reliance on accurate simultaneous measurement of wind and rain. This study has provided some suggestions for assessing the impact of wind driven rain and shown that it is necessary to consider all drop sizes, and a range of rain fall rates.

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