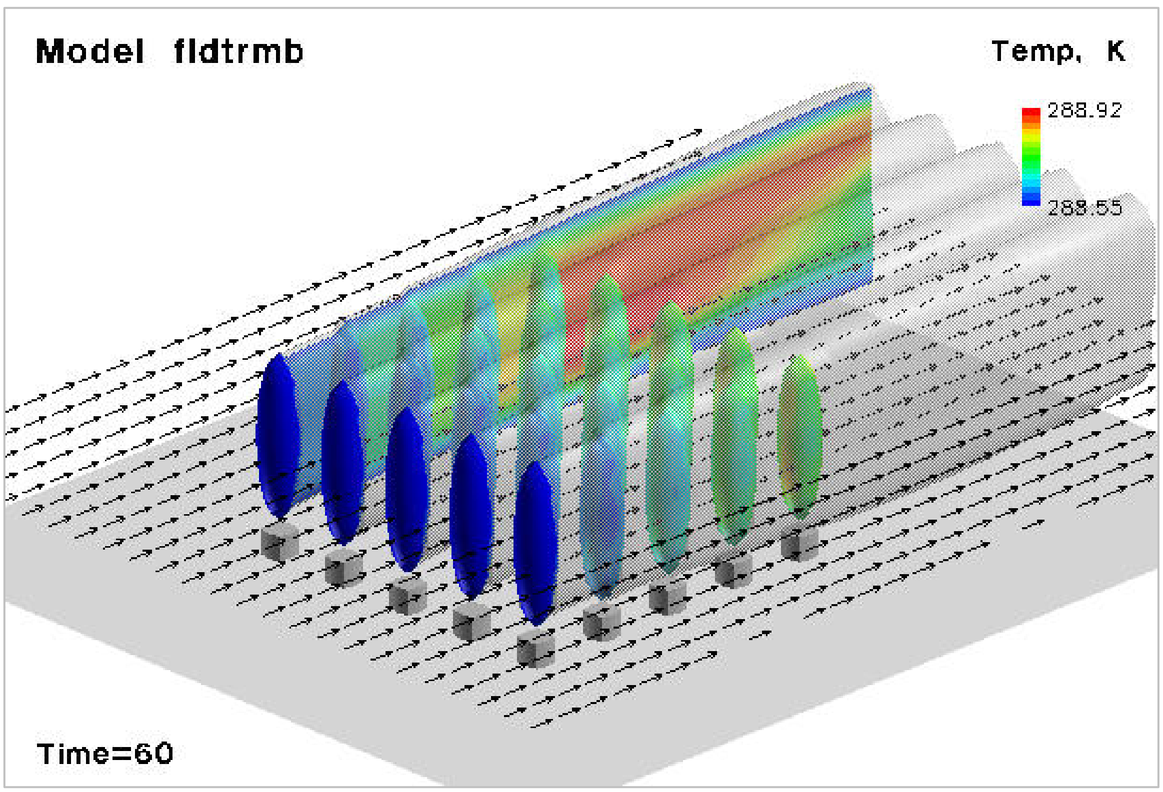
C A E S I M R E S E A R C H

Validation Study

Plant Transpiration



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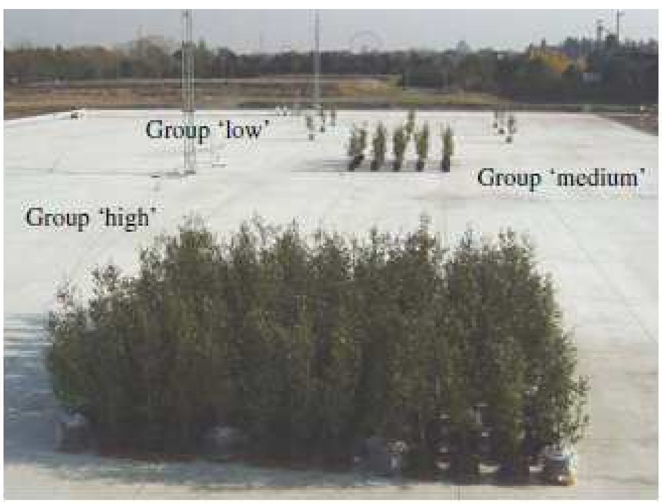
Transpiration Field Test Experiment

The publication "Field experiment on transpiration from isolated urban plants", Hagishima et al, 2007, presents the effects of pot plant density on transpiration rates in a series of field experiments.

Abstract:

The effect of pot plant density on plant transpiration rate was examined in a series of field experiments. Three spatial densities were created using 203 nearly homogeneous pot plants; the ratios of plant separation to plant height were 0·25, 0·5, and 3 for the 'high,' 'medium,' and 'low' groups respectively. The daily transpiration rate of 55 pot plants was measured for 28 days. During that period, the plants were randomly rotated each day to statistically eliminate individual characteristics and to successfully ascertain the effect of plant spatial density on the transpiration rate. As a best-case scenario, the soil for each plant was saturated at the start of each experiment. The results showed that the transpiration rate of potted plants in the 'low' group was about 1·5 times greater than that of the 'high' group. On the basis of the transpiration rate per unit of vegetation area projected on a horizontal plain, which is a general index used in meteorological modeling, the plants in the 'low' group evaporated 2·7 times as much water as those in the centre of the 'high' group. These results indicate the need for modified models that can consider the relative increase in evapotranspiration from vegetation in small-size plants or low spatial density of vegetation to estimate latent heat flux in urban areas. Copyright © 2007 John Wiley & Sons, Ltd.



(a) Overview of the experimental site with the group 'high' plants in the foreground.

(b) A single potted plant.

A CAESIM model has been developed representing one of the pot plant densities as described in the publication (medium density). The CFD model has been executed and compared with the published experimental results.

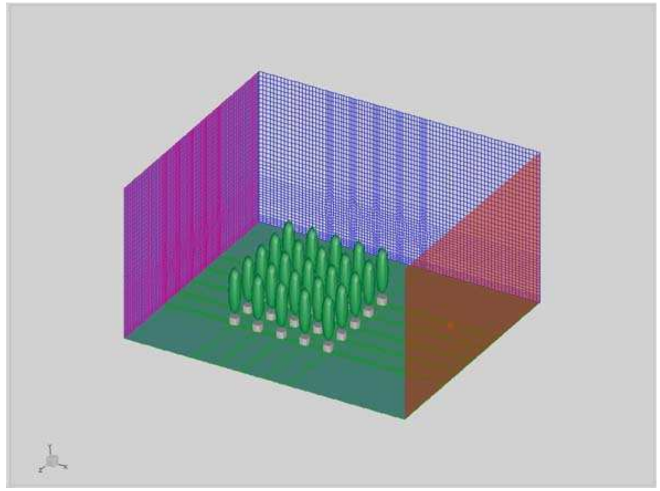
Some assumptions were made in order to best match the physical conditions of the experiment. For example, leaf area indices (LAI) are assumed to be moderate (LAI set to 2.0). In addition, the geometric modeling of each potted plant is estimated from the photos shown above.

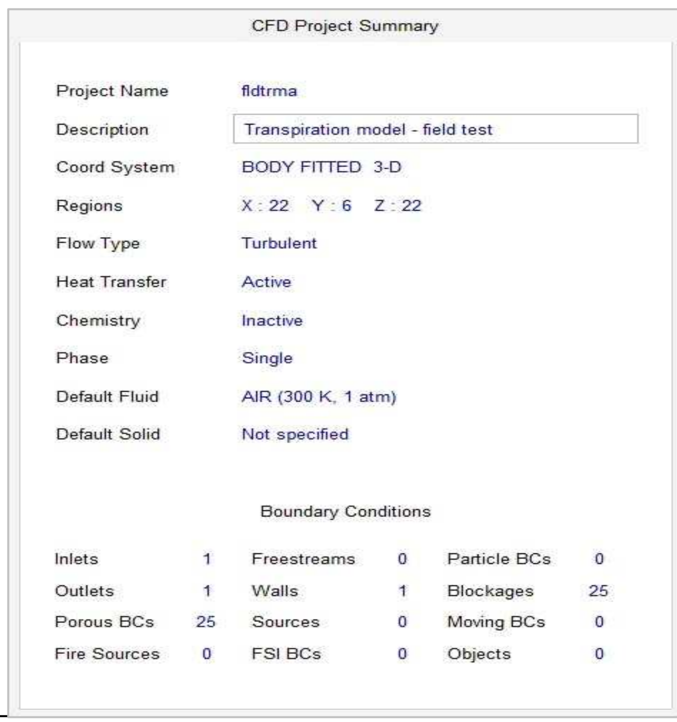
CFD Model Definitions

The settings for the CFD model developed are summaryized below.

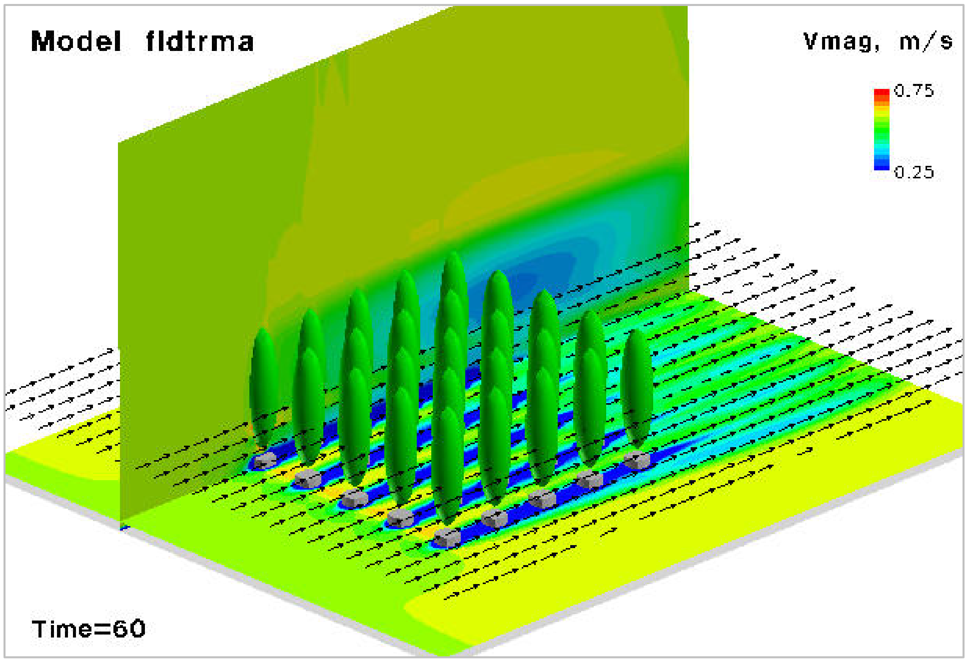
*Medium Density CFD Model "**fldtrma**"*

Turbulent flow
Heat transfer activated
Plant configuration: 5 x 5 (~4m by 4m)
Mesh distribution: 96 I 42 J 82 K
1 inlet BC (1 m/s wind velocity)
1 outlet BC
1 wall BC
5x5x2 customized volumetric source BCs
1 gravity force BC
1 initialization field BC
Fluid I set to air (density=1.177 kg/m^3)
Simulation timestep: 0.1 seconds
Tend: 60 seconds



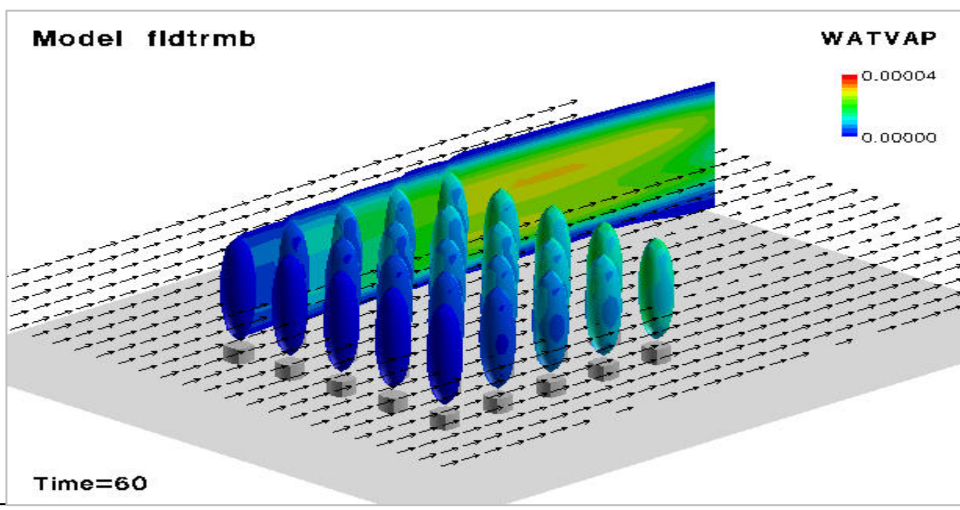


CFD Model "fldtrma" - Steady-State Flow Field

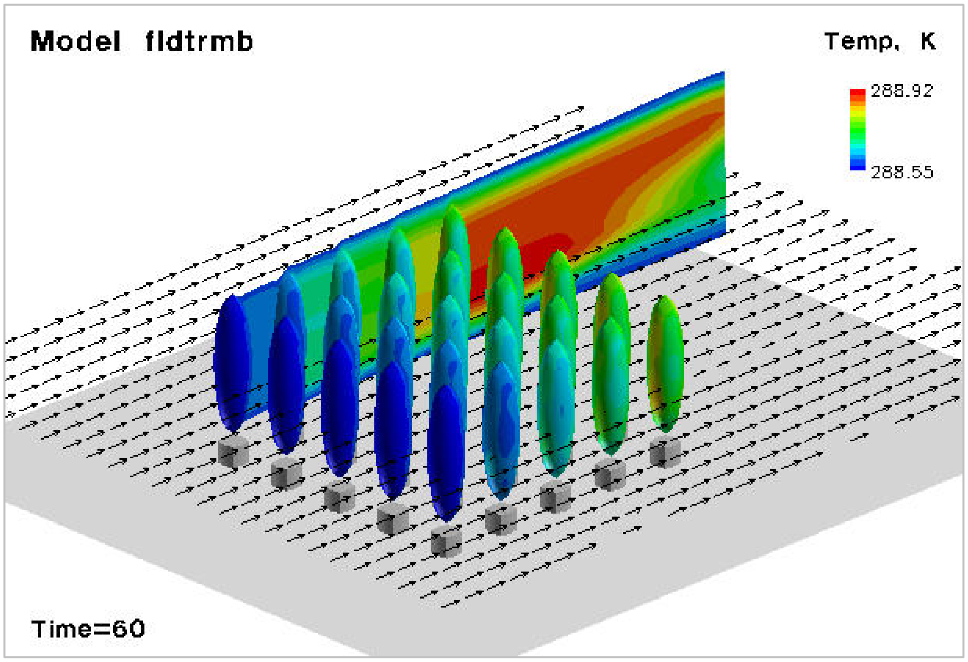


Note: CFD model " fldtrma" used to establish steady-state flow field

CFD Model " fldtrmb" - Water Vapor Field



CFD Model " fldtrmb" - Temperature Field



The average transpiration rate for the center potted plant was computed to be:

3.8e-6 Kg/m^2-s

The publication reported that the highest transpiration rate measured was 456.25 g/day (see Table below).

Table II. Leaf areas and transpiration rates of three selected plants

Plant	Average transpiration rate of three runs (g day^{-1})	Transpiration rate rank among all test subjects	Number of leaves	Leaf area (m^2 pot^{-1})	Crown volume[a] (m^3 pot^{-1})
#1	456·25	1st	2454	1·47	0·380
#2	227·25	23rd	1641	0·98	0·349
#3	149·5	50th	2015	0·99	0·264

To compute the actual transpiration rate in Kg/m^2-s, the measured value of total leaf area of 1.47 m^2 was used (also shown in Table II pg 1221). This results in a transpiration rate of:

(0.45625 kg/day) x (1 day / 24x60x60 sec) / (1.47 m^2)

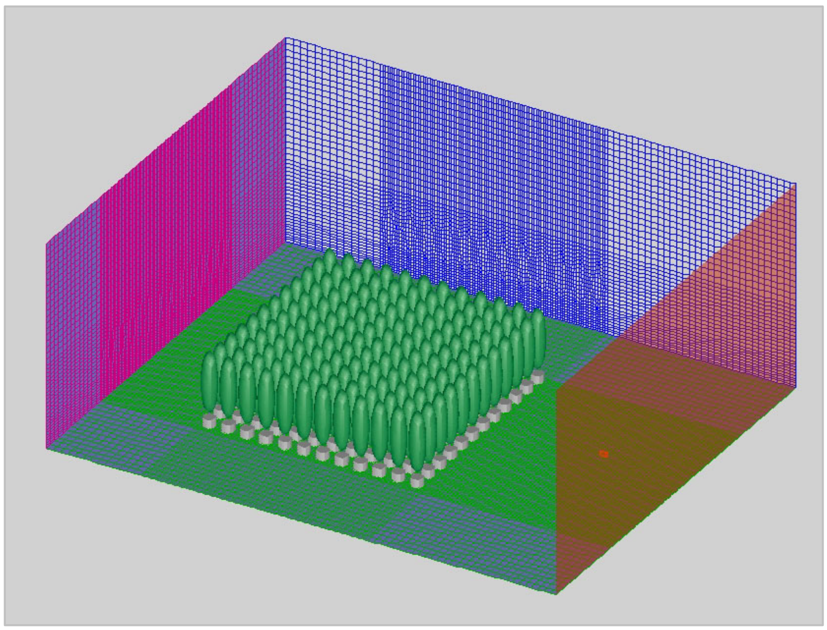
3.6e-6 Kg/m^2-s

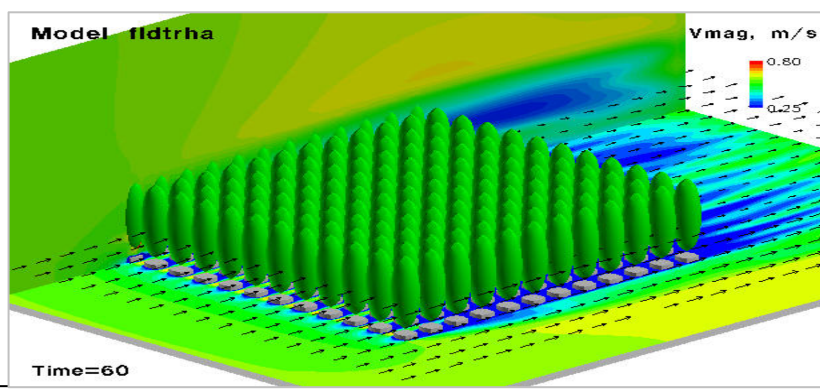
The values are quite comparable, and confirm that the transpiration modeling approach is performing well. It should be noted that even though the transpiration rate (per meter squared) is reasonable, <u>the resulting vapor introduction is controlled by the computation mesh fidelity</u>.

For the CFD model defined, the surface area resulting from the mesh definition results in a value of 2.33 m^2. This is larger than the measured total leaf area determined in the experiment.

Further algorithm development is recommended, with an upgrade to the algorithm required to automatically determine the mesh surface area (simulated plant surface area) to which the computed transpiration rate is applied.

This customized CAESIM simulation capability can be applied to any type of plant growth environment (including hydroponic systems that include water evaporation systems).





References

Hagashima, Narita, Tanimoto, 2007. Field experiment on transpiration from isolated urban plants, Hydrological Processes, 21, 12717-1222.