Abstract

The Hong Kong Observatory has been employing three identical lysimeters installed at the King’s Park Meteorological Station in Hong Kong for measuring Potential Evapotranspiration (PE) since 1951. Each lysimeter is non-weighable (percolation-type) and equipped with an overflow tank. The lysimeters were operated manually in the past through manually irrigating the grass of each lysimeter and manually taking overflow measurement. PE was deduced from these measurements through the formula PE = Irrigation + Rainfall – Overflow.

To streamline operation, the Observatory developed automated instruments in recent few years for irrigating and carrying out overflow measurements of the lysimeters. The design and implementation of the automatic lysimeters are described in this paper. PE measurements obtained from the automated instruments under different weather conditions in 2014 and 2015 were compared with those from the manual observations. Conclusion was drawn and full automatic operation of the lysimeters started from 1 January 2016.

1. Introduction

Three square lysimeters (Figure 1) were installed on a flat ground at the King’s Park Meteorological Station in October 1951 to measure PE (Chen, 1976). Each lysimeter is built of bricks and surfaced in cement plaster. They are all of the same size, each with an internal side of 2.0 m and an inside depth of 0.7 m. The three lysimeters are set in line with their rims just above the ground. Outlet pipes lead from the bottom of each lysimeter to respective overflow tanks (see Tank 1, 2 and 3 in Figure 2), which are located on a concrete step at a lower level. Each lysimeter is filled with ordinary local light soil turfed with local grass, but the bottom 10 cm are filled with granite chips in order to avoid clogging the output pipes.

Before 1 January 2016, operation of lysimeters was totally manual. It involved:

i) manually irrigating the grass of each lysimeter with fixed volume of water to provide an equivalent amount of 7.5 mm of rainfall through a lysimeter\(^1\) at fixed time slot (set at 3 p.m.) every day;

\(^1\)30 litres of water through the grass field of a lysimeter with area 2m x 2m = 4 m\(^2\) is equivalent to 7.5 mm of rain.
ii) emptying the water in each overflow tank into an in-house graduated metal bucket marked with divisions of 0.2 mm of rainfall (see inset in Figure 2) at fixed time slot (set at 11 a.m. in the next morning) to reset the tank and to measure the equivalent amount of water overflow from a lysimeter; and

iii) measuring the 24-hour accumulated rainfall amount recorded by a nearby raingauge at fixed time slot (also set at 11 a.m. in the next morning).

Assuming that the moisture contents in the lysimeters at the time of measurement remain the same every day, the difference between the added water (from daily irrigation and precipitation) and the overflow amount would represent the PE of each lysimeter:

\[
\text{PE} = \text{Irrigation (7.5 mm)} + \text{Rainfall} - \text{Overflow}
\]

Each of the above figures is in unit of mm of rainfall through a lysimeter. Daily PE is taken as the average of the PE of the three lysimeters. The mean daily PE of each month is computed by taking the average of all daily figures in a month and is reported in the “Summary of Meteorological and Tidal Observations” published annually by Hong Kong Observatory (Hong Kong Observatory, since 1993).

2. Automation of lysimeter

In order to streamline operation, HKO started to design and develop automatic lysimeter since 2014. The automation work included designing and fabricating an auto-irrigation system to irrigate the grass of the lysimeter and the auto-overflow tank.

2.1 Instrument set-up

An in-house developed prototype automatic lysimeter (Auto-lysimeter 3) was built in mid-2014, which comprises:

i) an automatic irrigation system (Auto-irrigation system 3) for watering the grass field of Auto-Lysimeter 3;

ii) a pump installed outside the overflow tank – Tank 3 (Figure 3); and

iii) a stainless steel diaphragm water level transmitter mounted on a stainless steel stand placed inside Tank 3 (Figure 4).

A block diagram describing the configuration and operation of water level transmitter and pump for Auto-lysimeter 3 is in Figure 5.
The Auto-irrigation system 3 comprises:

(i) two plastic pipes installed on two opposite sides of the grass field of Auto-lysimeter 3 (Figure 6);

(ii) a water storage tank for holding 30 litres of water for irrigation (Figure 3); and

(iii) a pump for removing water from storage tank to irrigate grass field of Auto-lysimeter 3 (Figure 3).

Each plastic pipe is perforated with evenly spaced holes and can be rotated so that water from the storage tank can come out at different elevation angles in order to evenly irrigate both the edges and centre of the grass field (Figure 6). There is an outlet at the side of the water storage tank and the position of the outlet has been determined by filling exactly 30 litres of water in the tank. Water in excess of 30 litres will be overflown through the pipe connected to the outlet. The pump is controlled by a computer to remove water from the 30 litre-tank to sprinkle the grass field at 3 p.m. every day. A block diagram describing the configuration and operation of Auto-irrigation system 3 is in Figure 7.

The water level transmitter uses differential pressure level measurement technology to infer water level by measuring the pressure generated by the water inside the overflow tank. It also features digital temperature compensation, achieving an accuracy of ±0.1%.

2.2 Working Principle and measurement sensitivity of automatic lysimeter

A computer program is responsible for automatically logging the water level (in units of mm in height) registered by the water level transmitter inside Tank 3. The pump is also controlled by the computer program for automatically removing water from Tank 3. Water will be removed from Tank 3 to a lower level (set at 100 mm) in two scenarios:

(i) at 11 a.m. for daily reset (Figure 8); and

(ii) when water reaches a preset upper level (set at 400 mm) (Figure 9) so that tank overflown can be avoided during heavy rain.

The operation of the Auto-lysimeter 3 is such that there is no need to empty the tank during measurement at 11 a.m. By continuously logging the water level in Tank 3, the overflow water amount (in unit of mm of rainfall) can be deduced from the increase in water level recorded by the water level transmitter (in unit of mm height) from 11 a.m. in previous day.

To achieve this the change in water level (C) as measured by the water level transmitter
per mm of overflow from lysimeter has to be determined. As 1 mm of rainfall is 1 litre of rain water falling through 1 m² of area, 1 mm of overflow from lysimeter (area 2m x 2m = 4 m²) is 4 litres of water. The radius of Tank 3 is 28.5 cm. Hence

\[
C = \frac{4000}{\pi \times 28.5 \times 28.5} = 1.57 \text{ cm} = 15.7 \text{ mm}
\]

Overflow of Auto-lysimeter as measured at 11 a.m. can be deduced from the followings (see Figure 8)

\[
\text{Overflow} = \frac{(L_2 - L_1)}{C}
\]

where \( L_1 \) is water level inside tank at 11 a.m. in the previous day after reset; and
\( L_2 \) is water level inside tank at 11 a.m. in current day before reset.

For the case illustrated in Figure 8, namely PE measured at 11 a.m. on 23 April 2014:

Overflow = 5.0 mm
Irrigation = 7.5 mm
Rainfall = 6.0 mm

Hence \( \text{PE} = \text{Irrigation} + \text{Rainfall} - \text{Overflow} = 7.5 + 6.0 - 5.0 = 8.5 \text{ mm} \)

Automatic lysimeter has additional benefit compared to manual observations. Tank overflown due to heavy precipitation can be avoided, resulting in higher PE data availability in rainy weather. For instance, in respect of the heavy rain episode on 12 and 13 August 2014, water was removed 7 times during the 24-hour period before PE measurement was made at 11 a.m. on 13 August (Figure 9). In this case, manual PE observation was not possible due to tank overflown. PE of Auto-lysimeter 3, however, could be deduced as follows:

Overflow = 144.5 mm
Irrigation = 7.5 mm
Rainfall = 152.0 mm
\( \text{PE} = 7.5 + 152.0 - 144.5 = 15.0 \text{ mm} \)

2.3 Comparison of manual and automatic overflow measurements

In order to compare the performance of the manual and automatic PE measurements, both manual and automatic overflow measurements from Tank 3 were taken during the period from 24 January to 29 March 2014. To achieve this, the pump of the prototype Auto-lysimeter 3 was temporarily shut down during the period and Tank 3 was emptied manually at 11 a.m. Comparison results (see Table 1, Comparison No. 1) indicated that the automatic overflow measurements generally agreed with the manual observations from the same overflow tank (Tank 3).
As the comparison aforesaid confirmed the accuracy of the automatic instrument, Auto-lysimeter 3 commenced operation since 1 May 2014. Meanwhile, automation work of Lysimeter 1 based on the same design and equipment as Auto-lysimeter 3 proceeded. PE measurements of Auto-lysimeter 1 were then compared with manual PE measurements of Lysimeter 2 and PE measurements from Auto-lysimeter 3 for the period from 3 September to 15 October 2014. The comparison results are summarized in Table 1, Comparison No. 2 and 3.

Again the automatic measurements from Auto-lysimeter 1 generally agreed with the manual observations from Lysimeter 2 and the automatic measurements from Auto-lysimeter 3. Auto-lysimeter 1 was declared operational backdating to 3 September 2014.

To ascertain the reliability and accuracy of the automatic lysimeters, Auto-lysimeter 1 and 3 were put on parallel run operation with manual Lysimeter 2 for one year. After the parallel run, manual PE observations of Lysimeter 2 were compared with measurements of Auto-lysimeter 1 and 3 for the yearly period from 1 October 2014 to 30 September 2015. The comparison results are summarized in Table 1, Comparison No. 4 to 6.

Automatic measurements from Auto-lysimeter 1 and 3 generally agreed with manual observations from Lysimeter 2. In addition, the automatic measurements from the two automatic lysimeters also agreed well with each other.

Concerning data availability of the manual and automatic lysimeters, availability figure of Auto-lysimeter 1 and 3 were 98% and 96% respectively over the aforesaid yearly period. The two availability figures compared favourably with that of the manual PE observation from Lysimeter 2 (98%).

As accuracy and reliability of PE measurements from the automatic lysimeters were ascertained after one year of parallel run with manual PE observations, automation work of the last lysimeter – Lysimeter 2 proceeded based on the same setup as Auto-lysimeter 1 and 3. The work was completed on 9 November 2015. PE measurements from Auto-lysimeter 2 were compared with that of Auto-lysimeter 1 and 3 for the period 9 November to 31 December 2015. The comparison results are summarized in Table 1, Comparison No. 7 and 8. The PE measurements from Auto-lysimeter 2 agreed well with those from Auto-lysimeters 1 and 3.

Full automation of all three lysimeters started on 1 January 2016.

3. Conclusion

An automatic lysimeter was developed to automatically irrigate the grass field of the lysimeter as well as to automatically measure overflow inside overflow tank. The instrument
consisted of a water level transmitter to log down water level inside the overflow tank, and a pump to remove water from the tank during daily reset or during heavy rain. Both the water level transmitter and pump were controlled by computer program for operation.

PE measurements obtained from automatic lysimeters were compared with manual observations. Results indicated that they were in good agreement with each other. In addition to streamlining PE observations, automatic lysimeters also allow PE measurements during heavy rain which was previously not possible for manual observation owing to tank overflown.

4. Acknowledgements

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5. References


## Table 1 Comparison of PE measurements from two lysimeters

<table>
<thead>
<tr>
<th>Comparison No.</th>
<th>Time period</th>
<th>Lysimeter X to be compared (PE measurements denoted by $\text{PE}_x$)</th>
<th>Lysimeter Y to be compared (PE measurements denoted by $\text{PE}_y$)</th>
<th>Mean difference in PE = ($\text{PE}_x$-$\text{PE}_y$)* (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24 January to 29 March 2014</td>
<td>Automatic measurements from Auto-lysimeter 3</td>
<td>Manual measurements from Auto-lysimeter 3</td>
<td>-0.3</td>
</tr>
<tr>
<td>2</td>
<td>3 September to 15 October 2014</td>
<td>Automatic measurements from Auto-lysimeter 1</td>
<td>Manual measurements from Lysimeter 2</td>
<td>-0.5</td>
</tr>
<tr>
<td>3</td>
<td>3 September to 15 October 2014</td>
<td>Automatic measurements from Auto-lysimeter 1</td>
<td>Automatic measurements from Auto-lysimeter 3</td>
<td>-0.5</td>
</tr>
<tr>
<td>4</td>
<td>1 October 2014 to 30 September 2015</td>
<td>Automatic measurements from Auto-lysimeter 1</td>
<td>Manual measurements from Lysimeter 2</td>
<td>-0.4</td>
</tr>
<tr>
<td>5</td>
<td>1 October 2014 to 30 September 2015</td>
<td>Automatic measurements from Auto-lysimeter 3</td>
<td>Manual measurements from Lysimeter 2</td>
<td>+0.2</td>
</tr>
<tr>
<td>6</td>
<td>1 October 2014 to 30 September 2015</td>
<td>Automatic measurements from Auto-lysimeter 1</td>
<td>Automatic measurements from Auto-lysimeter 3</td>
<td>-0.7</td>
</tr>
<tr>
<td>7</td>
<td>9 November to 31 December 2015</td>
<td>Automatic measurements from Auto-lysimeter 2</td>
<td>Automatic measurements from Auto-lysimeter 1</td>
<td>+0.3</td>
</tr>
<tr>
<td>8</td>
<td>9 November to 31 December 2015</td>
<td>Automatic measurements from Auto-lysimeter 2</td>
<td>Automatic measurements from Auto-lysimeter 3</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

*The difference is computed only when PE measurements from both Lysimeters X and Y are available.*
Figure 1 Three square lysimeters at King's Park Meteorological Station of Hong Kong Observatory.
Overflow tanks of lysimeters at King’s Park during manual operation period – Tank 1, 2 and 3 for Lysimeter 1, 2 and 3 respectively. Tank 2 comprises two tanks, 2a and 2b to cater for increased overflow during heavy rain situations.

Measuring bucket graduations marked with divisions in 0.2 mm of rainfall falling through Lysimeter 3

Figure 2

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Figure 3 Pumps and water storage tank for Auto-irrigation system 3 of prototype Auto-lysimeter 3.
Figure 4  Stainless steel diaphragm water level transmitter (4a) mounted on a stainless steel stand (4b) and placed inside Tank 3 (4c) of prototype Auto-lysimeter 3.
**Auto-Lysimeter 3**

- Grass
- Soil
- Filter
- Tank 3
  - radius 28.5 cm
  - ht 90 cm
- Water Level Transmitter
- Pump
- RS-485
- Device Server
- AC Power
- iBoot
- Computer Server
- Intranet
- Report 1-min average

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**Figure 5** Block diagram of configuration and operation of water level transmitter and pump of prototype Auto-lysimeter 3.
Figure 6 Watering of (a) near edges and (b) near centre of grass field of prototype Auto-lysimeter 3 by Auto-irrigation system 3.
Figure 7  Block diagram of configuration and operation of Auto-irrigation system 3.

Example text: Figure 8 Trace of water level inside Tank 3 of prototype Auto-lysimeter 3 on 22 and 23 April 2014 as measured by water level transmitter.
Figure 9  (a) Trace of water level inside Tank 3 of prototype Auto-lysimeter 3 as measured by water level transmitter; (b) One minute rainfall as measured by automatic raingauge at King’s Park Meteorological Station on 12 and 13 August 2014.