The Role of Ventilation
15th AIVC Conference, Buxton, Great Britain
27-30 September 1994

Water Evaporation of 5 Common Indoor Plants Under Various Climate Conditions

B Strickler

ETH, Swiss Federal Inst. of Technology, Research Group of Building Services, P O Box 49 8093 Zurich, Switzerland

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ETH, Swiss Federal Institute of Technology
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P.O.Box 49, 8093 Zurich, Switzerland

Synopsis

In recent years plants have increasingly become an integral part of building interior design. Greened office space and large enclosures can provide a better human environment not only because of psychological reasons. Due to photosynthesis, plants interact with the "aerial" environment. Water evaporation affects room air humidity and temperature. Water uptake rates of five common plants in typical indoor climate conditions have been studied. Water evaporation of these plants can now be predicted in architectural design studies. Simulation of a typical office room in summer and winter show that intensive planting can significantly increase air humidity. As a conclusion, this extra humidity should be removed by natural ventilation in summer while in winter it helps to provide comfortable air conditions. The study shows that the effect of indoor plants' water evaporation on air temperature is little.

The plant family

Dizygotheca véitchii "Castor", common name false aralie; petit boux calédonien

Family Araliaceae with approx. 20 species, originated in Australia and some Pacific Islands. Requires a minimum air temperature of 18°C and a minimum illuminance level of 1200 lux.

Dracaena deremensis "Warnekii", common name Warneckeii Dracaena

Family Agavaceae with 40 species known originated on the Canary islands, in the tropical and subtropical parts of Africa, Asia and the south-east Asian island. Warnekii Dracaena originated in east Africa.
Requires a minimum air temperature of 13°C and a minimum illuminance level of 400 lux.

Ficus benjamina, common name ficus

Family Moraceae with approx. 2000 species. Species cultivated as indoor plants are originated in South-East Asia.
Requires a minimum air temperature of 12°C and a minimum illuminance level of 1000 lux.

Hedera hélix, common name English ivy

Family Araliaceae with approx. 7 species originated in Europe and Asia.
Requires a minimum air temperature of 18°C and a minimum illuminance level of 1000 lux.

Philodendron imperial, common name philodendron

Family Araceae with approx. 275 species originated in the tropical forests of Latin America.
Requires a minimum air temperature of 15°C and a minimum illuminance level of 500 lux.

Mechanism of transpiration

The plant loses taken up water by transpiration through the stomata. Less than 1% is converted into carbohydrates. Transpiration occurs at the foliage skin boundary where atmospheric air is not saturated. Intercellular water diffuses through the stomata and then enters the atmospheric boundary layer in gaseous form. The thickness of this layer depends on occurring air movements. It varies from a few millimetres in calm to zero in wind situations. The boundary layer structure also depends on the foliage hair structure.

The 1st Fick diffusion equation describes the mechanism of water transpiration

$$\frac{dm}{dt} = -D \cdot q \cdot \frac{\partial c}{\partial x}$$

Transpiration (dm/dt) most intense in conditions with high concentration gradients ($\partial c / \partial x$) and large surface (q), the diffusion constant D being component specific.

The quantity of water transpiration is controlled by the stomata which can adjust their surface according to the momentaneous plant's need. With fully opened stomata, foliage can lose up to 50-70 % of the evaporation from an open surface. One has to take into account that all total stomata surface covers only 1-2% of the foliage.

Water transpiration can be determined by measuring water uptake with a scale. As less than 1% of the water uptake is converted into carbohydrates, this method is satisfying, especially during short survey periods.

Experimental set-up

The test cabins

3 test cabins (phytotrons) at the Swiss Federal Research Station for Fruit-Growing, Viticulture and Horticulture were used for our measuring campaign during 3 weeks in June 1993. Each phytotron was equipped with 2 sets of our plant family making a total of 10 plants. Plant arrangement provided similar light exposure. The climate in each phytotron was controlled in order to obtain constant conditions by the use of heating/ cooling/ humidification/ dehumidification devices. The experiment was set-up in order to get uptake figures of each plant depending on the main parameters air temperature, relative humidity and illuminance.

During the measuring campaign, temperatures in each phytotrons were set-up at constant levels (15°C; 20°C; 25°C). Relative humidity (40%; 60%; 80%) and illuminance (dark; level I; level I+II) were kept constant for a "day period" of 12 hours followed by a 12 hour "night period".

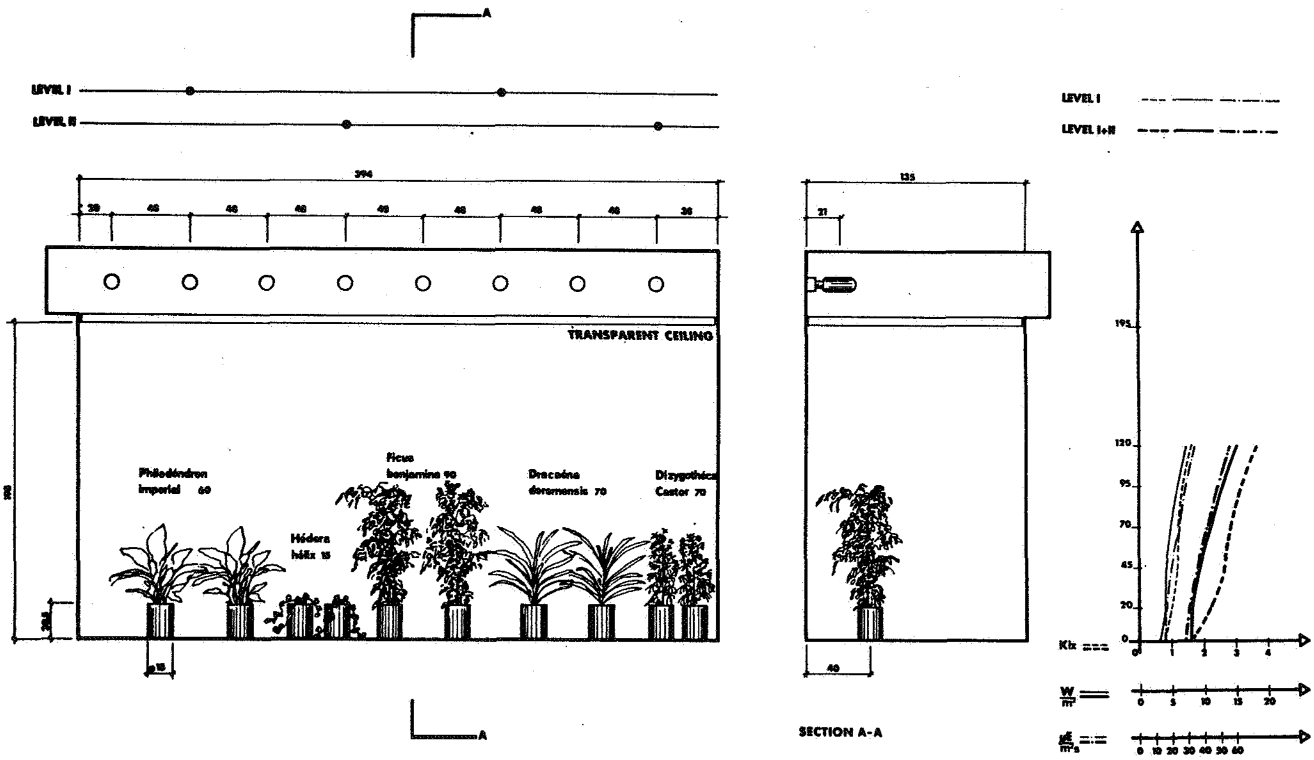

Fig. 1 Plant arrangement and light levels in the phytotrons

Light quality

The phytotrons were equipped with high-pressure metal halide lamps (EYE-Clean Ace MT 400 DL) with its favourable spectral energy distribution. The lamps were arranged so that horizontal light level distribution was even.

Hydroculture planting system

Our plants were placed in geometrically identical hydroculture pots supported in Leca, a lightweight expanded clay aggregate of pale brown colour. For irrigation and nutrition, water enriched with N: 60 mg/l, P: 22 mg/l, K: 96 mg/l, Mg: 16 mg/l, Fe: 7 mg/l was used.

Water uptake measurement

During 12-hour periods where climate was kept constant, water uptake of each plant pot was monitored. To obtain net figures of the plant without the pot's evaporation, uptake of "unplanted" pots of the same size and filled with the same amount of Leca granulate were included. Measurements were carried out with the precision scale Mettler-Toledo PM 6000. This scale has a range of 6000g with an accuracy of 0.01g. Pots had a maximal weight of 2400g and values were monitored with an accuracy of 0.1g.

Leaf area and leaf area index (LAI)

Total leaf area of each individual plant was measured in order to obtain comparable results. A LI-COR areameter which measures light transmission reduction was fed with the plant's total foliage by a conveyer. The following table shows average leaf area values:

Dizygotheca véitchii "Castor"	approx.	0.300	m^2
Dracaena deremensis "Warnekii"		0.200	
Ficus benjamina		0.750	
Hedera hélix		0.110	
Philodendron Imperial		0.450	

The characteristics of a plant's foliage density can be described with the leaf area index (Leaf Area Index = LAI):

$$LAI = \frac{total\ leaf\ area}{plant\ ground\ area}$$

Values of LAI ranges from 0.45 (ground cover plants) to 14 (bushes). The plants we used had the following LAI values:

Dizygotheca véitchii "Castor"	approx.	5
Dracaena deremensis "Warnekii"		0.7
Ficus benjamina		2
Hedera hélix		-
Philodendron Imperial		1.4

Results

The following diagrams (fig 2 to 6) show net water uptake rates in g/m^2 h depending on air temperature, air relative humidity and illuminance. Each value is the arithmetical average obtained from 2 plants exposed to the same climate. Figure 7 shows average values of the whole plant family.

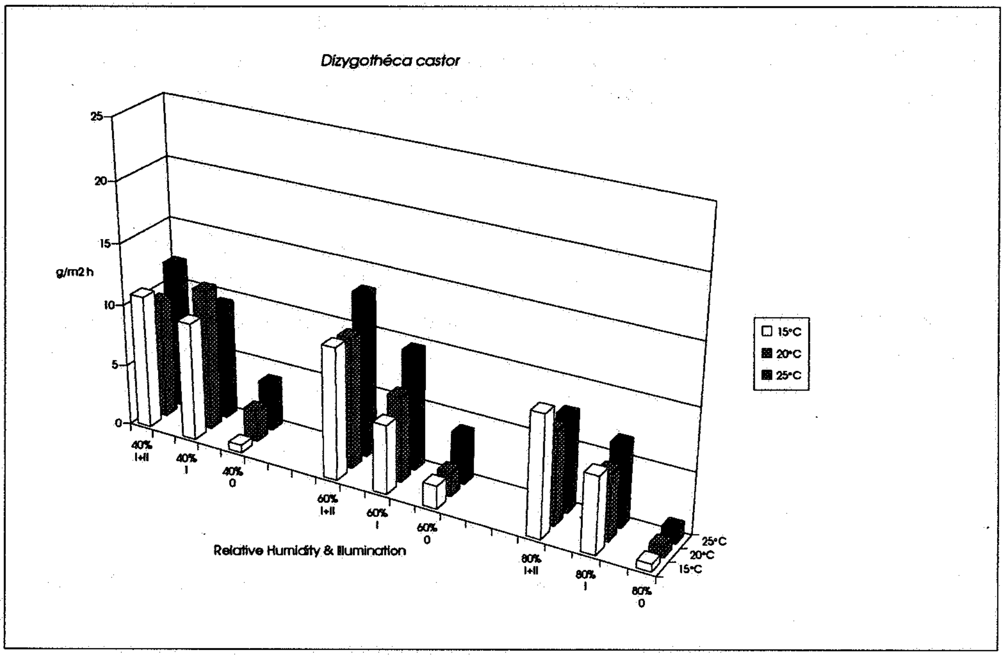

Fig. 2

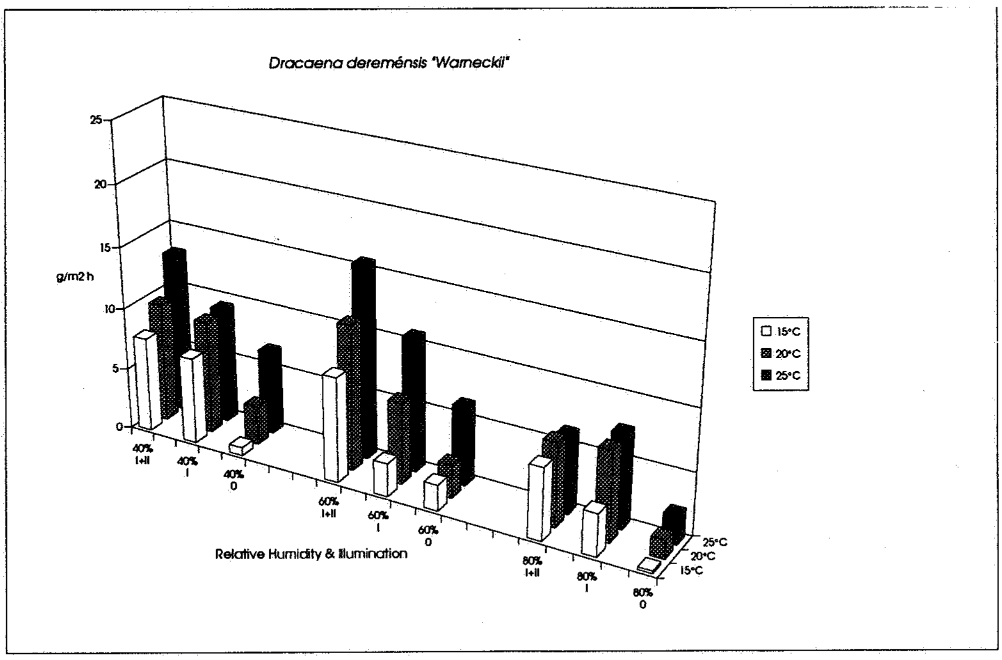

Fig. 3

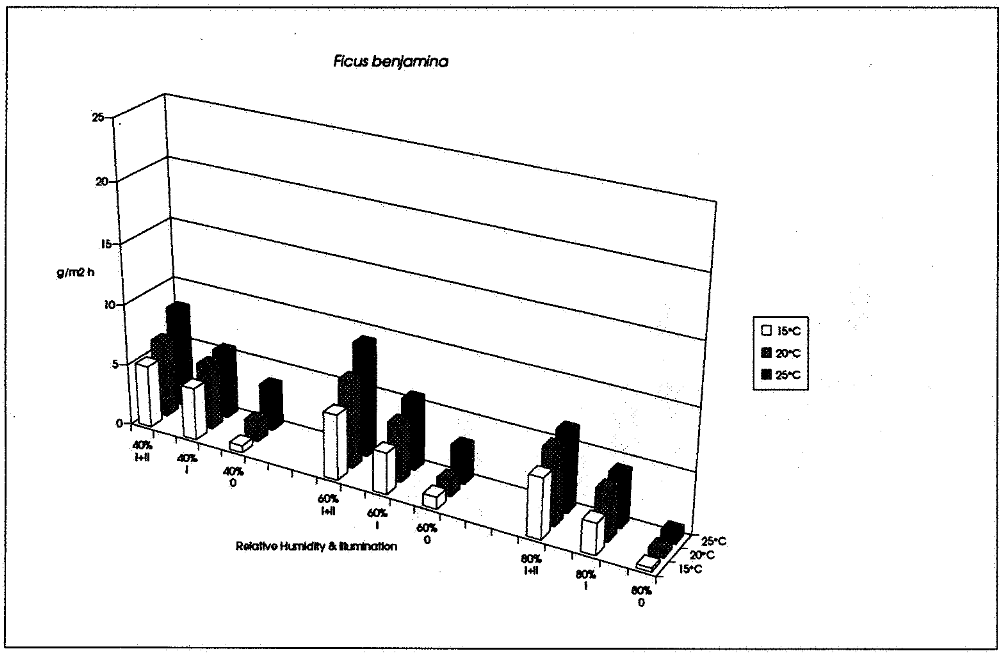
Ficus benjamina
25
20
15
g/m2 h
10
5
0
40% I+II
40% I
40% 0
60% I+II
60% I
60% 0
80% I+II
80% I
80% 0
Relative Humidity & Illumination
25°C
20°C
15°C
15°C
20°C
25°C

Fig. 4

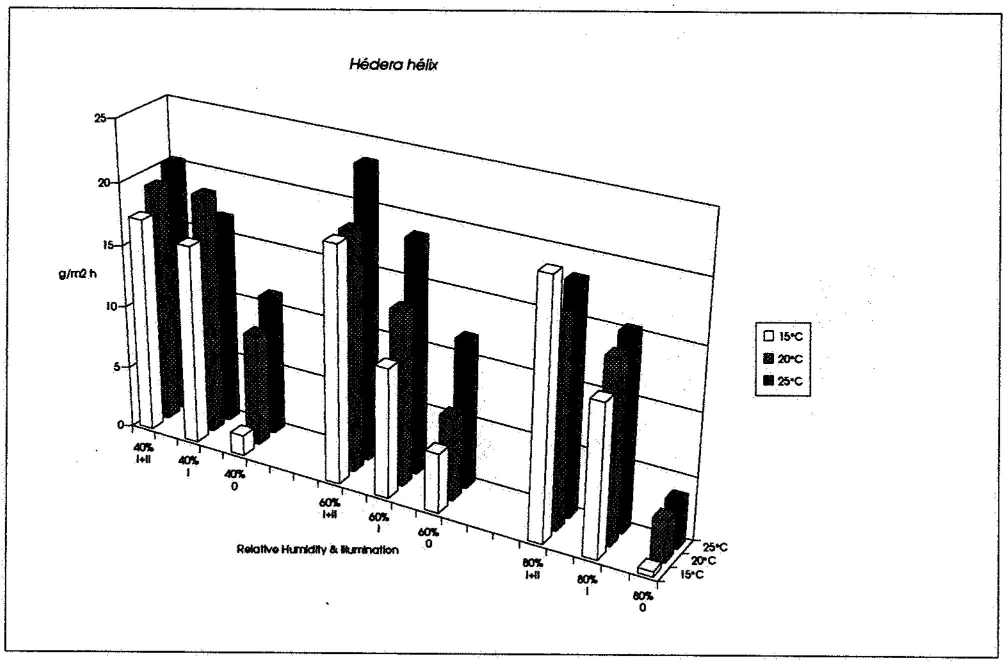
Hédera hélix
25
20
15
g/m2 h
10
5
0
40% I+II
40% I
40% 0
60% I+II
60% I
60% 0
80% I+II
80% I
80% 0
Relative Humidity & Illumination
25°C
20°C
15°C
15°C
20°C
25°C

Fig. 5

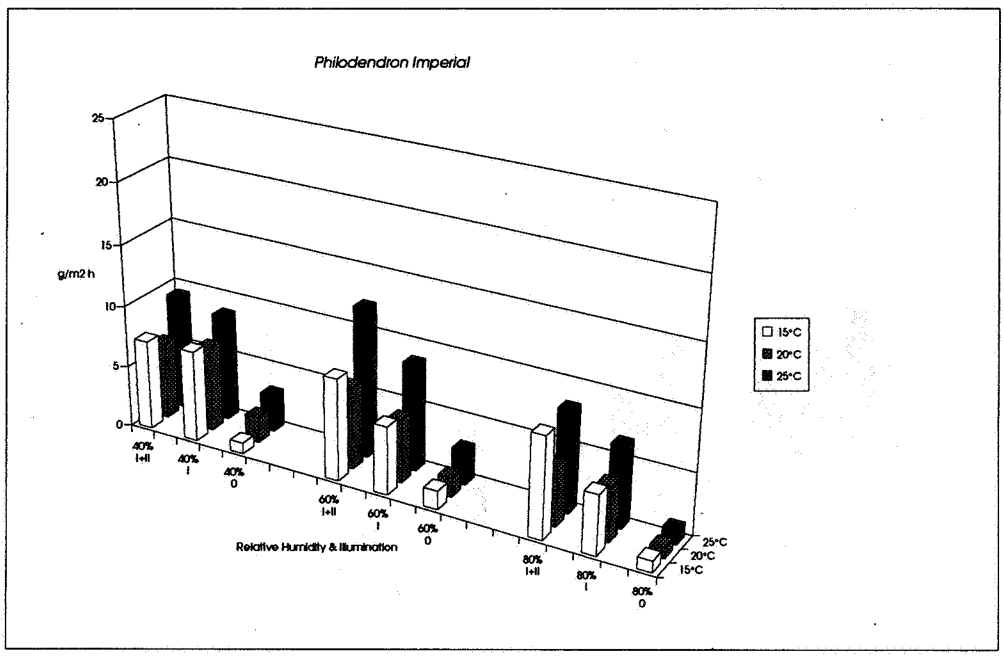
Philodendron Imperial
g/m2 h
25
20
15
10
5
0
40% I+II
40% I
40% O
60% I+II
60% I
60% O
80% I+II
80% I
80% O
Relative Humidity & Illumination
25°C
20°C
15°C
15°C
20°C
25°C

Fig. 6

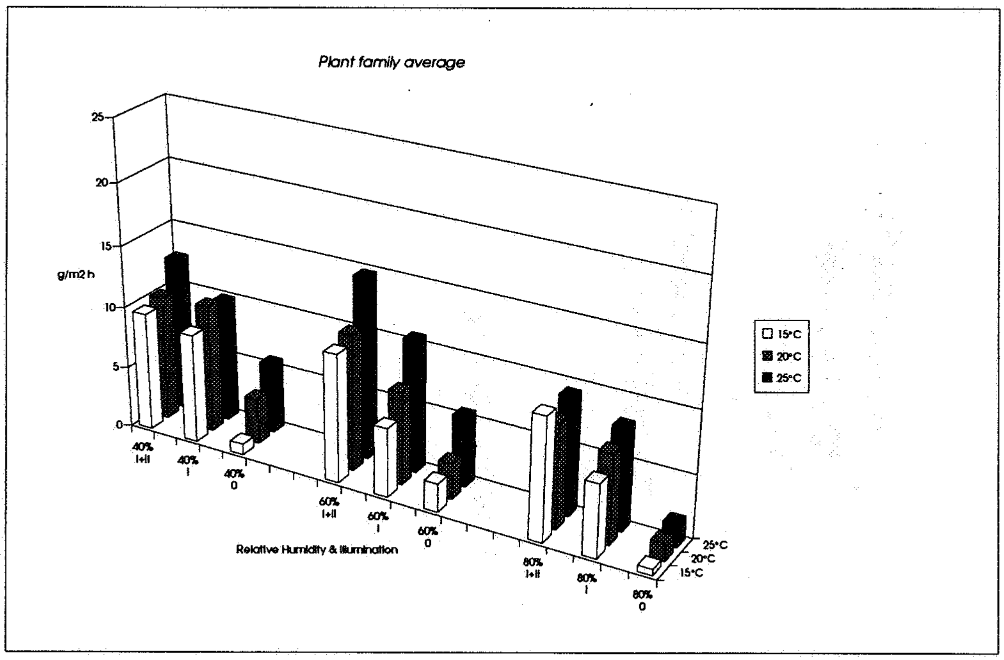
Plant family average
g/m2 h
25
20
15
10
5
0
40% I+II
40% I
40% O
60% I+II
60% I
60% O
80% I+II
80% I
80% O
Relative Humidity & Illumination
25°C
20°C
15°C
15°C
20°C
25°C

Fig. 7

Plant effects on indoor air humidity and temperature

The model room

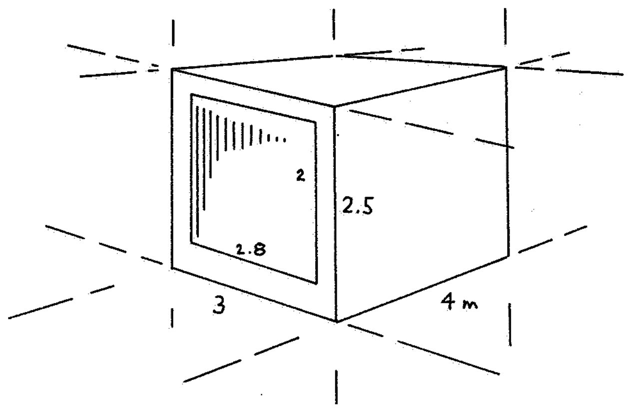

Fig. 8 Model room geometry

Outdoor climate

Our model room was exposed to climate extreme both in winter and summer. For the town of Zurich, detailed weather data are available in the form of the Design Reference Year (DRY) weather file. With this weather file, together with the model room's thermal parameters and properties, data were obtained by the use of the PC program SUNCODE V5.6. Figures 9 to 12 show predicted humidity and air temperature levels for the coldest (26 January) and the hottest (28 July) day.

Plants in the model room

According to our study in the phytotron, of the plants we used, English ivy has the highest evaporation rate. Advantages of this plant are it needs little extra space when used as a wall covering and has modest requirements of light levels and temperature. For our thermal model we fixed the following values:

Water evaporation of $4m^2$ English Ivy	day	night
in summer	72g	16g
in winter	72g	24g
(evaporation cooling power)	(50W)	

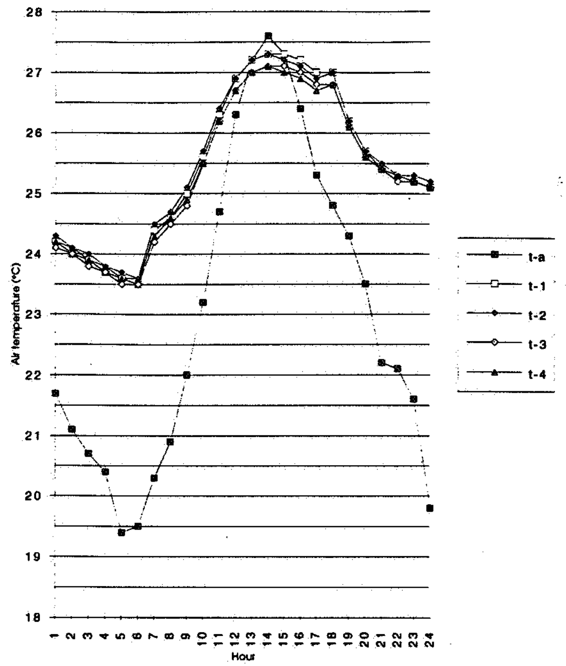

Fig. 9 Change in air temperature (T) on 28 July

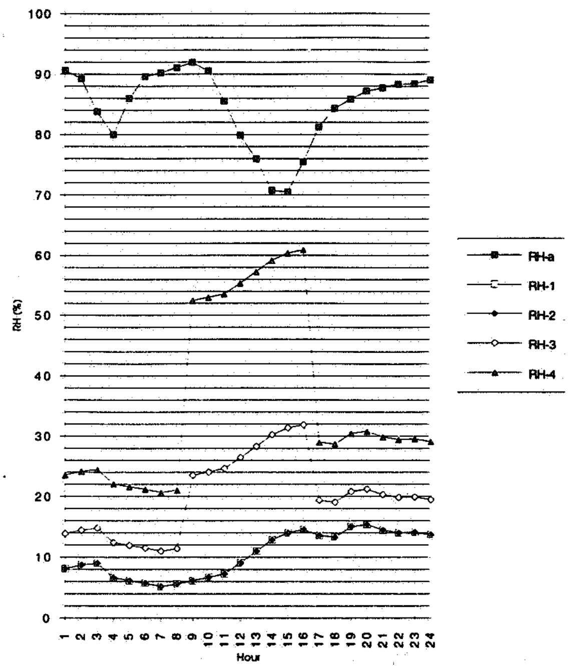

Fig. 10 Change in relative humidity (RH) on 26 January

a outdoor conditions
-1 indoor conditions without plants, air change rate n=0.8 1/h
-2 indoor conditions without plants, air change rate n=0.3 1/h
-3 indoor conditions with plants, air change rate n=0.8 1/h
-4 indoor conditions with plants, air change rate n=0.3 1/h

Summary and discussion

- *Plant water evaporation rates vary highly depending on plant species and indoor climate conditions. Evaporation rate do not depend linearly on humidity levels. Most plants will tolerate humidity levels as low as 40% but usually prefer levels between 60-80%.*

- *Humidity levels can only be increased in situations where effective plants provide a high foliage surface. Air change rates should be well below 1/h.*

- *The effect of evaporative cooling by plants is negligible.*

- *Intensive indoor planting requires an integral design method in order to provide a pleasant appearance, long plant life and comfortable room conditions both in winter and summer. A greened atrium can be a humidity source in winter but in summer, extra humidity has to be removed from the building.*

Addresses of "indoor climate gardeners"

LOG ID
Dieter Schempp, Sindelfinger Strasse 85, Glashaus, D - 72070 Tübingen, Germany

ATELIER FOR INTERIOR LANDSCAPE AND ECOLOGY
Fritz Wassmann, Hofenstrasse 69, CH - 3032 Hinterkappelen-Bern, Switzerland

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19 July 1994