Estimating the Effects of Wall Greening on Improving the Thermal Environment

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Abstract : This study aimed to quantitatively assess the effects of wall greening, which is attracting attention as a countermeasure against the heat island phenomenon in cities, in mitigating the thermal environment by measuring the surface temperature and MRT of panels covered with vegetation and concrete walls (painted white). As a result, the surface temperature of panels was lower about 2～4°C without peak time, and MRT was also about 11°C lower at peak time. And then, by measuring the evapotranspiration from wall panels, and calculating the latent heat flux from the measurement data. The analysis showed that the evapotranspiration from the vegetation on the panels was about 4.1kg/m^2 (4.1mm), and the latent heat flux from the panels was about 60% of the net heat emission. The study suggests that the effect of wall greening in decreasing sensible heat flux could bEquantitatively assessed.

Keywords : heat island, wall greening, thermal environment, MRT, evapotranspiration , latent heat flux

1. Background and Purpose of the Study

A heat island phenomenon has become remarkable by increase of artificial heat disposal as a result of increasement of earth surface covered by concrete or asphalt and decreasement of greenery spaces and the water surface, a car with city activity or an air conditioner in an urban region, and "Outline of the Policy Framework to Reduce Urban Heat Island Effects" was decided in March 2004 by Inter-Ministry Coordination Committee to Mitigate Urban Heat Island, and it is necessary and urgent to promote the measures strongly.

It is assumed that it is effective to increase greenery spaces in a city as a measure to improve the coverage of the ground surface, and in a city area where land use has been highly accumulated, it is necessary to promote the greening of roof-tops and walls of buildings on private lands which occupied the most part of city area. Comparing with roof-top greening, wall greening is still indeveloping process.

As the technological task in order to develop and defuse wall greening in the future, Shimomura [1] has point out the stable supply and growth characteristic of plant materials which could be used for wall greening, such as rearranging of a species name and a kind name, measurement method of adhesive power on various surface structures and grasp of growth characteristic of plants.

In addition, Muto [2] has point out problems for planning and designing, such as building use and design, plant forms and intervals, based on the hearing investigation using evaluation Grid method, from sight and psychological aspect.

Development Bank of Japan[3] has pointed out maintenance methods , as problems of panel-type wall greening and crimbing up/sagging-type wall greening, such as difficulty of uniform splinkling water, and pruning, and also pointed out lack of information, as a problem in the spread, such as quantitative effect by wall greening , contents/ expense of maintenance, at the time of construction.

As effects of thermal environment improvement concretely by ;building greening, it could be expected to reduce sencible heat flux by increasing latent heat flux with evapotranspiration from plants and basement soil.

On evaluating transpiration effects for plants used for wall greening, Nojima[10] tried to assumEquantity of transpiration from measurement of transpiration velosity, but it was not sufficient for inspection about adjustment between actual measurement values in this estimation. In addition, Haginoshima[11]proposed to estimatEquantity of transpiration of wall greening, based on the experiment using the SAT meter, it was not enough for accumulation of data and substantial inspection.

Therefore, this study aimed to evaluatEquantitatively on improving effects of thermal environment at the outside of a building,we compaired surface temperature and MRT between wall greening panels, using two kinds of plants of *Euonymus fortunei* and *Hedera herix*, and a concrete wall (the white painted), and then examined the effect of reduction of sencible heat flux on wall greening panels, based on latent heat flux which was caluculed from quantity of evapotranspiration measured by weight method

2. Method of Study

(1) The establishment of experimental devices

We sat two examination bodies of green panel, using a wall surface of building, which faced south on the first floor roof-top of a experiment ridge in the Building Research Institute.We installed green panel of examination bodies above 1～3m from the roof-top surface, 0.5m apart from wall surface of the building.

In addition, a concrete outer wall surface (the white painting) of an experiment ridge was used for a wall surface of non covered concrete to compare with wall greening surface.

One unit of green panel was used peat-moss base, length 30cm*width 30cm*thickness 8cm,and we sat examination bodies that one body was 1.8m*1.8m, composed of 36 pieces of a green panel, each side 6*6 pieces.

The covering thickness of plants was about 8-12cm. About watering plants on the examination bodies, We installed a drip-type splincler in the green panels for 10 minutes at 18:00, frEquency once in 3rd day, except the rainy day so that basement of a panel could not dry .

We measured with the eye that there were no great differencies between each condition of plant growth using the unit which constituted a green panel. The examination bodies were carried in an experiment institution on July 25, 2005.Each examination body and placement of measurement machineries were shown in Fig.-1, and the establishment situation of each examination body was also shwn in Photo - 1.

(2) Method of measurement

Measurement method is concretely as follows.

①A long-short wavelength radiometer and a glove thermometer were sat 0.5m apart from the wall surface of the examination body and, and about 2m height from roof top, approximately on the middle of it.

②T-type thermocouples (φ 0.2mm) were installed on five points, four corner and center of the each examination body, in order to measure the surface temperature of the examination bodies and the concrete wall. In addition, to except influence of direct solar radiation to a installed part, we painted elasticity paint of white, as same as concrete wall, on the top of aluminum tape in the establishment side of a concrete wall.

③We also installed a thermo-hygrometer, an anemo-scope meter, a pyrheliometer about 3m apart from the green wall examination bodies.

④We installed measurement machineries on July 25, 2004 and performed from July 28th to August 28 by automatic measurement. We recorded the measurement distance every one minute.

⑤All the leaves of a unit 30cm*30cm after measurement were removed in order to grasp a plant growth state on a unit which consisted of a green panel examination body, and then leaf area was read with a scanner.

⑥A unit, as Equal one that constituted a green panel, was also installed near the examination bodies fpr measuring the weight. (cf. Photo. 1)

The establishment situation of green panels and measurement machineries were shown in Fig.-1.

3. Results

3.1 The general weather outlook

A change of temperature, humidity, intensity of solar radiation and wind velocity, as climatic condition of seven

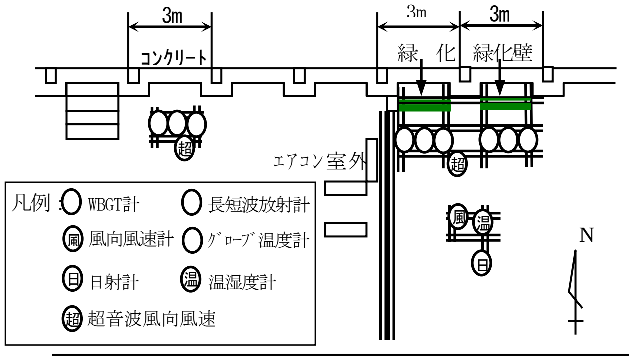
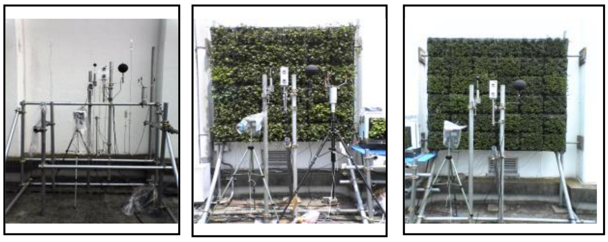


Fig..1 Measurement machineries placement



左：コンクリート壁面　中：ヘデラヘリックス　右：アメリカツルマサキ
(白色塗装)

Photo. 1 The setting situation of the examination bodies

Photo.2 The measurement situation of quantity of evapotranspiration using electronic scales

days from August 16 to August 22, were shown in Fig.-2.

Although the rain falled from the previous night to 1:00 only on August 16, the highest temperature became over 30 degrees for four days from August 16th to 22nd. The most highest temperature during the measurement period was 33.6℃ degrees in August 20, the most lowest temperature was 21.6℃ in August 17, and the average temperature was 27.3℃. In addition, wind velocity was 0～1.8m/sec, and wind direction was mainly south-west wind. It was recorded south-west wind of 1.0m/s daylong on August 22. Humidity was 56-97%, and the average humidity of six days was 76.6% except August 16th when it was rainy.

Taking up August 21 when weather was stable daylong and, measurement results of surface temperature and MRT value were shown as follows.

Table 1 A list of measurement machineries

Measurement Item	Measurement Machinery Name	Maker Name (Model No.)	Qty.
Temperature Humidity	Thermometer/Hygrometer	Vaisala Co., Ltd. (HMP45D)	1
Direction of the wind Wind velocity	Anemoscope/Anemometer	Ogasawara Instrument Co., Ltd. (CW105)	1
	Supersonic Anemoscope/ Anemometer	Eko Instruments Co., Ltd. (MR -130)0)	2
Quantity of sunlight	Pyrheliometer	Prede Co., Ltd. (PCR -02)2)	1
Quantity of long wave emission Quantity of radiation Quantity of incidence sunlight Quantity of reflection sunlight	Length Wave Radiometer	Eikoh Seiki Instruments Co., Ltd. (MR -50)0)	3
Blackball temperature	Glove Thermometer	Prede Co., Ltd. (BST131)	3

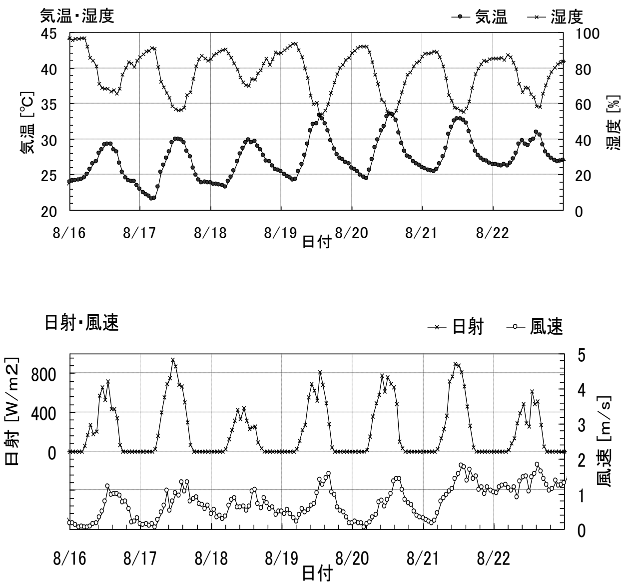


Fig..2 The general weather outlook during measurement periods(quantity of sunlight/the wind velocity, temperature/the humidity)

3.2 Surface temperature

Changes over time in surface temperature of a concrete wall surface and green panels in August 21 was shown in Fig.-3. Surface temperature of each wall was revised measured long wavelength radiation by longwave emittance, and calculated.

Surface temperature of *Hedera herix* has became approximatelyas same as it of a concrete wall from 9:00 by 12:00, but green panels reduced 2-4 degrees lower than a concrete wall except these hours.As a result of measured solar reflectance of green panel materials, a concrete wall recorded 0.70 high numerical value, whereas green panels showed 0.25～0.27.

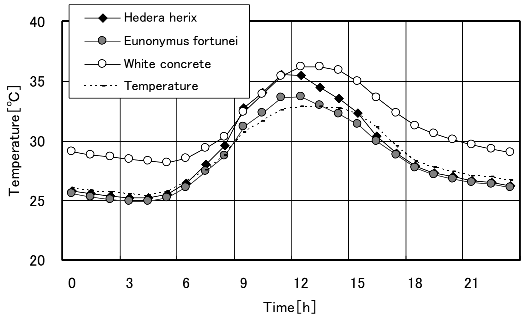


Fig. -3 Changes over time in surface temperature

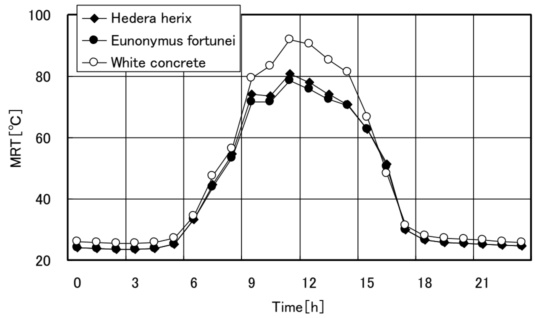


Fig.-4 Changes over time in MRT

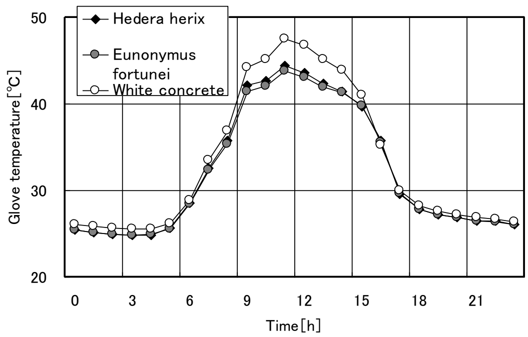


Fig.-5 Changes over time in a glove thermometer

Thus, the reason why difference between surface temperature of green panels and a concrete wall shrank at peak time was supposed that not only leaf temperature incleased but also surface

temperature of a concrete wall was controlled to increase, as a concrete wall was painted white and the sunlight was reflected.

In green panels, surface temperature of Eunonymus fortunei was 1.8℃ lower than it of Hedera herix at peak time, and difference of surface temperature was shown between using plants.

3.3 Evaluation of thermal environment improvement effect by MRT (Mean Radiant Temperature)

Paying attention to radiant environment, we verified thermal environment improvement effects by MRT of wall greening in the place of relatively near human living space. MRT (Mean Radiant Temperature) was one of the sensible indexes to show a feeling of heat, and shown average heat radiation caught from all neighboring directions[6]. To be concrete; using blackball glove temperature (Tg), dry-bulb temperature (Td) of a glove thermometer and the ultrasonic wind anemometer (V) , MRT was calculated with Eq. (2).

$$MRT = T_g + 2.37\sqrt{V} \times (T_g - T_d) \quad \cdots \quad (2)$$

Tg: Blackball glove temperature [℃], Td: Dry-bulb temperature [℃], V: Wind velocity [m/s]

Changes over time in a calculation result of August 21 was shown in Fig.-5.Thus, green panels changed consistently with lower temperature in the daytime than a concrete wall. Difference of temperature between both examination bodies enlarged, as temperature rised.

At 11:00, the greatest peak time, *Hedera herix* showed 80.9℃ and Eunonymus fortunei showed 78.5℃ in green panels, whereas a concrete wall showed 91.8℃. Temperature of green panels showed 11～13 lower than a concrete wall.Difference of temperature caused by difference of using plants could be hardly recognized, and differences of using examination bodies also could be scarcely shown at night.

Changes over time in glove temperature of green panels and a concrete wall was shown in Fig.-5.The reason why MRT value showed very high value of 91,8℃ was supposed that a globe thermometer showed 47.6℃, and difference from air temperature showed 15.1℃.Green panels changed with lower temperature than a concrete wall, and difference between both spread, as temperature rised, it was shown that MRT of green panels reduced about 11℃ lower at peak time, comparing with it of a concrete wall.

The reason of these differences was supposed that as a concrete wall was painted white, it was effected mainly by difference of albedo (solar reflectance) , comparing with green panels.Thermal environment improving effects in outdoor spaces by wall greening could be estimated quantitatively by using MRT as an index.

3.4 Measurement results of quantity of transpiration by weight method

3.4.1 Quantity of evapotranspiration by day

Putting one unit of green panels using Eunonymus fortunei on the electronic balancEquantity of evapotranspiration of unit panel was caluculated from weight change by automatic measurement every one minute, and quantity of evapotranspiration per unit 1 ㎡ was converted from the area ratio.

As for measurement value of weight, moving average of 30 minutes was taken, in order to average unevenness of measurement value of the electronic balance by influence of wind. The quantity of integrating evapotranspiration per day during a measurement period was calculated from quantity of weight change of 24 hours, from 0:00 until 24:00. Changes over time in qantity of evapotranspiration in the daytime per unit (soil + plant) 1 ㎡ was shown in Fig.-4.

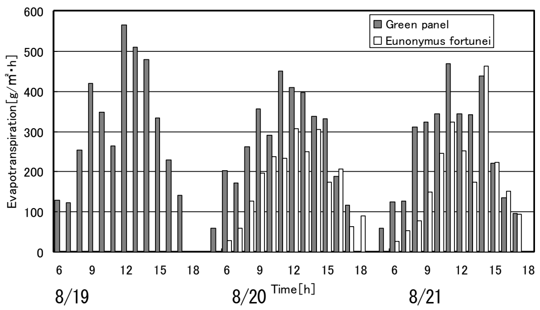


Fig.6 Changes of quantity of evapotranspiration (8/19-8/21)

Table 2 Result of measurement for quantity of evapotranspiration

Division	Item	August 19th	August 20th	August 21st	Average
A unit	Quantity of day evapotranspiration [g/㎡]	4,308	4,015	3,833	4,052
	Peak time [g/㎡]	576	457	487	507
A plant	Quantity of day transpiration [g/㎡]	-	2,443	2,434	2,438
	Peak time [g/㎡]	-	311	392	351
Quantity of day transpiration / Quantity of day evapotranspiration		-	0.61	0.64	0.60

Quantity of integrating evapotranspiration from measured results was shown in Table -2. It was recorded 4,308g/㎡ in August 19, the most highest, 4,015g/㎡ in August 20, and it was decreased gradually with 3,833g/㎡ in August 21.Tendency of decrease of quantity of evapotranspiration corresponded approximately with decreasing tendency of percentage of soil volume water content. ThEquantity of evapotranspiration per day during three days, when two days passed from watering, was 4,052g/㎡ on average.

According to Fig.-4, each measured day approximately similar changed, it was shown that quantity of evapotranspiration tended to increase, as temperature and intensity of solar radiation increased, the highest value of quantity of evapotranspiration showed 457～576g/㎡・h, when temperature and intensity of solar radiation showed the highest value at 12:00, as peak time.

3.4.2 Quantity of transpiration per day from plants

For two days of August 20 and 21st, one unit of green panels examination bodies was covered by polyethylene and quantity of transpiration from the *Eunonymus fortune* was calculated.

Quantity of day transpiration provided from measurement result was shown in Table-2. It was recorded 2,443g/㎡ in August20, 2,434g/㎡ in August 21, and average for two days was 2,438g/㎡. The highest peak of quantity of

Table-3 Latent heat flux and quantity of net radiation

Division	Item	A kind	August 20	August 21	Average
Latent heat flux [LE]	Integration per day [MJ/㎡]	(a) unit (b)plants	9.70 5.90	9.27 5.88	9.49 5.89
		(b)/(a)	0.61	0.63	0.62
	Peak time [W/㎡]	(a)unit (b)plants	304.8 207.5	325.6 262.3	315.2 234.9
		(b)/(a)	0.68	0.81	0.74
Quantity of net radiation [Rn]	Integration per day [MJ/㎡]		7.65	8.72	8.19
	Peak time [W/㎡]		326.3	369.4	347.9

transpiration was recorded 311g/㎡ at 12:00 in August 20, 392g/㎡ at 14:00 in august 21, and the average of two days showed 351g/㎡. Thus, quantity of transpiration from plants (*Eunonymus fortunei*) was Equivalent to about 60% of quantity of evapotranspiration from a panel unit.

3.4.3 Relation between latent heat flux and quantity of net radiation

Based on quantity of evapotranspiration provided from a measurement value by weight method, latent heat flux was caluculated by Eq. (1).

$$LE = L \times E$$

$$L = 2.5\times10^6 - 2400 \times \theta a \quad \dots (1)$$

LE: Latent heat flux［W/㎡］, L: Latent heat of vaporization［(J/kg］, E : Evaporation velosity［kg/㎡・h］, θa: surface temperature［℃］

The result was shown in Table-3. ThEquantity of integrating latent heat flux per day was 9.70MJ/㎡ in August 20th, and the highest value was 304.8W/㎡ at 14:00 as peak time.

Similarly, thEquantity of it was 9.27MJ/㎡ in August 21, and the highest value was 325.6W/㎡ at 12:00 as peak time. On average of two days, thEquantity of integrating latent heat flux per day was 9.49MJ/㎡, the highest value was 315.2W/㎡ as peak time.

In addition, as for latent heat flux by transpiration of the *Eunonymus fortunei*, quantity of integration per day was 5.90MJ/㎡ in August 20, and the highest value was 207.5W/㎡ at 12:00 as peak time. Similarly, quantity of it was 5.88MJ/㎡ in August 21, and the highest value was 262.3W/㎡ at 14:00 as peak time.

On average of two days, quantity of integrating latent heat flux per day was 5.89J/㎡, which occupied about 60% of it of a panel unit, and the highest value at peak time was 234.9W/㎡,which occupied about 70% of a panel unit. Then, thermal effects by latent heat flux was verified from relation with quantity of net radiation. The quantity of net radiation was calculated by Eq. (2), based on the incidence emission quantity that was clarified from each measurement value of quantity of atomospheric radiation, surface radiation, incident solar radiation, and reflected solar radiation with a length wave radiometer.

$$Rn = (S\downarrow - S\uparrow) + (L\downarrow - L\uparrow) \quad \dots (2)$$

Rn: Quantity of net radiation［W/㎡］, S ↓: Quantity of incident solar radiation［W/㎡］, S ↑: Quantity of reflected solar radiation［W/㎡］, L ↓: Quantity of atomospheric radiation［W/㎡］, L ↑: Quantity of surface radiation［W/㎡］

Calculation result was shown in Table 3. In addition, changes over time in latent heat flux and quantity of net radiation was also shown in Fig.5. Then, a state of day change of latent heat flux was similar with quantity of net radiation. As quantity of net radiation increased, latent heat fluxes also increased. Both of them had increased in peak hours, from 12:00 till 14:00, after then they had decreased.

As for quantity of net radiation, it recorded less than 100W/㎡, from 6:00 to 8:00 and from 16:00 to 18:00, and decreased extremely less than latent heat flux. It was thought that the transportation of heat, as latent heat flux, by evaporation from a unit continued and exceeded quantity of net radiation, whereas quantity of solar radiation suddenly had decreased in these hours when sun's altitude lowered.

The quantity of integrating net radiation per day was 7.65MJ/㎡ in August 20, and the highest value was 326.3W/㎡ at 13:00 as peak time. Similarly, thEquantity of it was 8.72MJ/㎡ in August 21, and the highest value was 369.4W/㎡ at 13:00 as peak time. On average of two days, thEquantity of integrating net radiation per day was 8.19MJ/㎡, the highest value was 347.9W/㎡ at peak time.

Relation between latent heat flux and quantity of net radiation was shown in Fig.-6. In this study, more than 100W/㎡ of quantity of net radiation that evapotranspiration was relatively stable was treated as the object of our analysis.

Equilateral correlation was accepted between latent heat flux and quantity of net radiation, and latent heat flux was inclined to rise, as quantity of net radiation rose. About 60% of quantity of net radiation was used as latent heat flux on a unit panel, according to a degree of leaning of a regression line.Similarly, Equilateral correlation was recognized between latent heat flux by transpiration of the *Eunonymus fortunei* and quantity of net radiation, and about 50% of quantity of net radiation was used as latent heat flux.

In these circumstances, it was suggested that contribution by quantity of transpiration of plants was higher than it by quantity of evaporation of basement soil, as for the accrual quantity of latent heat flux to it of net radiation. It could be said that as a ratio of latent heat flux for quantity of net radiation became higher, it could restrain to rise sensible heat flux for the outside of building and could contribute to improve thermal environment.

Therefore, it was also suggested that latent heat flux by evapotranspiration held most of quantity of net radiation so that reduction effects of sensible heat flux by the wall greening using green panels was large, especially thermal effect by transpiration from a plant was high. Transpiration from plants was almost performed through pores on the leaves surface, and it is said that quantity of transpiration from except pores was only about 5％[12].

When the water, which is discharged in the atmosphere by evapotranspiration from green panels, is changed from liquid to gas, latent heat is consumed .

Latent heat could not cause a rise of outside temperature, and as quantity of evapotranspiration increased more, latent heat fluxes increased more. It was expected to restrain increase of sensible heat flux which caused the heat island phenomenon. Kato[13] reported that average quantity of evapotranspiration per day was around 6.5mm, as a result of analyzing relation between quantity of evapotranspiration and soil water, intensity of solar radiation, installing containers made by plastic on the asphalt road surface, using the lightweight soil and the decomposed granite soil as compost, and using two kinds of plants of *Sedum mexicanium* and *Tifton grass*.

As a result of this measurement, quantity of evapotranspiration per day by wall greening was 3.6mm by a unit area. Comparing with precedent studies, the measurement value in this study showed lower. It was guessed as a main factor that the leaf area index of the using plant was 1.18, comparatively littlEquantity of leaf, and the water preservation condition of compost was different, without water during the measurement period by weight method. On the other hand, as for relation between latent heat flux and quantity of net radiation, latent heat flux from green panels was held about 60% for quantity of net radiation.

As a result that we[14] measured quantity of transpiration by weight method, using *Hedera Canariensis* which was planted in a planter in past fiscal year, latent heat flux was occupied about 25% of quantity of net radiation, lower than 1/2 of this measurement result. Using plants were different, so it could not be compared simply, it was thought that effectiveness of evapotranspiration rose higher in the case of using green panels than using planters, because of unifying plant and soil.

Evapotranspiration was different greatly by differences of soil condition, so it was suggested that it should be effective for increasing latent heat flux by wall greening to exist and consititute basement soil unified with plants.

Summary

We tried to measure with experiments using wall greening panels in order to estimatEquantitatively the improvement effects of thermal environment for outside of a building by wall greening. Main results provided from this study were as follows.

①The surface temperature of green panels fell down around 2-4℃ at the peak time in the daytime, comparing with it of a concrete wall.

②As for MRT which was calculated from a measurement value of blackball temperature, green panels were about 11℃ lower than a concrete wall at peak time.

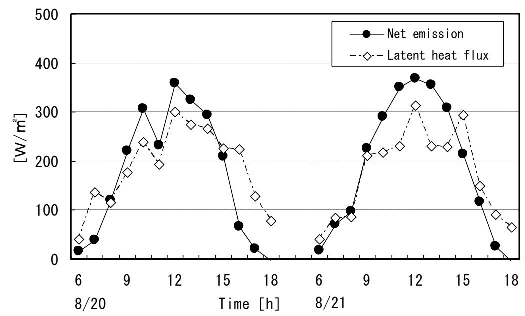


Fig.-7 Changes over time in heat flux and net radiation

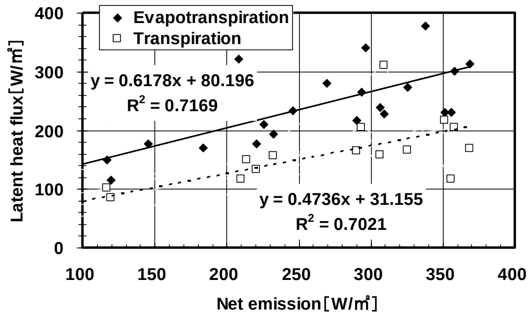


Fig.-8 Relationship between latent heat flux and net radiation

③Quantity of integrating evapotranspiration per day from a panel unit was about 4.1kg/㎡(≒ 4.1mm) , quantity of transpiration from plants was about 2.4kg/㎡(≒ 2.4mm), which ccupied about 60% of the whole evapotranspiration from a unit.

④Equilateral correlation was accepted between latent heat flux and quantity of net radiation, and the ratio of a latent heat flux with evapotranspiration occupied in quantity of net radiation was shown about 60%.

In future, it would be necessary for estimating the improvement effects of thermal environment by greening the outside of a building to accumulate more basic data of a kind of plants, covered degree, difference of greening type and so on.

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