APPENDIX 1

VTT BUILDING AND TRANSPORT

RESEARCH REPORT

Developing long term durability of marble facades

Subproject "Environmental conditions"

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Encl.: Final report (96 pages)

VTT

CONTENTS

1 BACKGROUND

The need for conserving, restoring and protecting stone buildings and monuments throughout the world is growing continuously. This is particularly actual in the historic cities of Europe where marble and other calcareous stones have been commonly used. The decay of old stone structures is becoming a remarkable technical and economic problem. Deteriorated stone facades may in some cases even represent a considerable safety risk. The durability problems have led to a strong decrease in the use of marble for outdoor applications.

One of the most important reasons for the deterioration and fouling of natural stones is the rising amount of acid compounds and other impurities coming mainly from industrial and traffic sources. Today stone structures are exposed to harsher environmental conditions than ever before. Thin stone veneers that are commonly used nowadays are even more sensitive for weathering than traditional massive stone structures.

Carrara marble was used as the original facade material for Finlandia Hall. In the early 1980's the marble plates began to warp. Warping was especially noticeable in larger plates because of lapping. It also became apparent that the plates' inner strength was rapidly weakening. Extensive studies were undertaken to determine the cause of the deterioration. The conclusion was that the phenomenon was mainly due to climatic factors and especially to acid rain, which gradually converts marble to gypsum.

The badly damaged marble facade of Finlandia Hall was renewed during the autumn of 1998 and the spring of 1999. In connection with the refurbishment, the City of Helsinki launched the research project "Developing long-term durability of marble facades" known as "MARA-project". The main aims of the project were to extend the service life of the new facade, to formulate an appropriate maintenance strategy and to create reliable technical criteria and methods to assess the suitability of marble for facade applications.

As already stated above the degradation of marble is a universal problem, which has been especially highlighted by recent cases of damage to old buildings and historic monuments. However, in Europe there are also a number of other architecturally significant new buildings that have fallen victim to the same kind of deterioration as Finlandia Hall. Because research results can therefore be widely exploited, the MARA-project received financial support from the EU's Raphael cultural heritage programme.

VTT Building and Transport was responsible for four subprojects of the main study. The primary goals of these subprojects were to determine the deterioration mechanism of marble, to set requirements for a durable marble facade structure and to develop a reliable method for testing marble quality. The subprojects also included studies of the environmental conditions at Finlandia Hall and of the stresses these cause to marble, of the durability of different types of marble, of the performance of alternative structural solutions and of the possibilities of using protective treatments. The studies were made in co-operation with Helsinki University of Technology, Parma University in Italy and Cevalor in Portugal.

2 OBJECTIVE

The aim of the subproject was to record the real environmental conditions (temperature, humidity) and their annual variations prevailing at Finlandia Hall and in this way to determine the stressing factors that affect marble and the structures of the facades.

In order to achieve the goals set for the subproject it was divided into four tasks:

- designing and installing of the necessary measuring and recording devices
- regular recording of the environmental factors and processing of the data
- acquiring of other necessary information (pH, general weather conditions) and processing of the data
- conclusions and reporting of the results

3 EXPERIMENTAL

3.1 Measuring and recording arrangements

Prevailing temperatures were recorded from five different marble slabs, all of which were placed on the roof walls of Finlandia Hall. Four of the slabs were chosen in such a way that each one of them was directed towards a different cardinal point. The fifth slab was chosen to represent extreme values, and thus it was taken from the top of the tower part of the building (point A). The measuring points were as follows:

measuring point	wall	cardinal point
A	2	south
B	38	west
C	13	north
D	24	south
E	23	east

Temperatures were measured with copper-constantan thermocouples. In each slab specified above there were four thermocouples, which were measuring temperatures in outdoor air, in ventilation slot and on outer and inner surfaces of the marble slab. In the measuring point A there was also a fifth thermocouple, which was recording the outer surface temperature of a black granite slab beside the marble slab with the four other thermocouples. Temperatures were recorded once an hour in each point, and the values were saved into a data logger. Each of the measuring points A, B and C had their own small data logger, type Squirrel SQ 8. Measuring points D and E had a common data logger, type Squirrel 1000.

The recording of temperatures was started in May 1999, and it was continued until the end of February 2001. The data loggers were emptied at regular intervals, and the data collected was downloaded to a transportable computer. Due to power failures or logger malfunction some of the data was, however, lost during the measurement period.

Prevailing relative humidities were recorded from two marble slabs, which were the slabs of the temperature measuring points D and E. Humidities were measured with Vaisala sensors, type HMP 44. In both slabs there were three sensors, which were measuring relative humidities in outdoor air, in ventilation slot and in the middle of the marble slab. In order to measure humidity in the middle of the slabs, a hole (Ø 10 mm, length 150 mm) was drilled through the lower edge of the slabs before installing them on the roof wall. The sensor was put into the drilled hole, and the hole was sealed.

The recording was done as that of temperatures described above. The same data logger as for temperatures was used to save the humidity data.

3.2 Other information

The data concerning general weather conditions was acquired from the Finnish Meteorological Institute. Research results from the measurements of acidity of rain water were delivered by the Finnish Environment Institute.

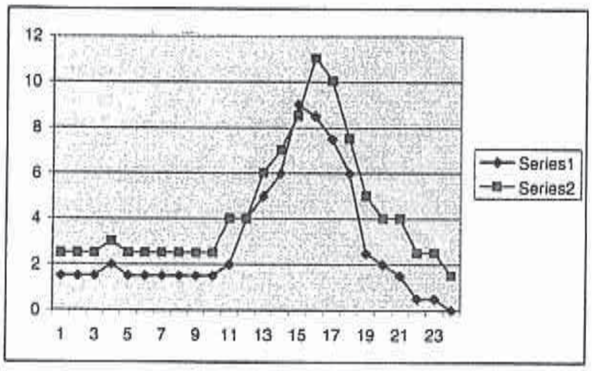
4 RESULTS

4.1 General remarks

The complete file of measurement data from Finlandia Hall is appended to this report as a CD-disc. The features of the results which were considered most important especially in regard of the stresses caused by the environmental factors to the marble facade are described more closely in chapters to follow. In most cases the daily maximum and minimum temperatures are used when examining the results.

4.2 Temperature gradient over the marble slab

Temperature gradient prevailing in the slabs was revealed by examining temperatures on outer and inner surfaces of marble. The results are presented in Figs. 1-5, each of which show four examples of the daily behaviour of surface temperatures of the measurement slabs. The days chosen for the examples represent various seasons.



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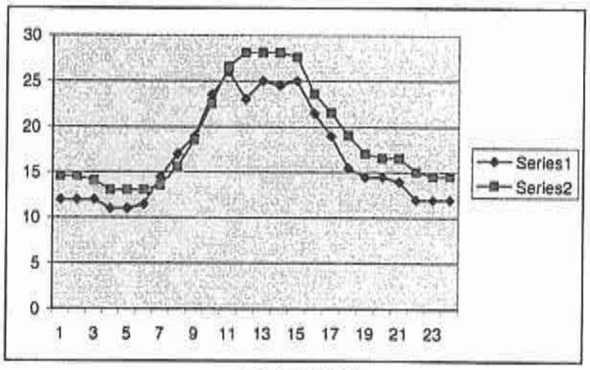

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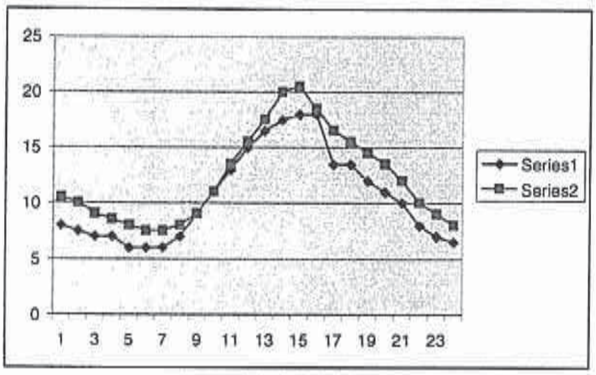

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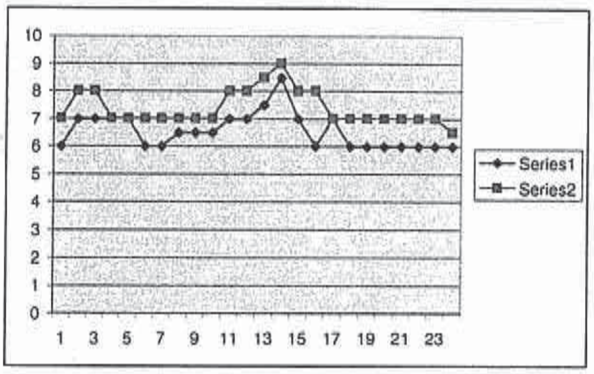

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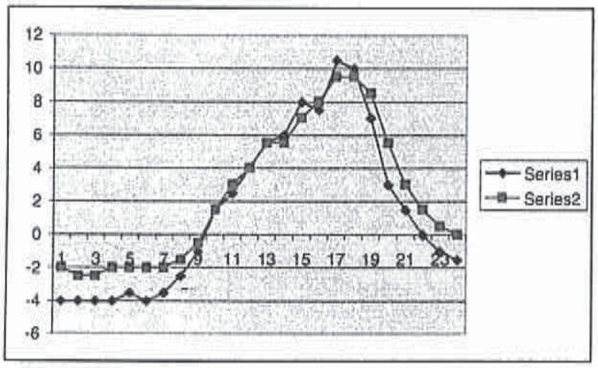
Figure 1. Measuring point A. Temperature of outer (Ser 1) and inner (Ser 2) marble surface (°C).



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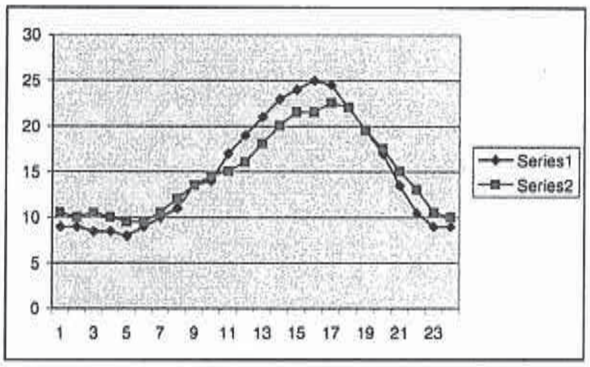

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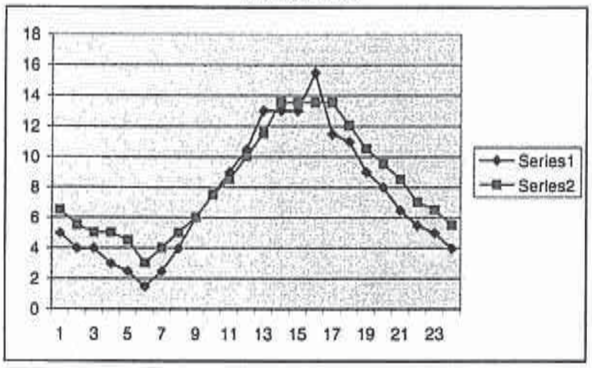

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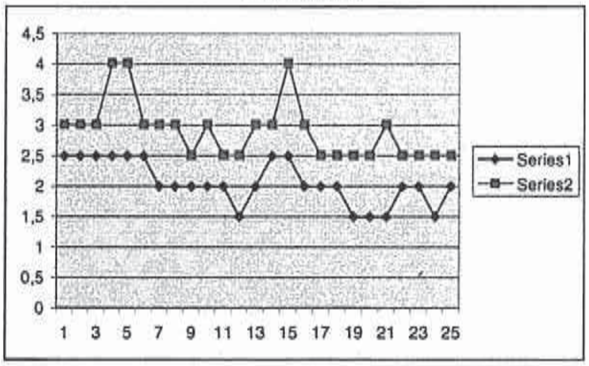

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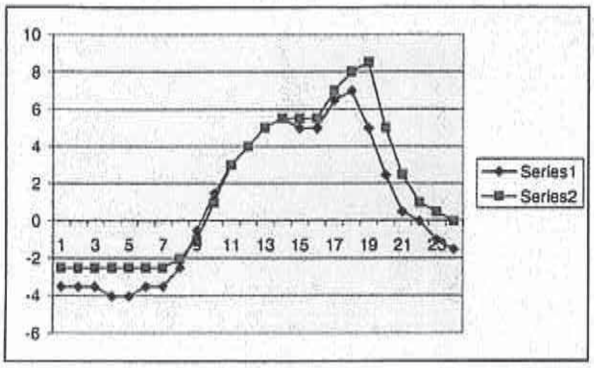
Figure 2. Measuring point B. Temperature of outer (Ser 1) and inner (Ser 2) marble surface (°C).



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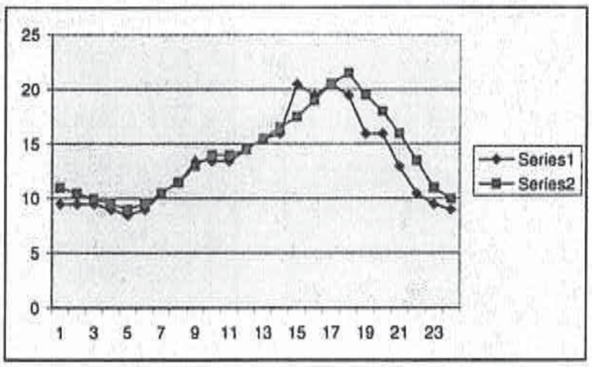

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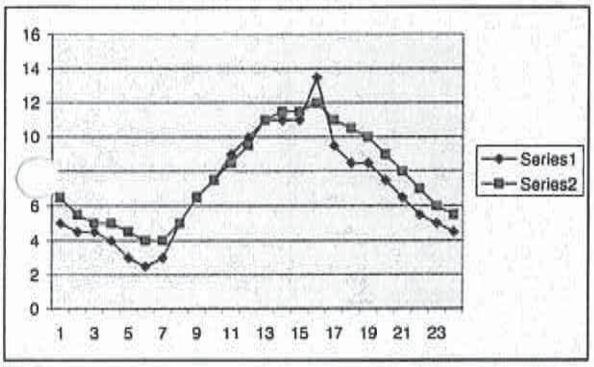

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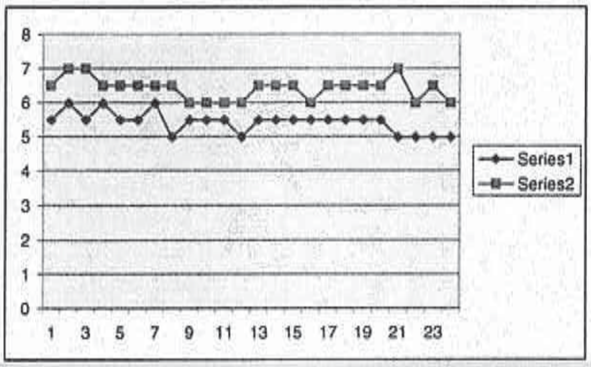

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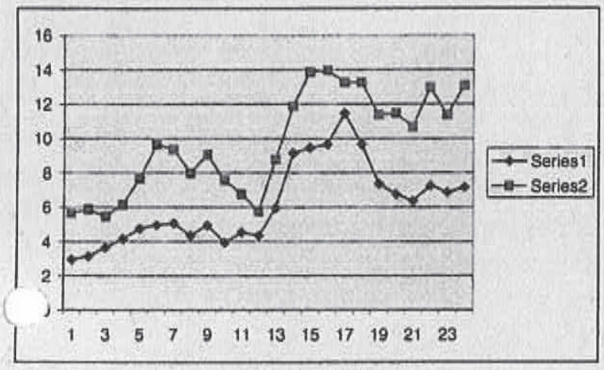
Figure 3. Measuring point C. Temperature of outer (Ser 1) and inner (Ser 2) marble surface (°C).



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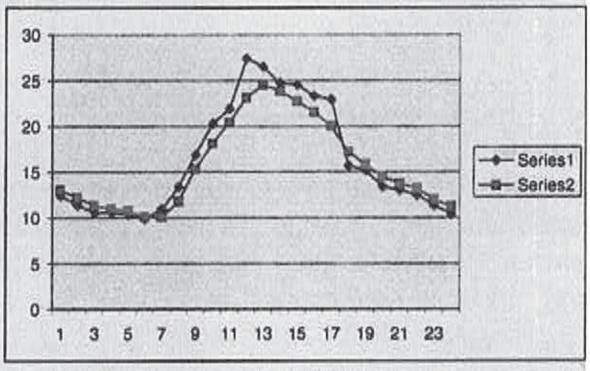

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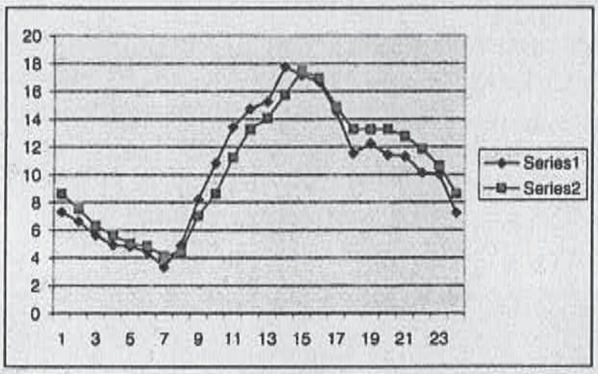

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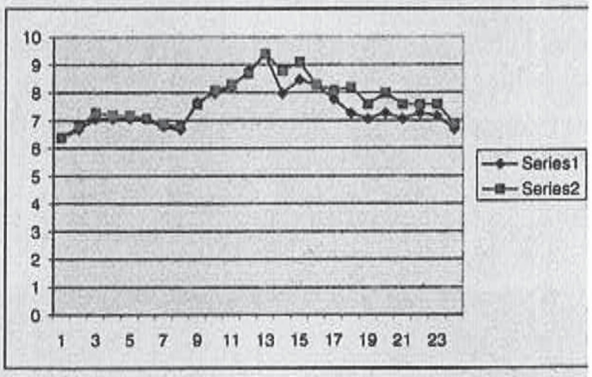

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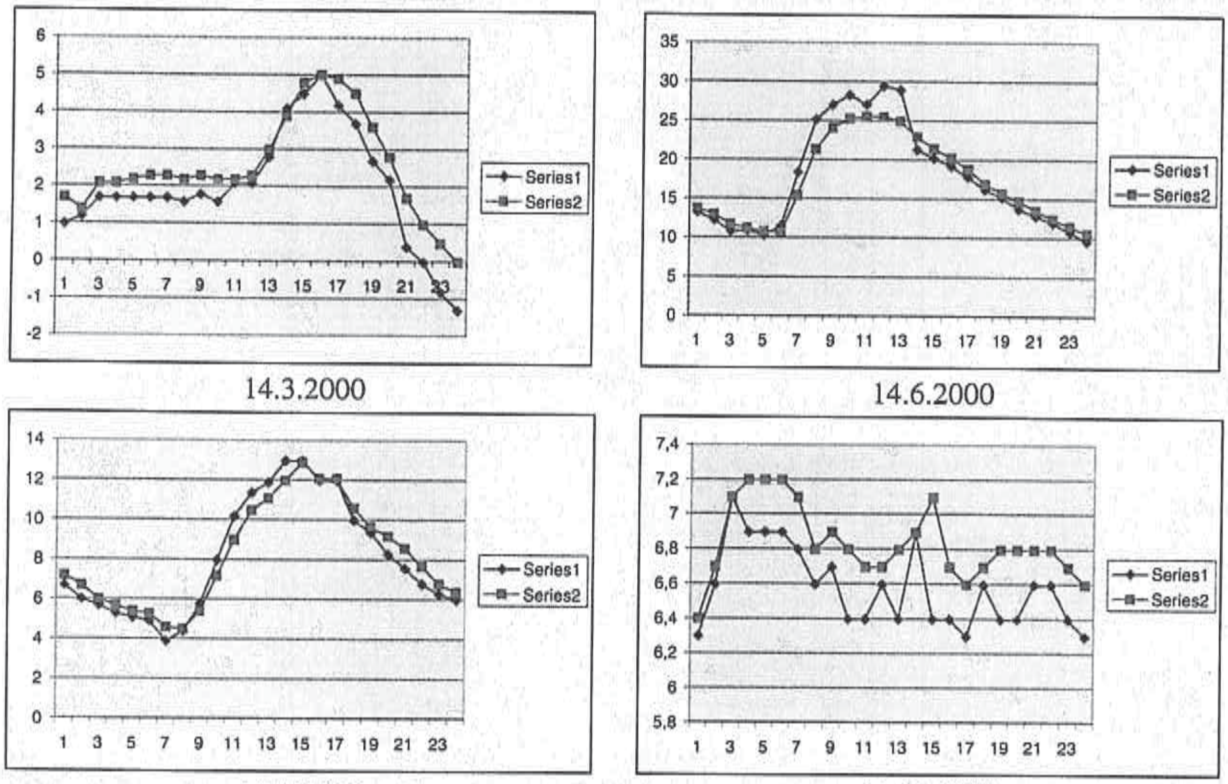
Figure 4. Measuring point D. Temperature of outer (Ser 1) and inner (Ser 2) marble surface (°C).



14.9.2000 14.12.2000

Figure 5. Measuring point E. Temperature of outer (Ser 1) and inner (Ser 2) marble surface (°C).

4.3 Daily variation of temperature

Daily variation of temperature was studied by using the maximum and minimum temperatures observed daily on outer and inner surfaces of marble slabs. The results from every measuring point are shown as pictures presented in this chapter, Figs. 6-92. The pictures are grouped into the series of four, each representing the same measurement period. The four pictures in the same series are coded with letters a-d, and they have the following meaning:

a) daily maximum (Series 1) and minimum (Series 2) temperatures on outer surface of marble (°C)
b) daily maximum (Series 1) and minimum (Series 2) temperatures on inner surface of marble (°C)
c) difference between daily maximum and minimum temperatures on outer surface of mable (°C)
d) difference between daily maximum and minimum temperatures on inner surface of marble (°C)

4.3.1 Measuring point A

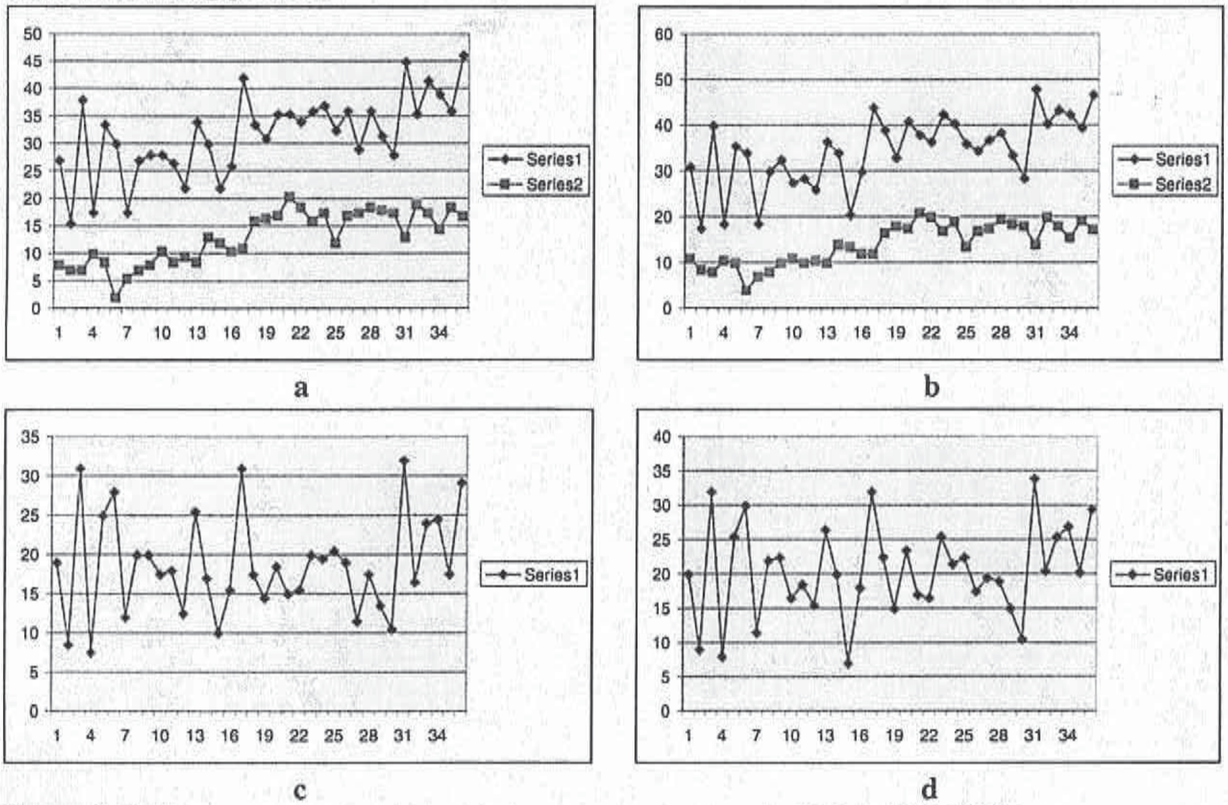


Figure 6. Daily temperature variation during measurement period 26.5.-30.6.1999.

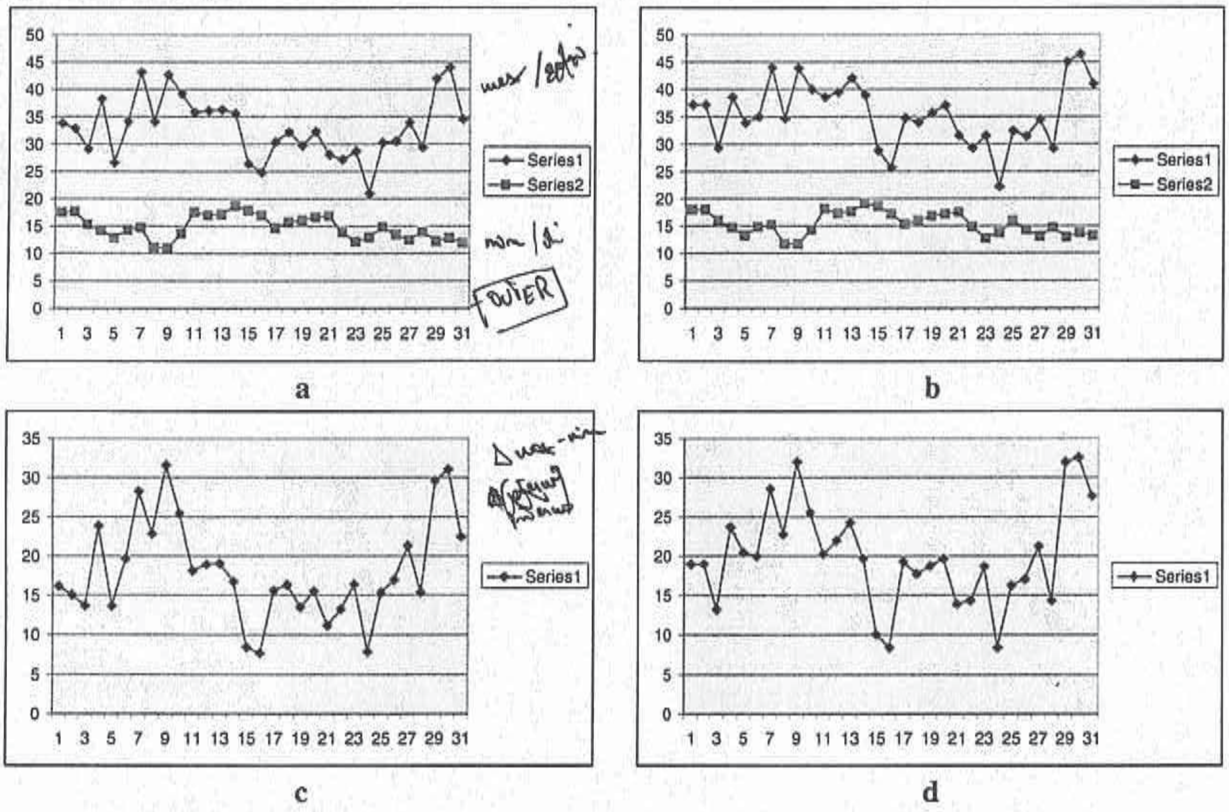


Figure 7. Daily temperature variation during measurement period 1.7.-31.7.1999.

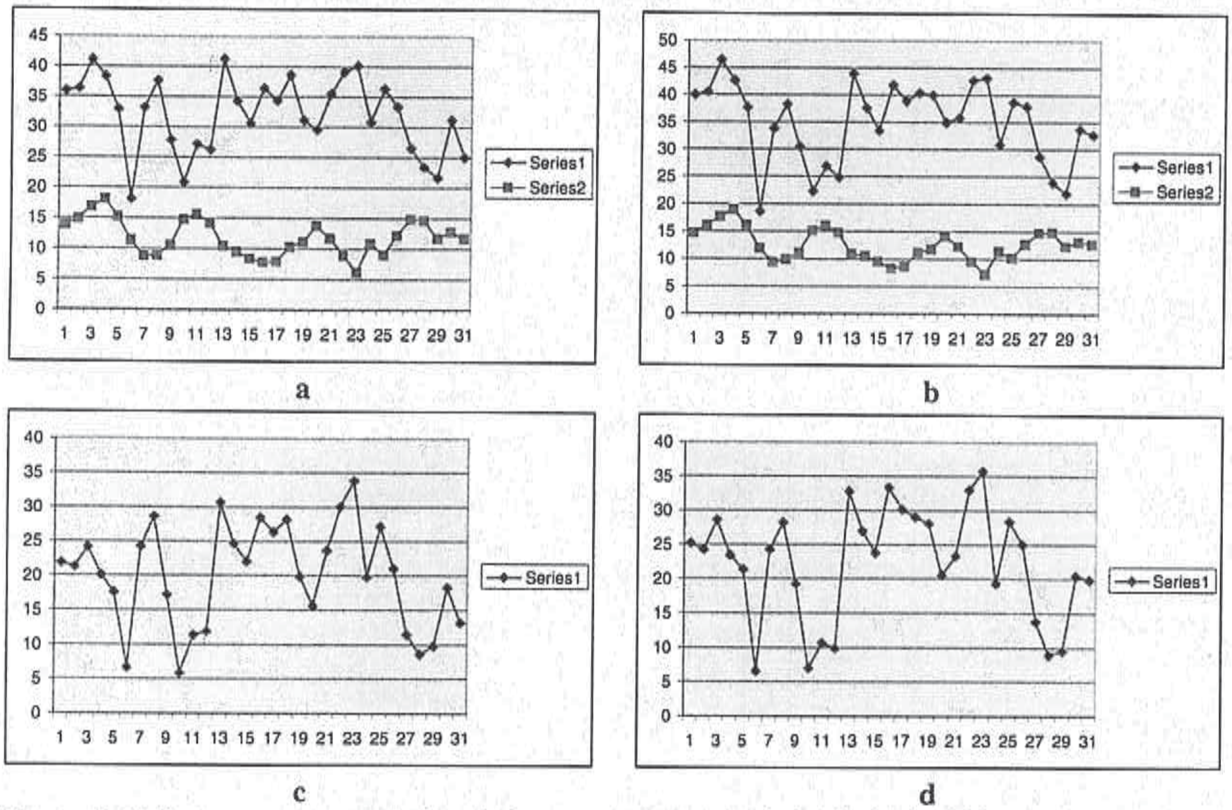


Figure 8. Daily temperature variation during measurement period 1.8.-31.8.1999.

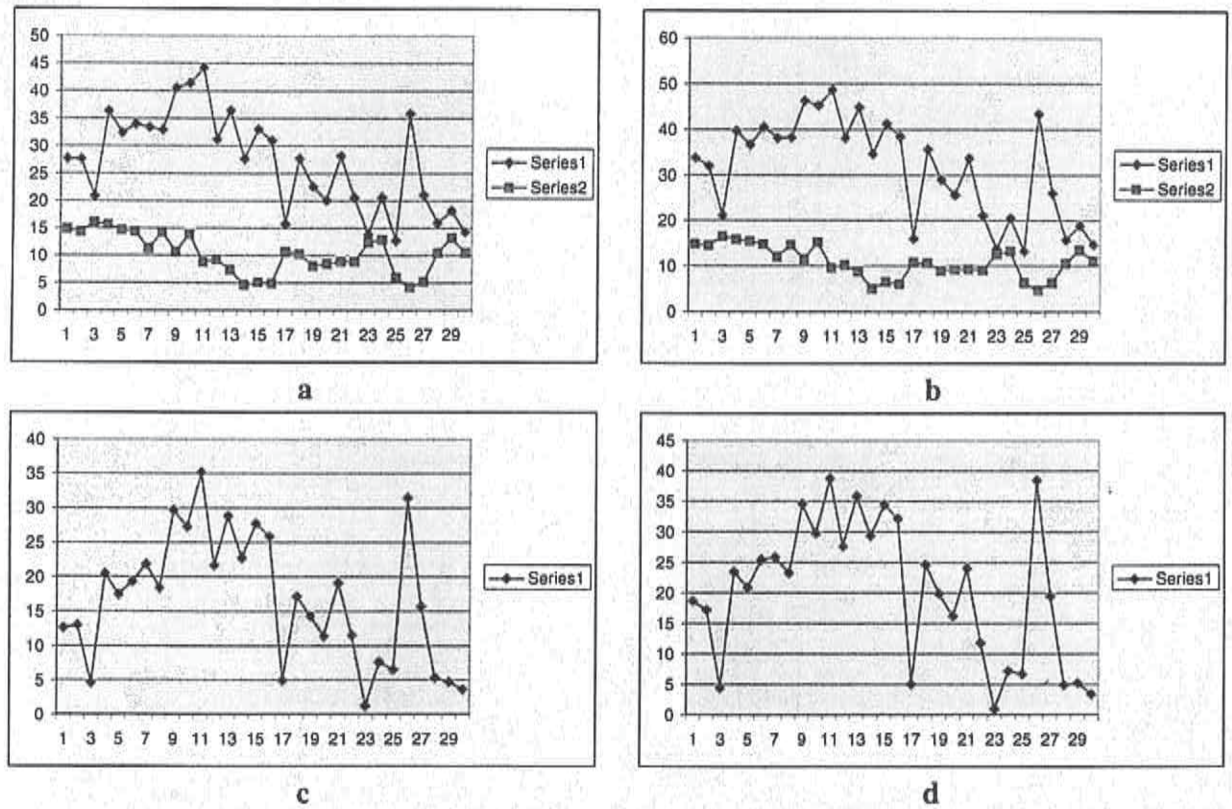


Figure 9. Daily temperature variation during measurement period 1.9.-30.9.1999.

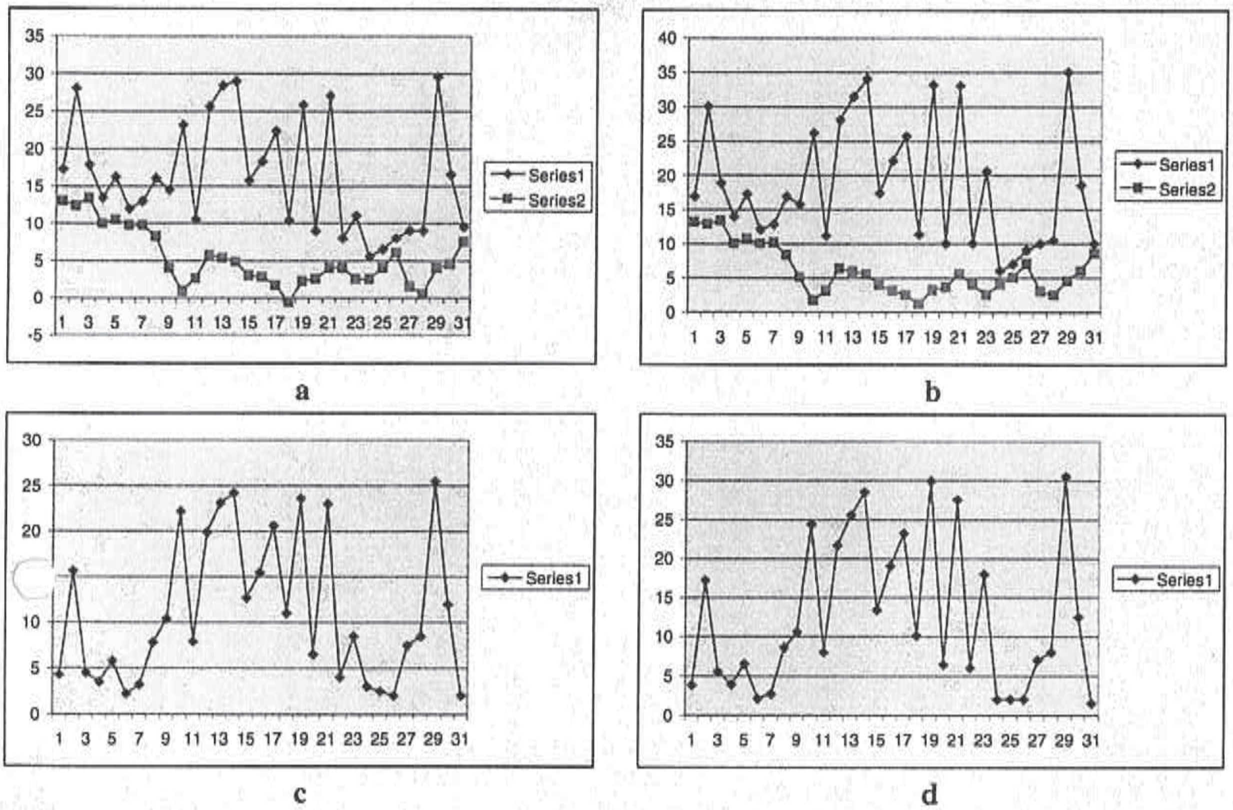


Figure 10. Daily temperature variation during measurement period 1.10.-31.10.1999.

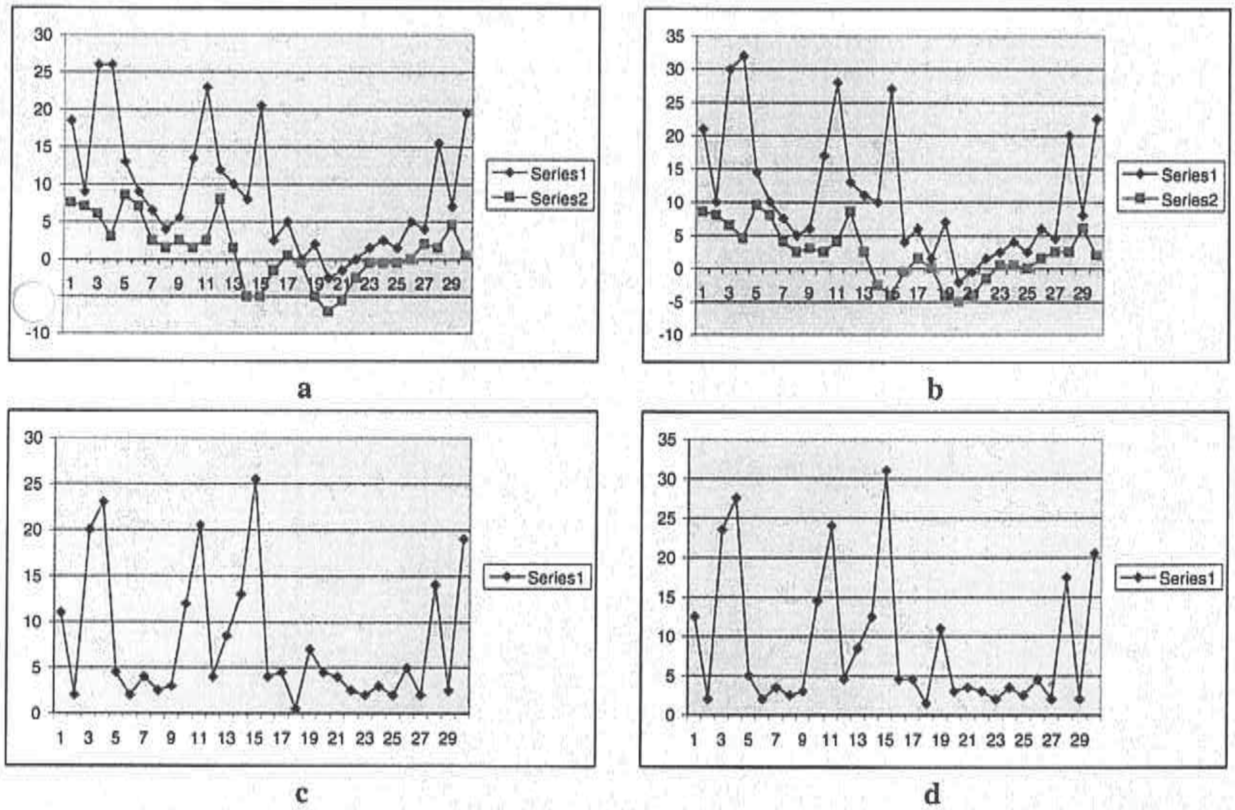


Figure 11. Daily temperature variation during measurement period 1.11.-30.11.1999.

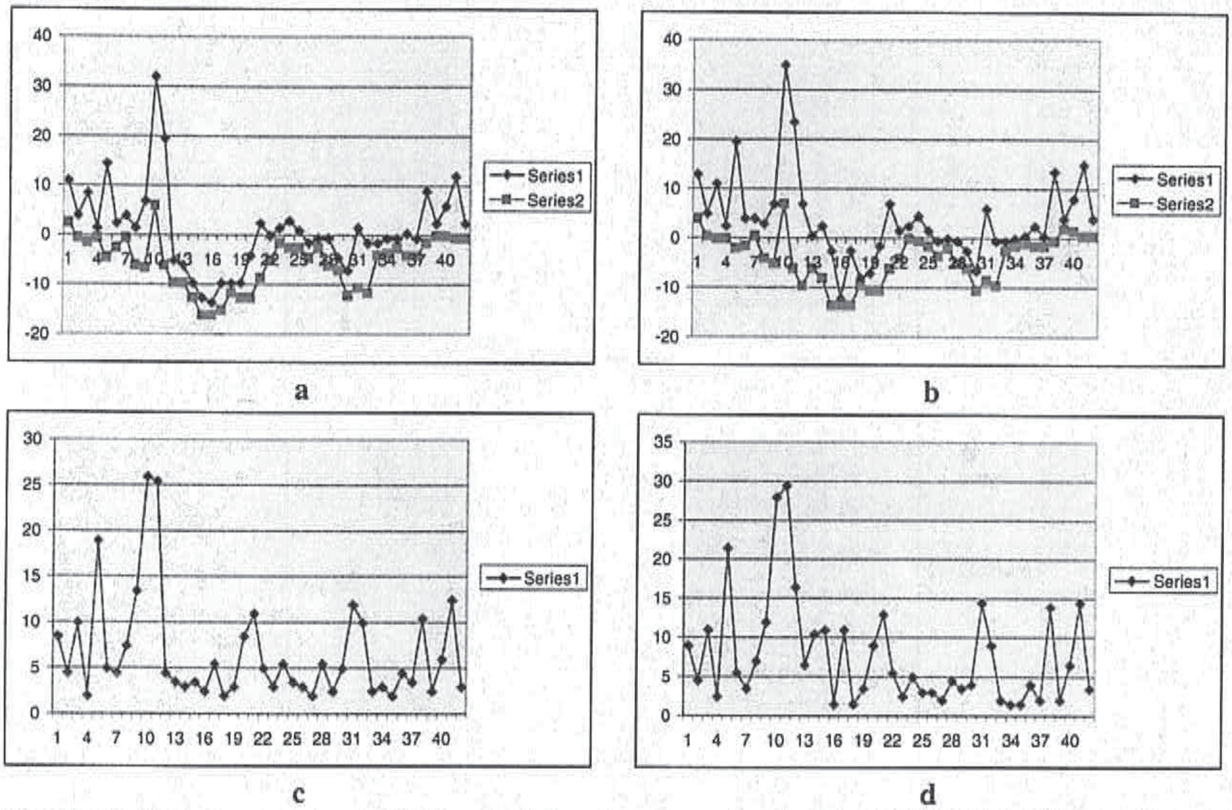


Figure 12. Daily temperature variation during measurement period 1.12.1999-11.1.2000.

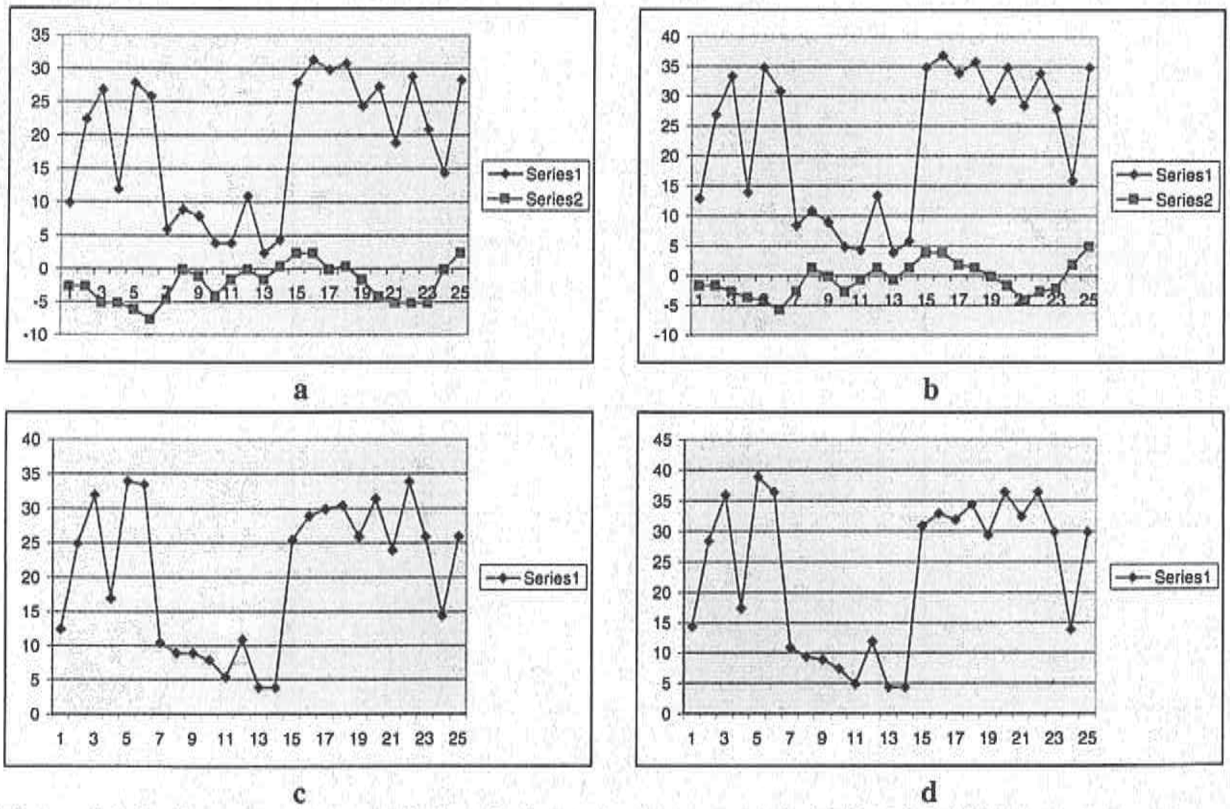


Figure 13. Daily temperature variation during measurement period 7.3.-31.3.2000.

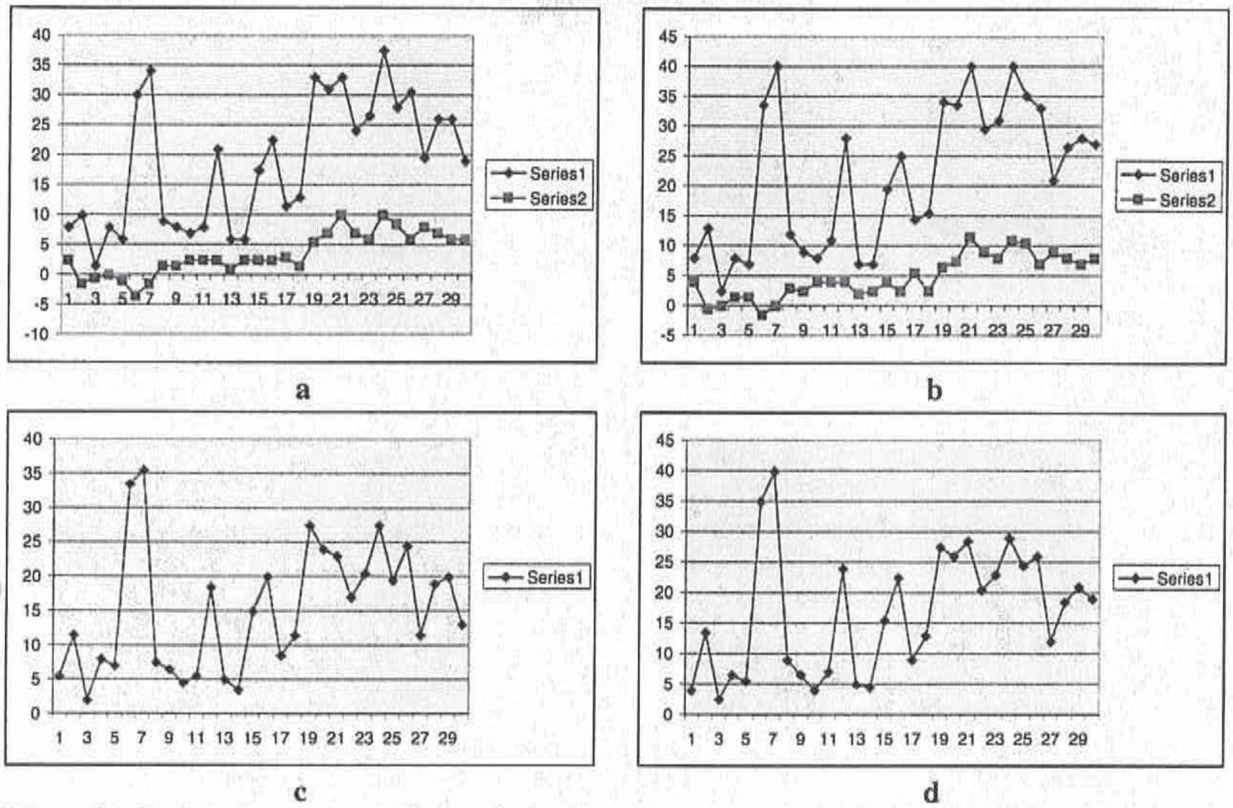


Figure 14. Daily temperature variation during measurement period 1.4.-30.4.2000.

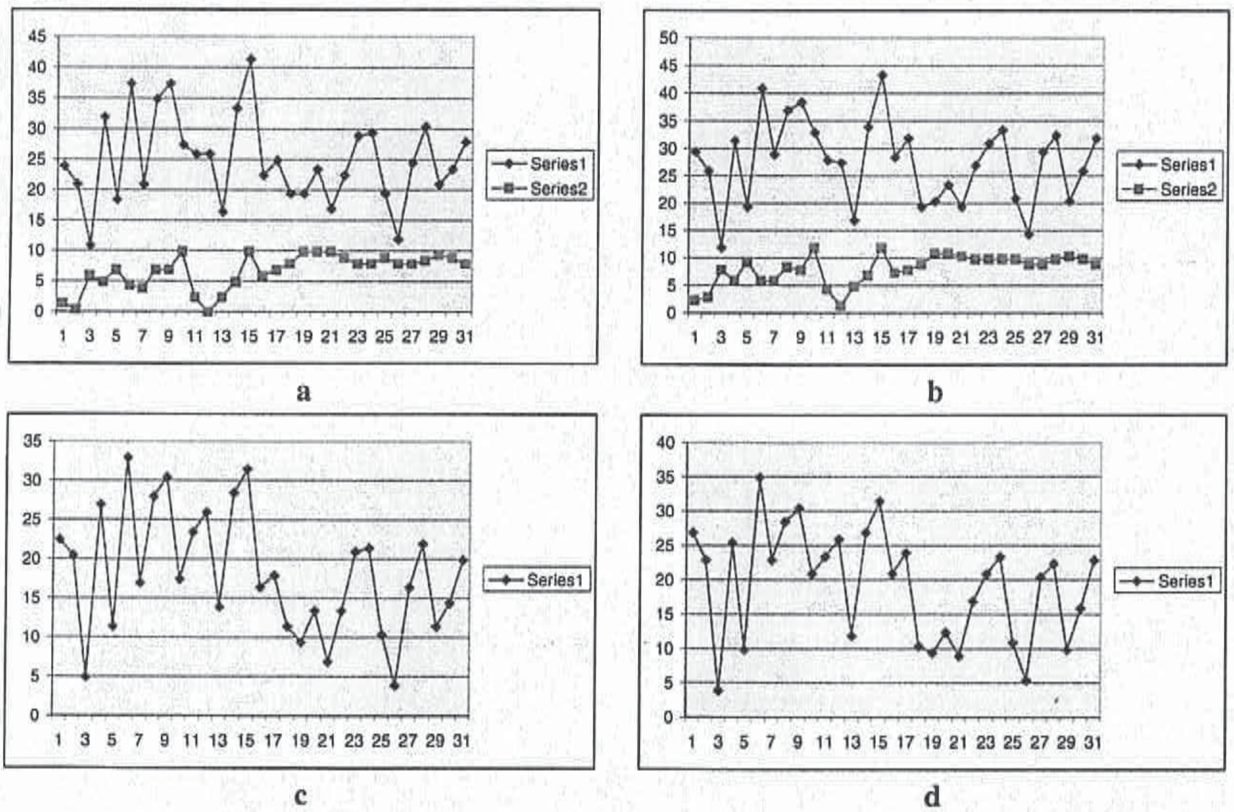


Figure 15. Daily temperature variation during measurement period 1.5.-31.5.2000.

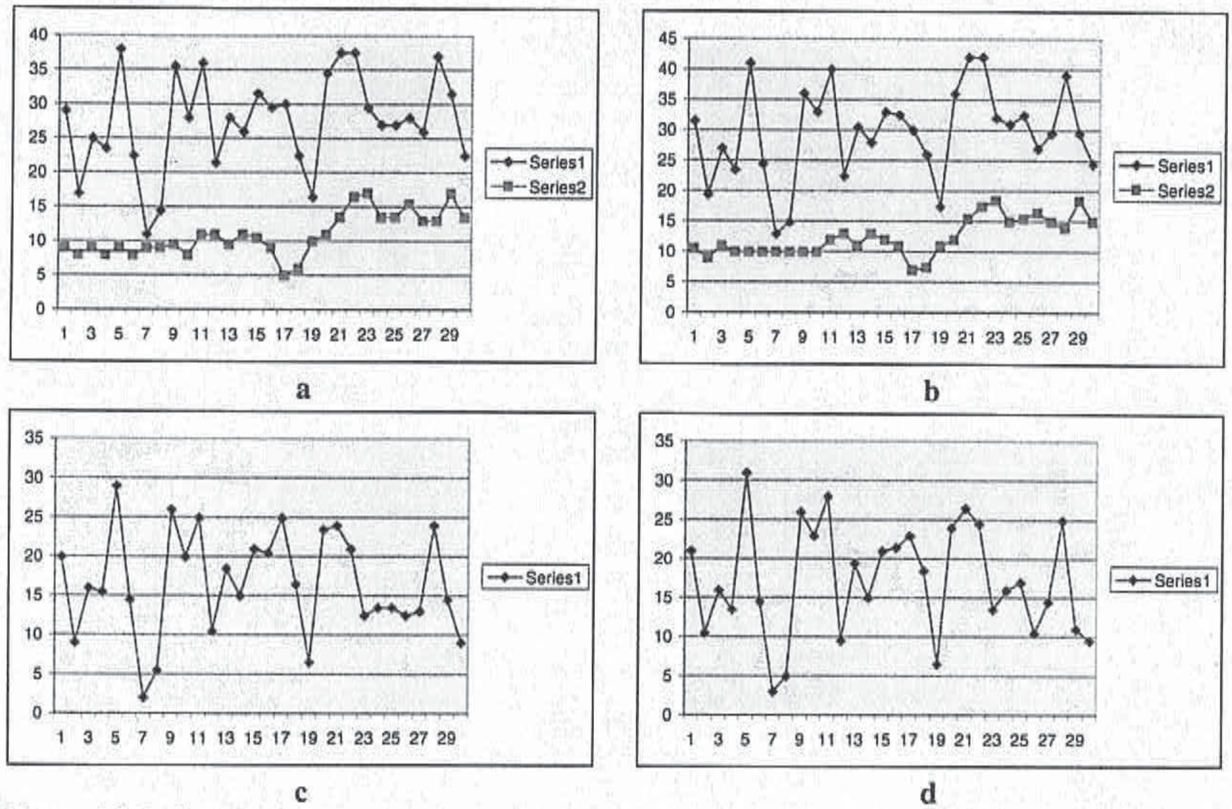


Figure 16. Daily temperature variation during measurement period 1.6.-30.6.2000.

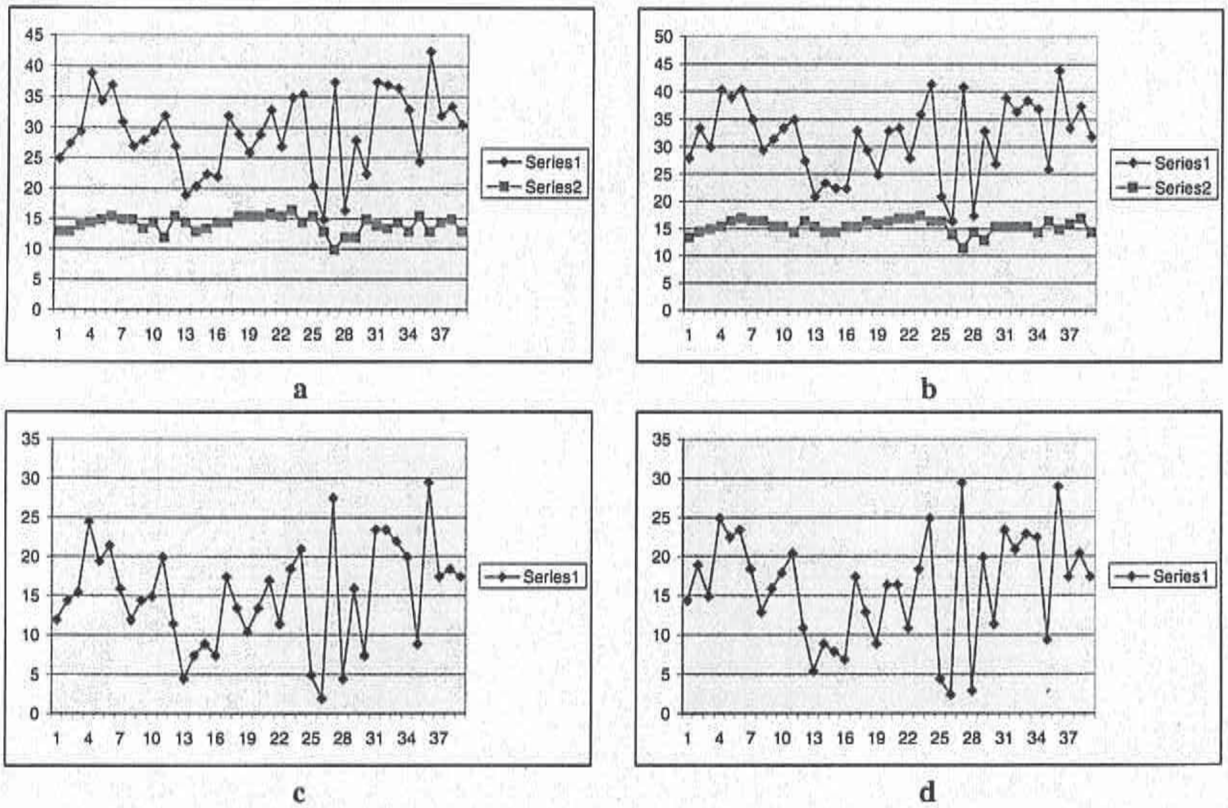


Figure 17. Daily temperature variation during measurement period 1.7.-8.8.2000.

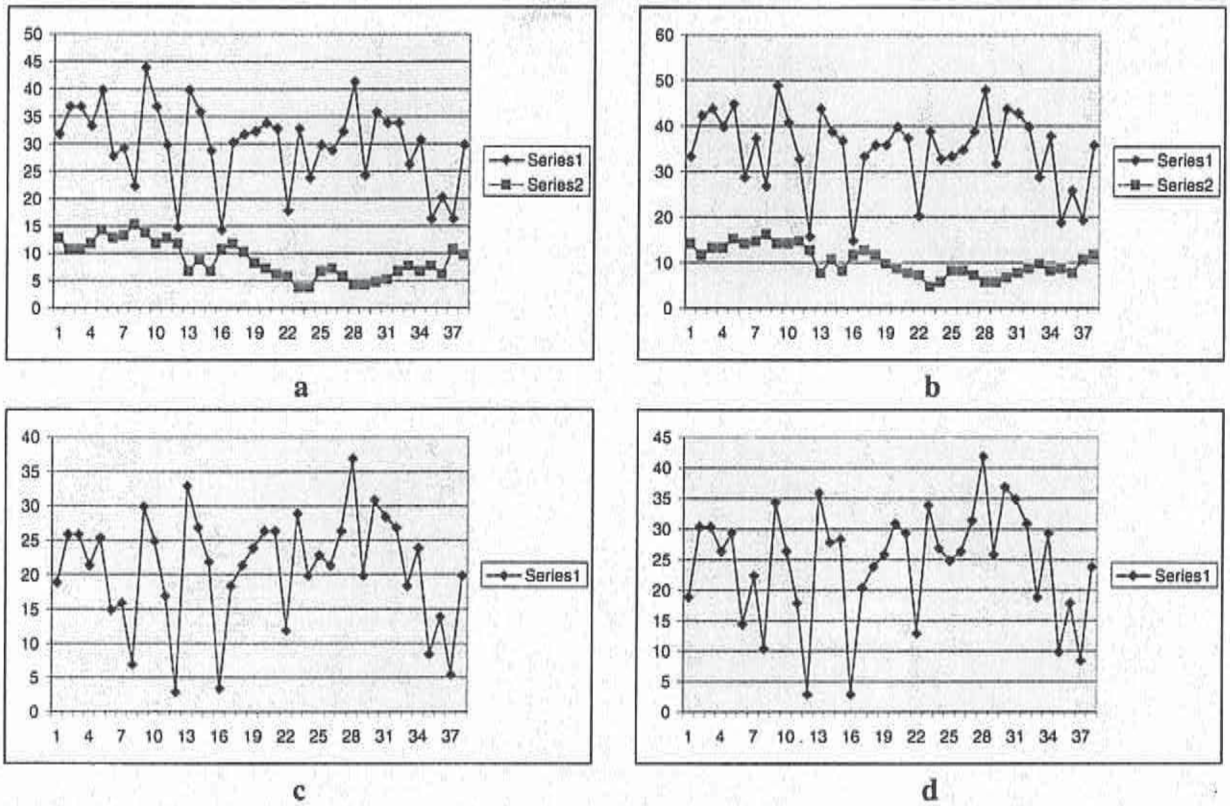


Figure 18. Daily temperature variation during measurement period 24.8.-30.9.2000.

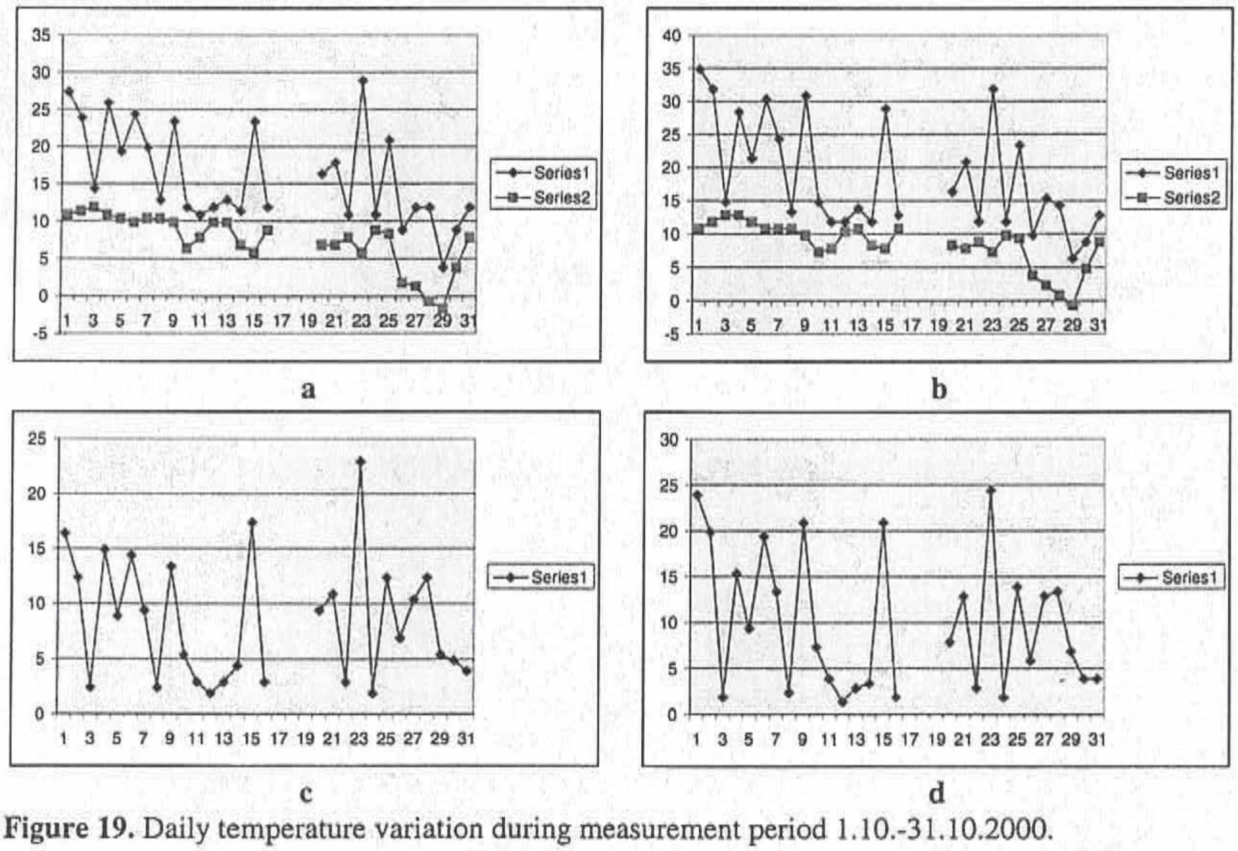


Figure 19. Daily temperature variation during measurement period 1.10.-31.10.2000.

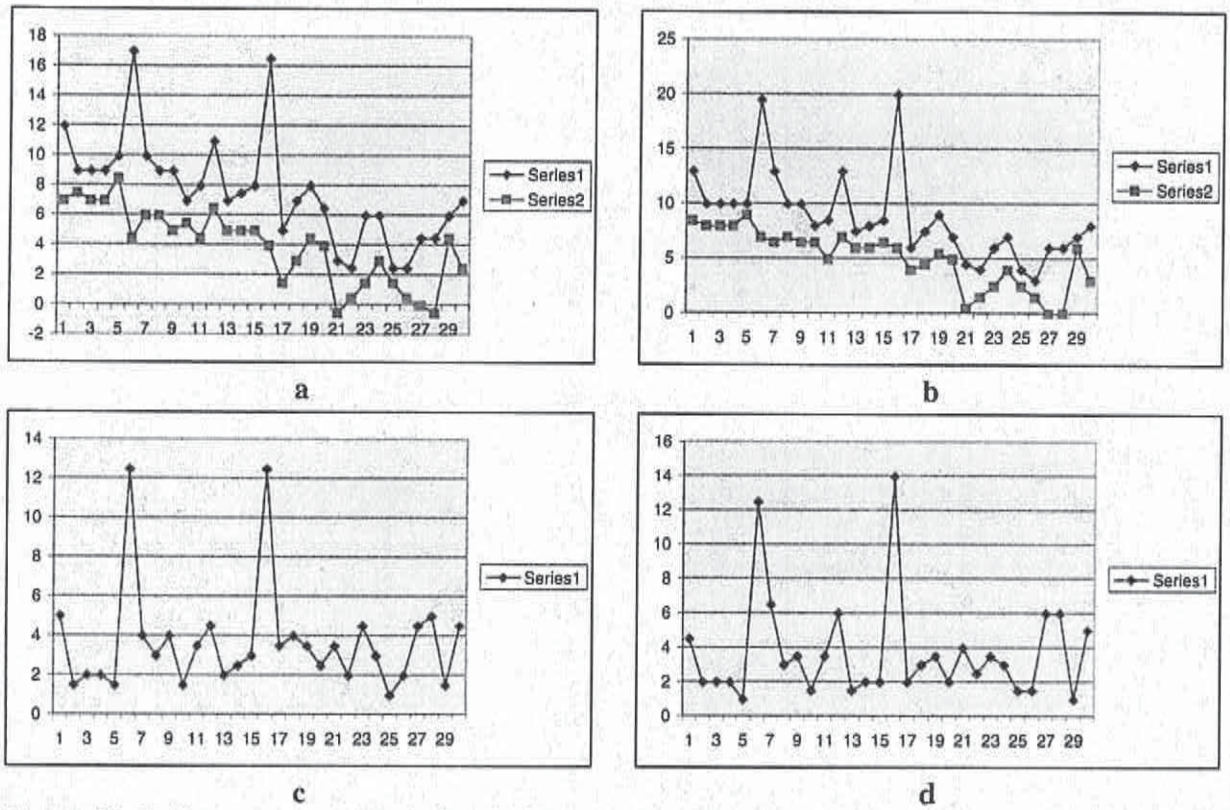


Figure 20. Daily temperature variation during measurement period 1.11.-30.11.2000.

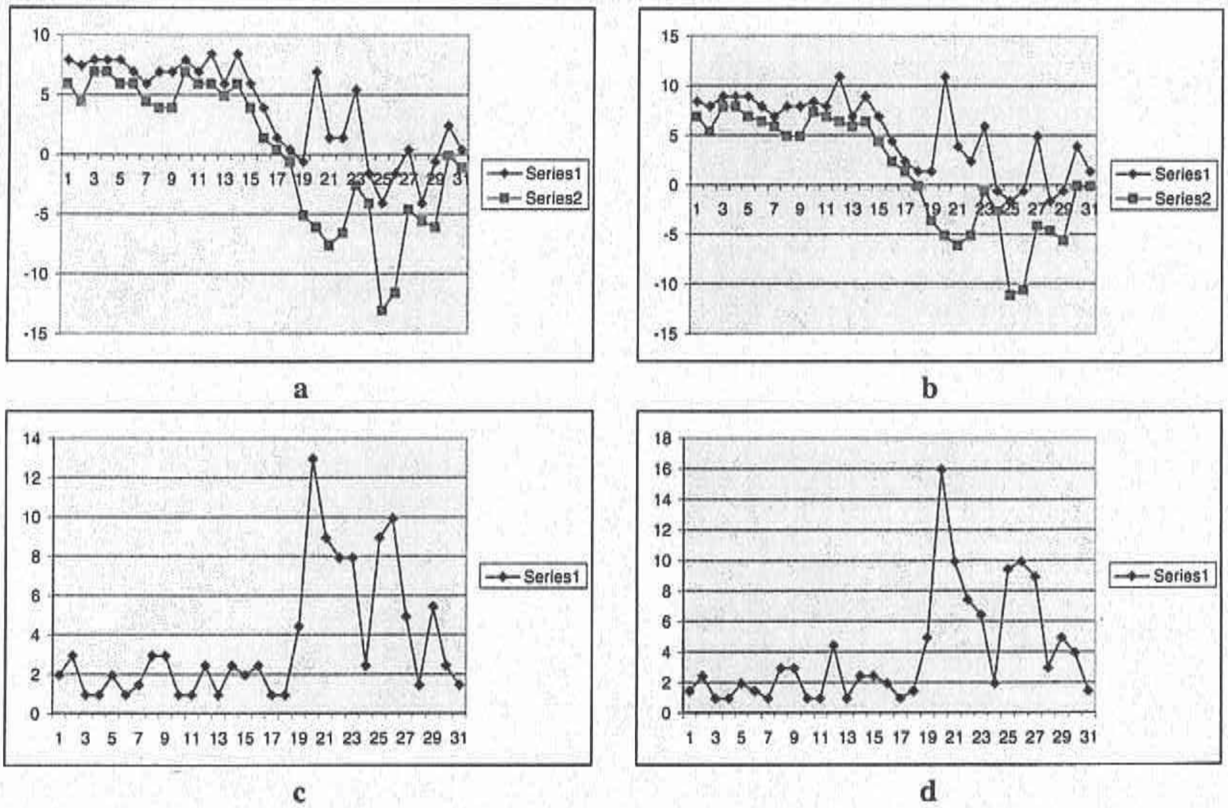


Figure 21. Daily temperature variation during measurement period 1.12.-31.12.2000.

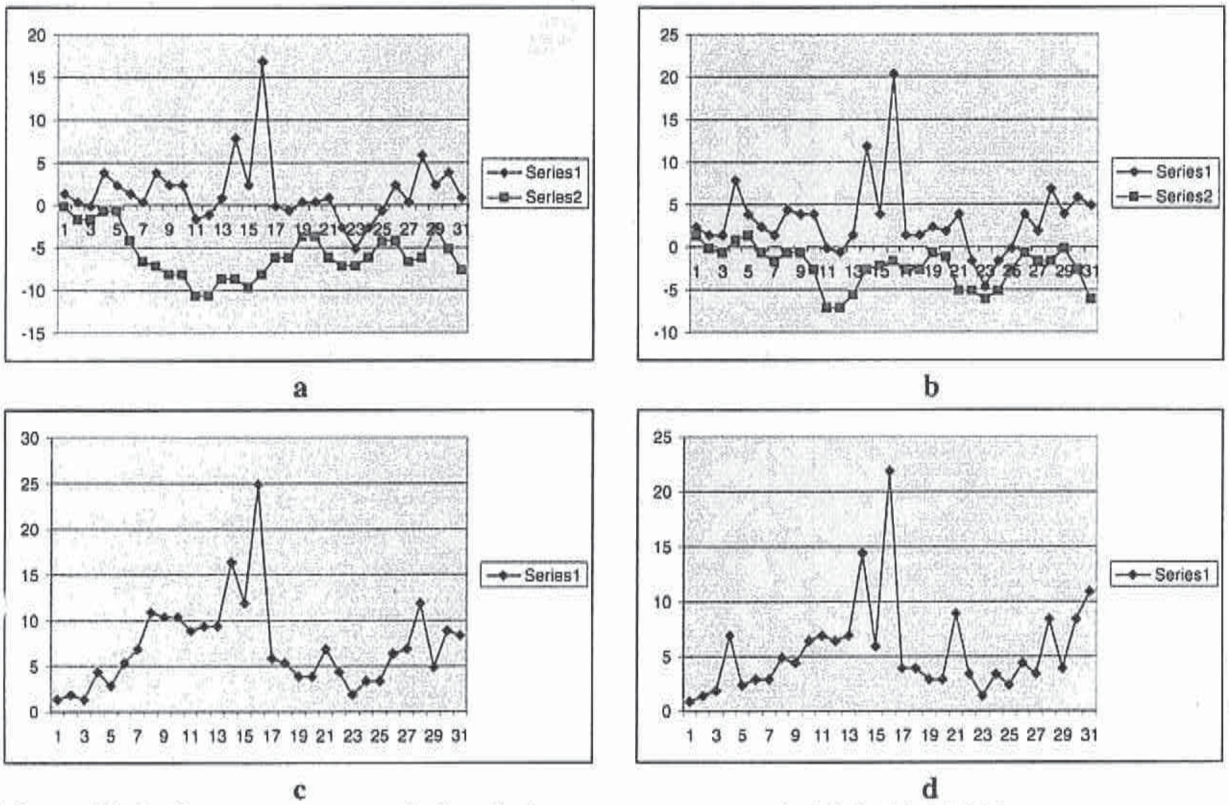


Figure 22. Daily temperature variation during measurement period 1.1.-31.1.2001.

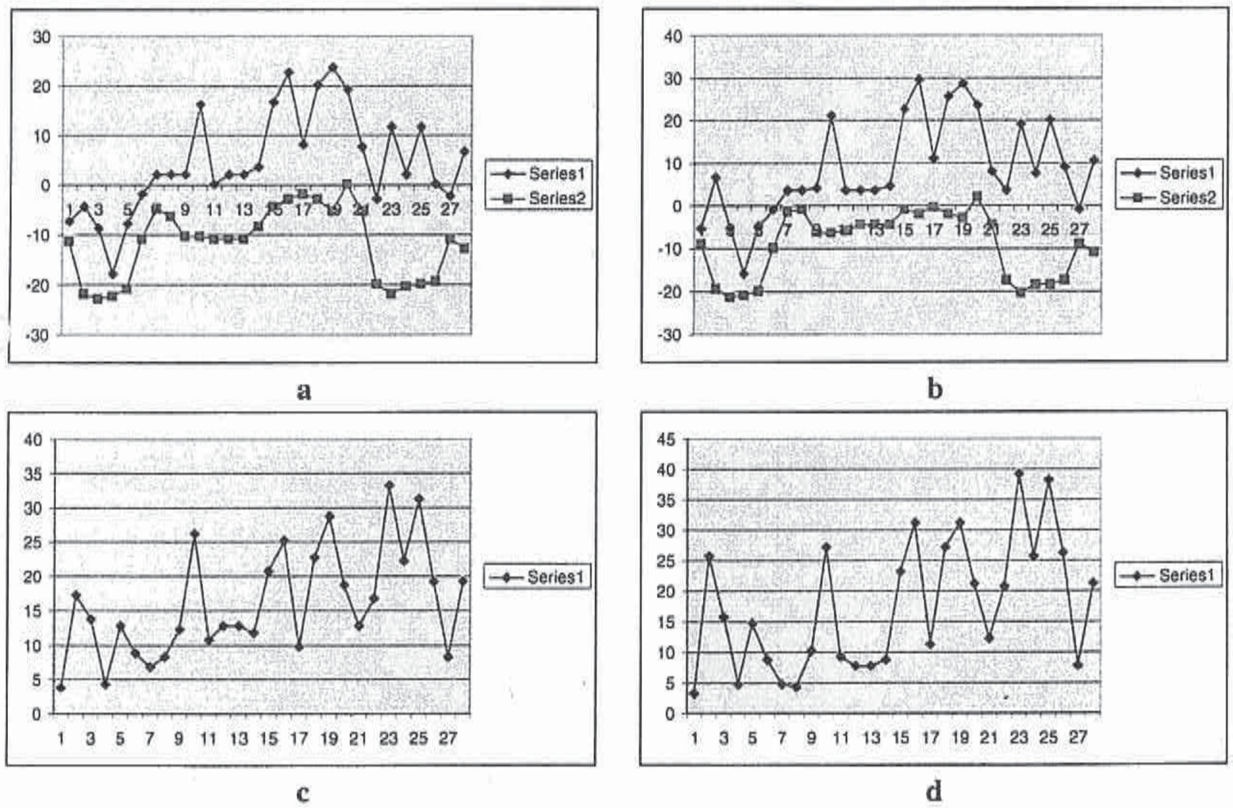


Figure 23. Daily temperature variation during measurement period 1.2.-28.2.2001.

4.3.2 Measuring point B

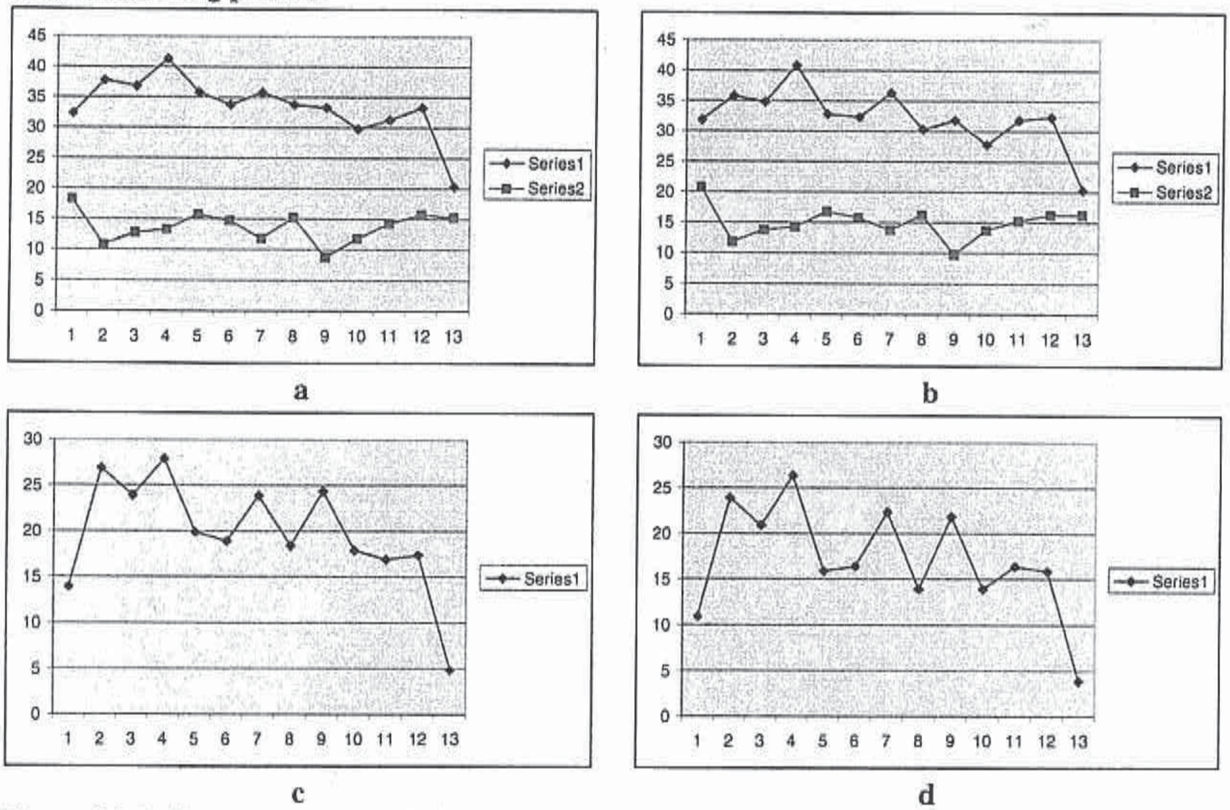


Figure 24. Daily temperature variation during measurement period 11.6.-23.6.1999.

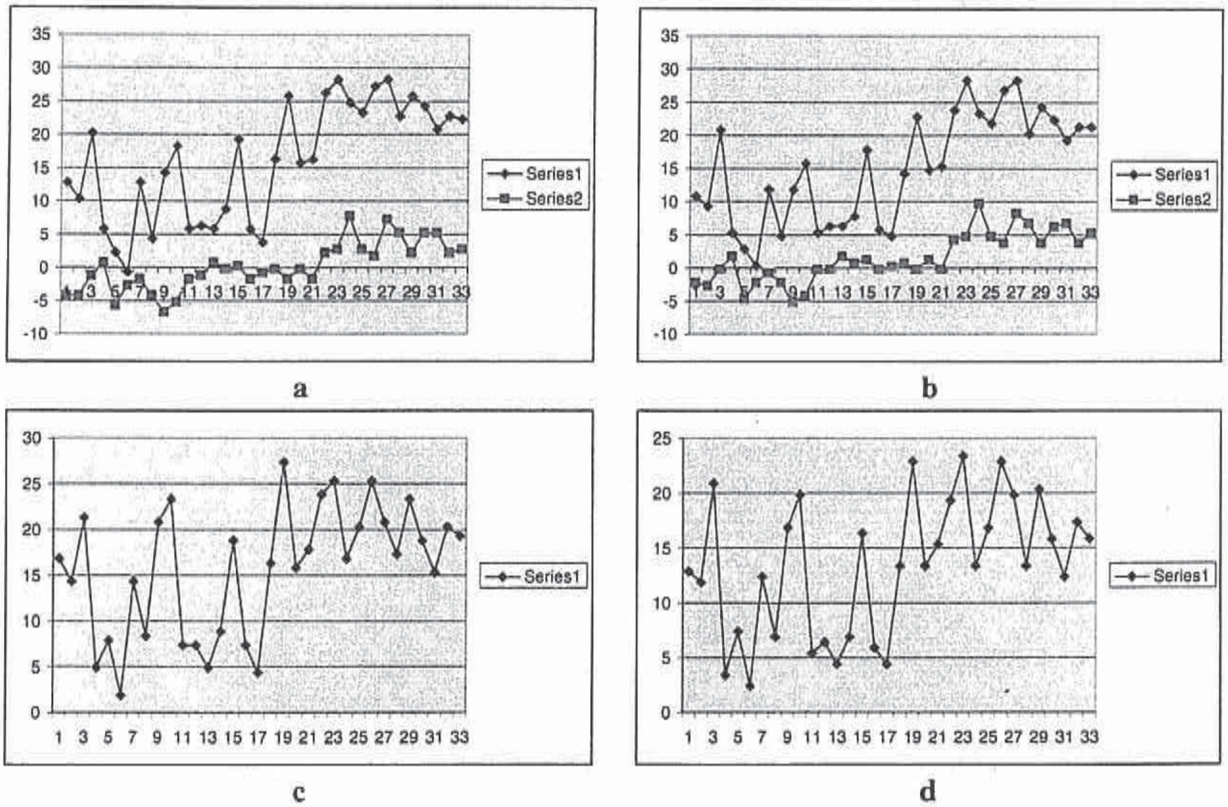


Figure 25. Daily temperature variation during measurement period 29.3.-30.4.2000.

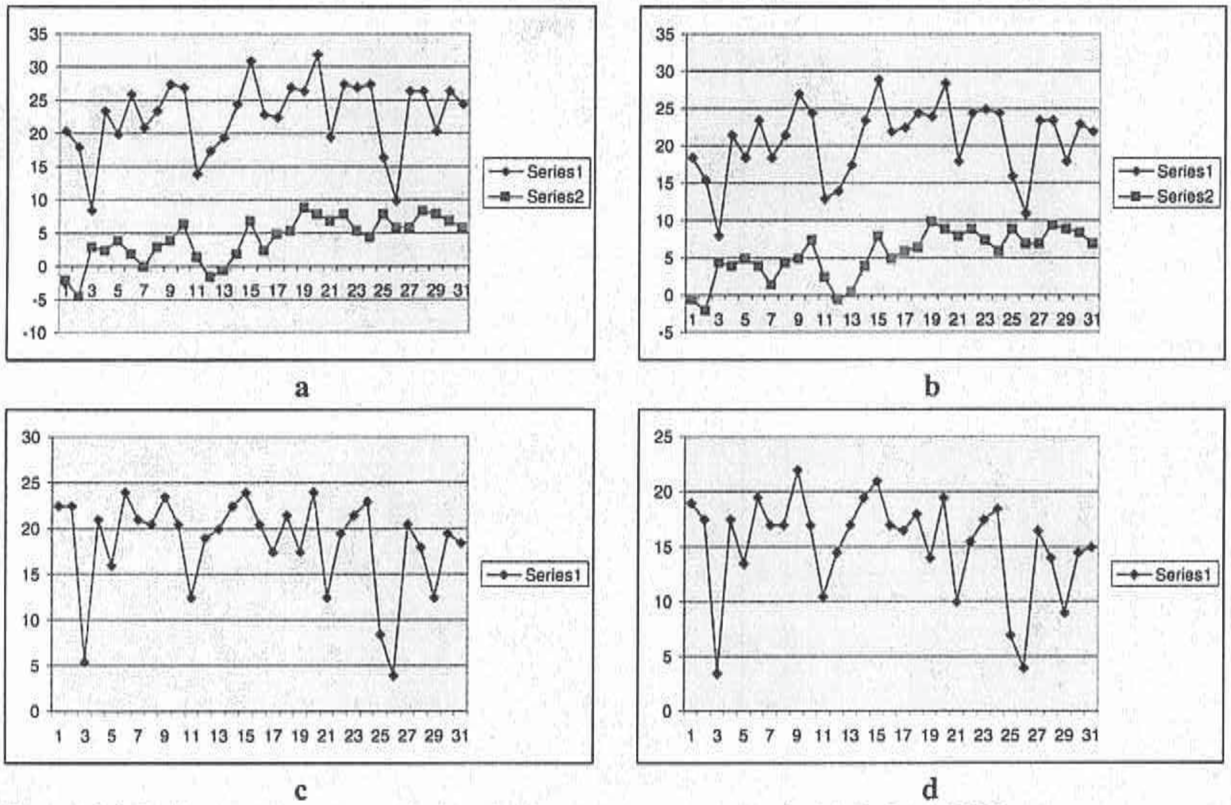


Figure 26. Daily temperature variation during measurement period 1.5.-31.5.2000.

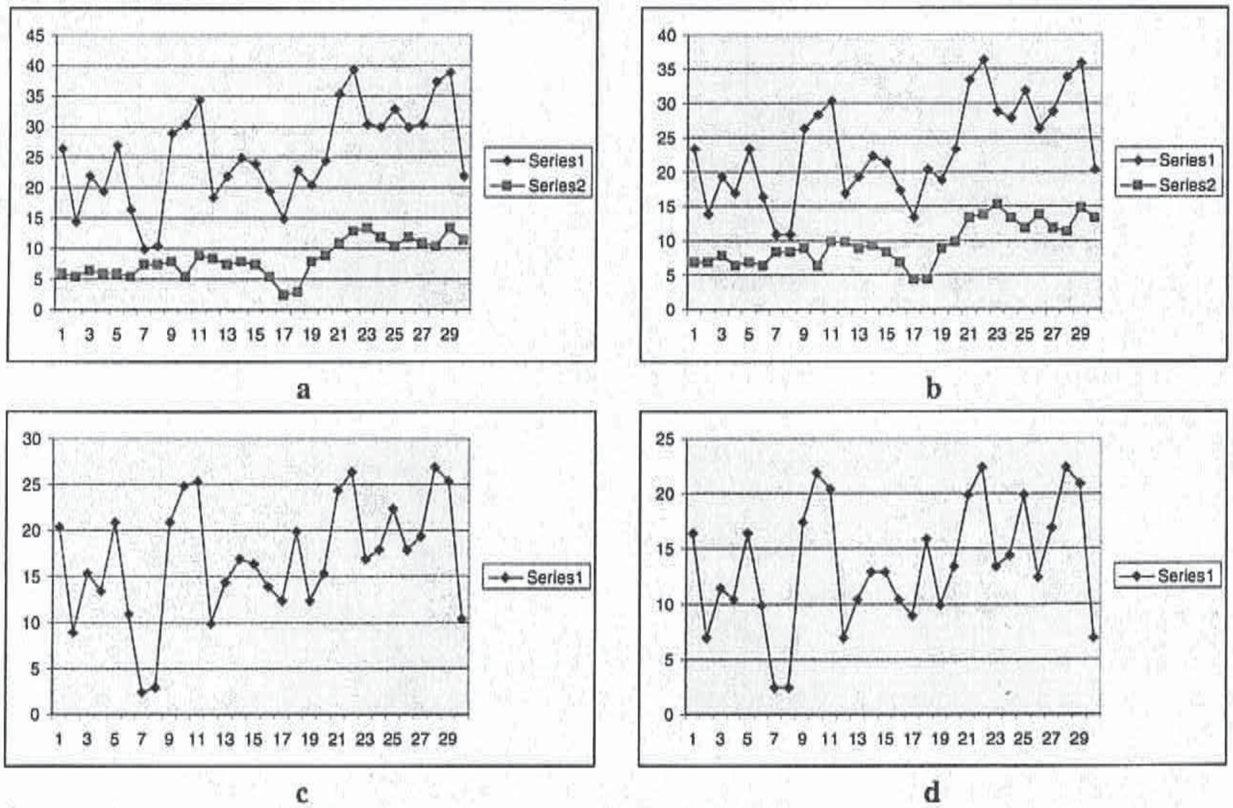


Figure 27. Daily temperature variation during measurement period 1.6.-30.6.2000.

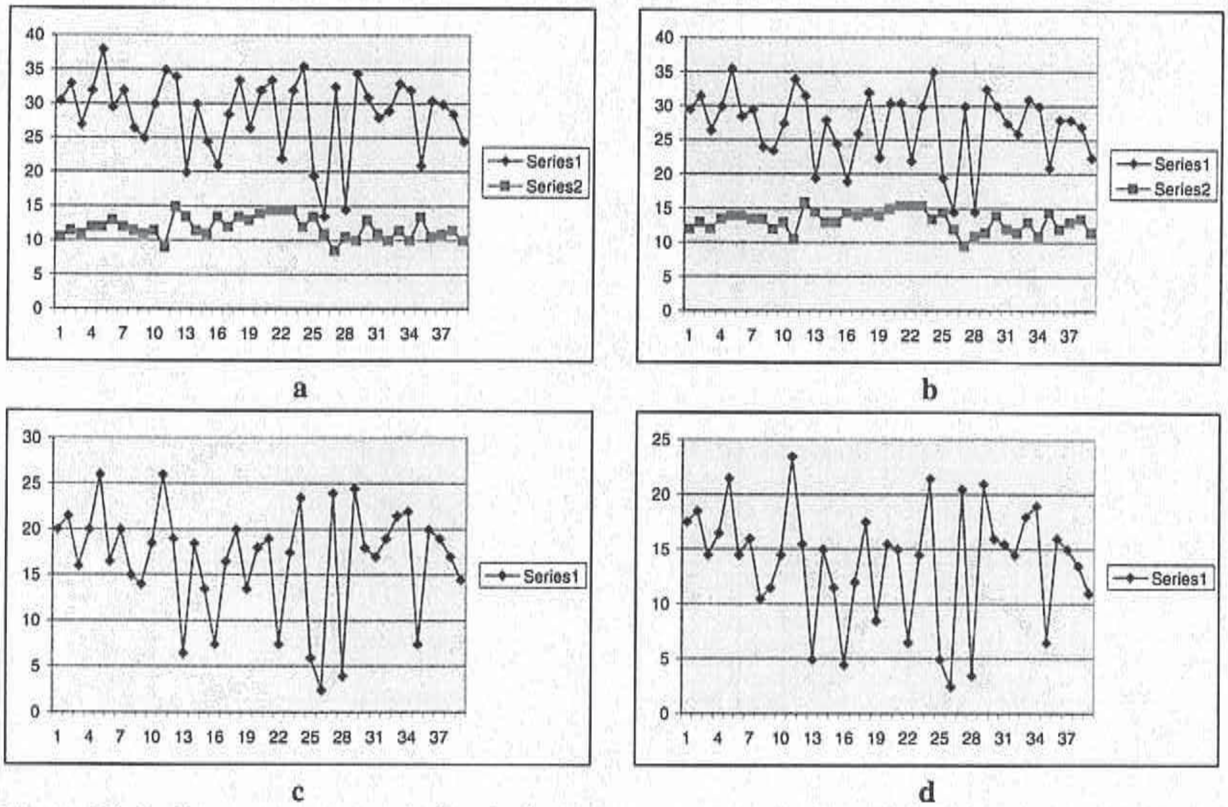


Figure 28. Daily temperature variation during measurement period 1.7.-8.8.2000.

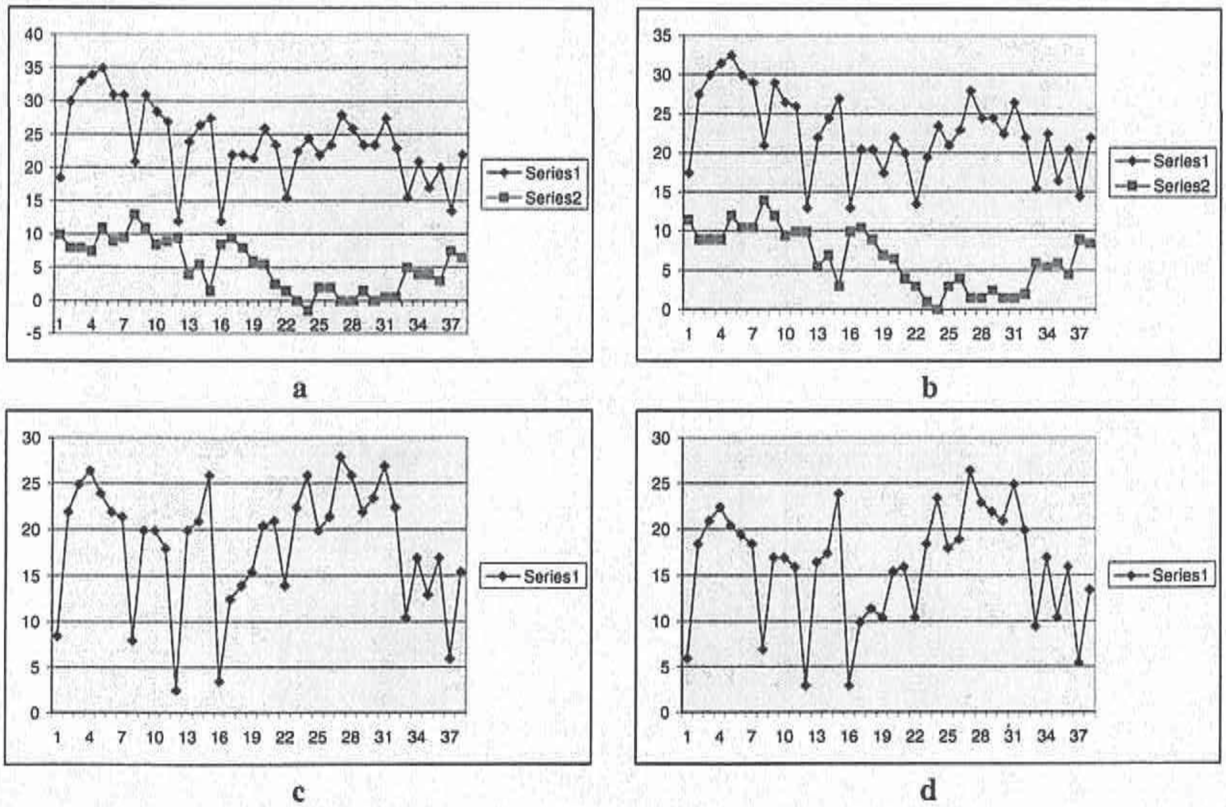


Figure 29. Daily temperature variation during measurement period 24.8.-30.9.2000.

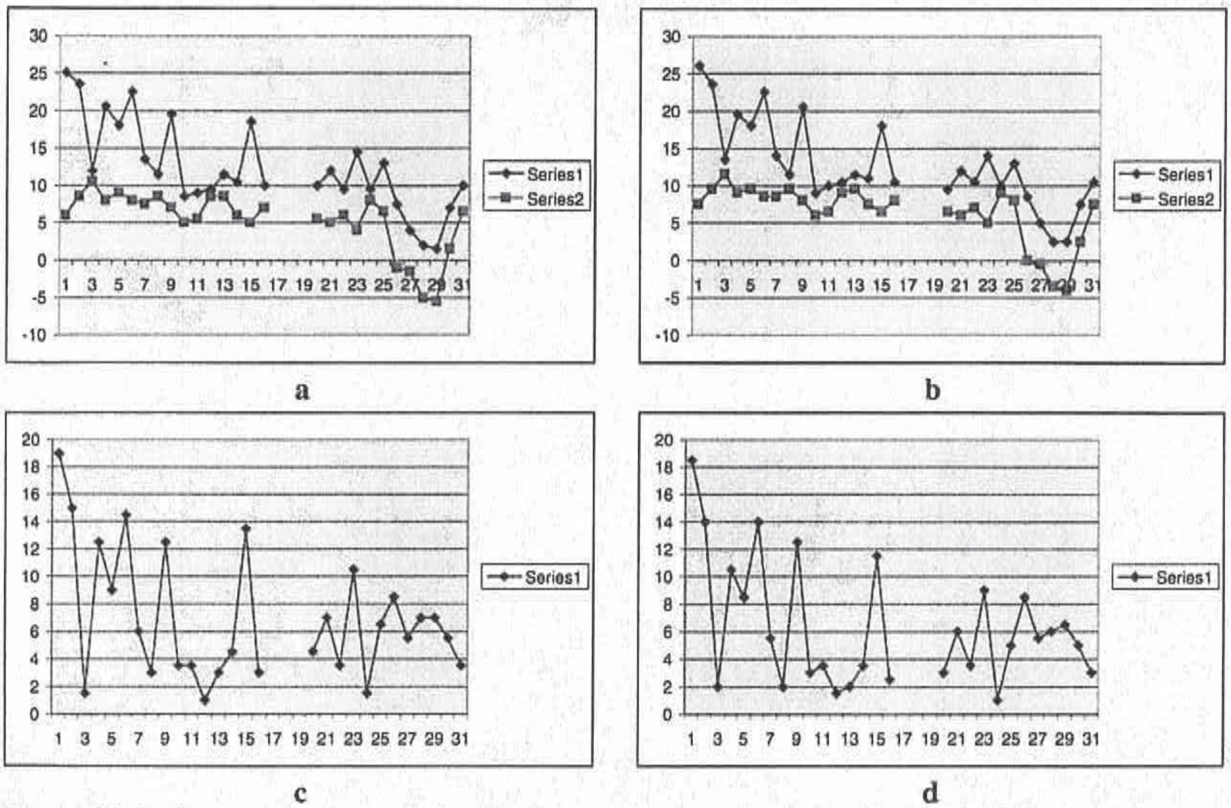


Figure 30. Daily temperature variation during measurement period 1.10.-31.10.2000.

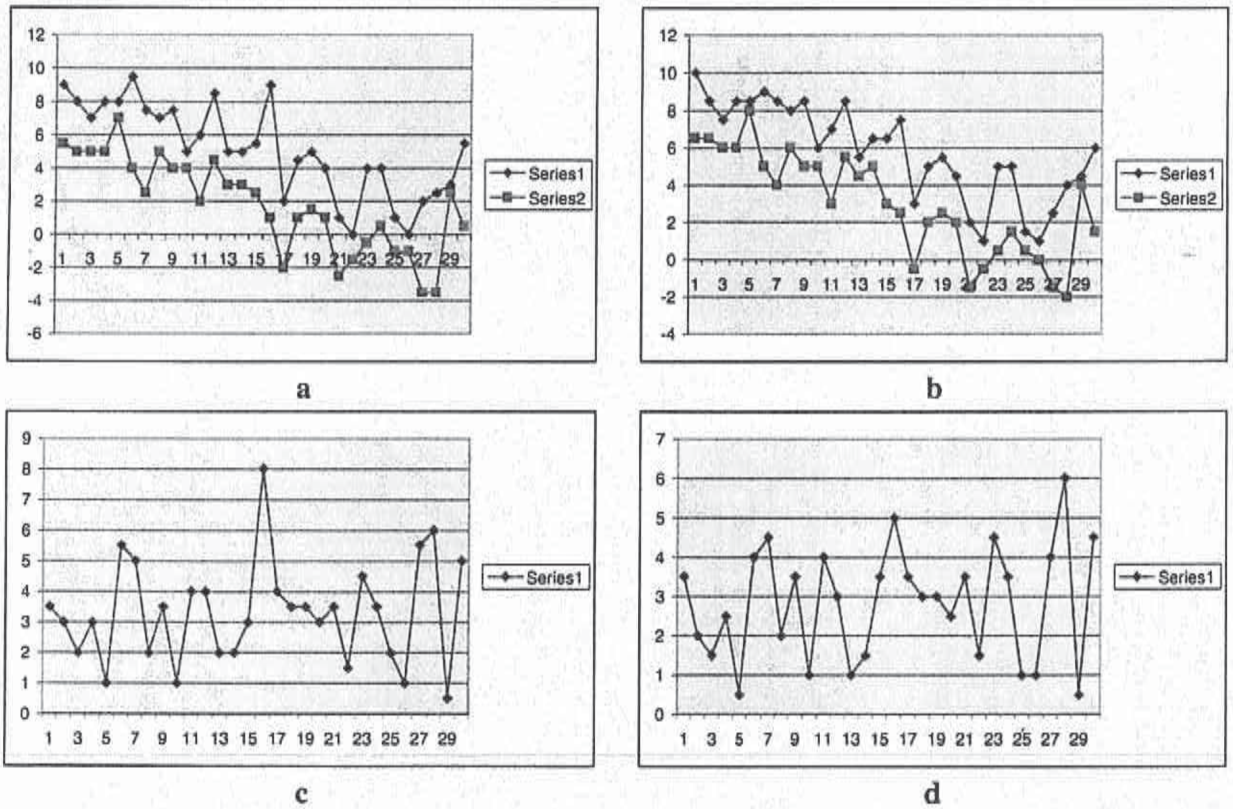
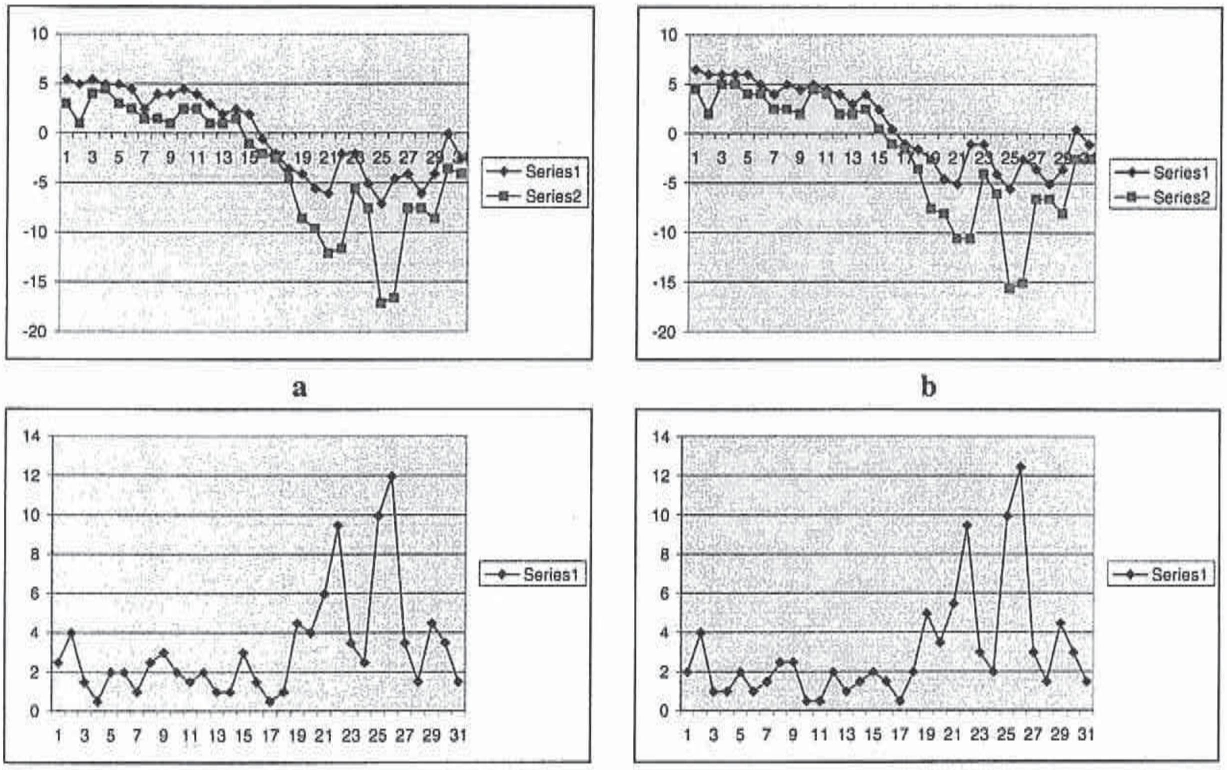


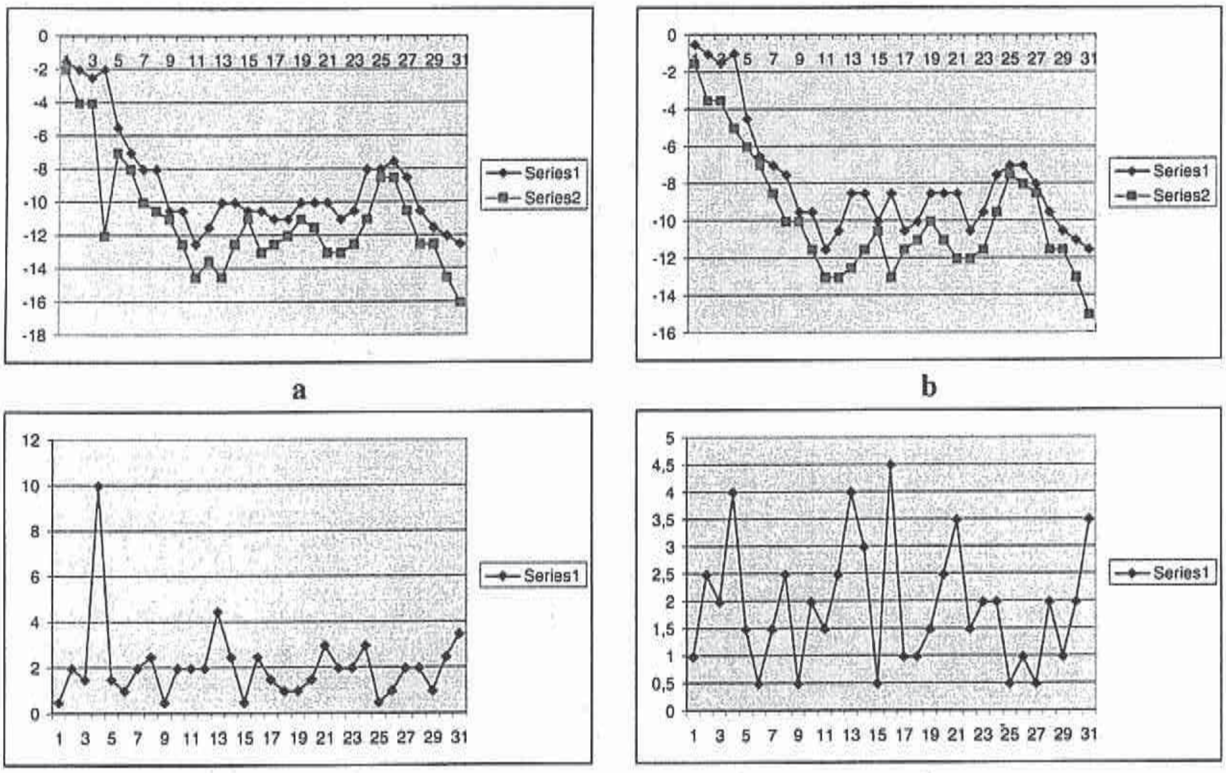
Figure 31. Daily temperature variation during measurement period 1.11.-30.11.2000.



a b

c d

Figure 32. Daily temperature variation during measurement period 1.12.-31.12.2000.



a b

c d

Figure 33. Daily temperature variation during measurement period 1.1.-31.1.2001.

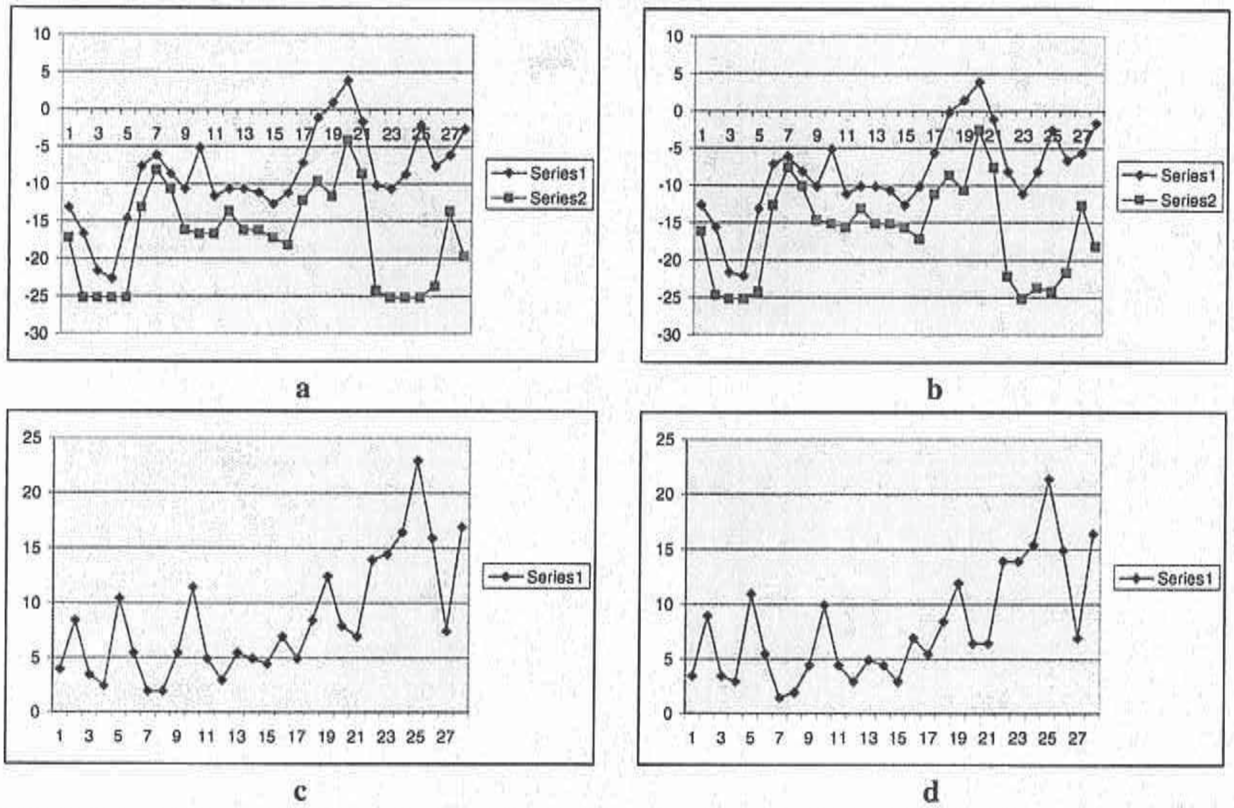


Figure 34. Daily temperature variation during measurement period 1.2.-28.2.2001.

4.3.3 Measuring point C

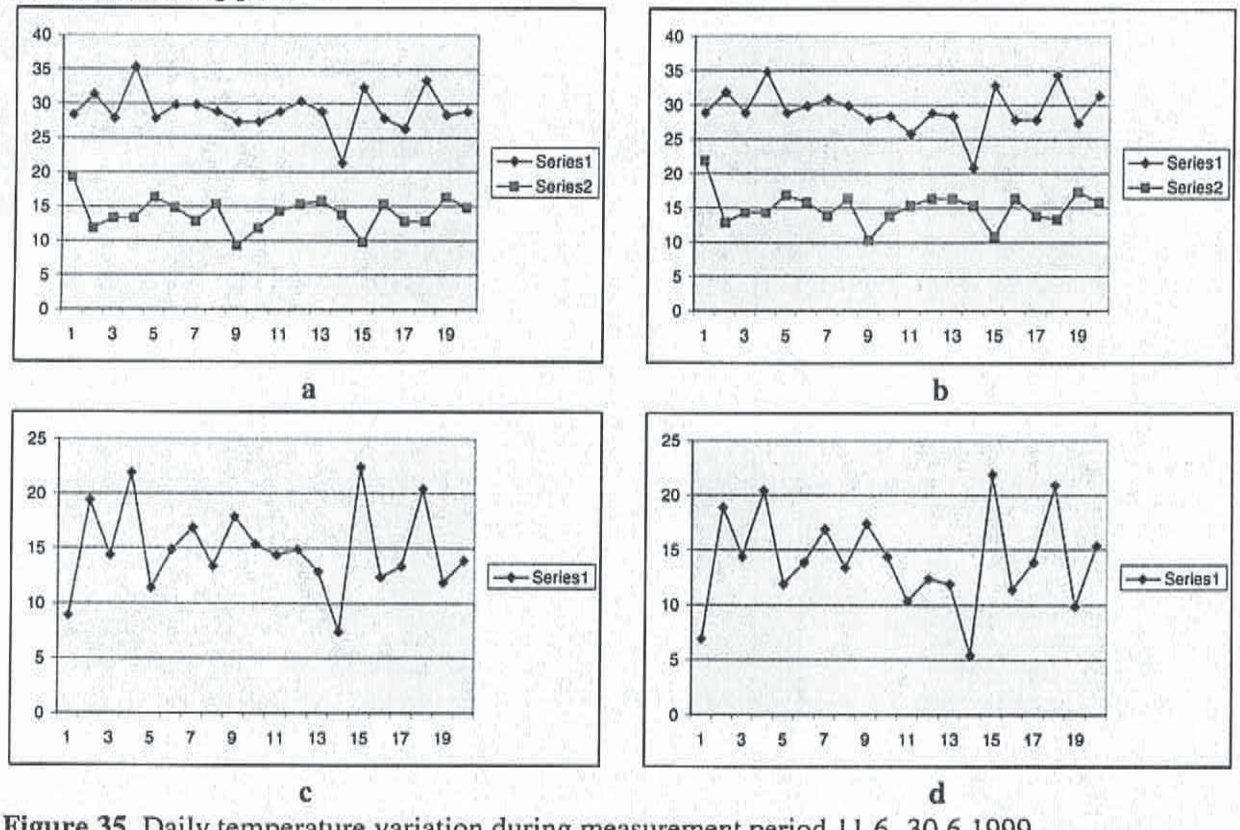


Figure 35. Daily temperature variation during measurement period 11.6.-30.6.1999.

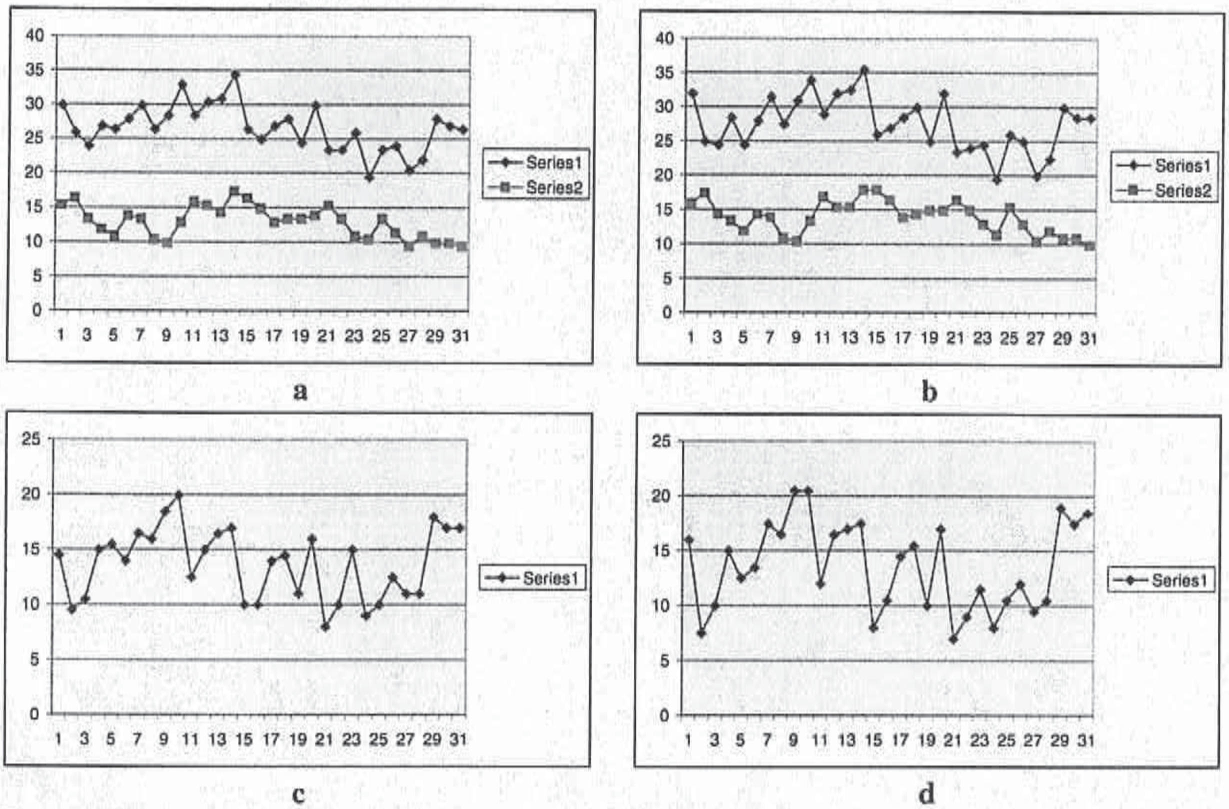


Figure 36. Daily temperature variation during measurement period 1.7.-31.7.1999.

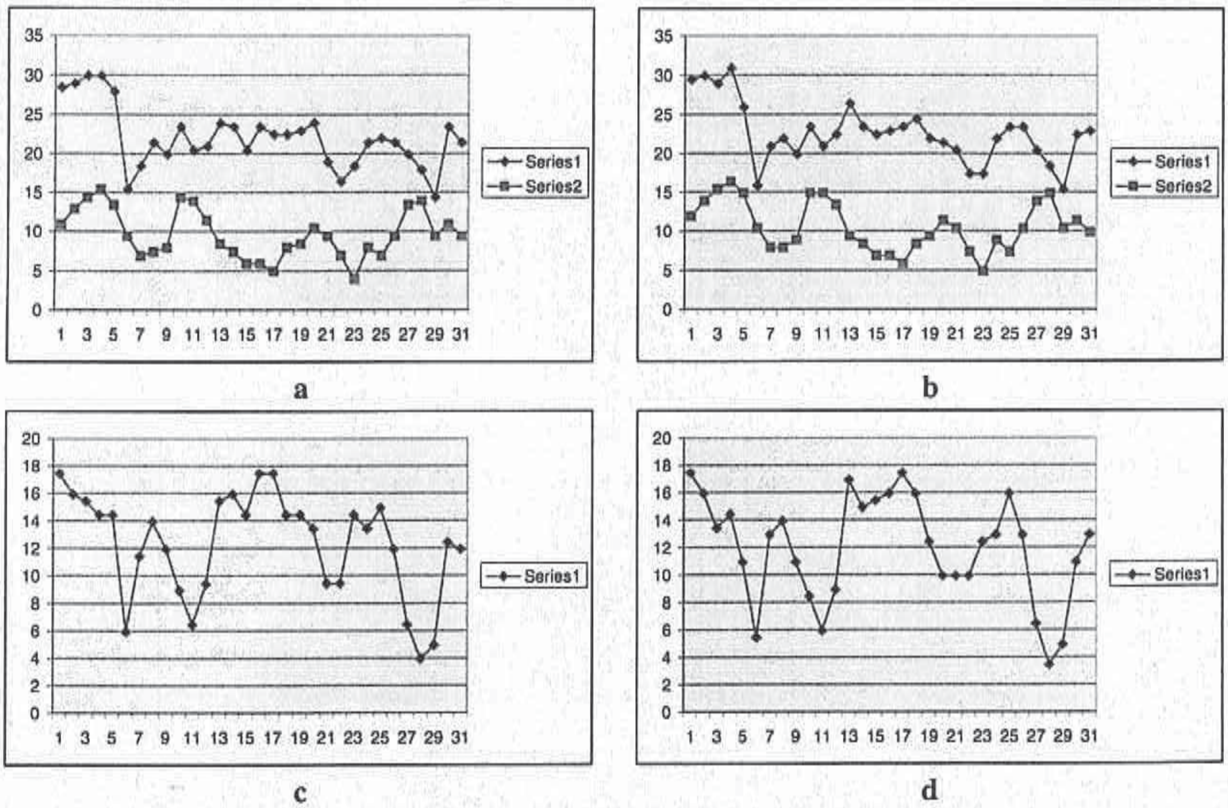


Figure 37. Daily temperature variation during measurement period 1.8.-31.8.1999.

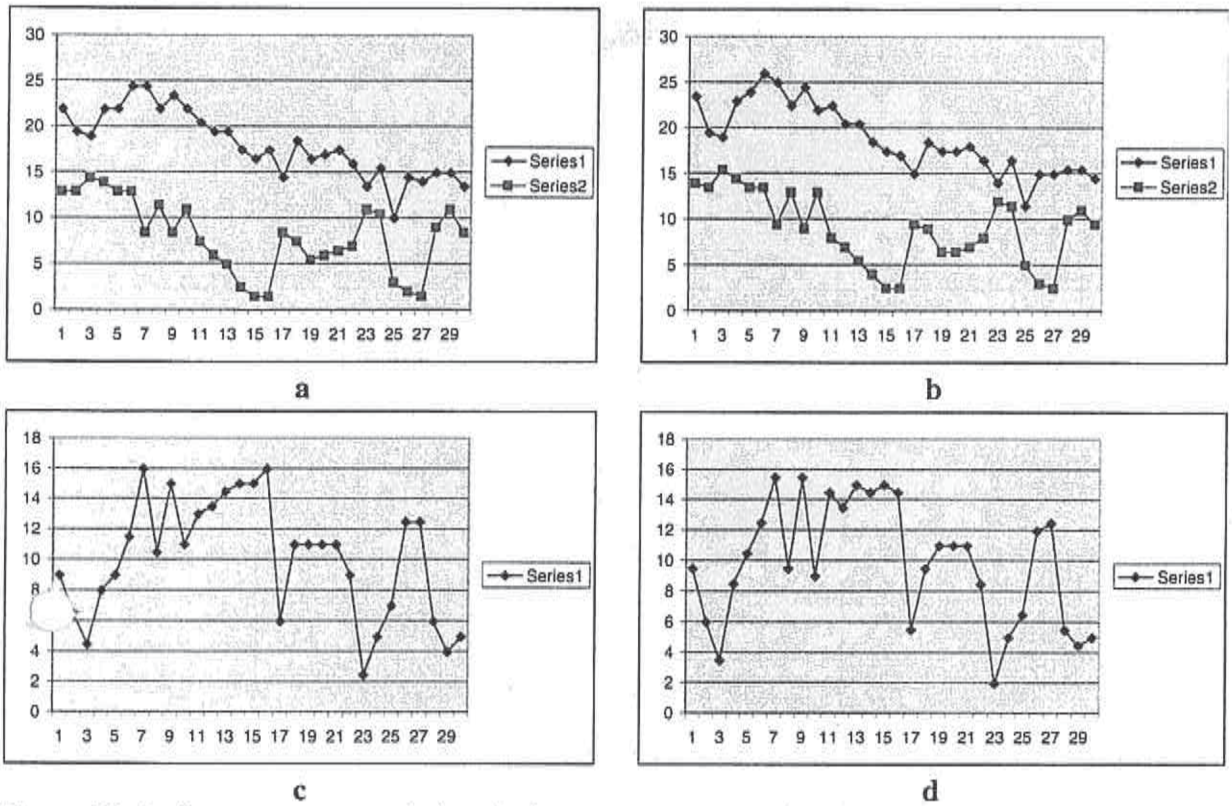


Figure 38. Daily temperature variation during measurement period 1.9.-30.9.1999.

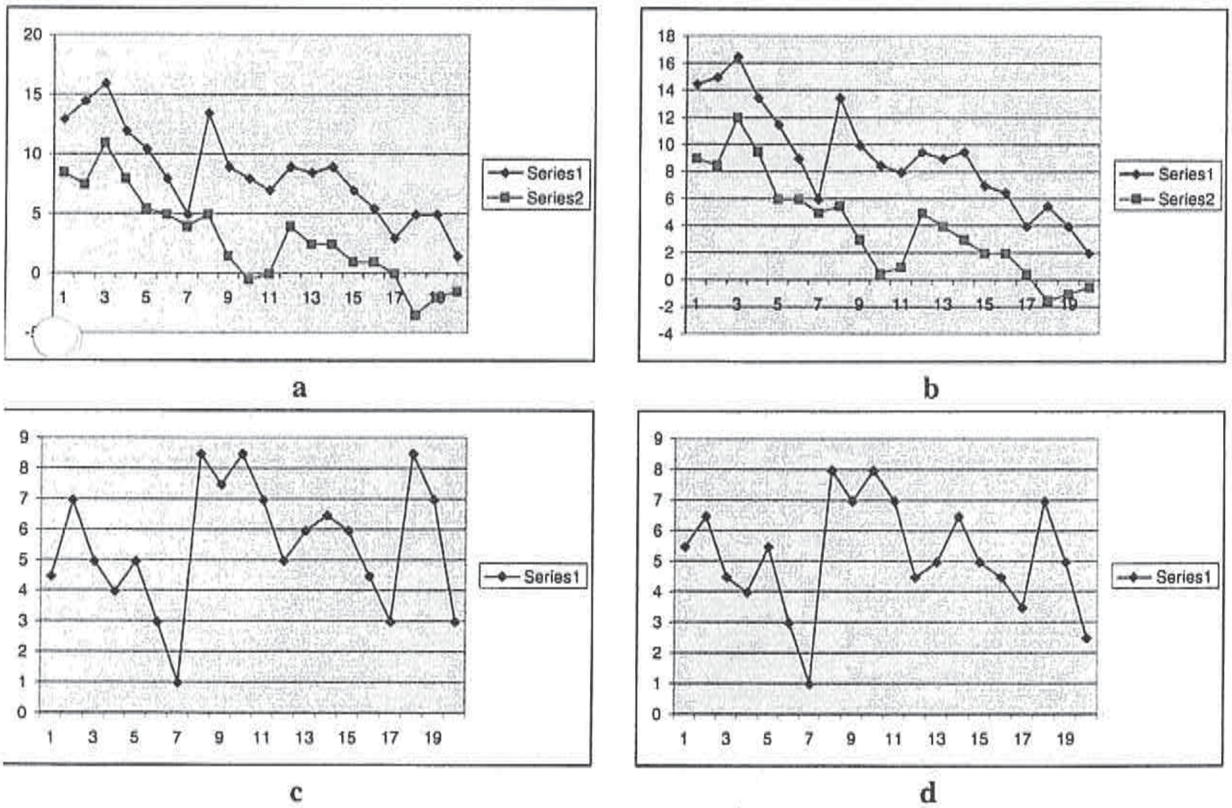


Figure 39. Daily temperature variation during measurement period 1.10.-20.10.1999.

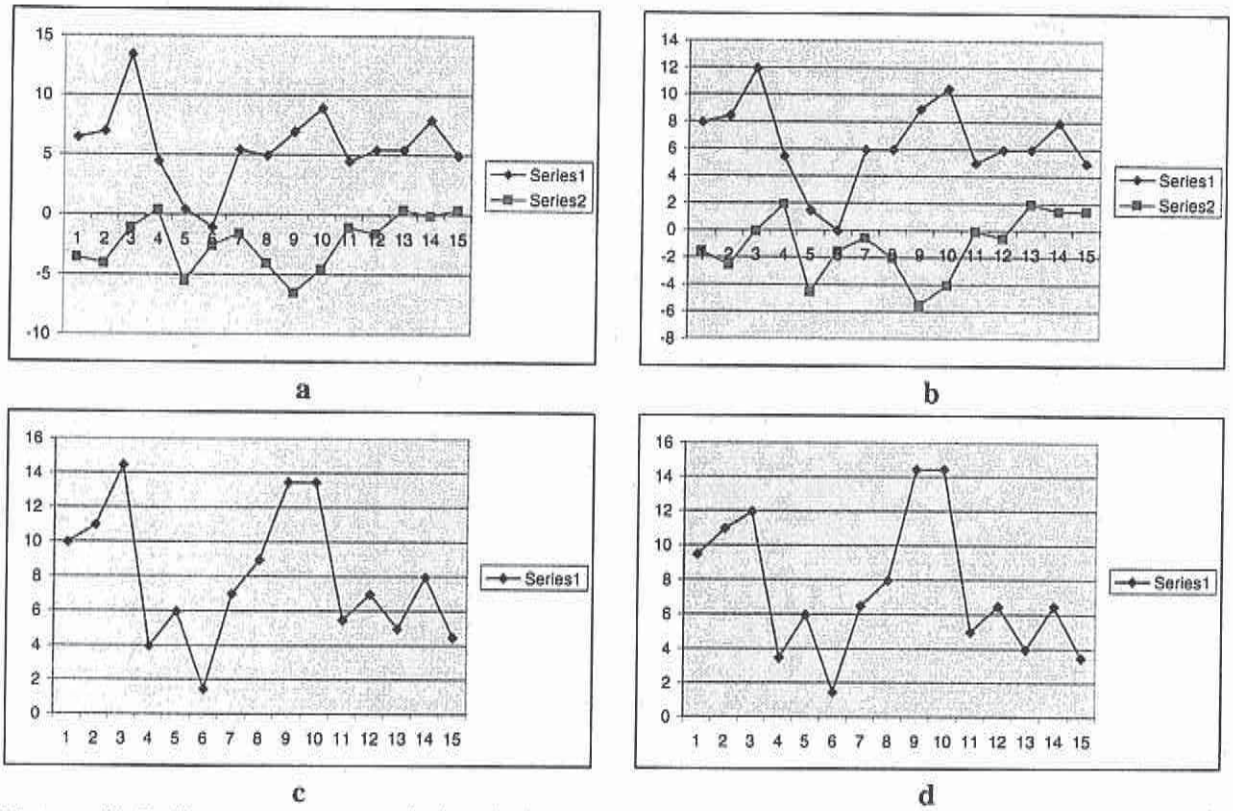


Figure 40. Daily temperature variation during measurement period 29.3.-12.4.2000.

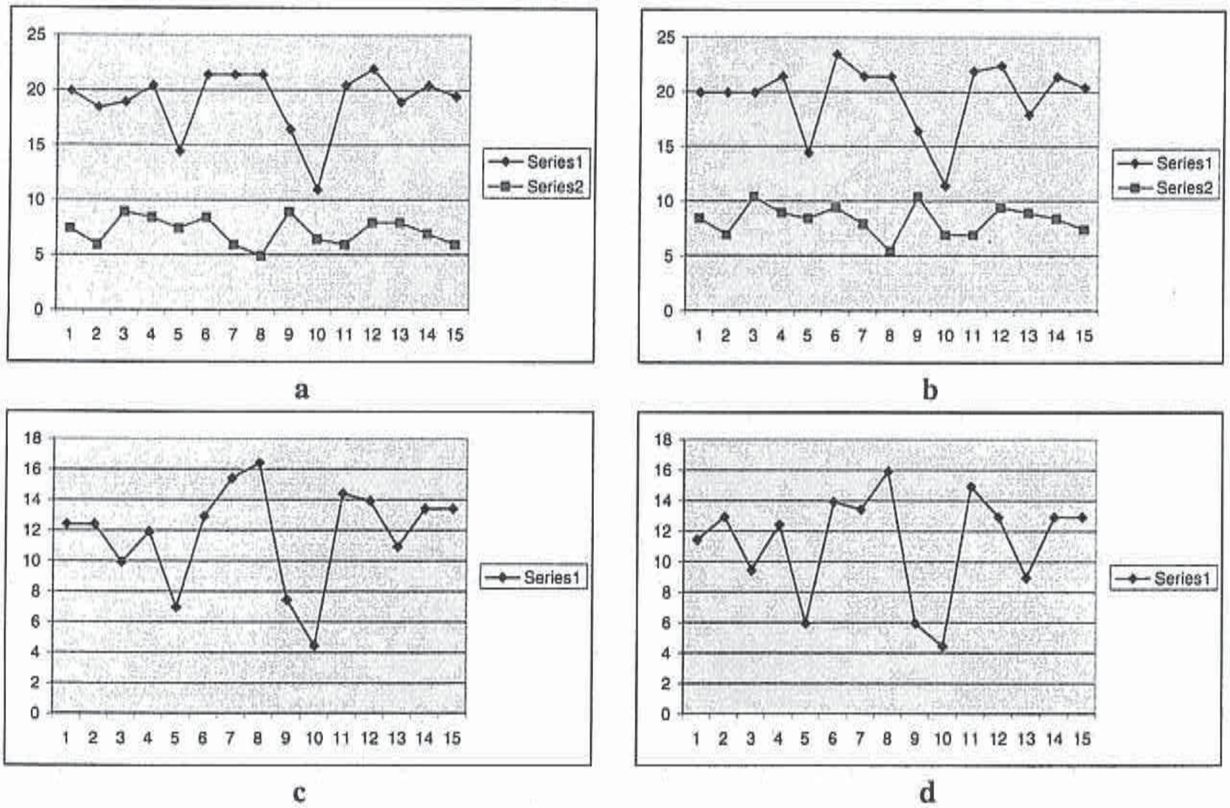


Figure 41. Daily temperature variation during measurement period 17.5.-31.5.2000.

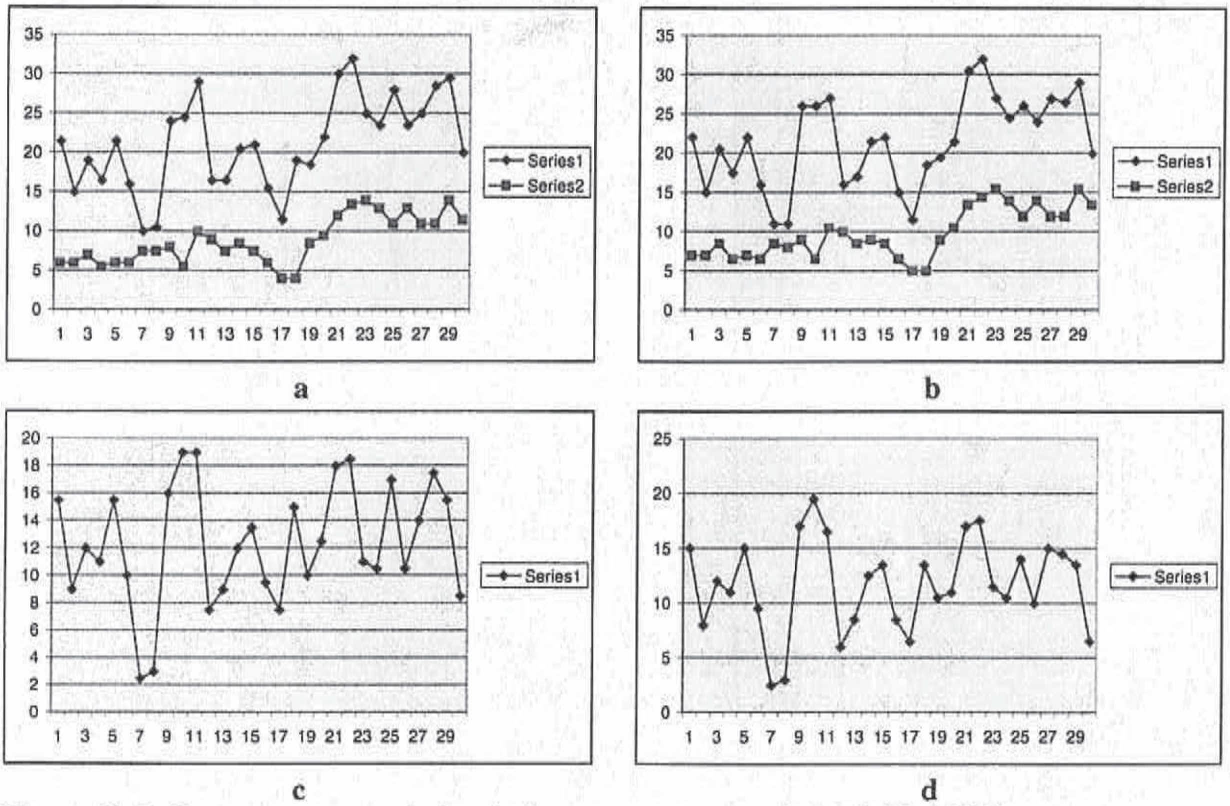


Figure 42. Daily temperature variation during measurement period 1.6.-30.6.2000.

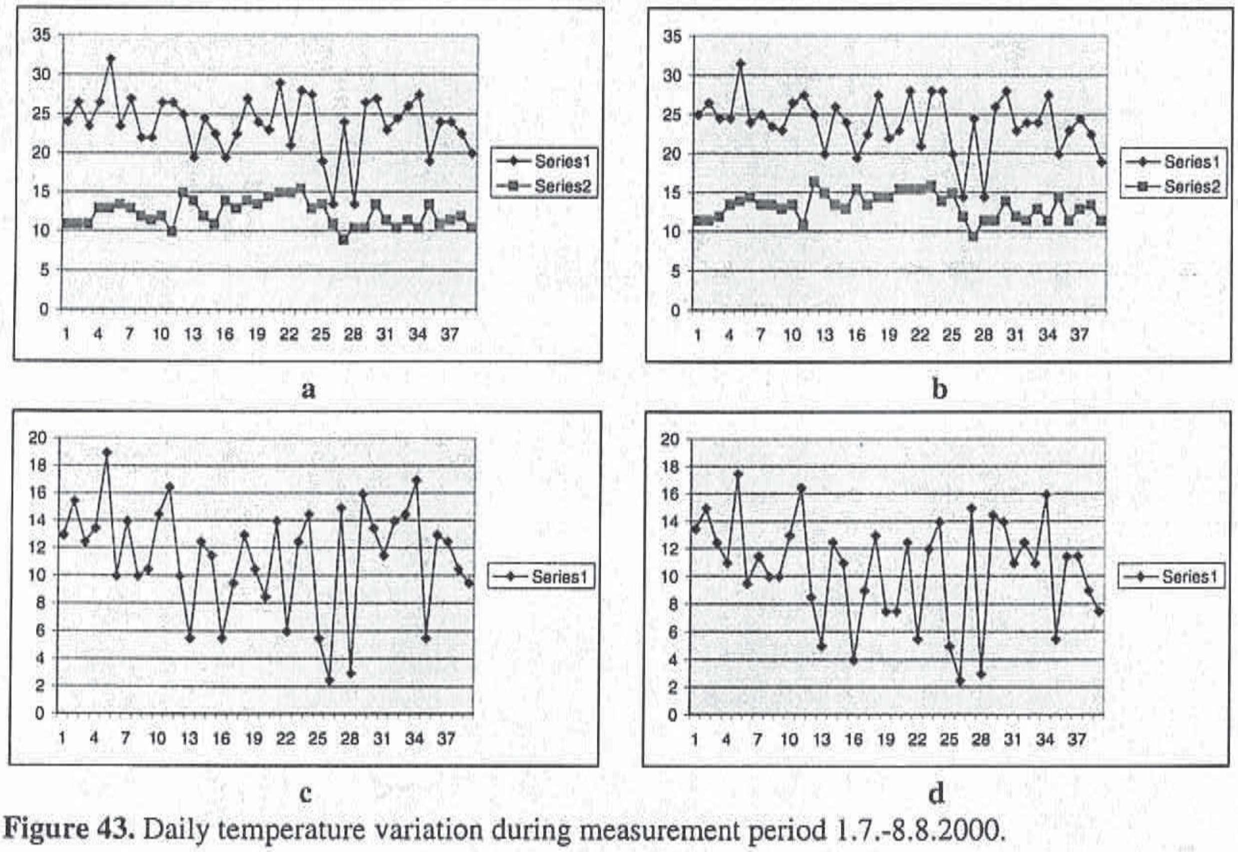


Figure 43. Daily temperature variation during measurement period 1.7.-8.8.2000.

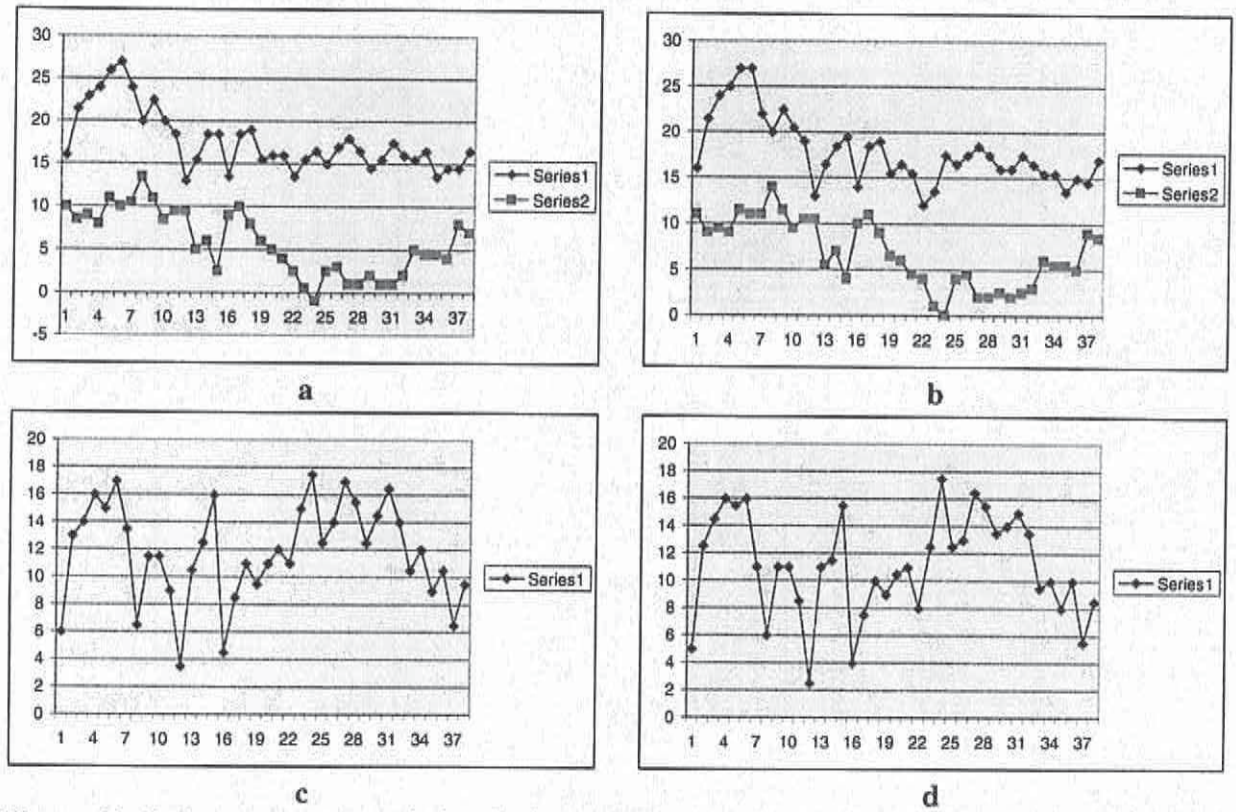


Figure 44. Daily temperature variation during measurement period 24.8.-30.9.2000.

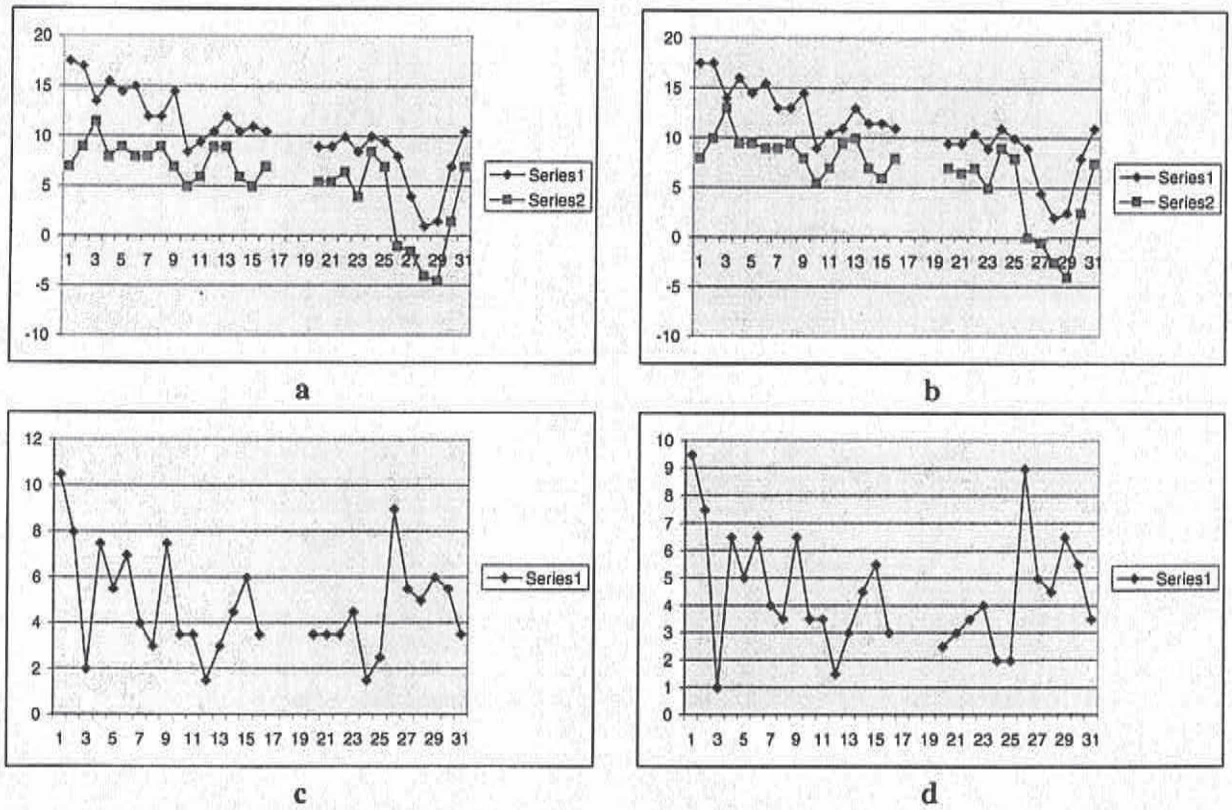


Figure 45. Daily temperature variation during measurement period 1.10.-31.10.2000.

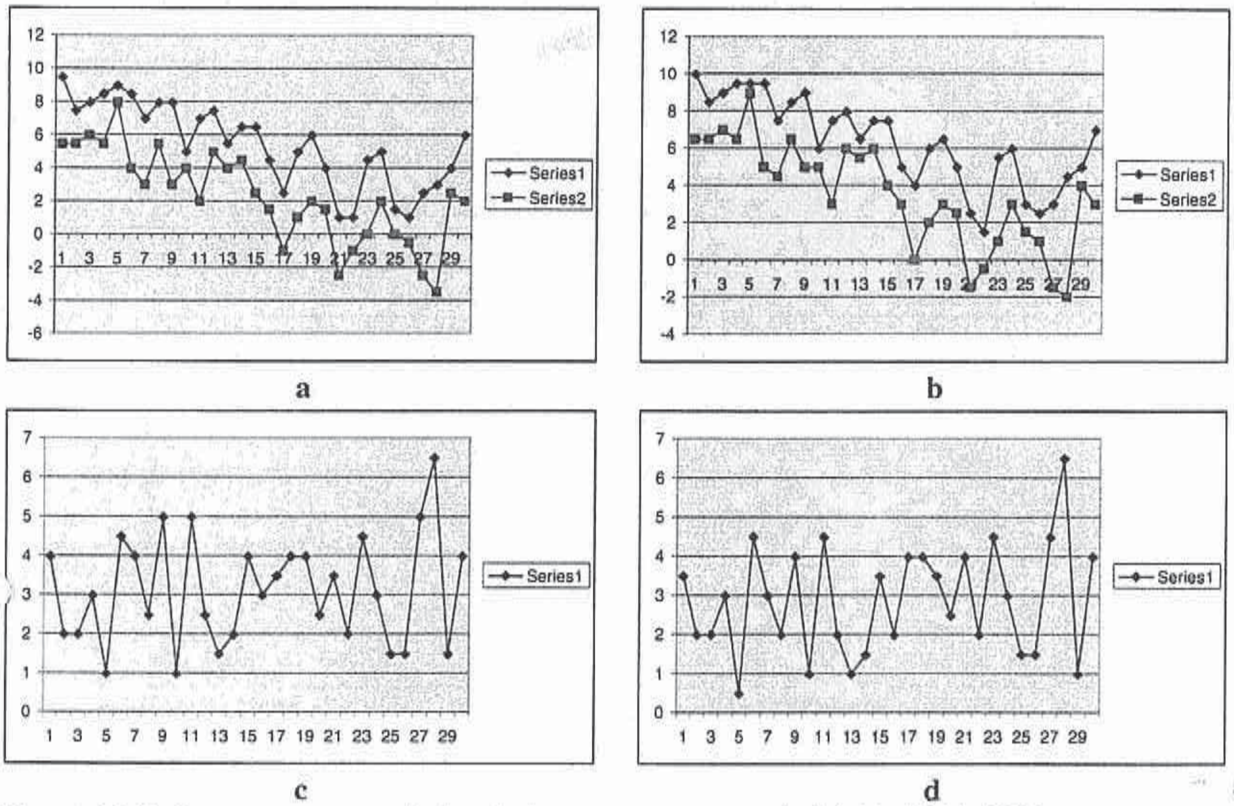


Figure 46. Daily temperature variation during measurement period 1.11.-30.11.2000.

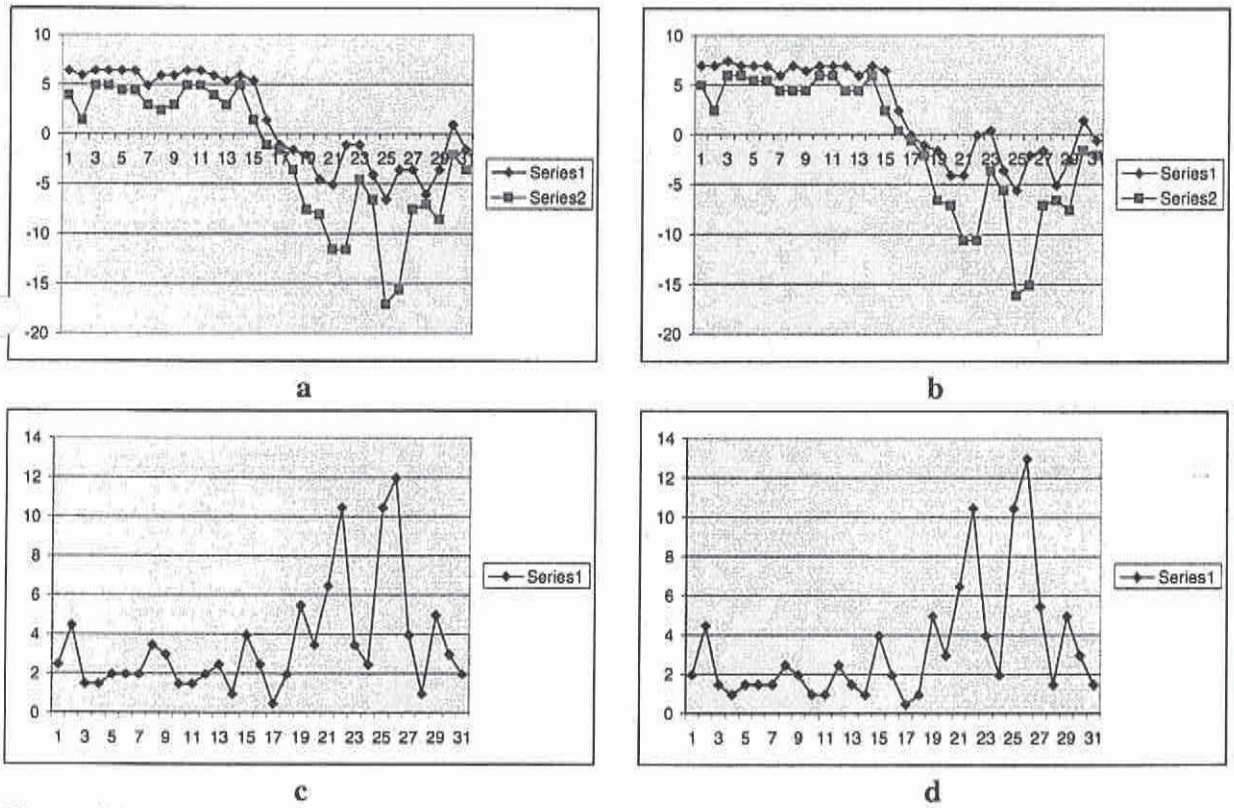


Figure 47. Daily temperature variation during measurement period 1.12.-31.12.2000.

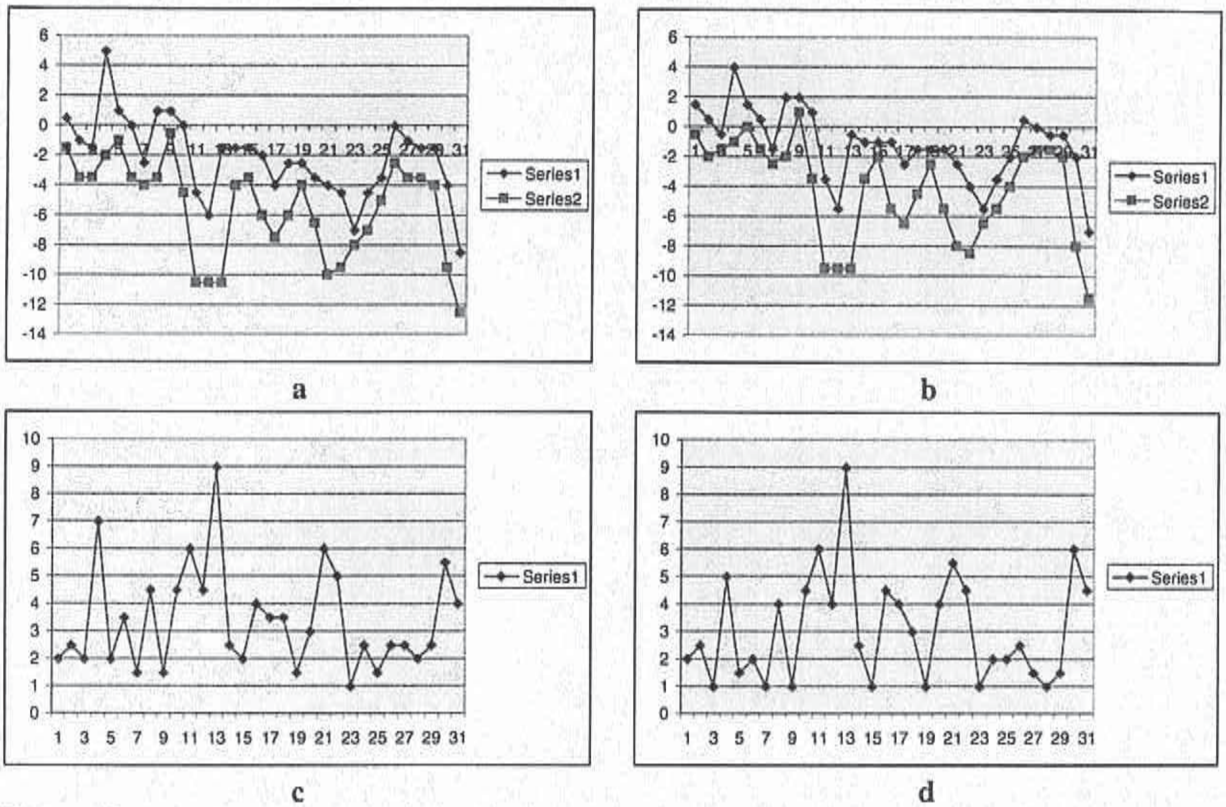


Figure 48. Daily temperature variation during measurement period 1.1.-31.1.2001.

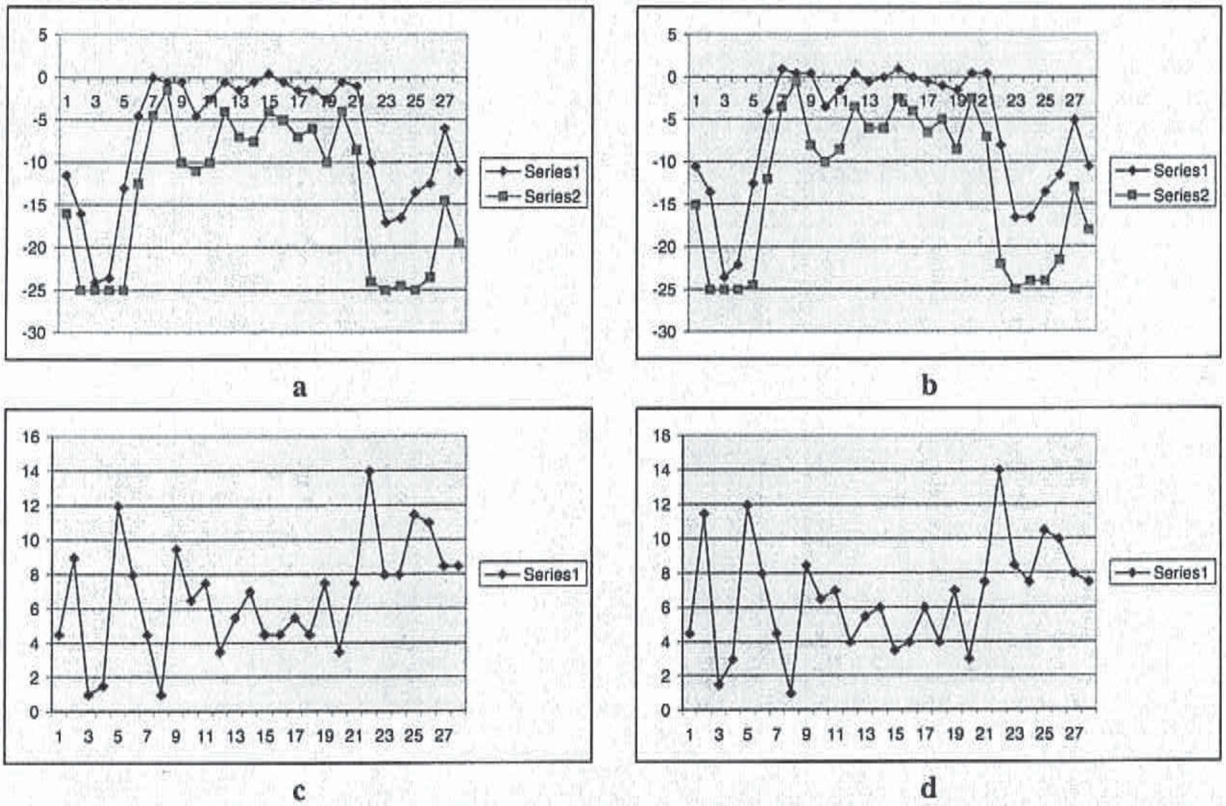


Figure 49. Daily temperature variation during measurement period 1.2.-28.2.2001.

4.3.4 Measuring point D

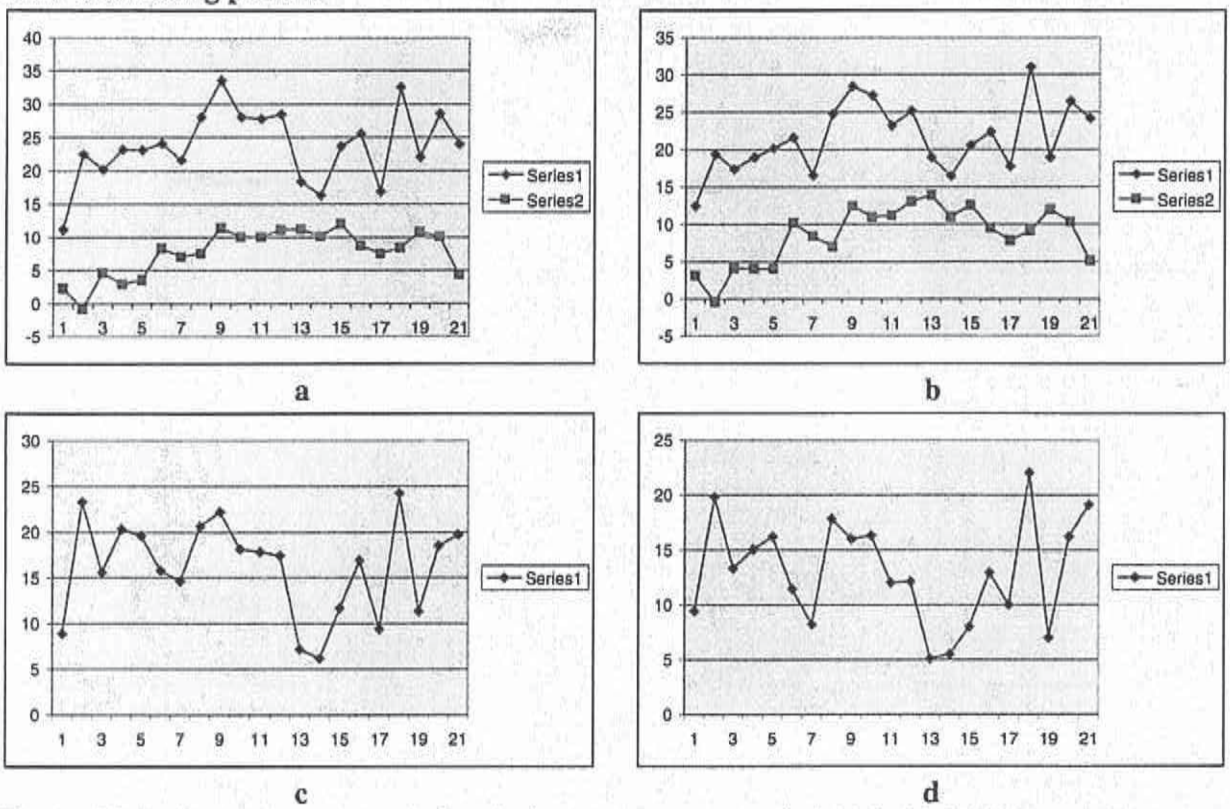


Figure 50. Daily temperature variation during measurement period 11.5.-31.5.1999.

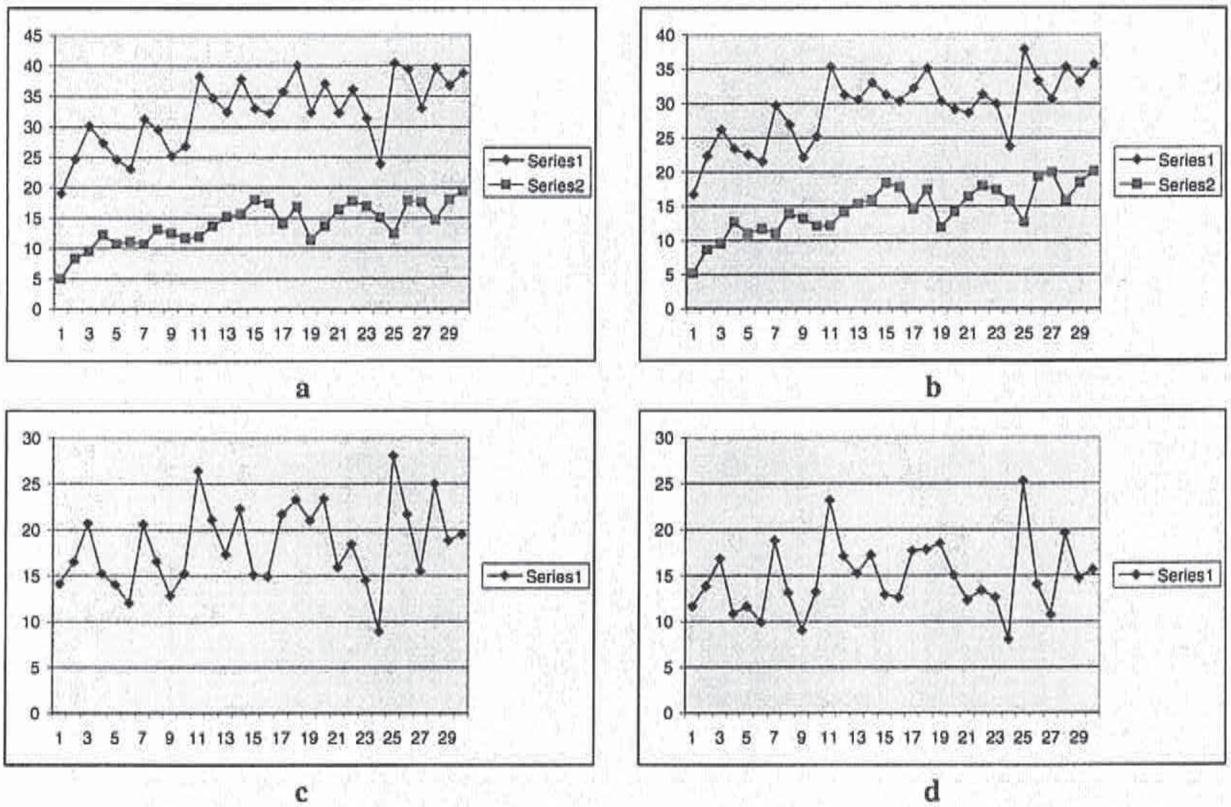


Figure 51. Daily temperature variation during measurement period 1.6.-30.6.1999.

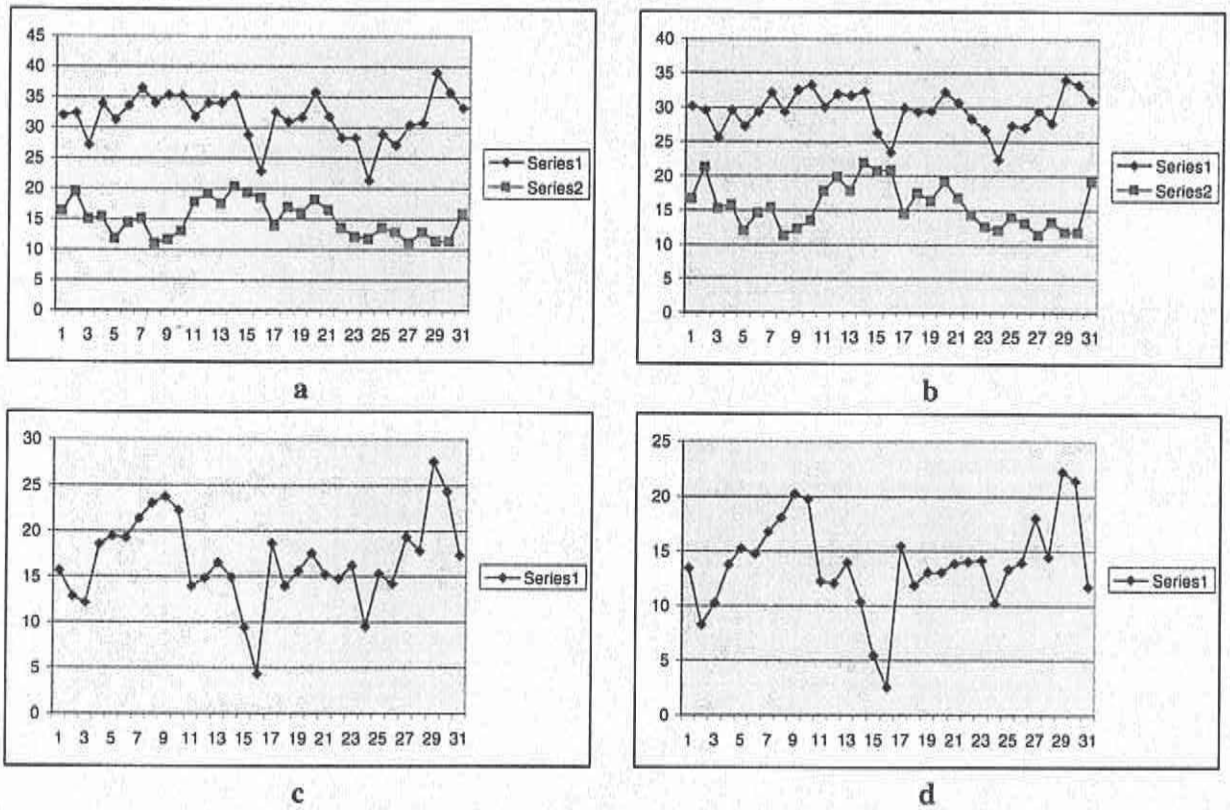


Figure 52. Daily temperature variation during measurement period 1.7.-31.7.1999.

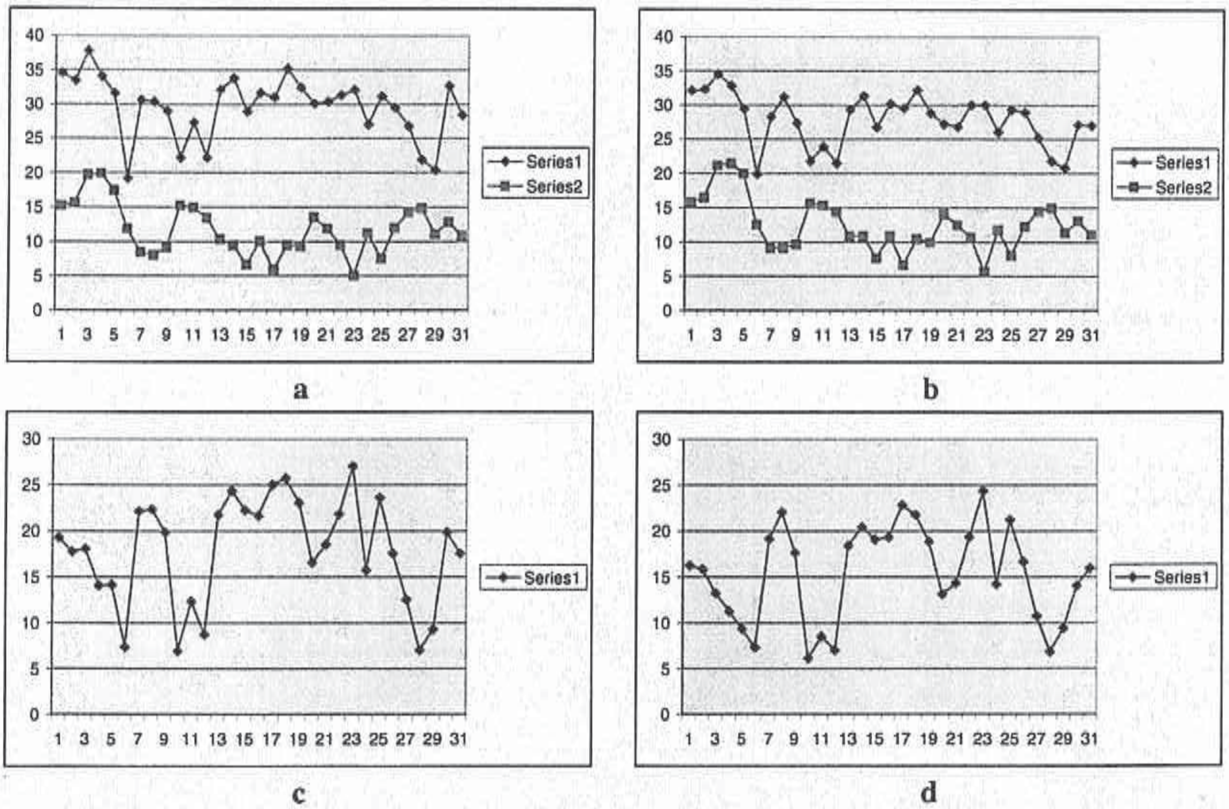


Figure 53. Daily temperature variation during measurement period 1.8.-31.8.1999.

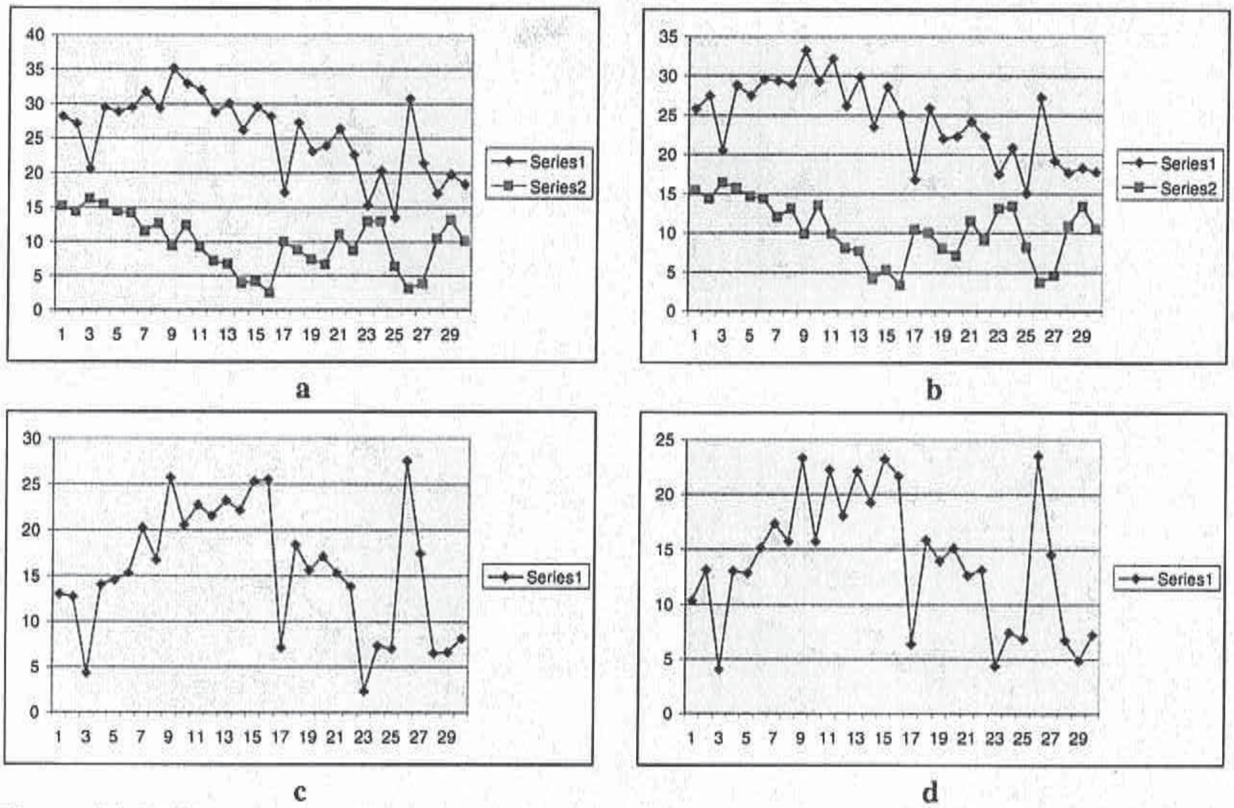


Figure 54. Daily temperature variation during measurement period 1.9.-30.9.1999.

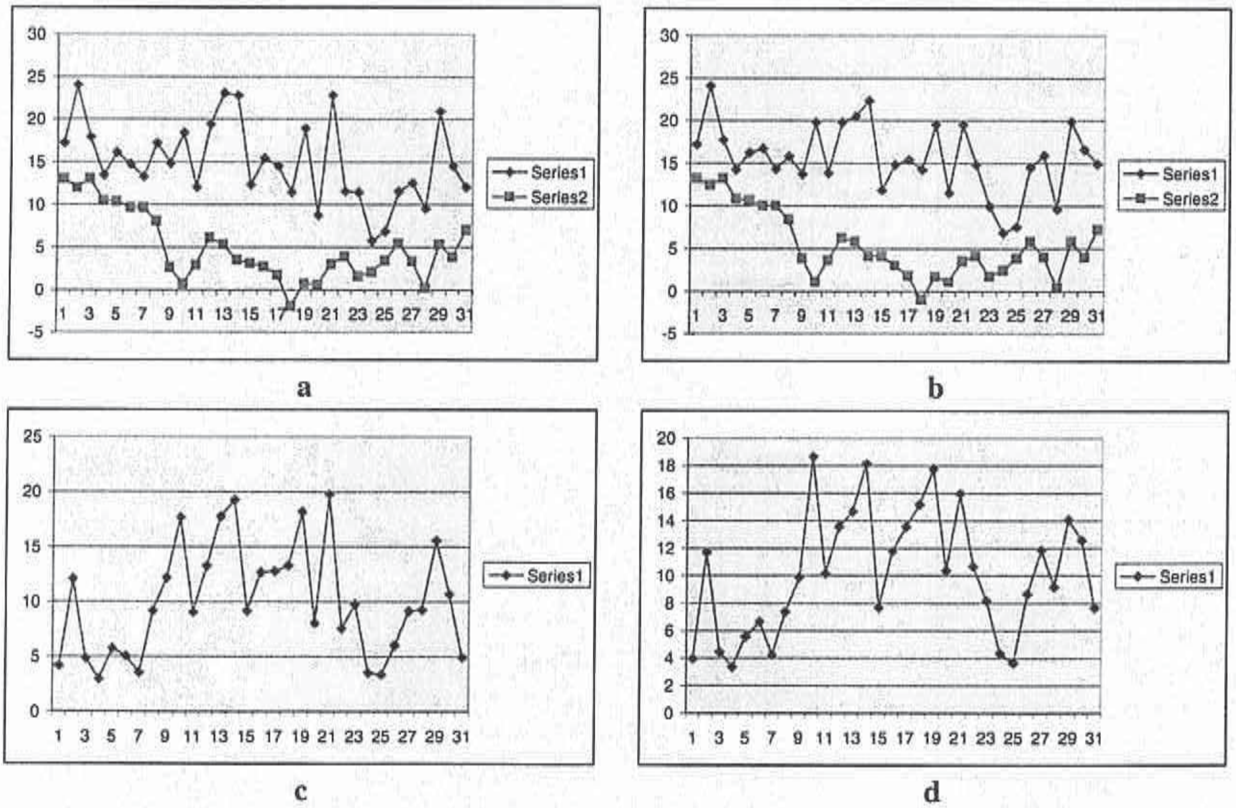


Figure 55. Daily temperature variation during measurement period 1.10.-31.10.1999.

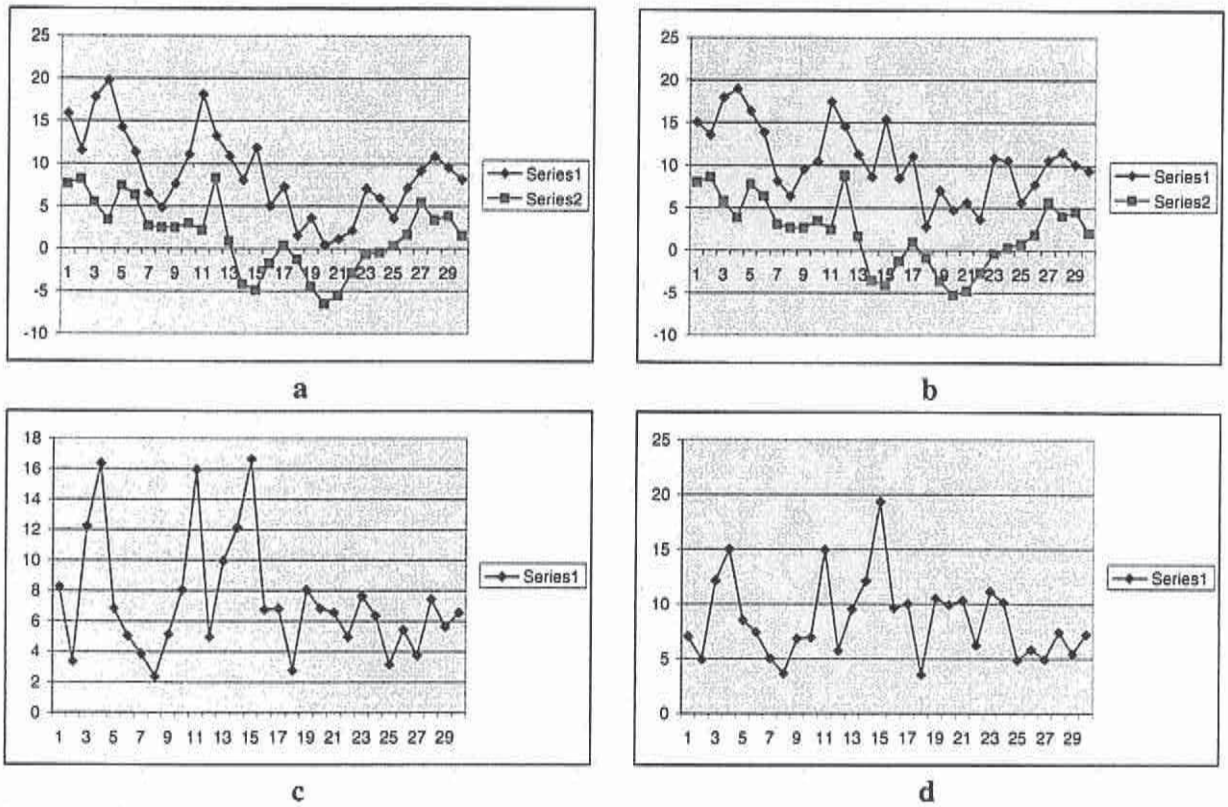


Figure 56. Daily temperature variation during measurement period 1.11.-30.11.1999.

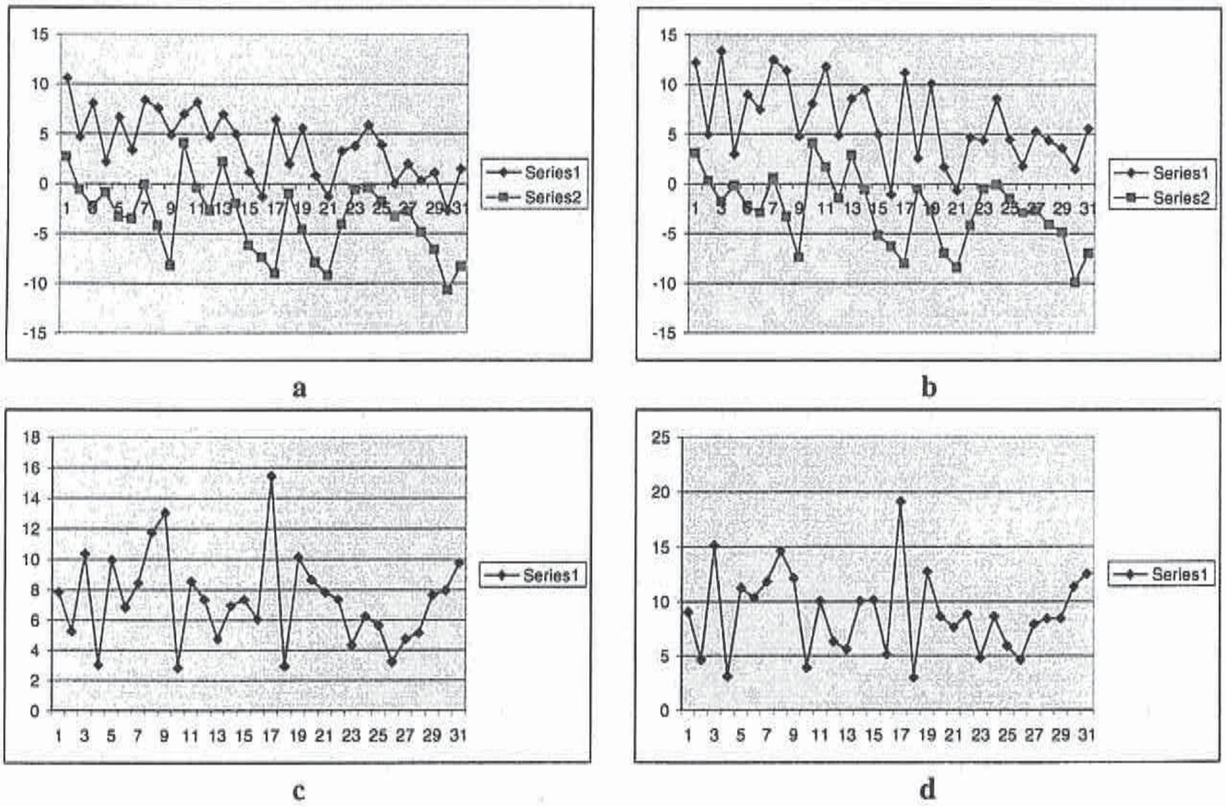


Figure 57. Daily temperature variation during measurement period 1.12.-31.12.1999.

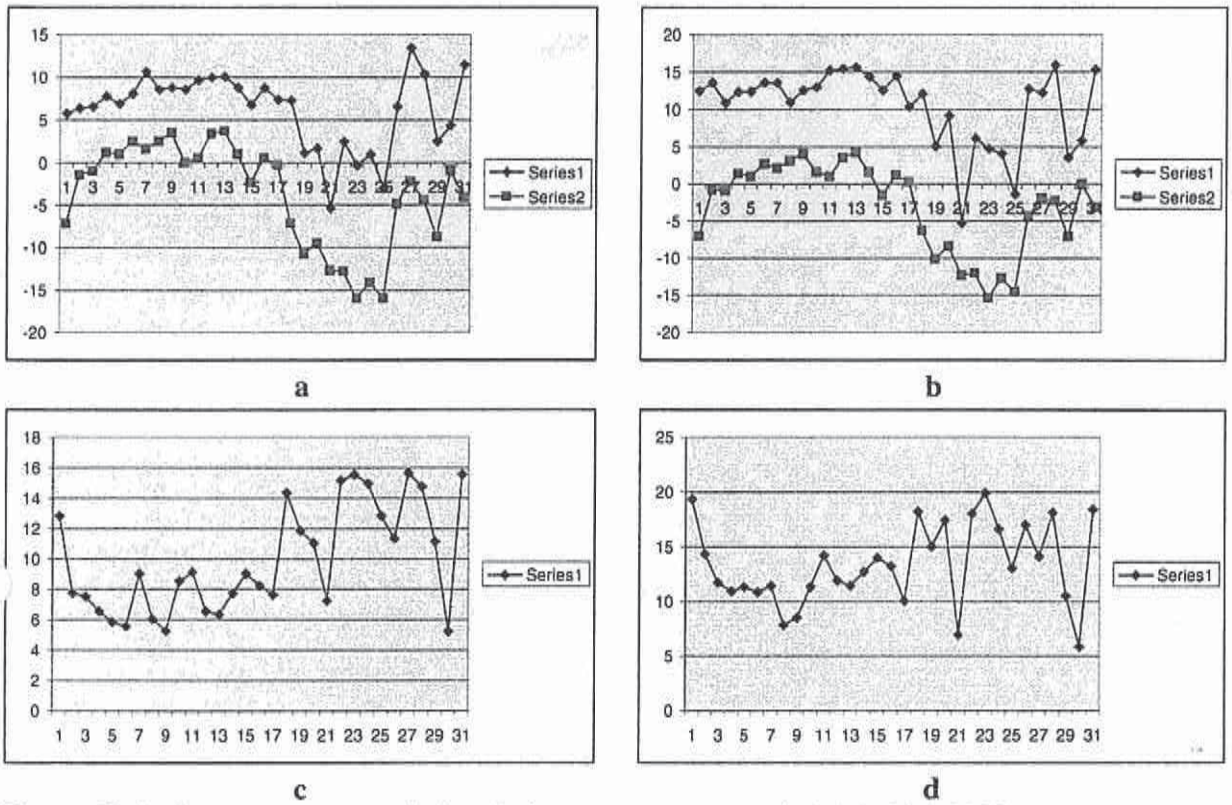


Figure 58. Daily temperature variation during measurement period 1.1.-31.1.2000.

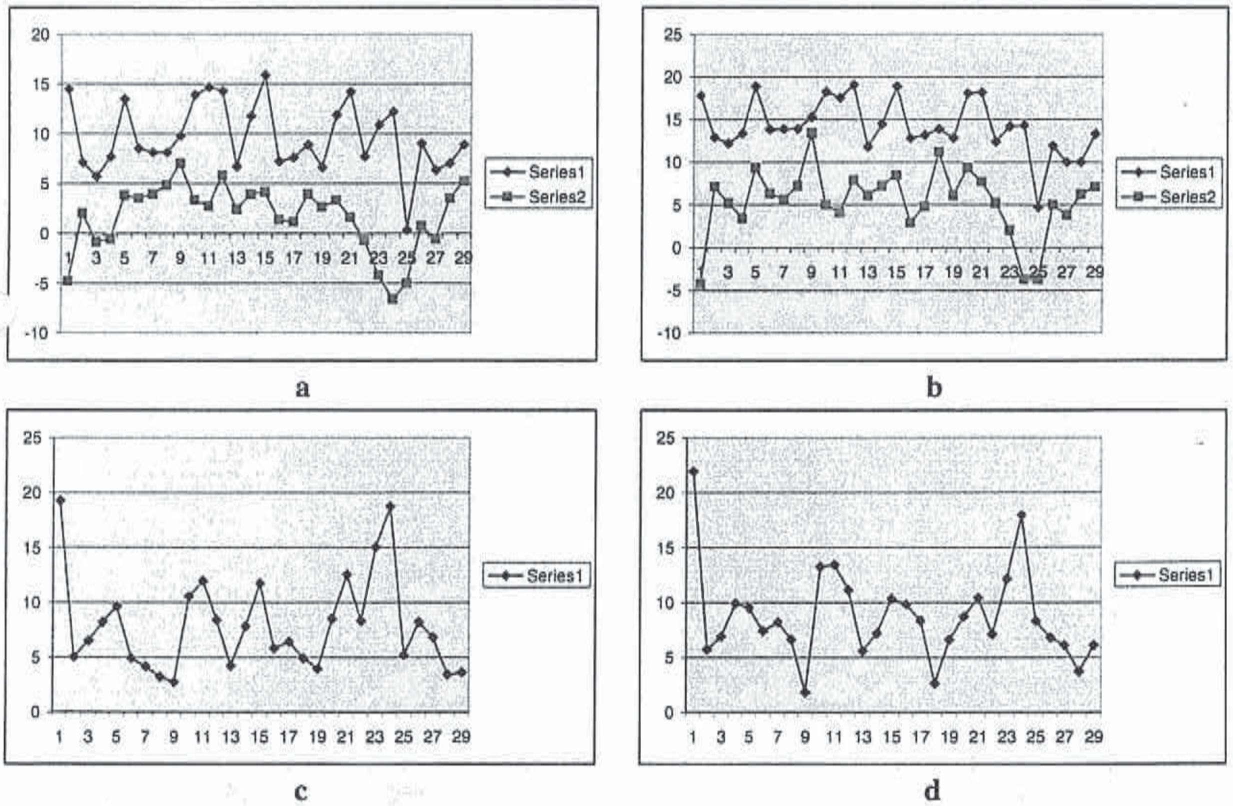


Figure 59. Daily temperature variation during measurement period 1.2.-29.2.2000.

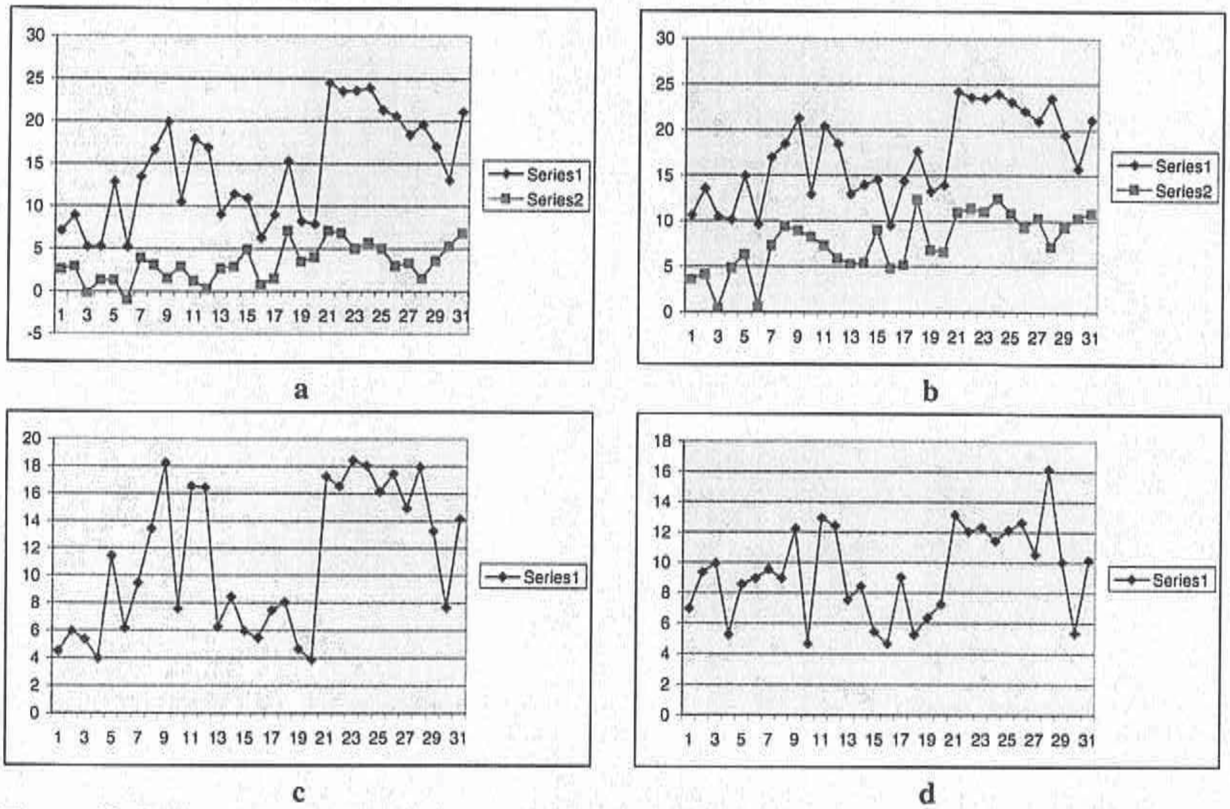


Figure 60. Daily temperature variation during measurement period 1.3.-31.3.2000.

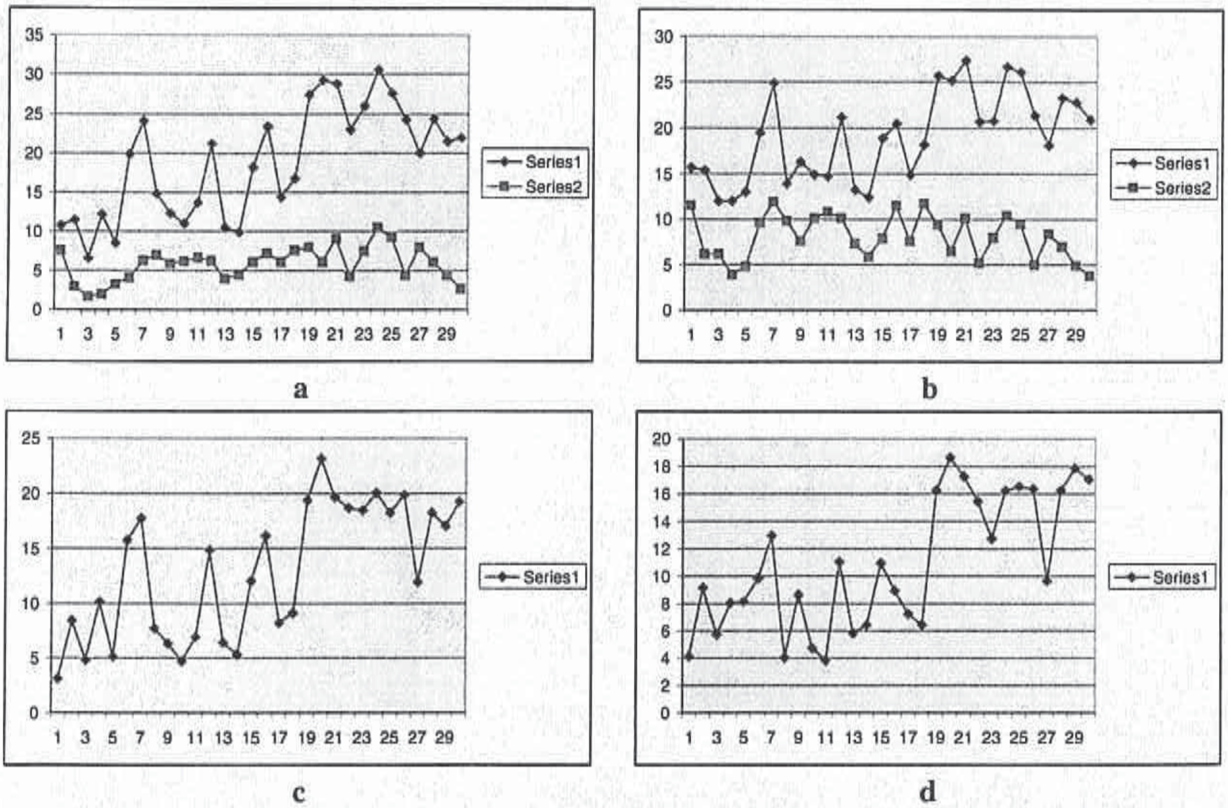


Figure 61. Daily temperature variation during measurement period 1.4.-30.4.2000.

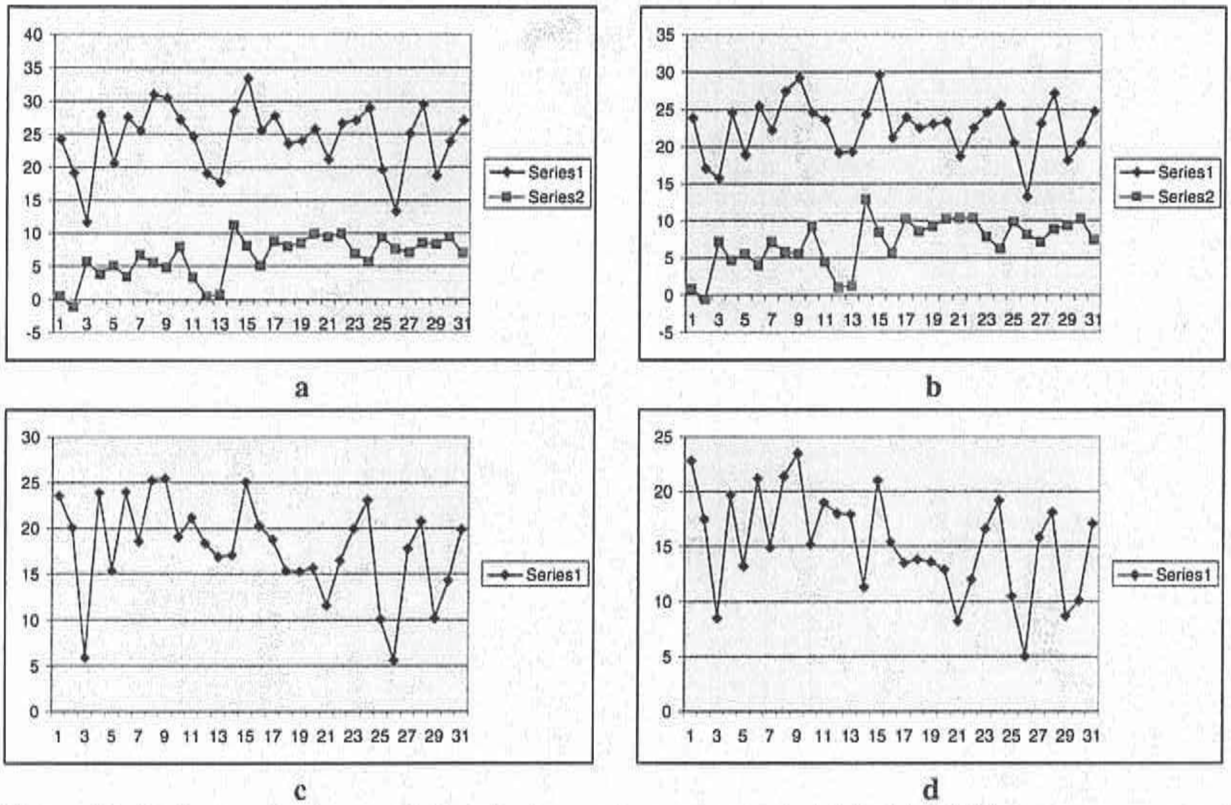


Figure 62. Daily temperature variation during measurement period 1.5.-31.5.2000.

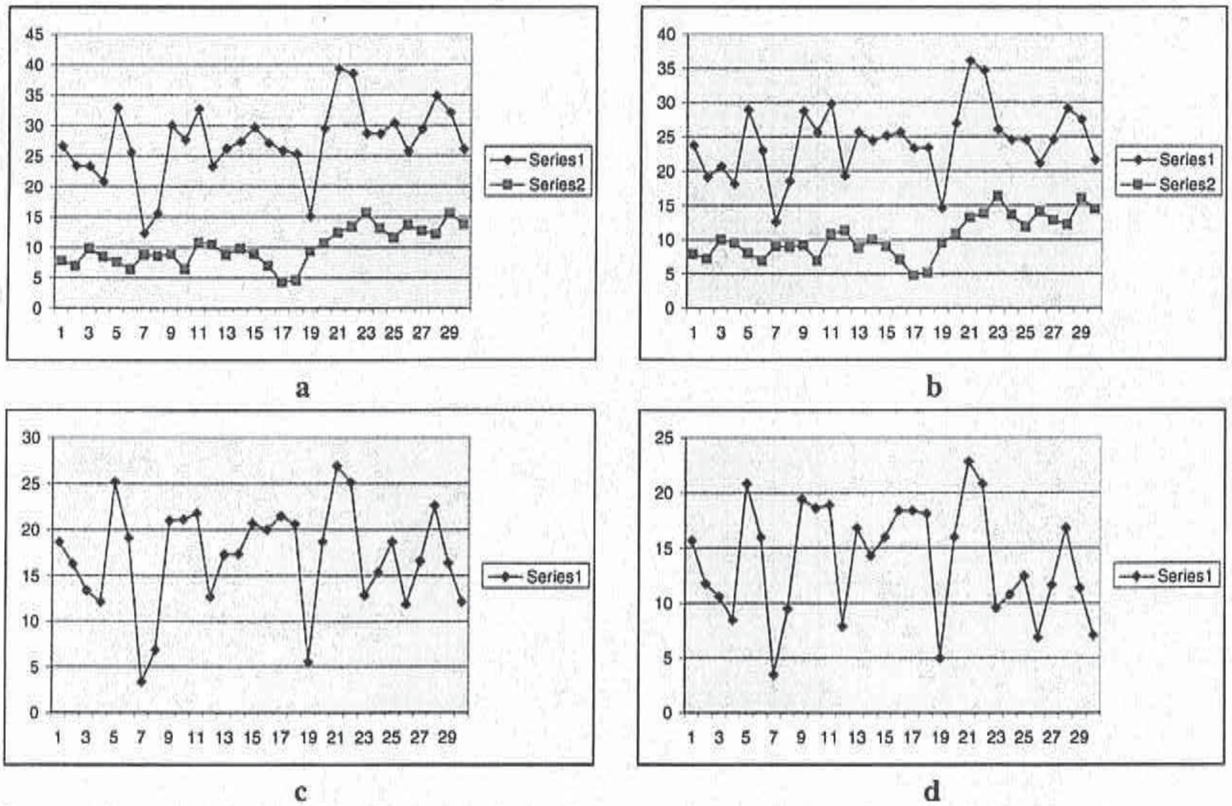


Figure 63. Daily temperature variation during measurement period 1.6.-30.6.2000.

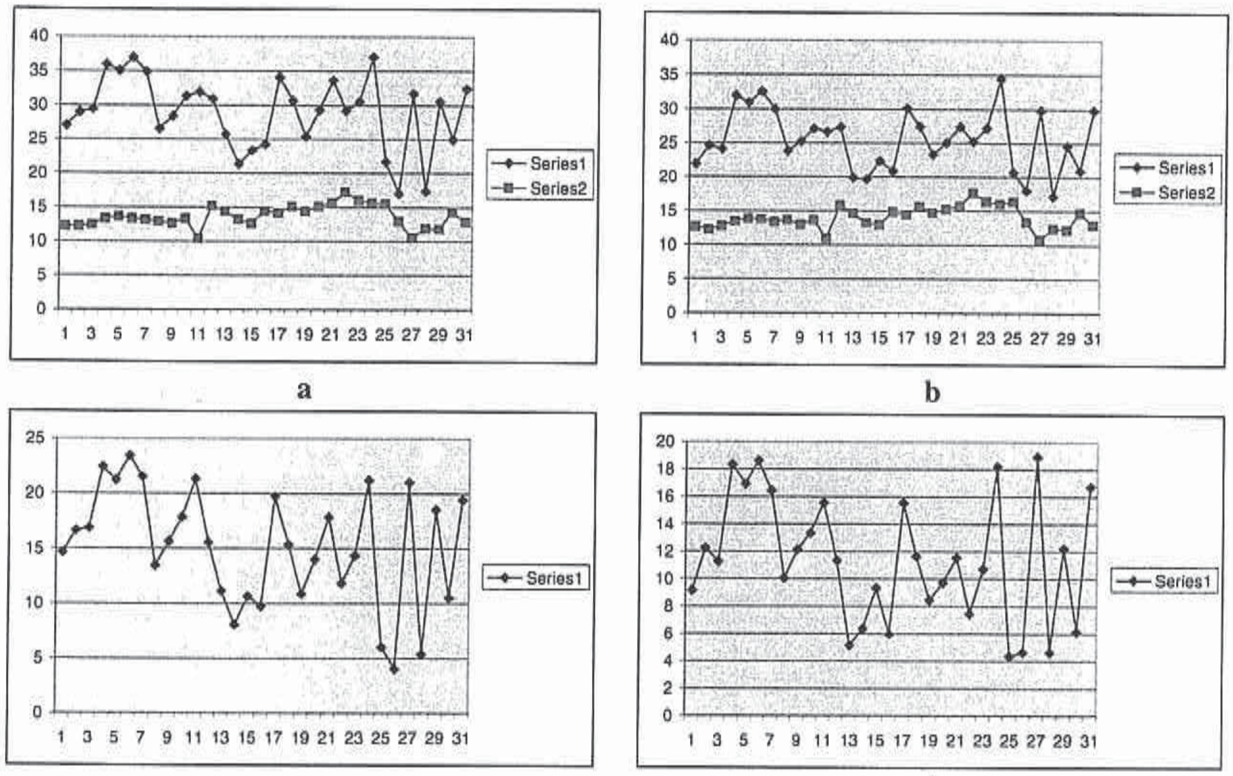


Figure 64. Daily temperature variation during measurement period 1.7.-31.7.2000.

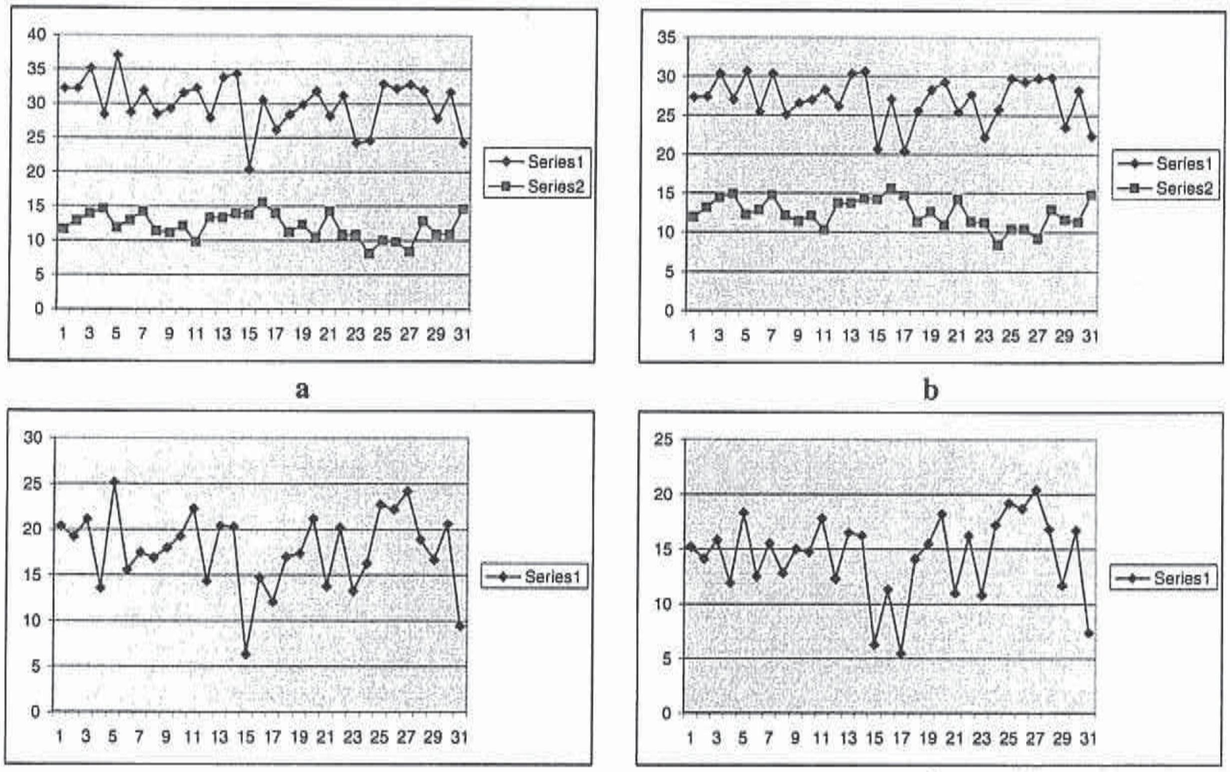


Figure 65. Daily temperature variation during measurement period 1.8.-31.8.2000.

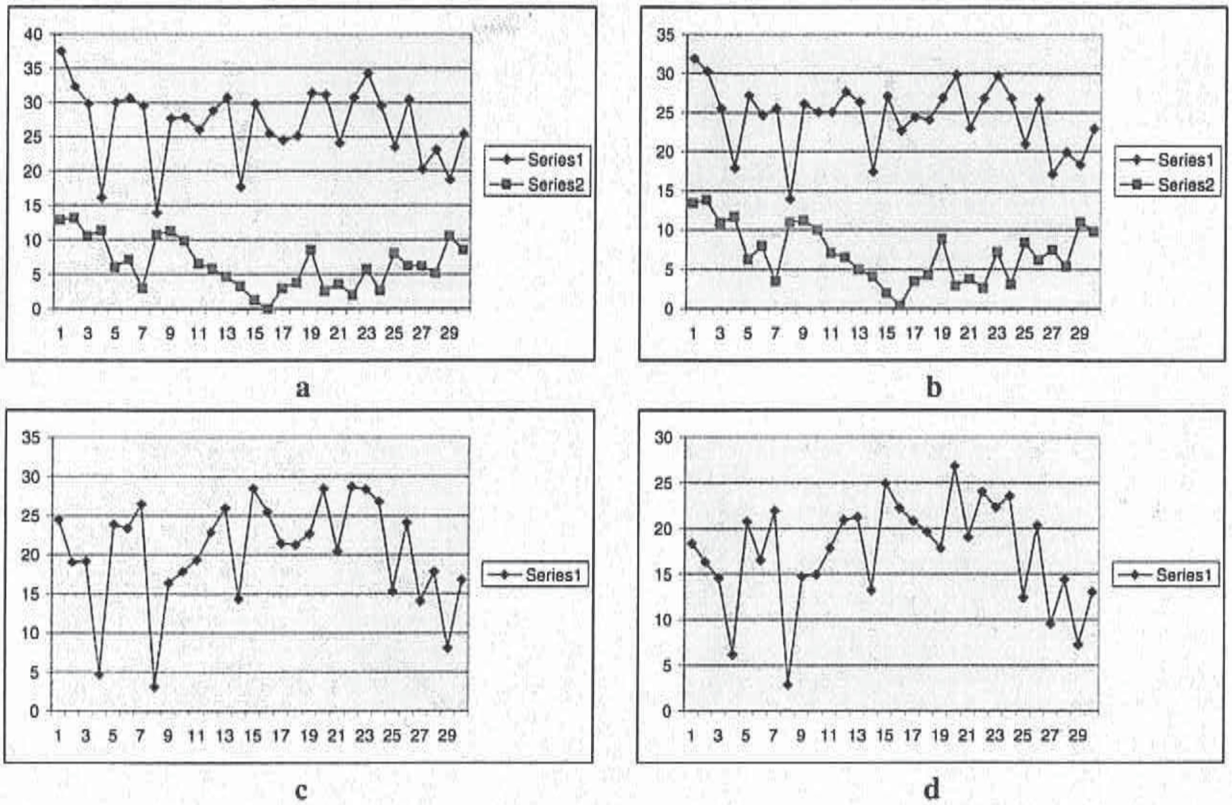


Figure 66. Daily temperature variation during measurement period 1.9.-30.9.2000.

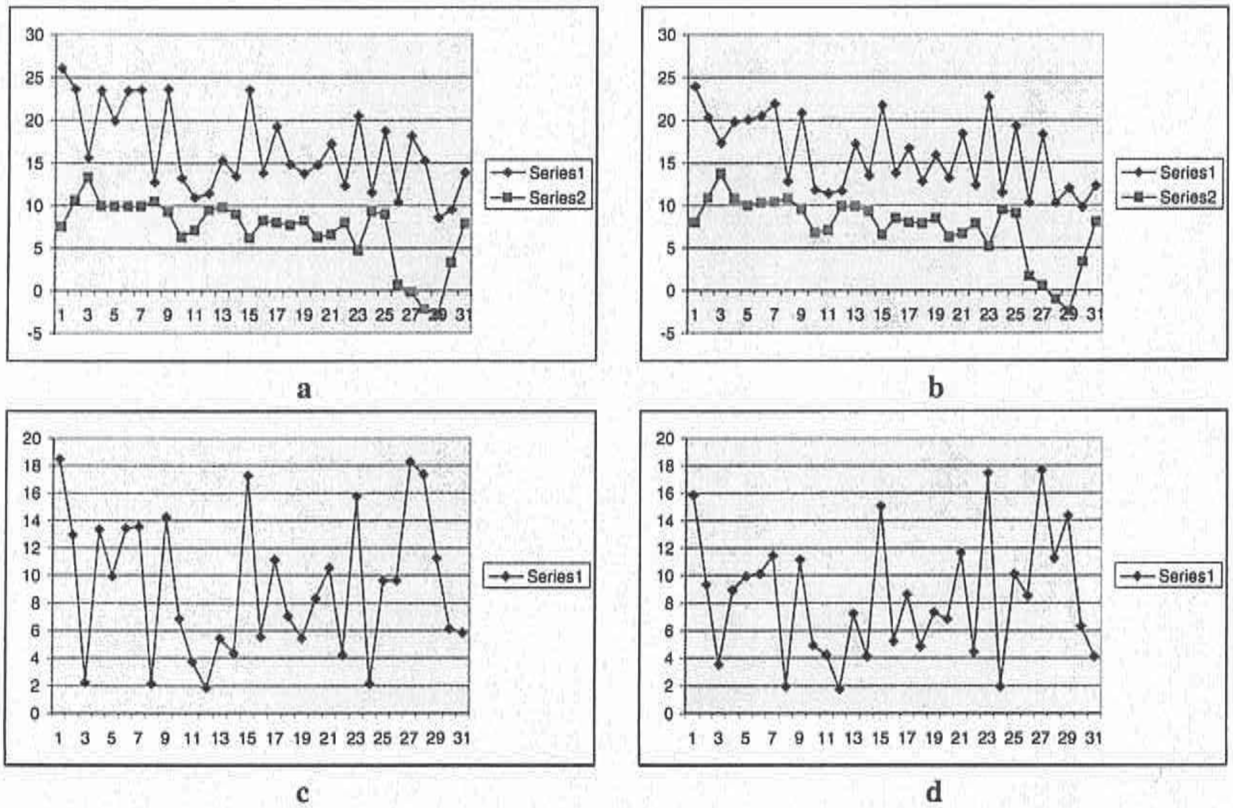


Figure 67. Daily temperature variation during measurement period 1.10.-31.10.2000.

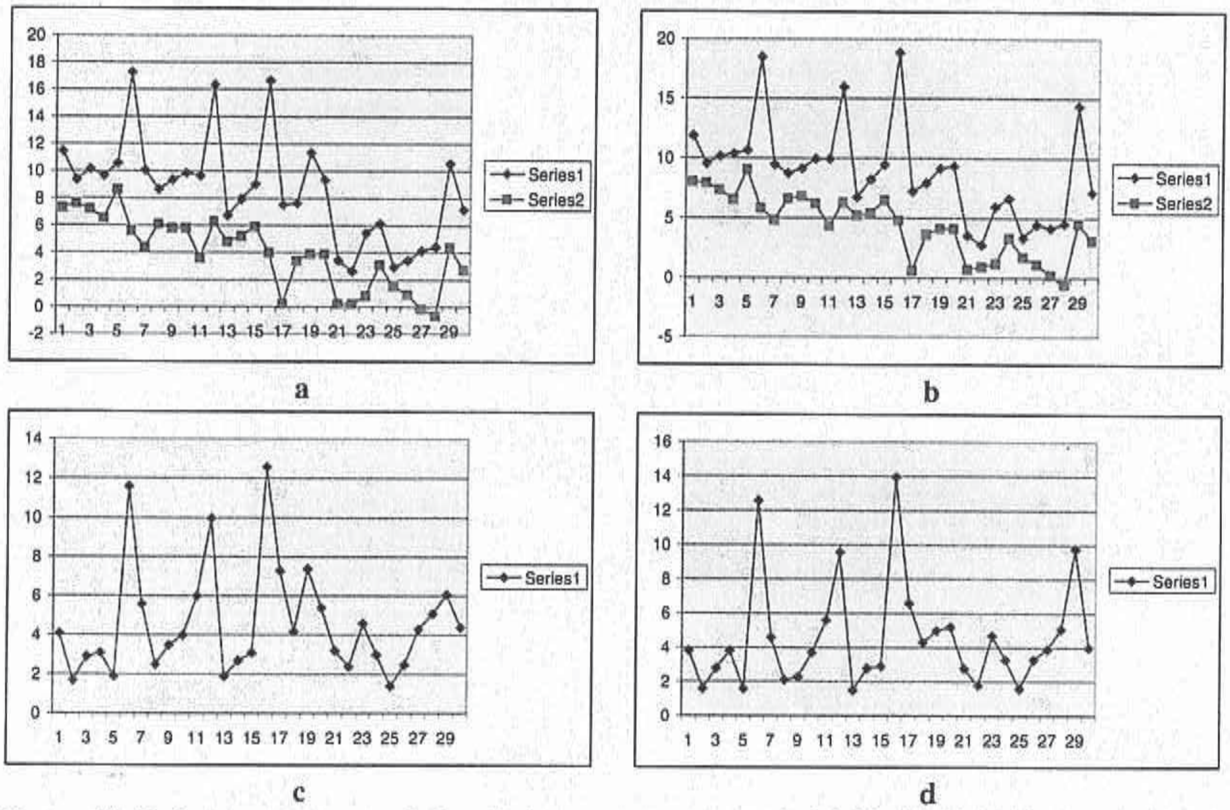


Figure 68. Daily temperature variation during measurement period 1.11.-30.11.2000.

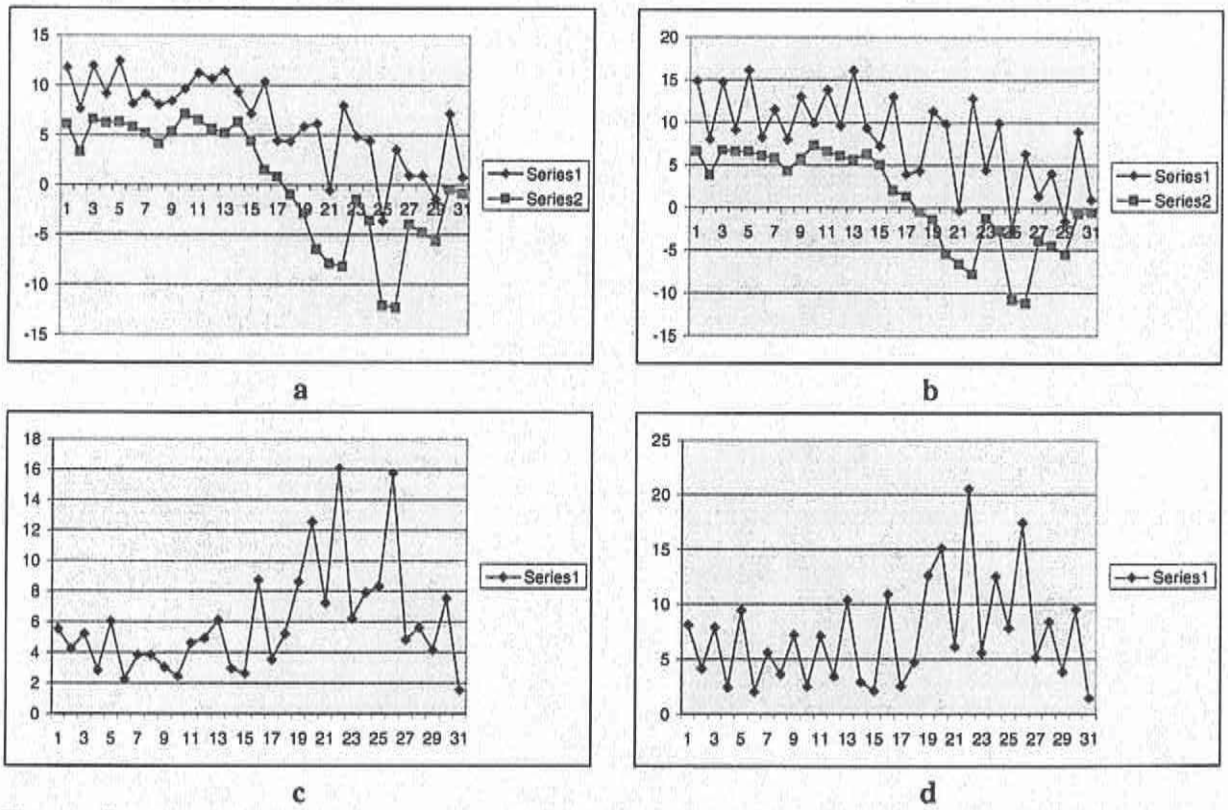


Figure 69. Daily temperature variation during measurement period 1.12.-31.12.2000.

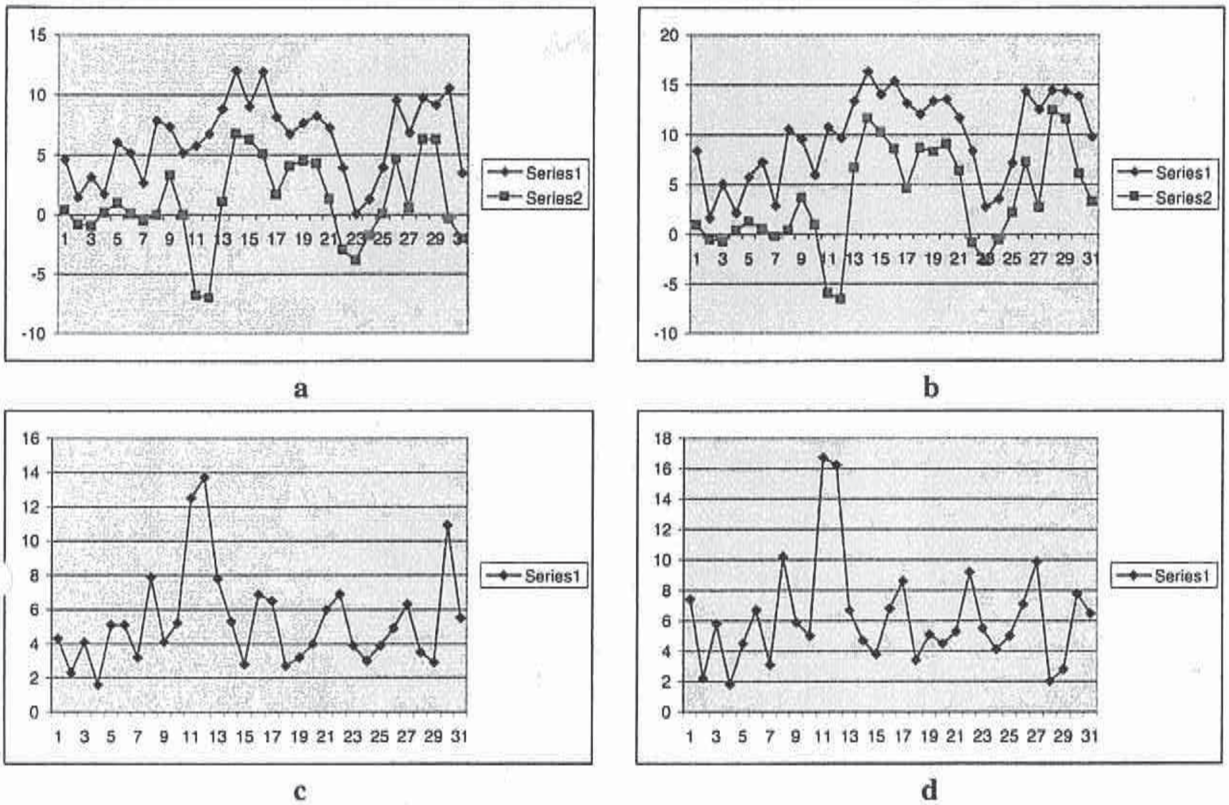


Figure 70. Daily temperature variation during measurement period 1.1.-31.1.2001.

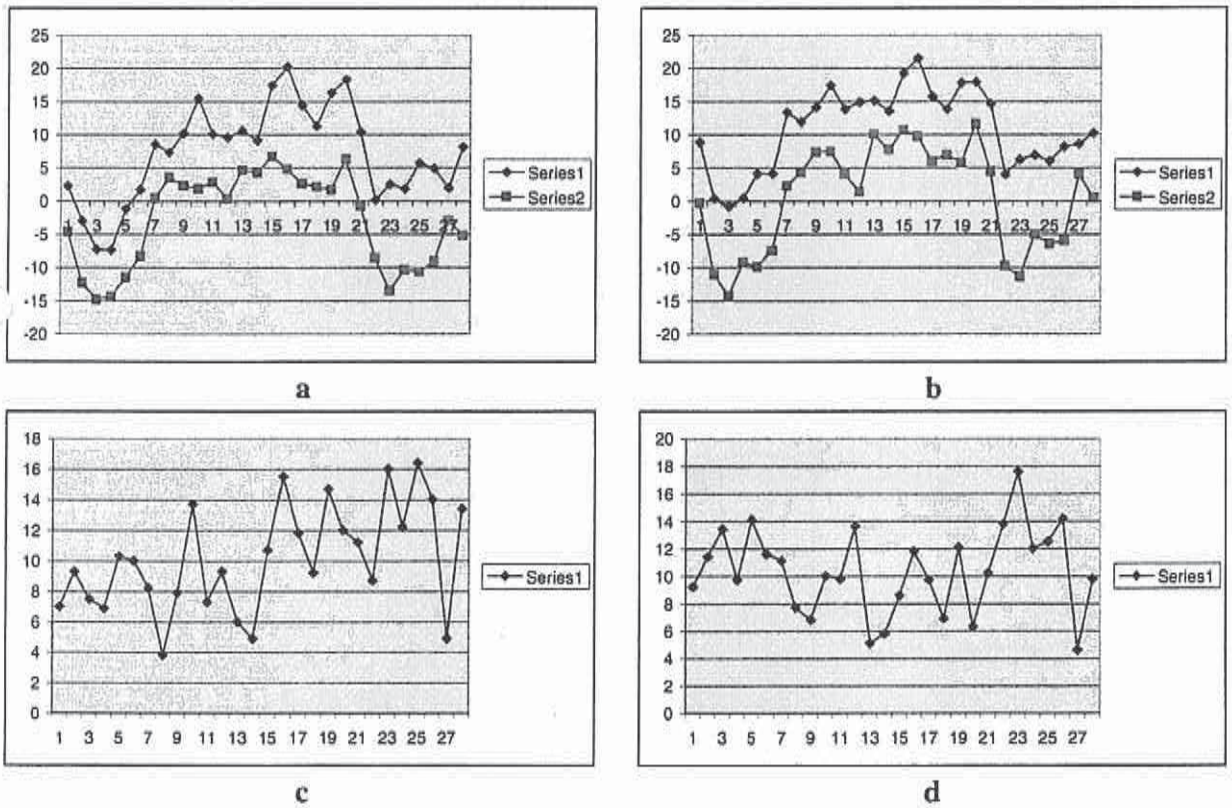


Figure 71. Daily temperature variation during measurement period 1.2.-28.2.2001.

4.3.5 Measuring point E

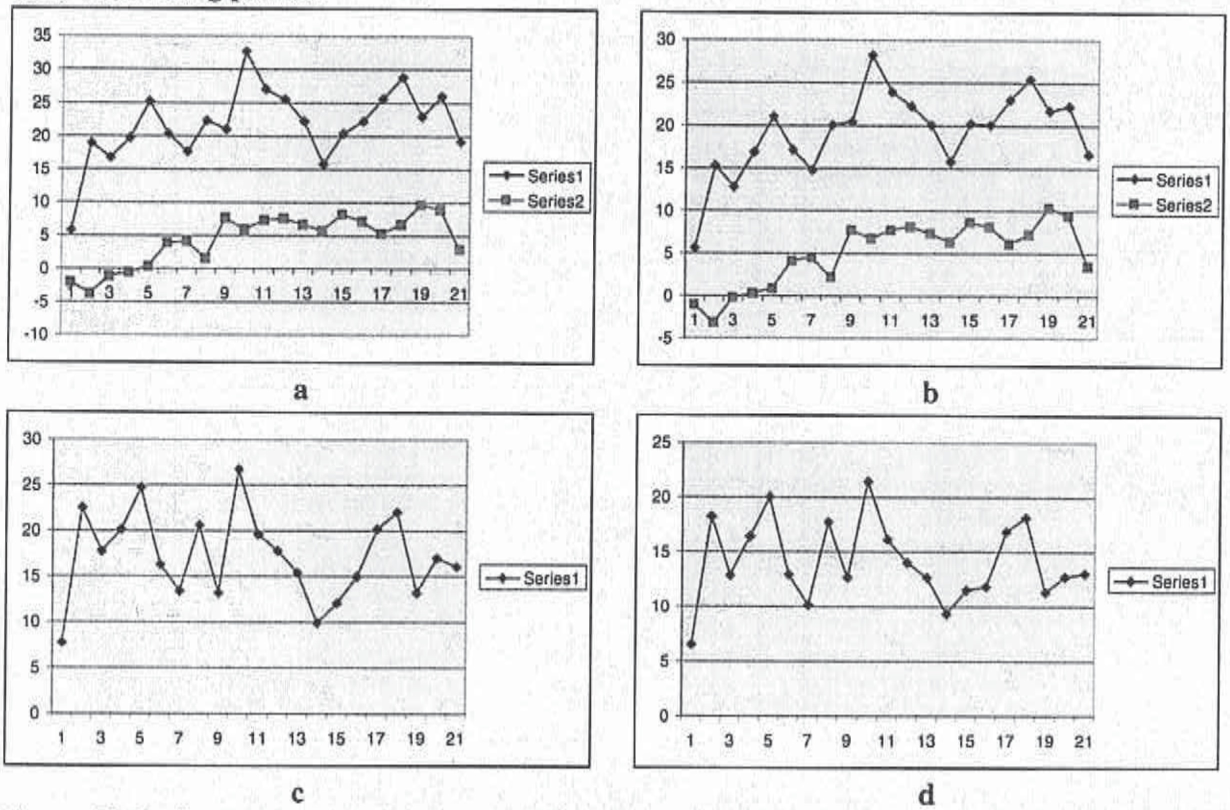


Figure 72. Daily temperature variation during measurement period 11.5.-31.5.1999.

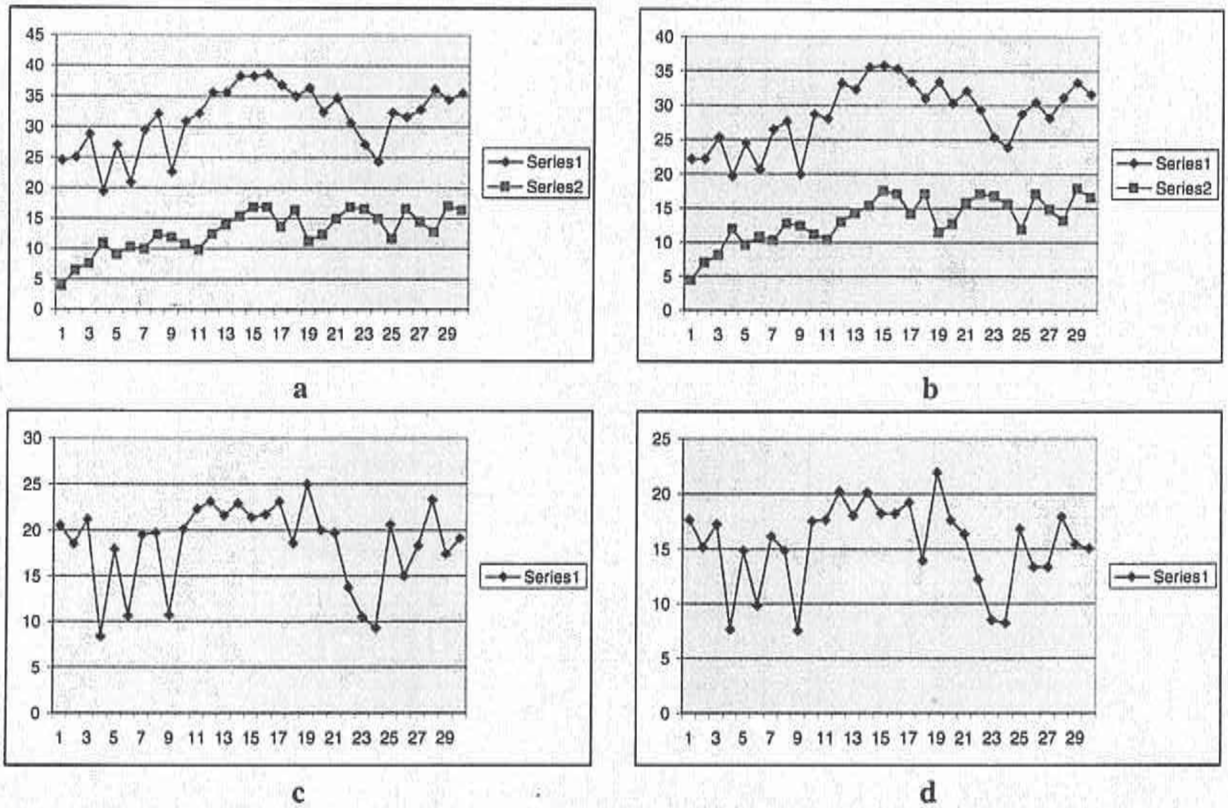


Figure 73. Daily temperature variation during measurement period 1.6.-30.6.1999.

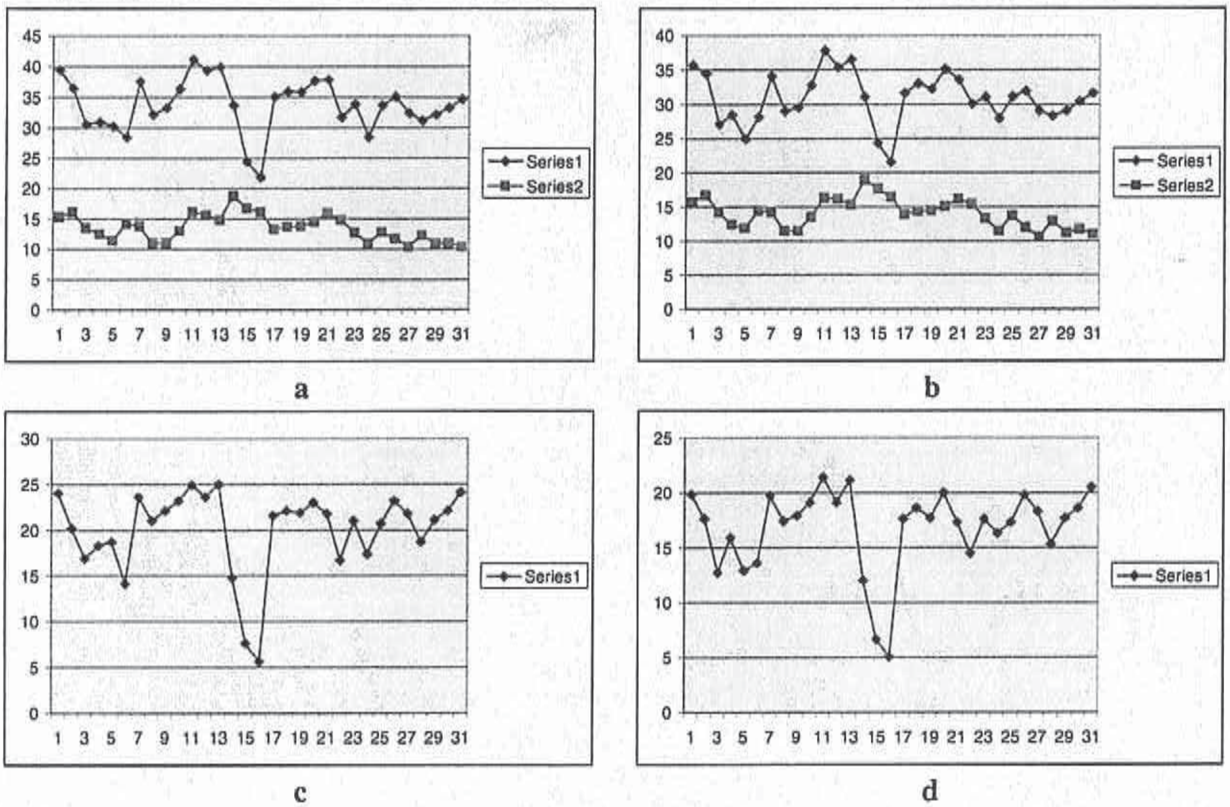


Figure 74. Daily temperature variation during measurement period 1.7.-31.7.1999.

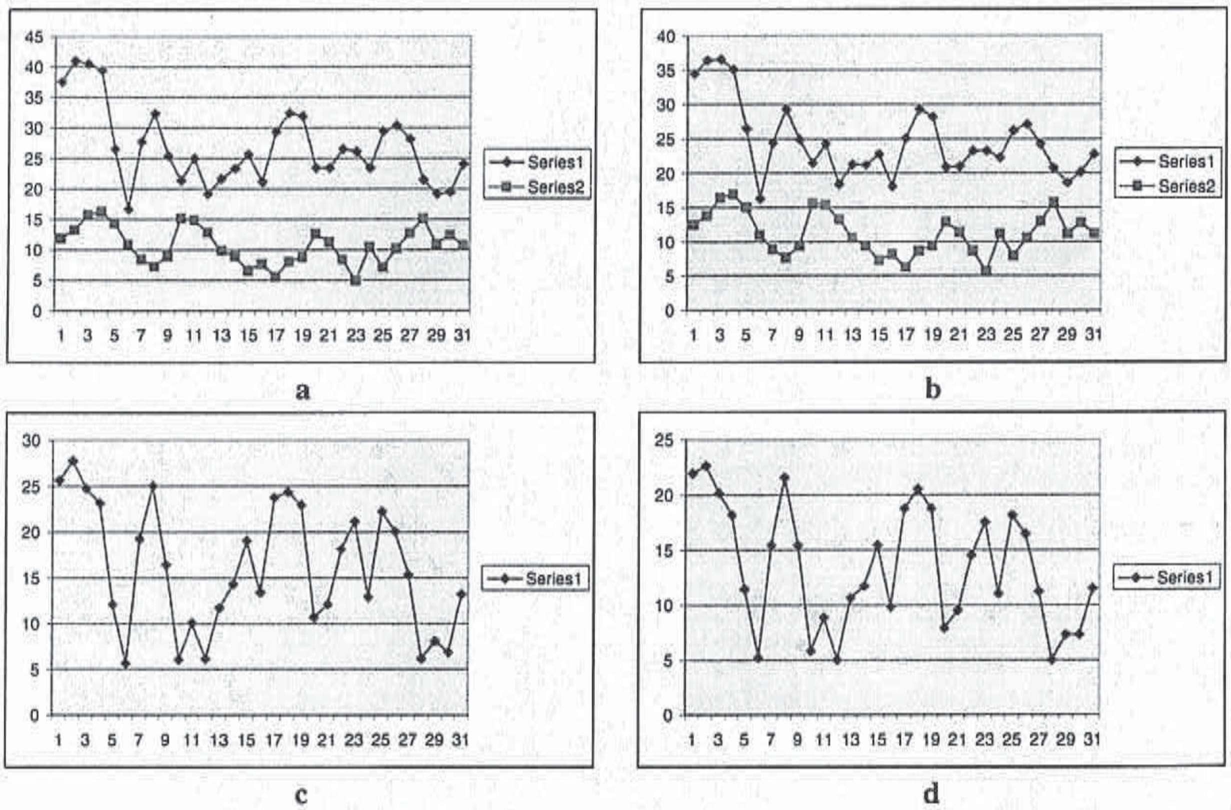


Figure 75. Daily temperature variation during measurement period 1.8.-31.8.1999.

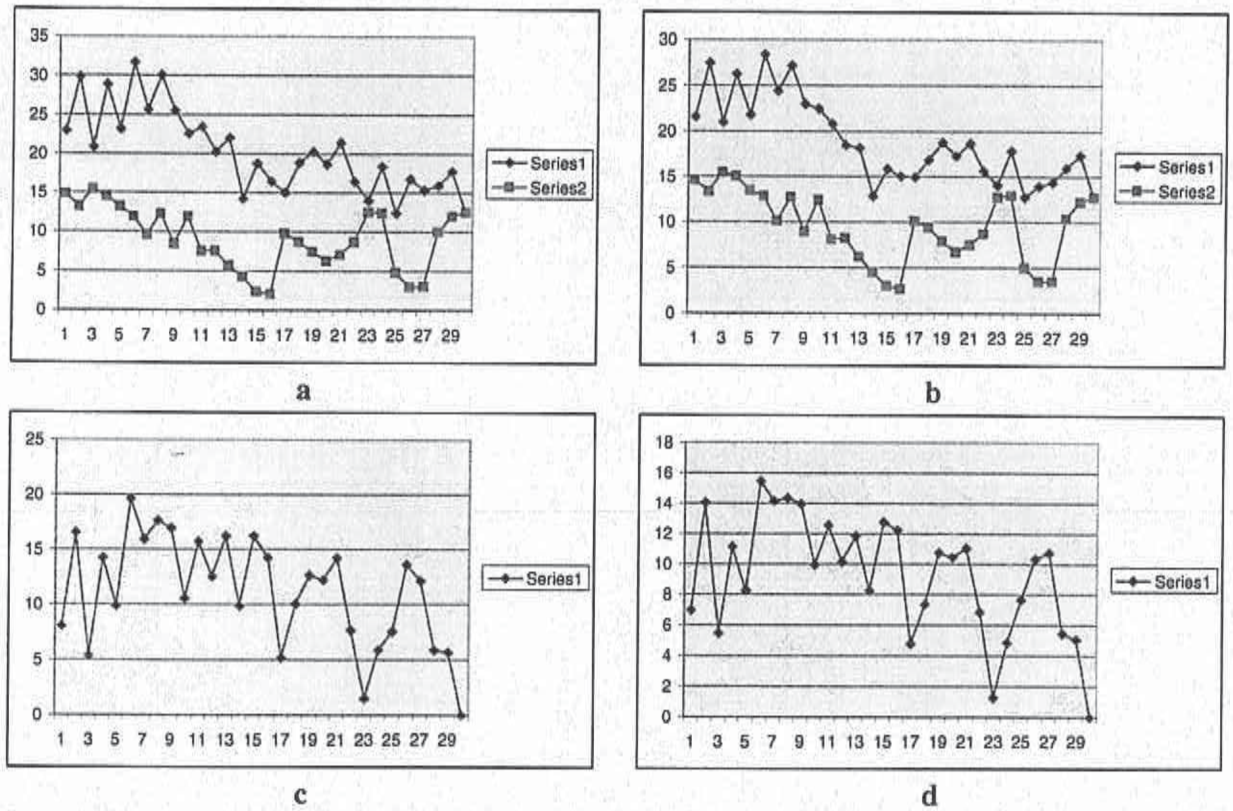


Figure 76. Daily temperature variation during measurement period 1.9.-30.9.1999.

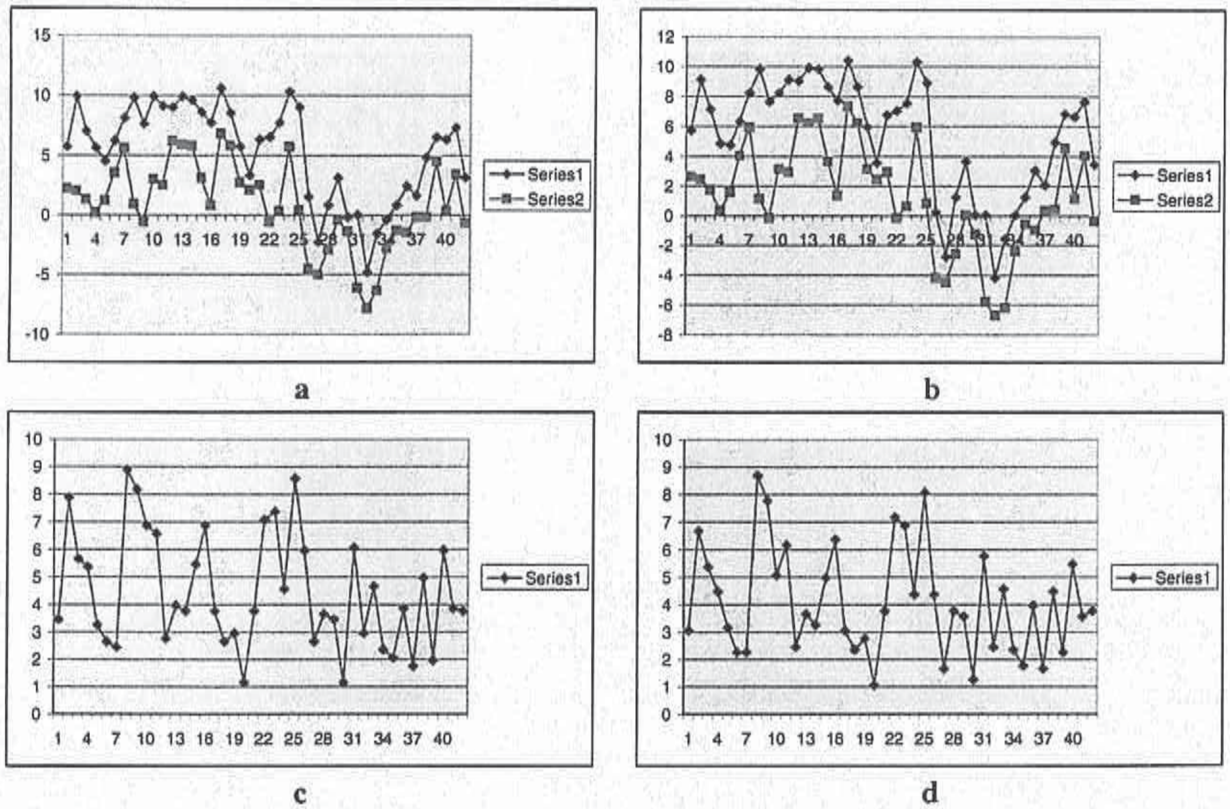


Figure 77. Daily temperature variation during measurement period 20.10.-30.11.1999.

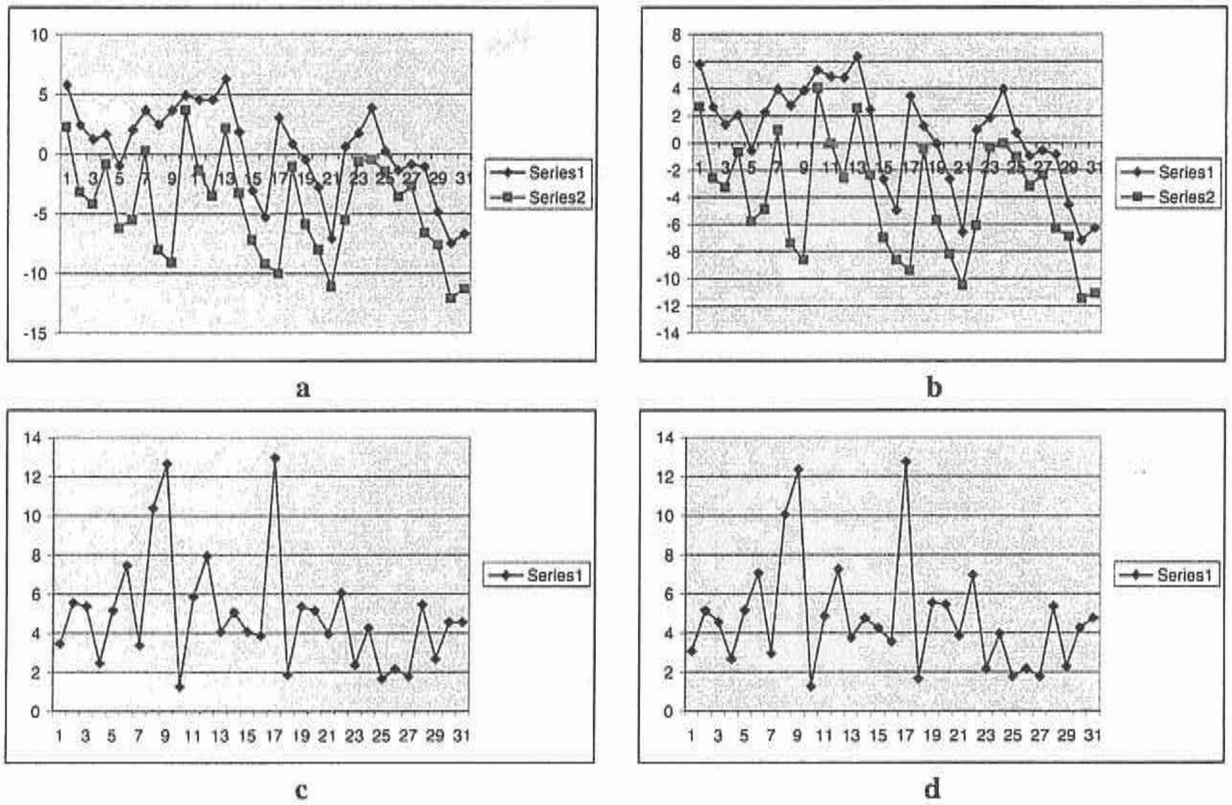


Figure 78. Daily temperature variation during measurement period 1.12.-31.12.1999.

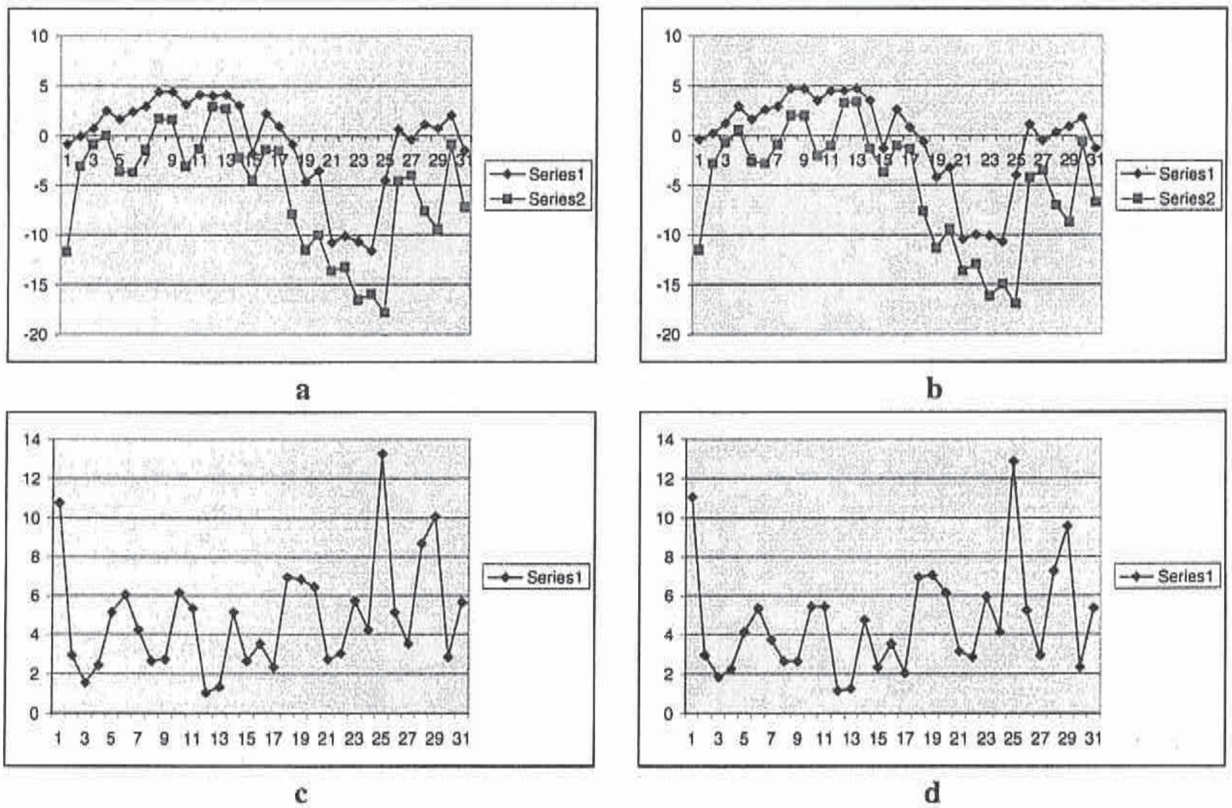


Figure 79. Daily temperature variation during measurement period 1.1.-31.1.2000.

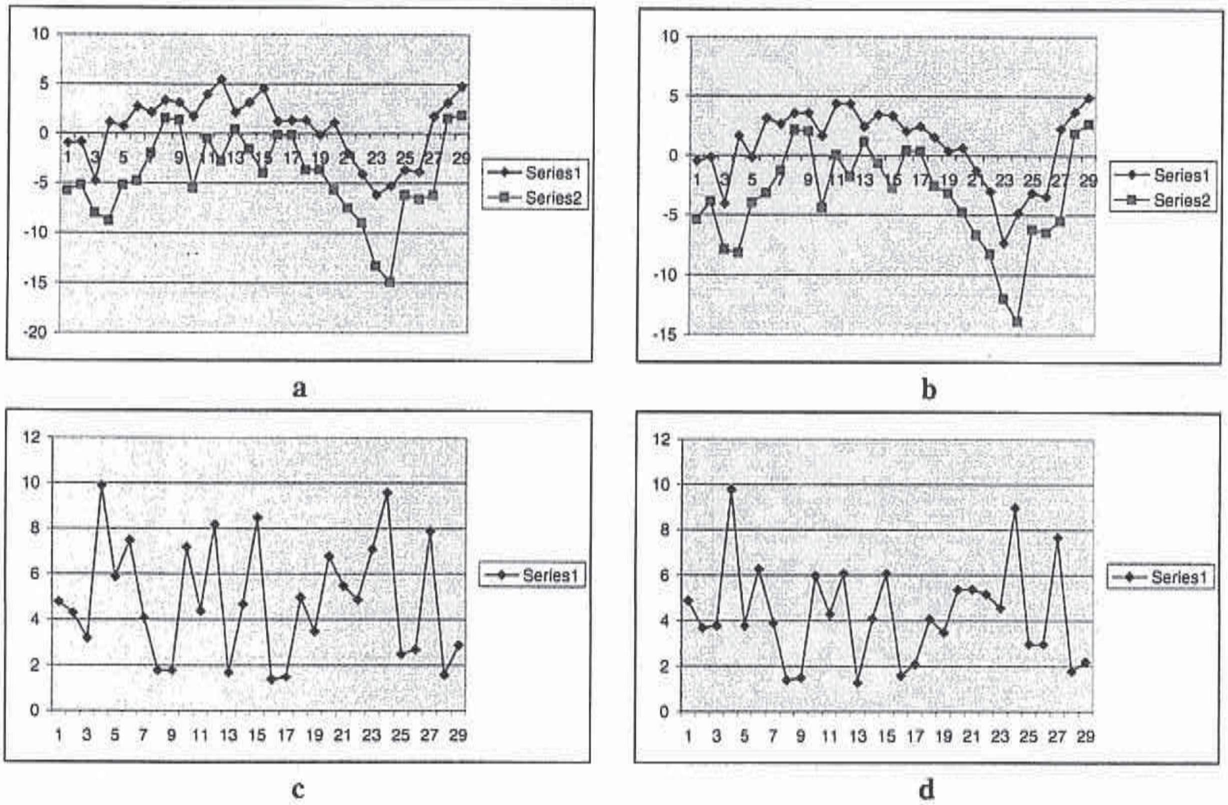


Figure 80. Daily temperature variation during measurement period 1.2.-29.2.2000.

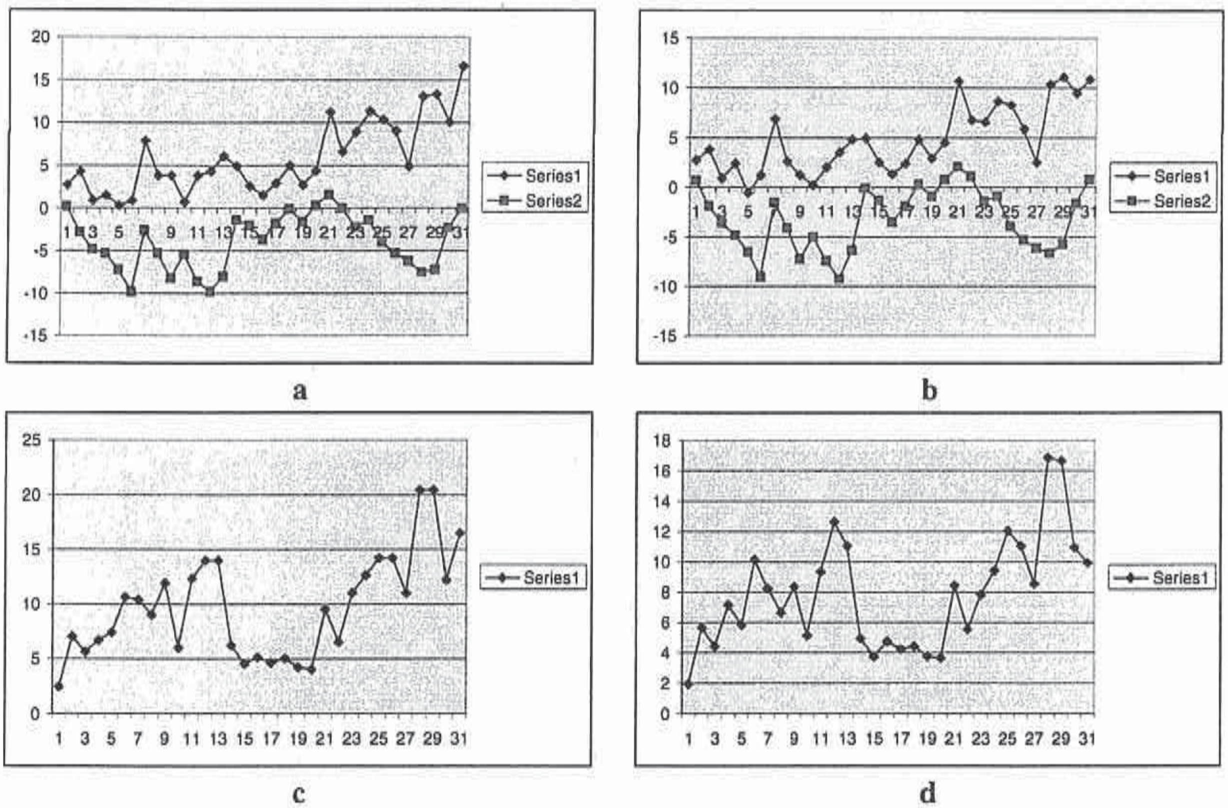


Figure 81. Daily temperature variation during measurement period 1.3.-31.3.2000.

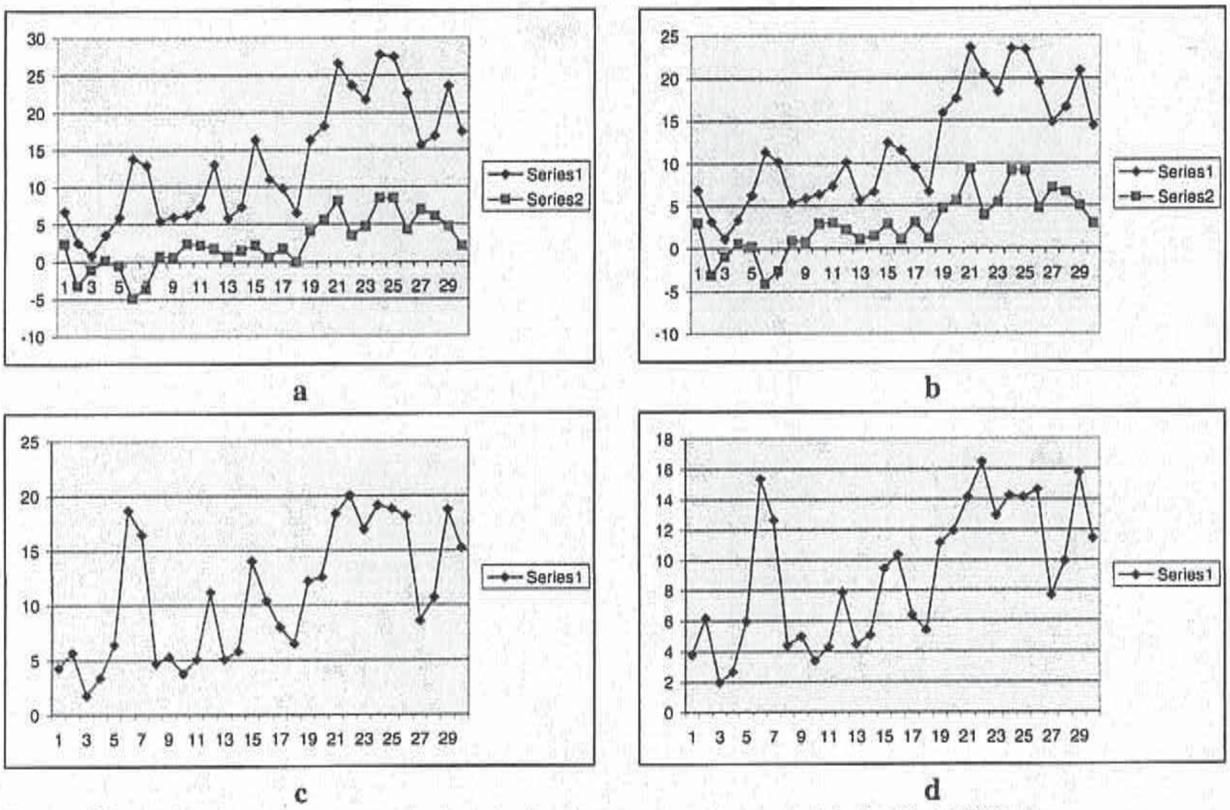


Figure 82. Daily temperature variation during measurement period 1.4.-30.4.2000.

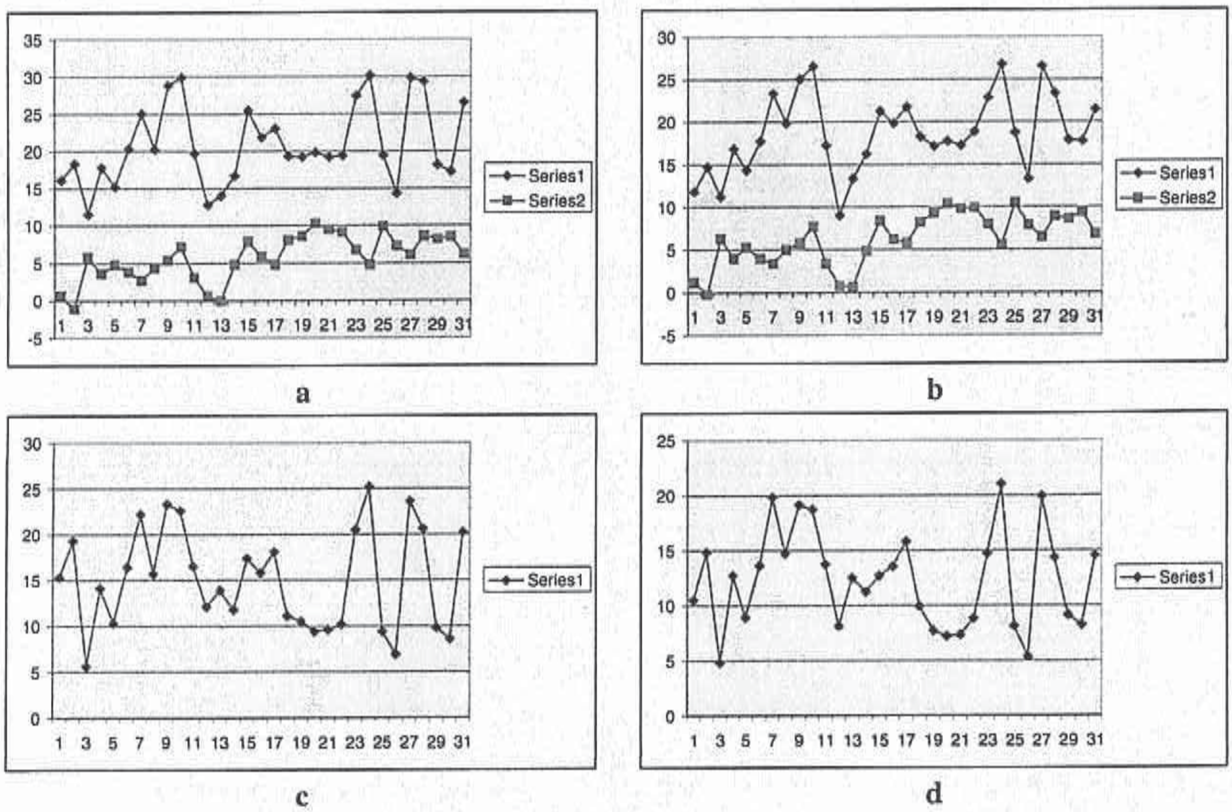


Figure 83. Daily temperature variation during measurement period 1.5.-31.5.2000.

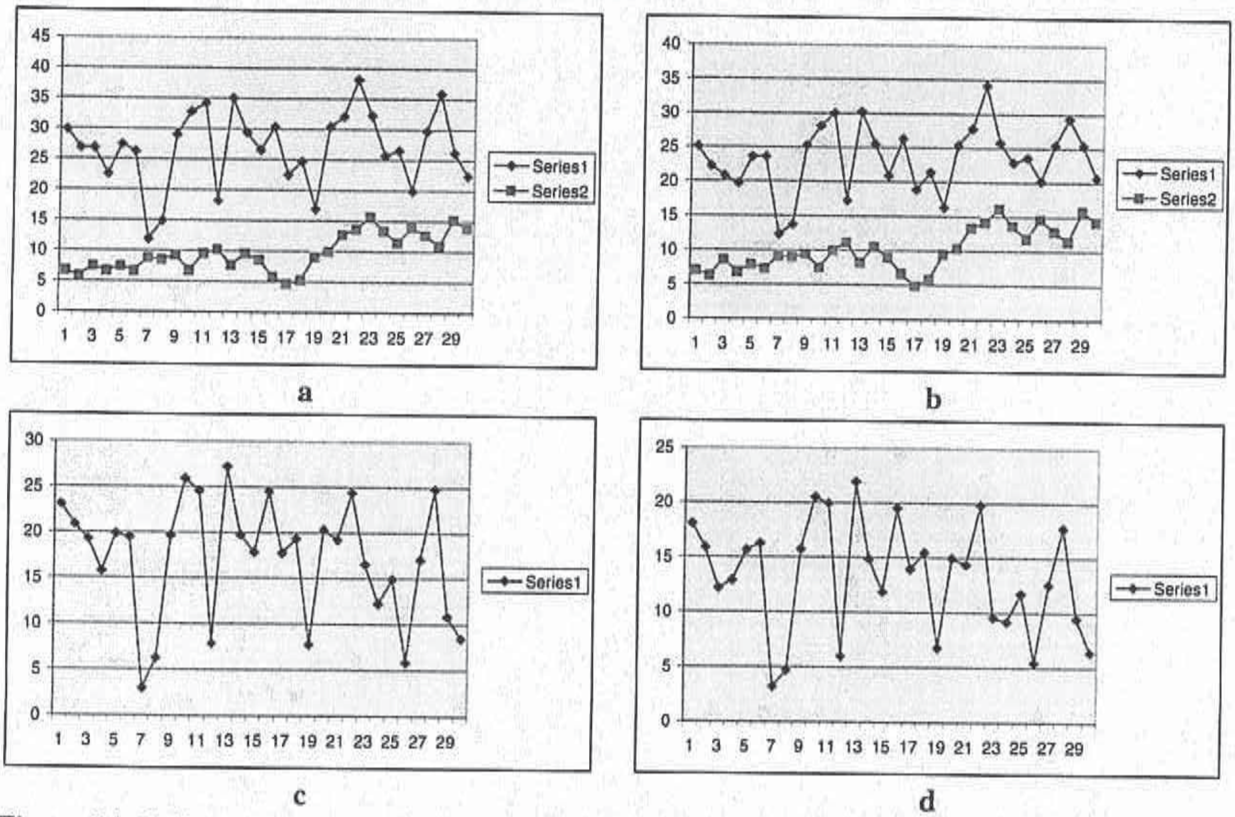


Figure 84. Daily temperature variation during measurement period 1.6.-30.6.2000.

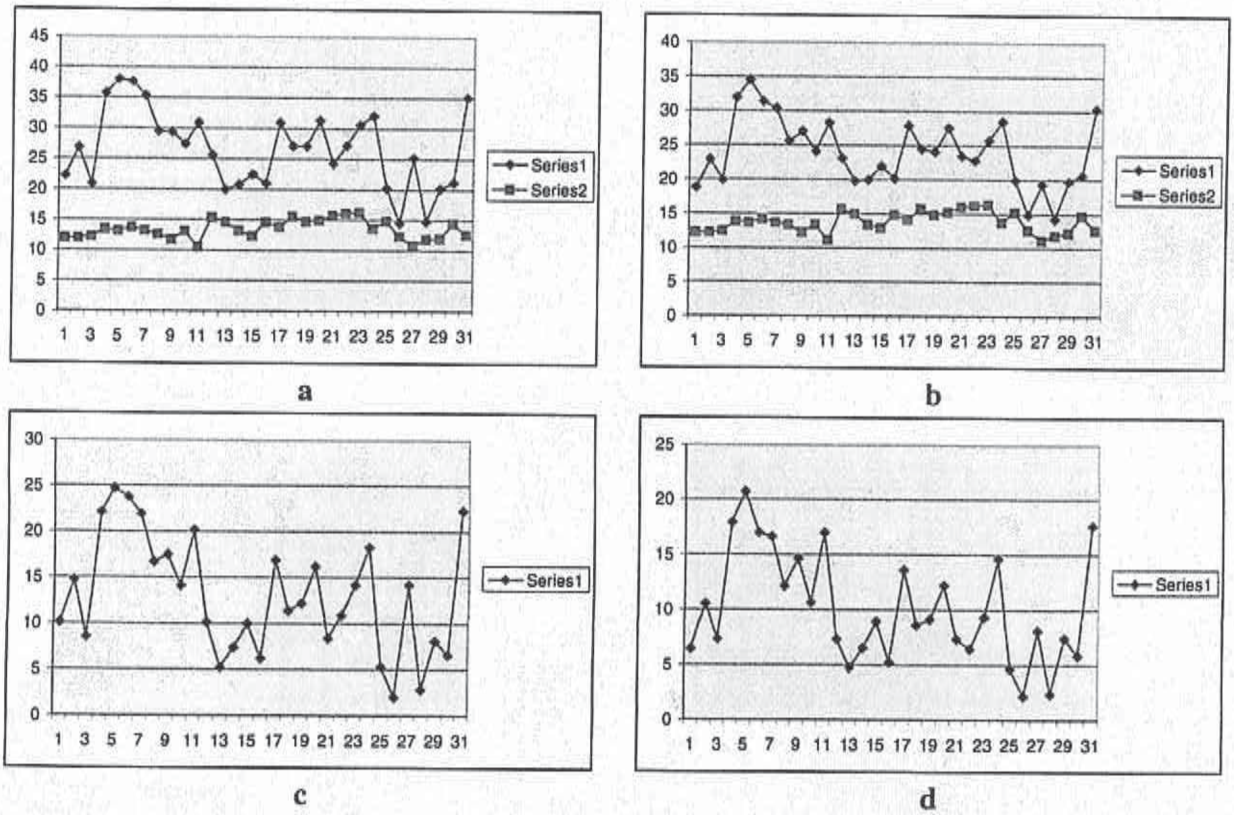


Figure 85. Daily temperature variation during measurement period 1.7.-31.7.2000.

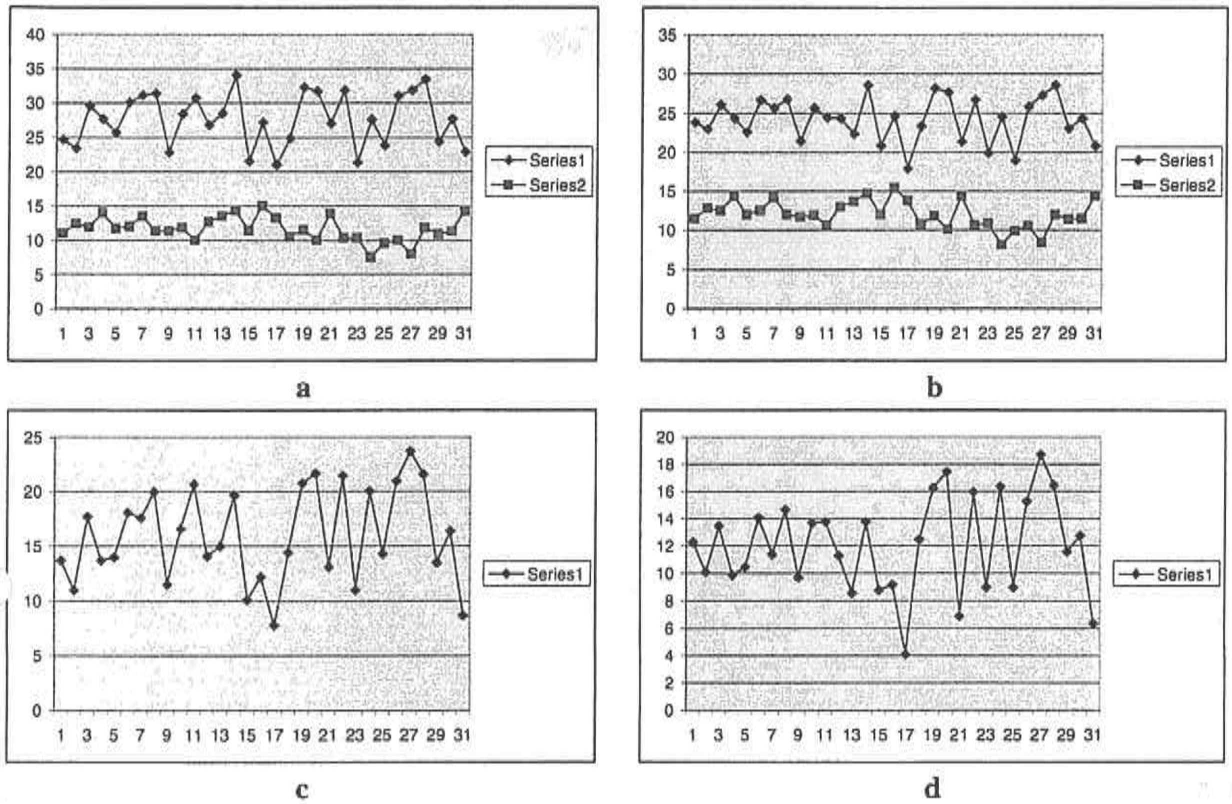


Figure 86. Daily temperature variation during measurement period 1.8.-31.8.2000.

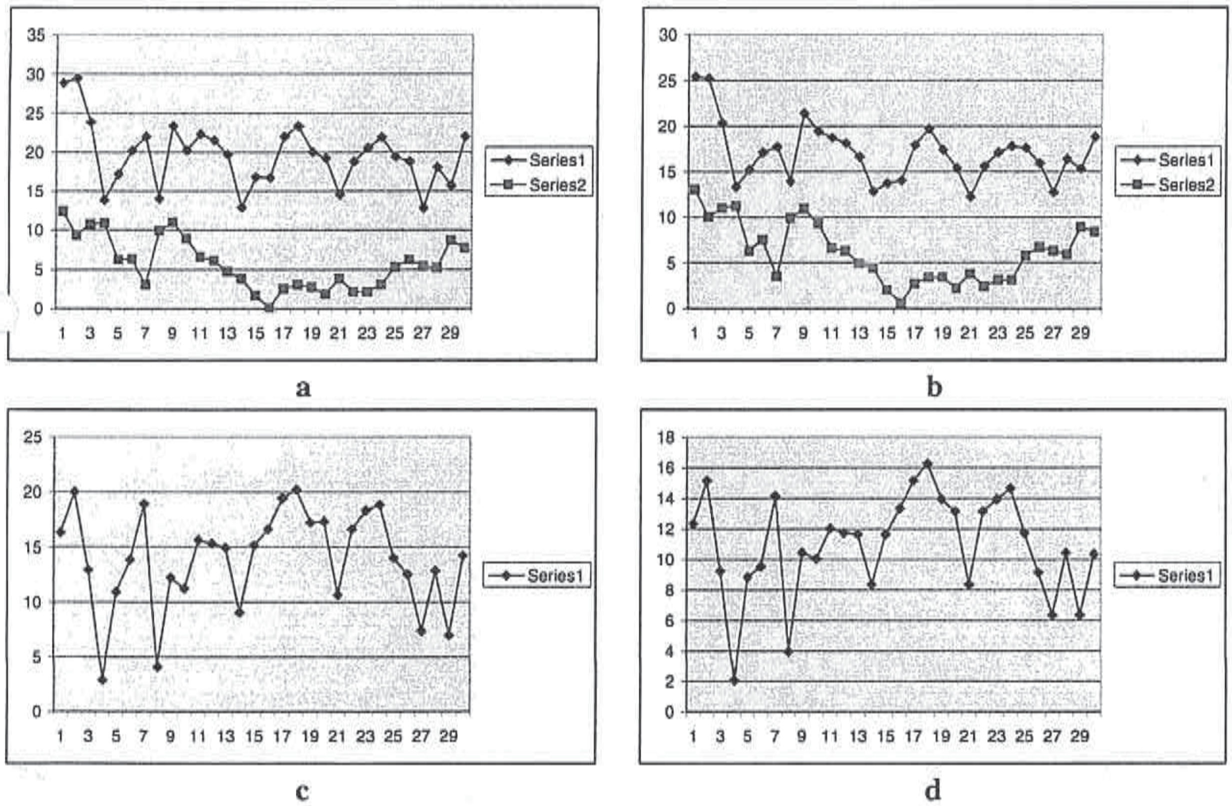


Figure 87. Daily temperature variation during measurement period 1.9.-30.9.2000.

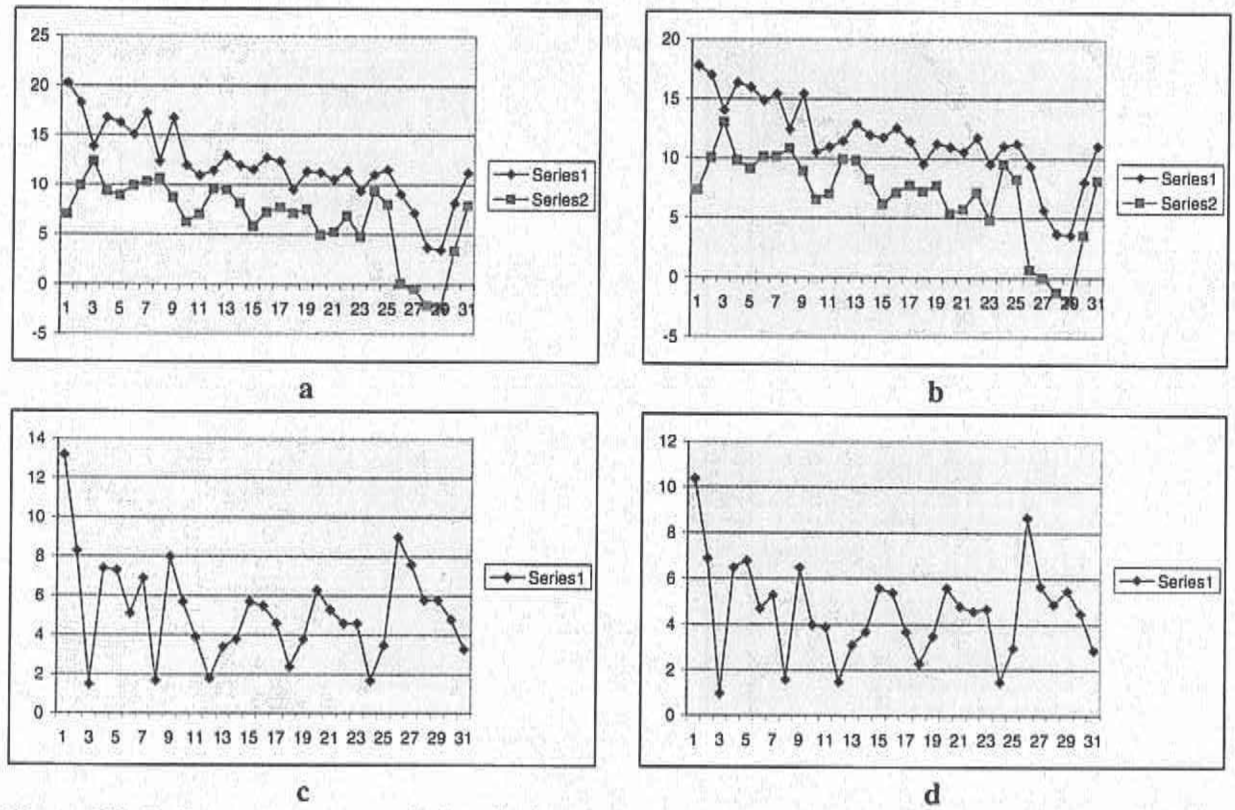


Figure 88. Daily temperature variation during measurement period 1.10.-31.10.2000.

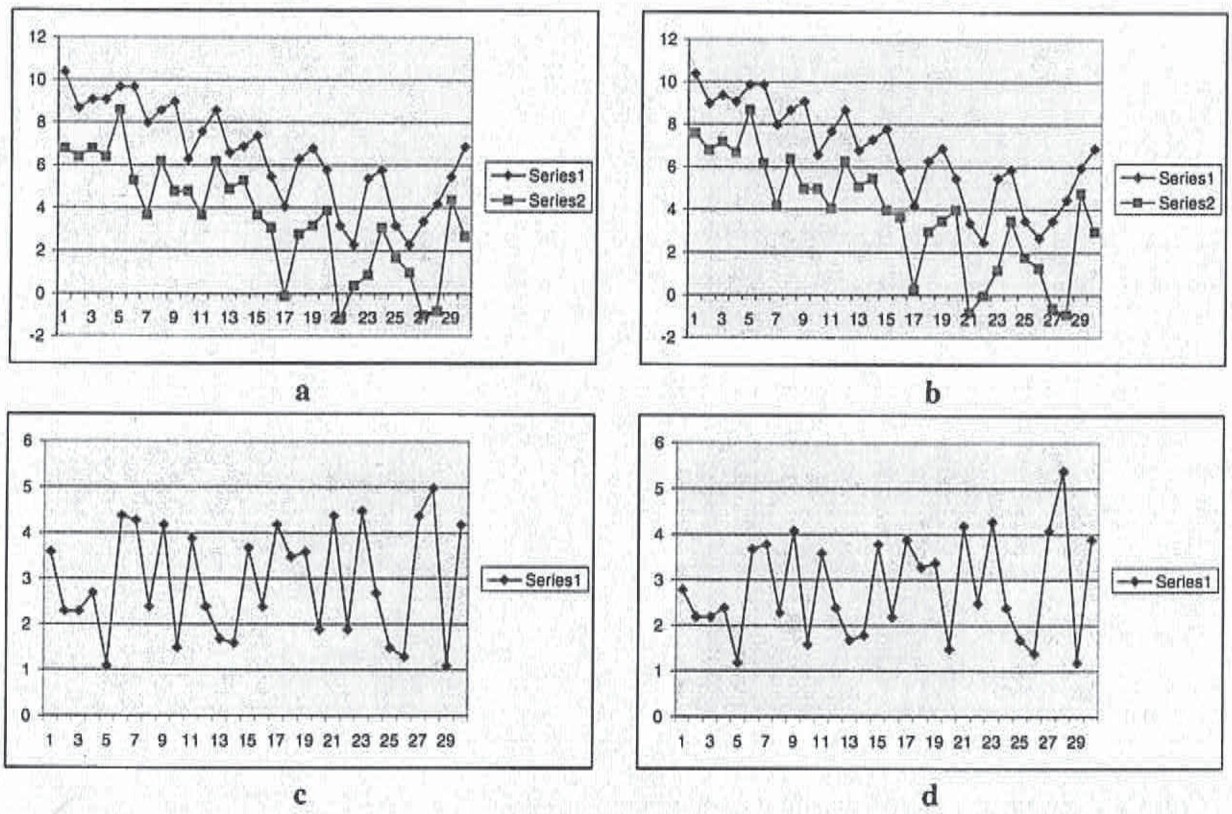


Figure 89. Daily temperature variation during measurement period 1.11.-30.11.2000.

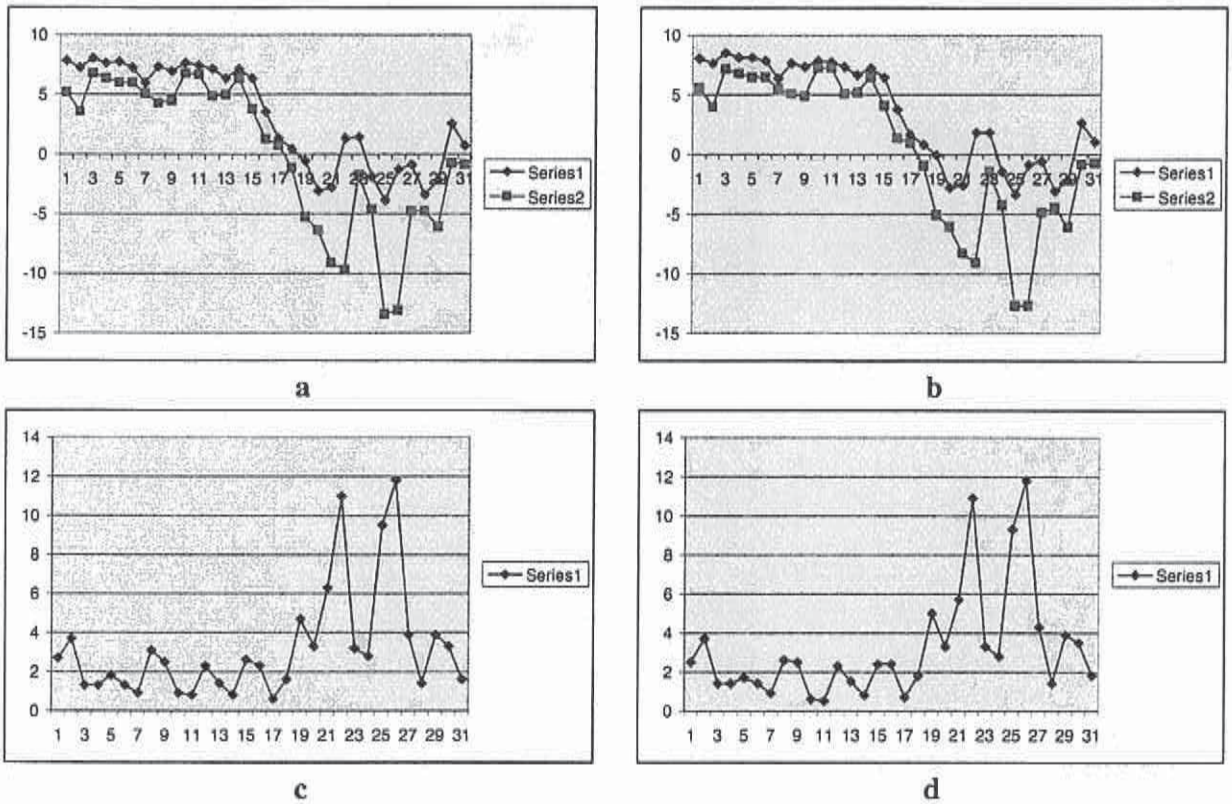


Figure 90. Daily temperature variation during measurement period 1.12.-31.12.2000.

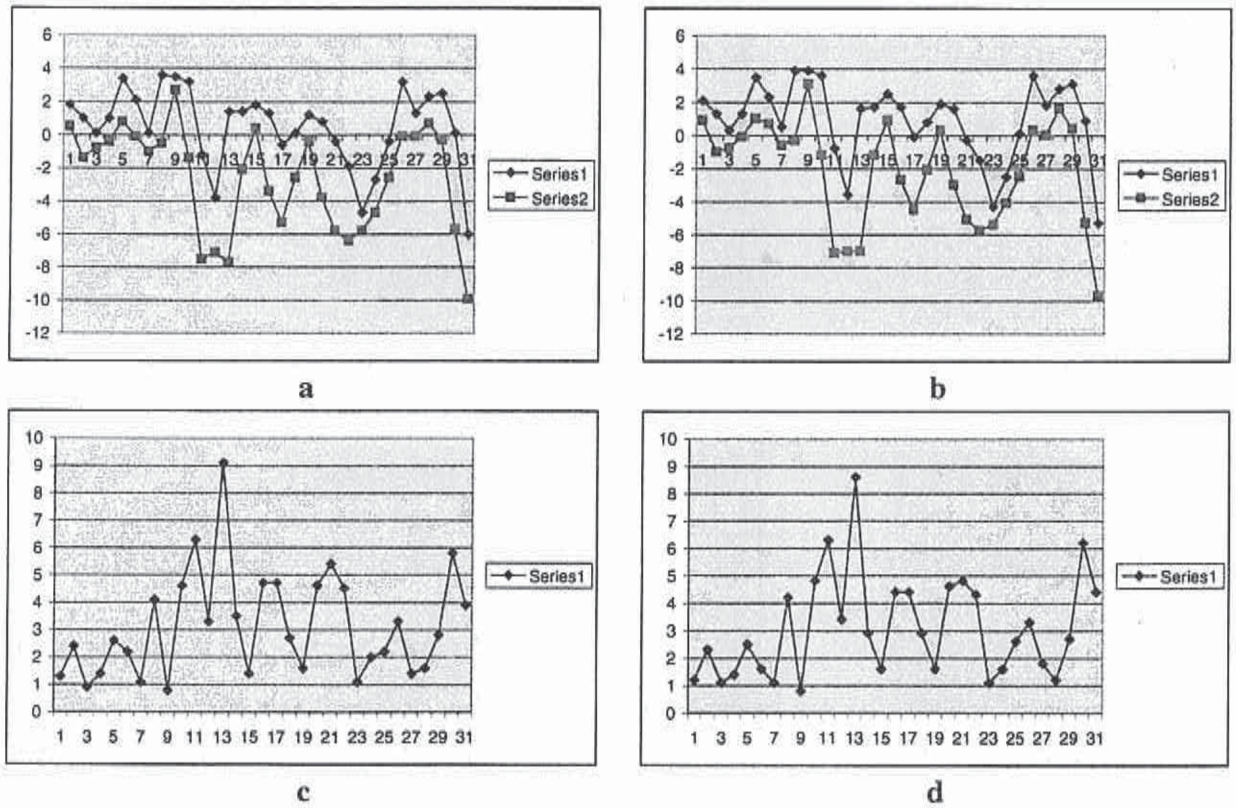
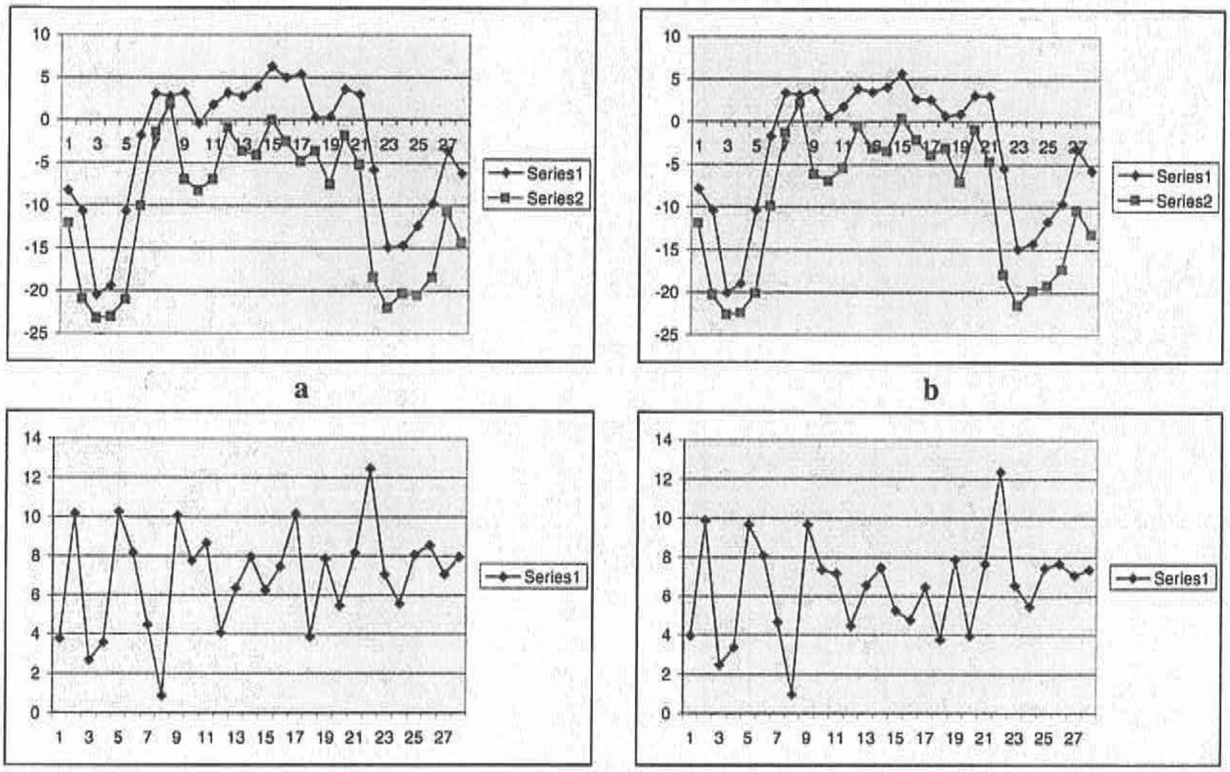


Figure 91. Daily temperature variation during measurement period 1.1.-31.1.2001.



a b c d

Figure 92. Daily temperature variation during measurement period 1.2.-28.2.2001.

4.4 Gradient of temperature variation in marble

The gradient of temperature variation over the marble slabs was examined as the difference between the range of temperature variation on outer and inner surfaces. The difference is calculated in such a way that the variation on inner surface is diminished from the variation on outer surface. Thus, a positive difference means that the variation has been greater on outer surface and a negative difference that the variation has been greater on inner surface. The results are shown in Figs. 93-179.

4.4.1 Measuring point A

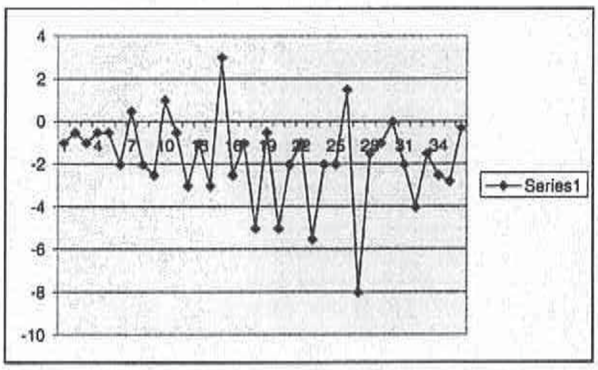


Figure 93. Gradient of temperature variation during measurement period 26.5.-30.6.1999.

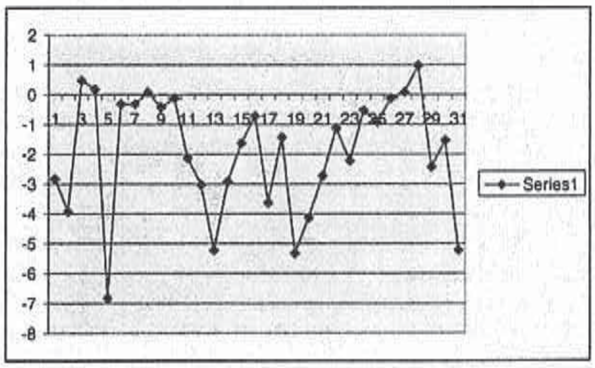


Figure 94. Gradient of temperature variation during measurement period 1.7.-31.7.1999.

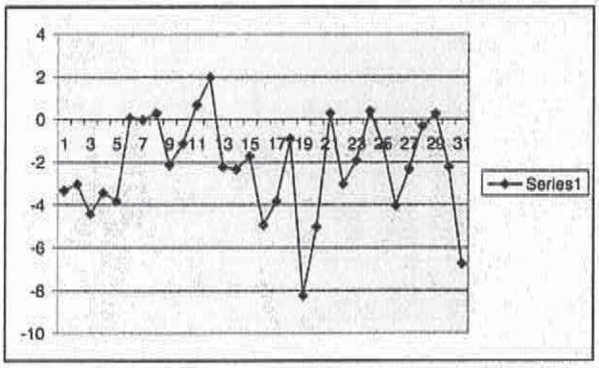


Figure 95. Gradient of temperature variation during measurement period 1.8.-31.8.1999.

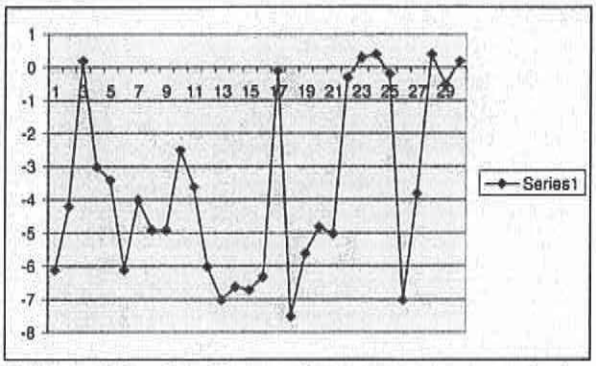


Figure 96. Gradient of temperature variation during measurement period 1.9.-30.9.1999.

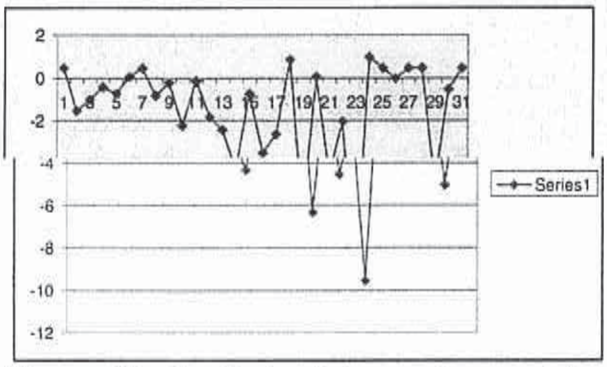


Figure 97. Gradient of temperature variation during measurement period 1.10.-31.10.1999.

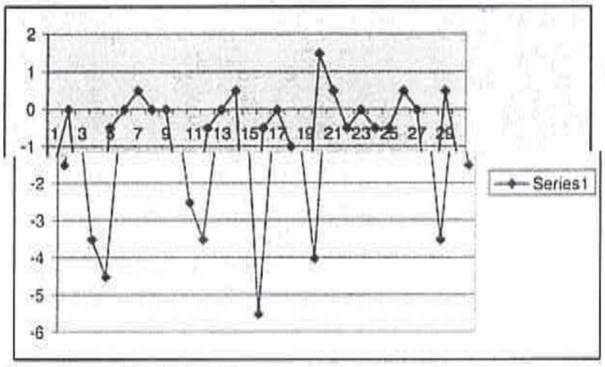


Figure 98. Gradient of temperature variation during measurement period 1.11.-30.11.1999.

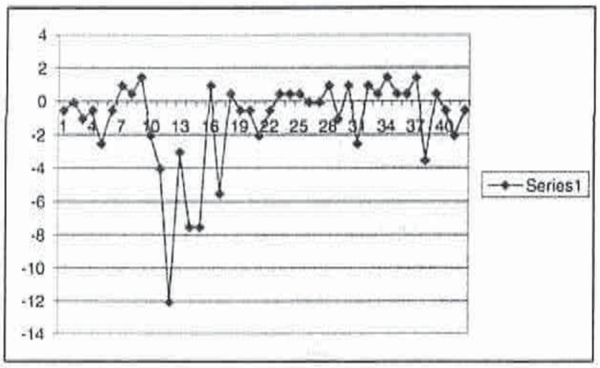


Figure 99. Gradient of temperature variation during measurement period 1.12.1999-11.1.2000.

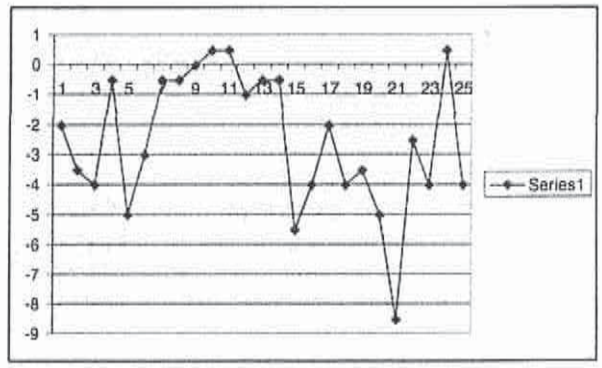


Figure 100. Gradient of temperature variation during measurement period 7.3.-31.3.2000.

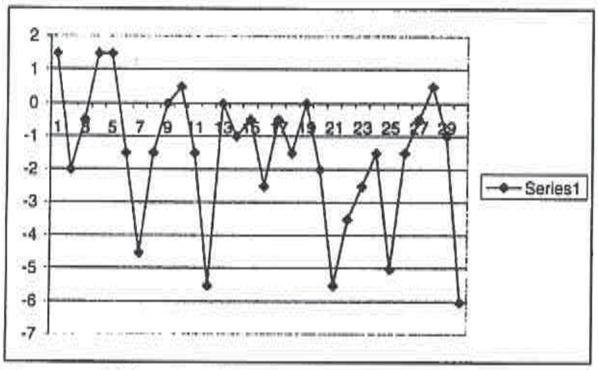


Figure 101. Gradient of temperature variation during measurement period 1.4.-30.4.2000.

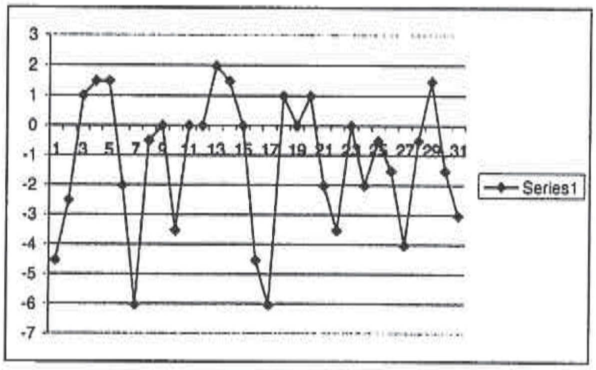


Figure 102. Gradient of temperature variation during measurement period 1.5.-31.5.2000.

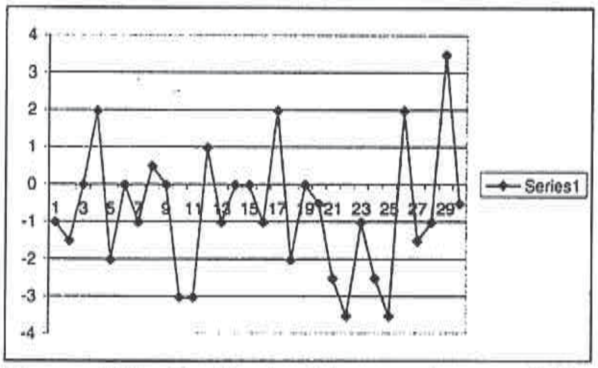


Figure 103. Gradient of temperature variation during measurement period 1.6.-30.6.2000.

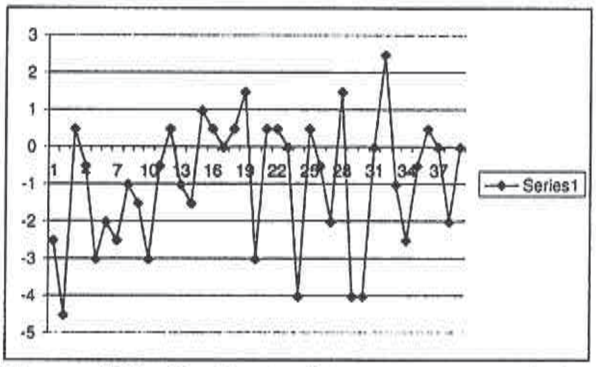


Figure 104. Gradient of temperature variation during measurement period 1.7.-8.8.2000.

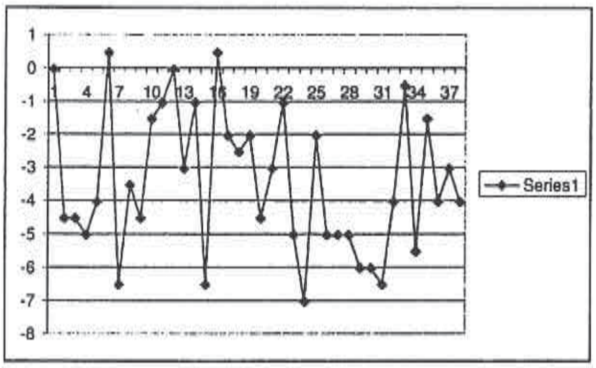


Figure 105. Gradient of temperature variation during measurement period 24.8.-30.9.2000.

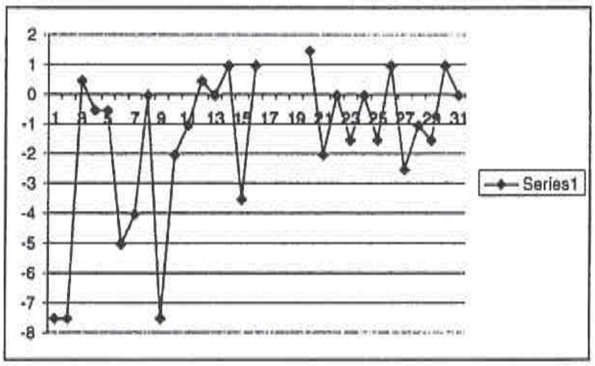


Figure 106. Gradient of temperature variation during measurement period 1.10.-31.10.2000.

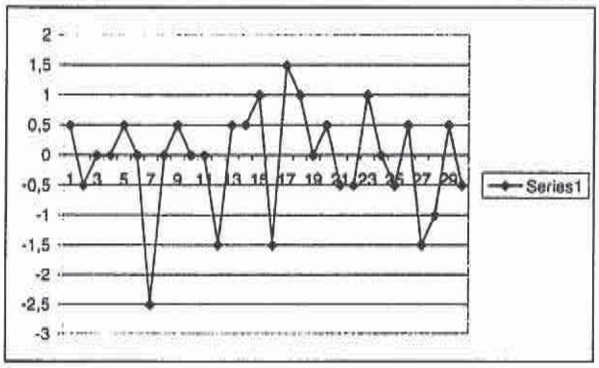


Figure 107. Gradient of temperature variation during measurement period 1.11.-30.11.2000.

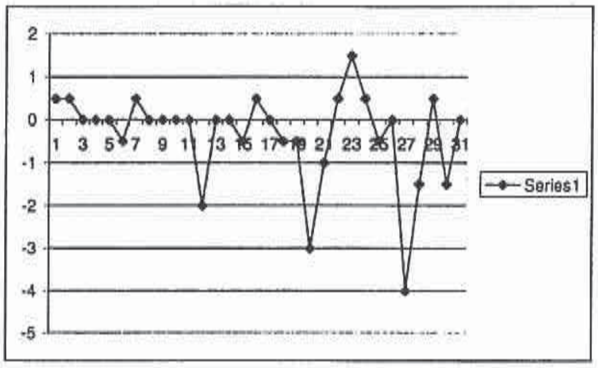


Figure 108. Gradient of temperature variation during measurement period 1.12.-31.12.2000.

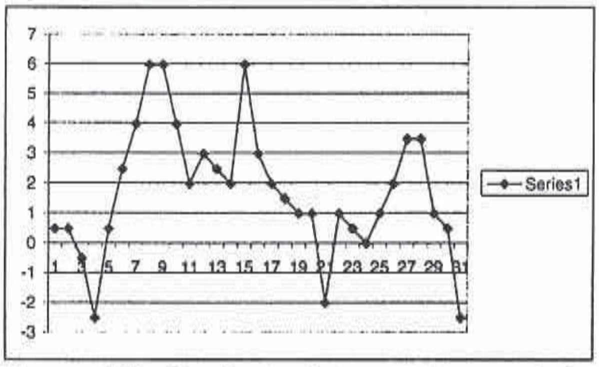


Figure 109. Gradient of temperature variation during measurement period 1.1.-31.1.2001.

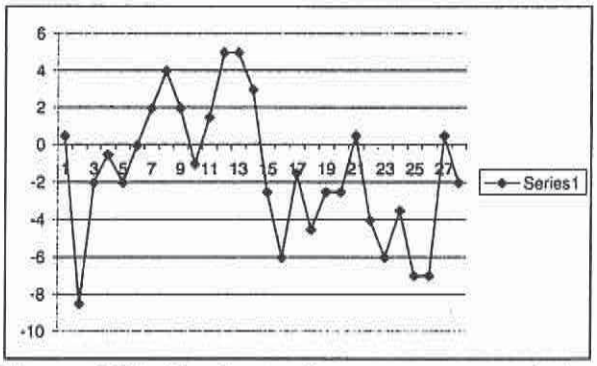


Figure 110. Gradient of temperature variation during measurement period 1.2.-28.2.2001.

4.4.2 Measuring point B

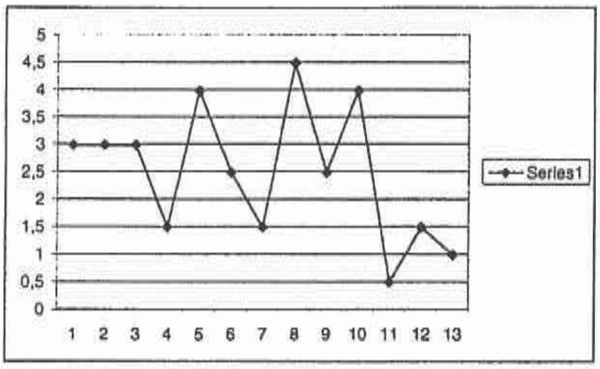


Figure 111. Gradient of temperature variation during measurement period 11.6.-23.6.1999.

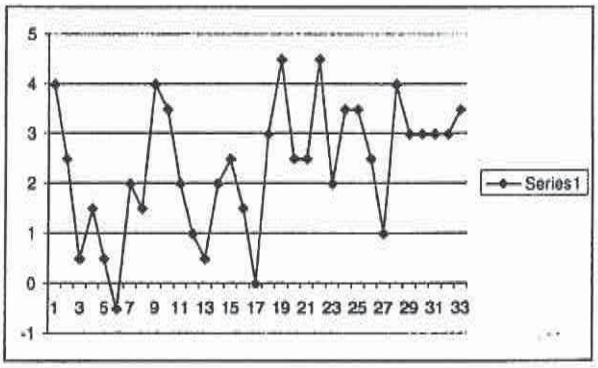


Figure 112. Gradient of temperature variation during measurement period 29.3.-30.4.2000.

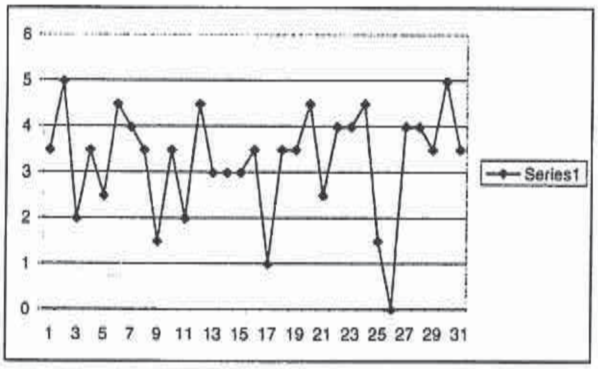


Figure 113. Gradient of temperature variation during measurement period 1.5.-31.5.2000.

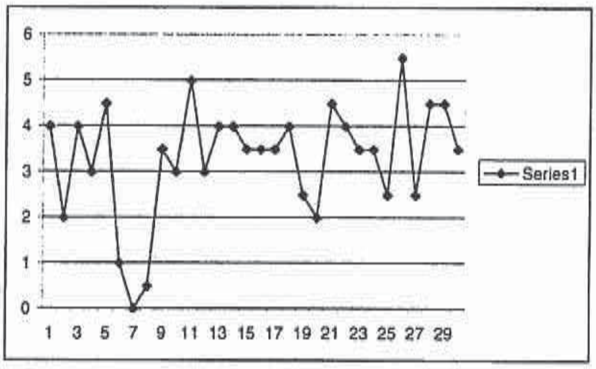


Figure 114. Gradient of temperature variation during measurement period 1.6.-30.6.2000.

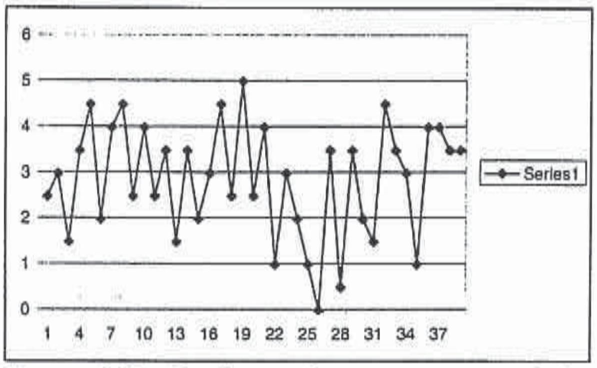


Figure 115. Gradient of temperature variation during measurement period 1.7.-8.8.2000.

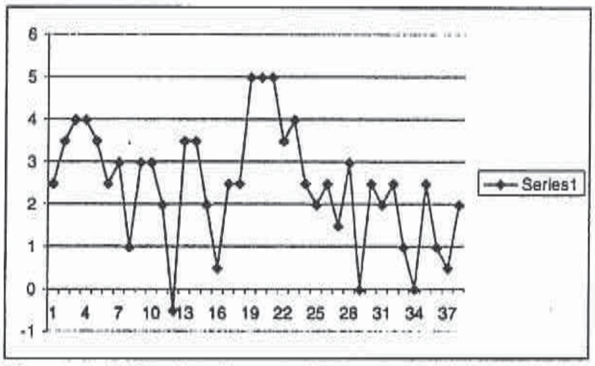


Figure 116. Gradient of temperature variation during measurement period 24.8.-30.9.2000.

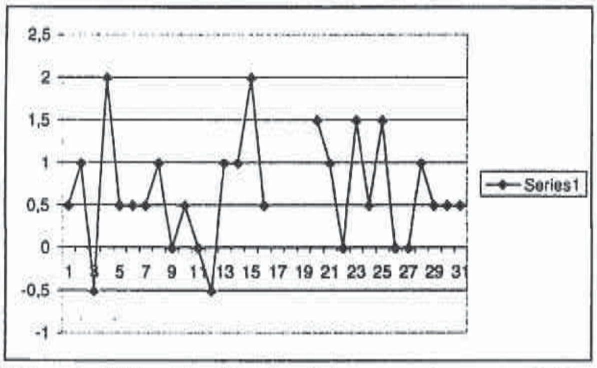


Figure 117. Gradient of temperature variation during measurement period 1.10.-31.10.2000.

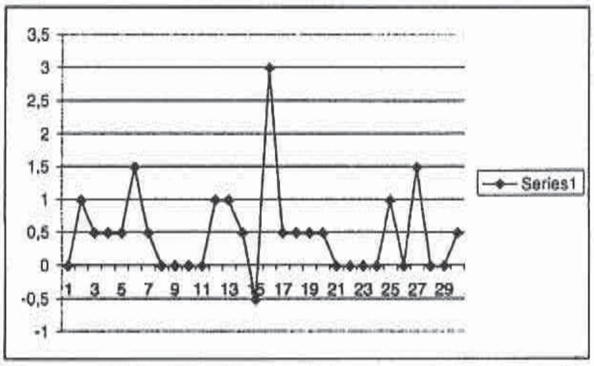


Figure 118. Gradient of temperature variation during measurement period 1.11.-30.11.2000.

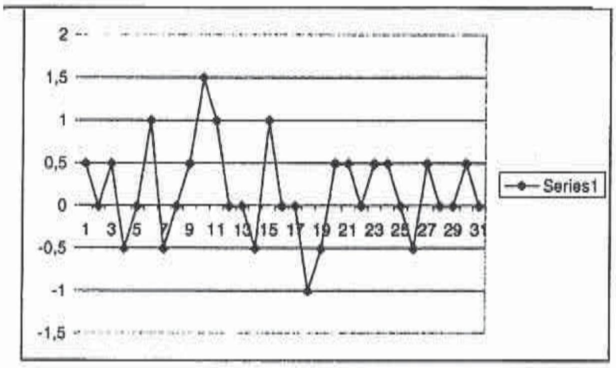


Figure 119. Gradient of temperature variation during measurement period 1.12.-31.12.2000.

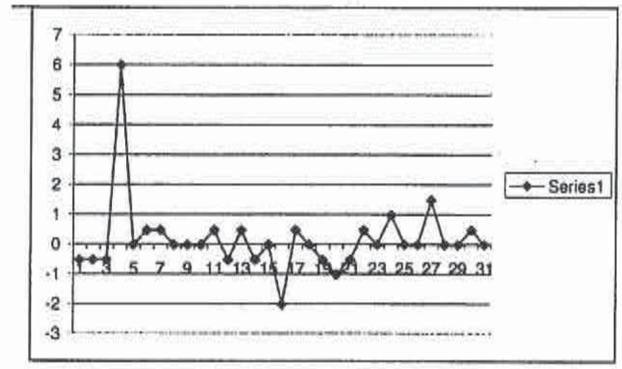


Figure 120. Gradient of temperature variation during measurement period 1.1.-31.1.2001.

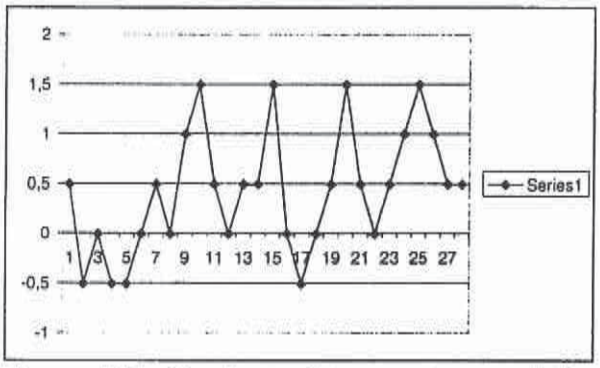


Figure 121. Gradient of temperature variation during measurement period 1.2.-28.2.2001.

4.4.3 Measuring point C

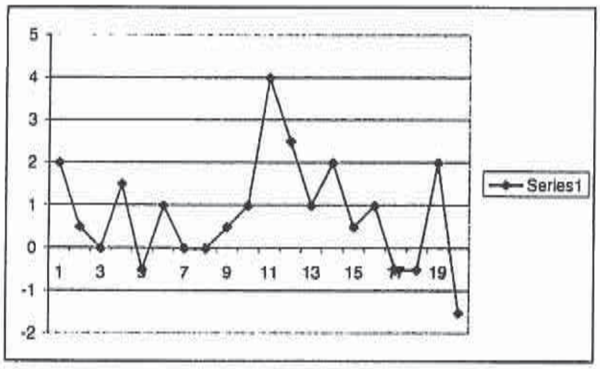


Figure 122. Gradient of temperature variation during measurement period 11.6.-30.6.1999.

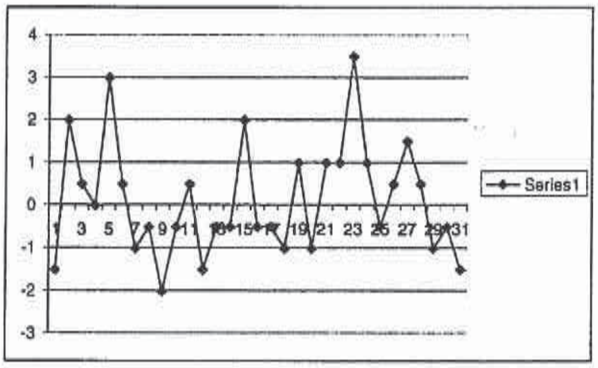


Figure 123. Gradient of temperature variation during measurement period 1.7.-31.7.1999.

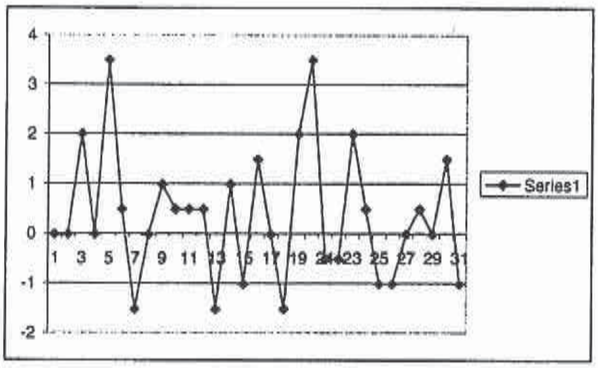


Figure 124. Gradient of temperature variation during measurement period 1.8.-31.8.1999.

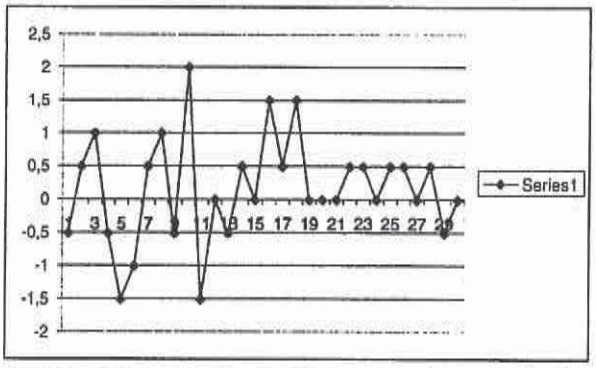


Figure 125. Gradient of temperature variation during measurement period 1.9.-30.9.1999.

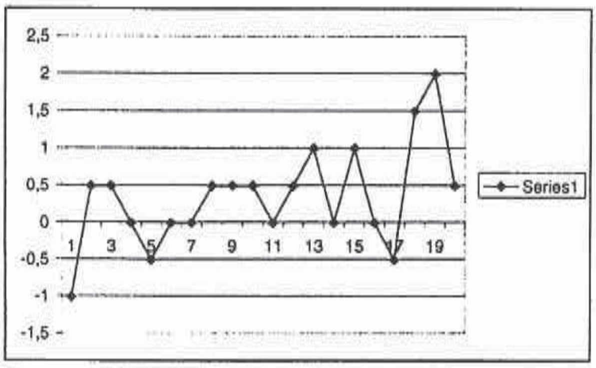


Figure 126. Gradient of temperature variation during measurement period 1.10.-20.10.1999.

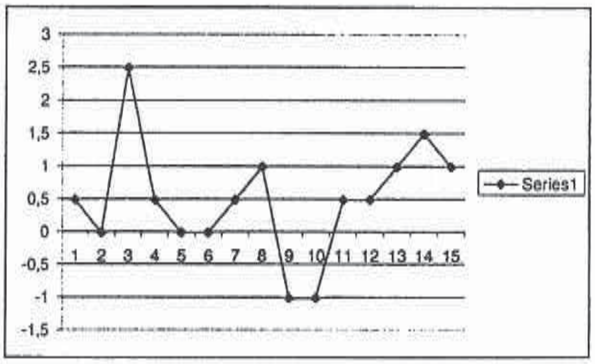


Figure 127. Gradient of temperature variation during measurement period 29.3.-12.4.2000.

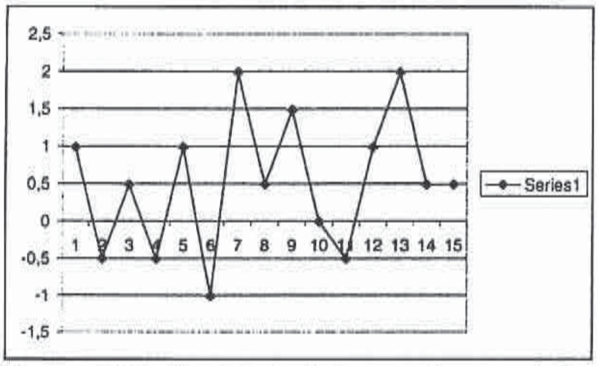


Figure 128. Gradient of temperature variation during measurement period 17.5.-31.5.2000.

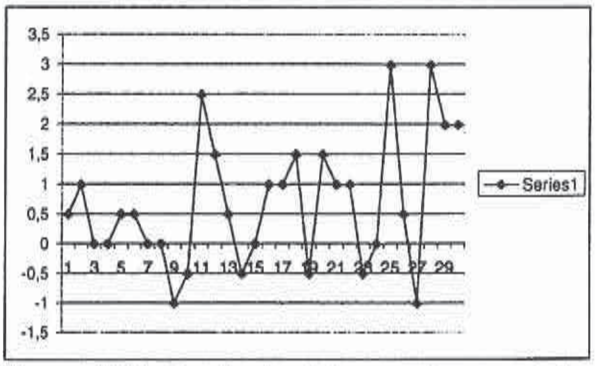


Figure 129. Gradient of temperature variation during measurement period 1.6.-30.6.2000.

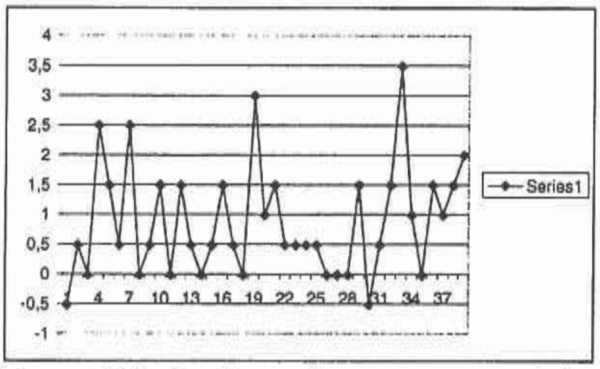


Figure 130. Gradient of temperature variation during measurement period 1.7.-8.8.2000.

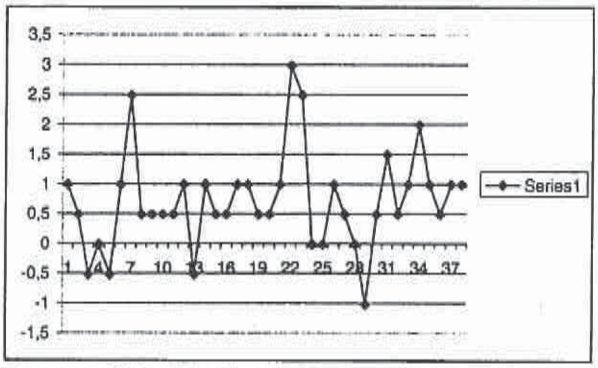


Figure 131. Gradient of temperature variation during measurement period 24.8.-30.9.2000.

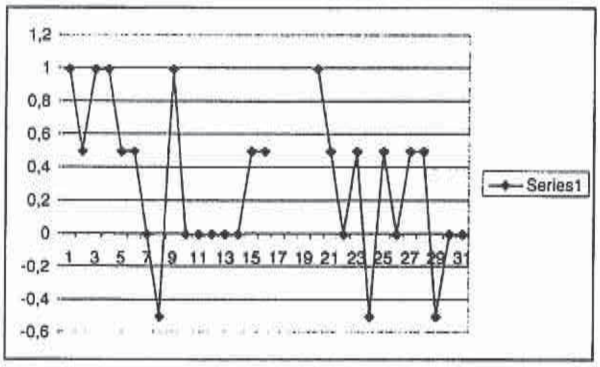


Figure 132. Gradient of temperature variation during measurement period 1.10.-31.10.2000.

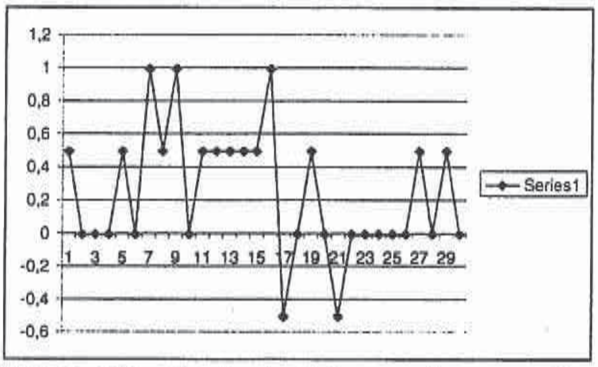


Figure 133. Gradient of temperature variation during measurement period 1.11.-30.11.2000.

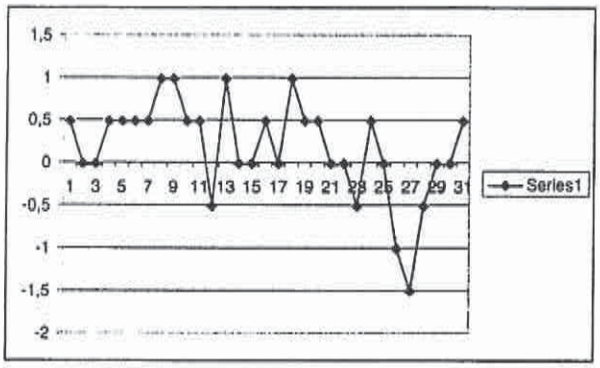


Figure 134. Gradient of temperature variation during measurement period 1.12.-31.12.2000.

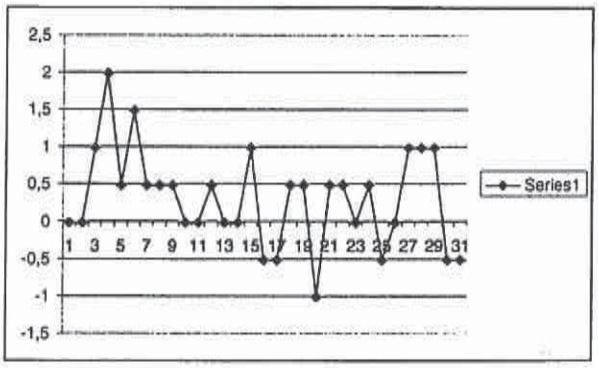


Figure 135. Gradient of temperature variation during measurement period 1.1.-31.1.2001.

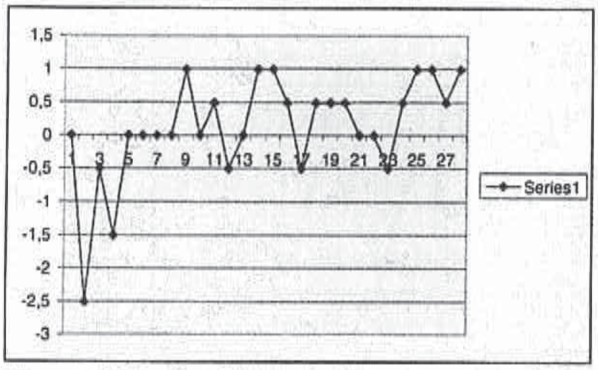


Figure 136. Gradient of temperature variation during measurement period 1.2.-28.2.2001.

4.4.4 Measuring point D

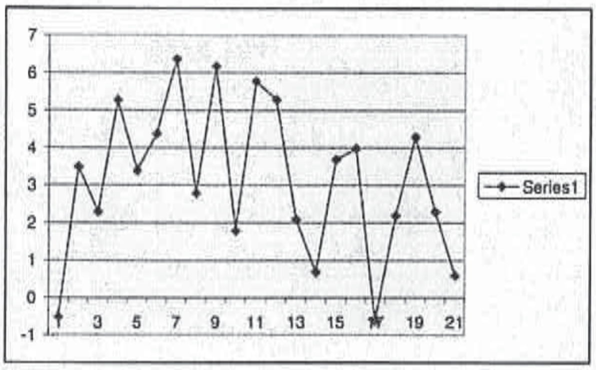


Figure 137. Gradient of temperature variation during measurement period 11.5.-31.5.1999.

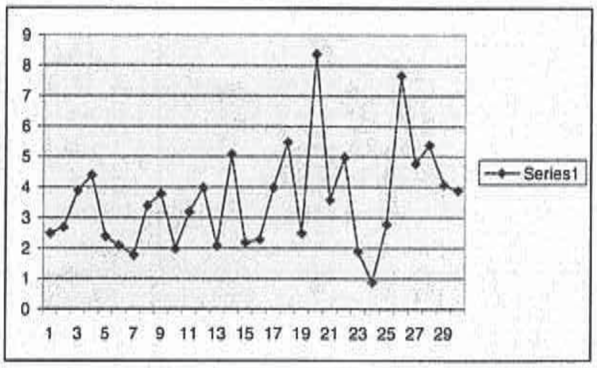


Figure 138. Gradient of temperature variation during measurement period 1.6.-30.6.1999.

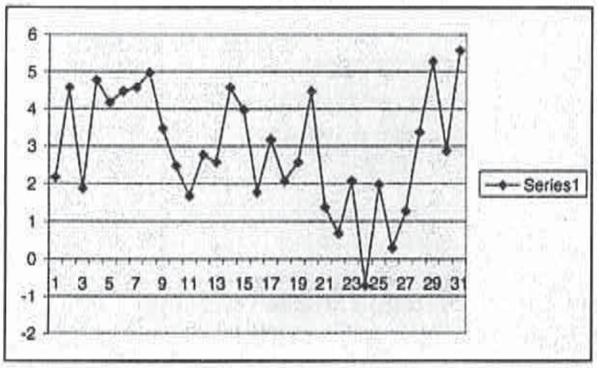


Figure 139. Gradient of temperature variation during measurement period 1.7.-31.7.1999.

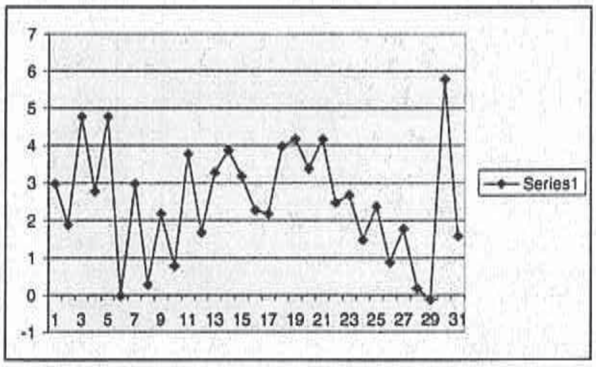


Figure 140. Gradient of temperature variation during measurement period 1.8.-31.8.1999.

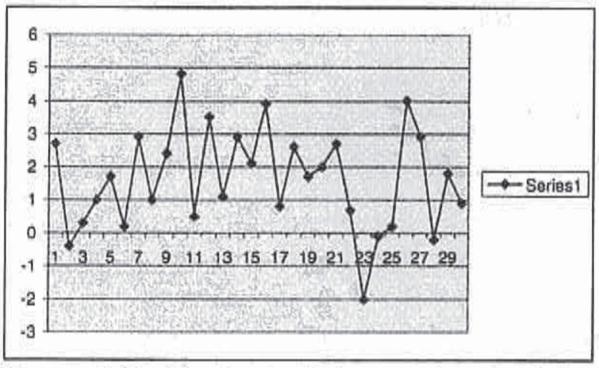


Figure 141. Gradient of temperature variation during measurement period 1.9.-30.9.1999.

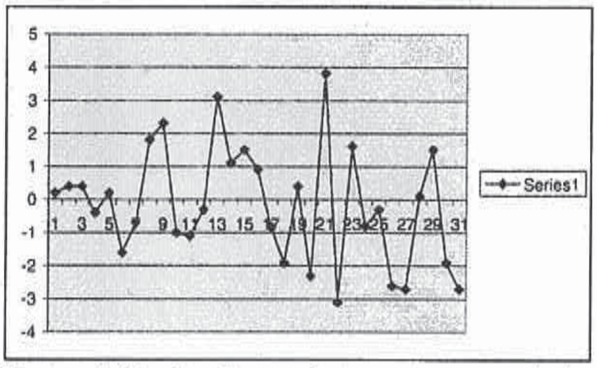


Figure 142. Gradient of temperature variation during measurement period 1.10.-31.10.1999.

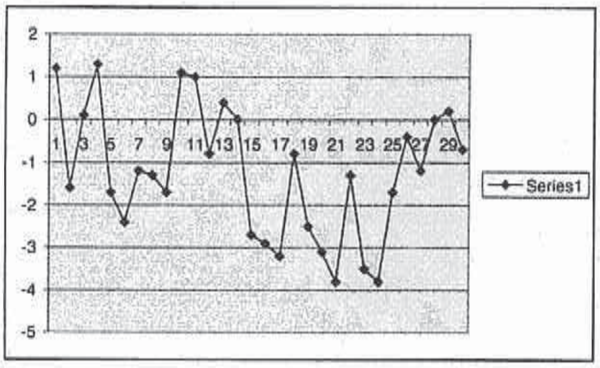


Figure 143. Gradient of temperature variation during measurement period 1.11.-30.11.1999.

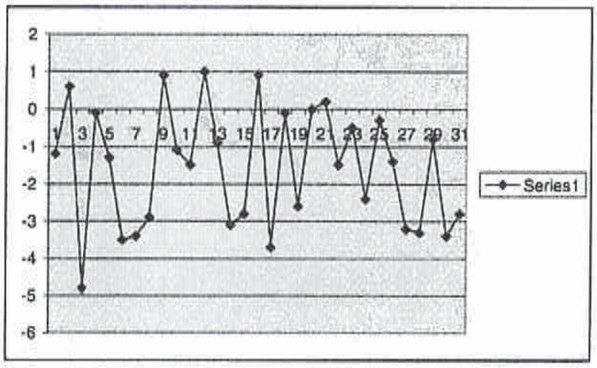


Figure 144. Gradient of temperature variation during measurement period 1.12.-31.12.1999.

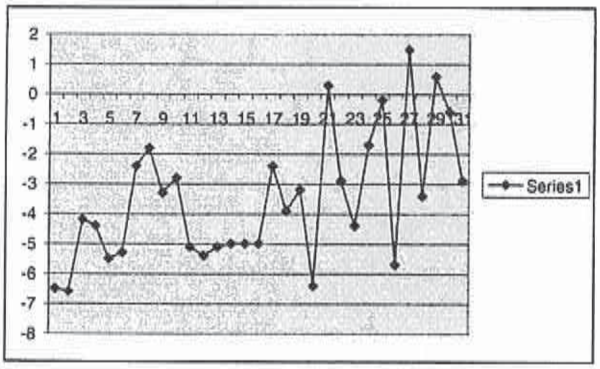


Figure 145. Gradient of temperature variation during measurement period 1.1.-31.1.2000.

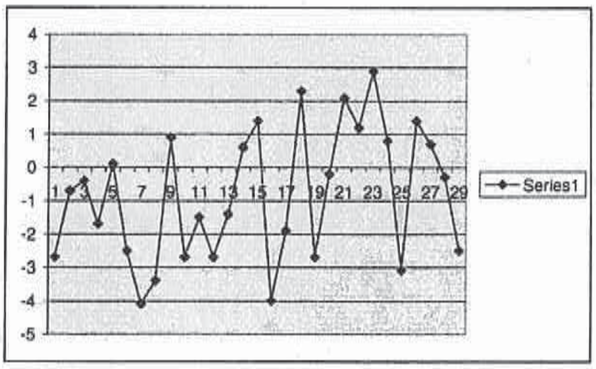


Figure 146. Gradient of temperature variation during measurement period 1.2.-29.2.2000.

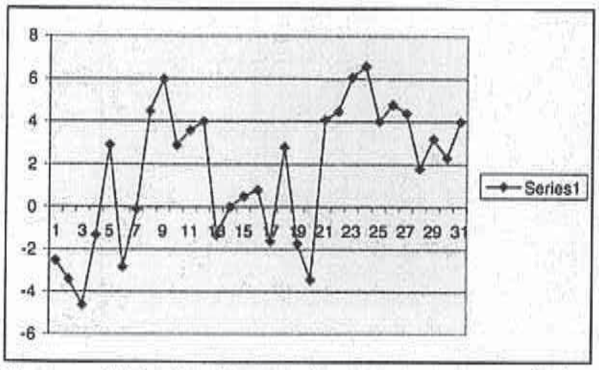


Figure 147. Gradient of temperature variation during measurement period 1.3.-31.3.2000.

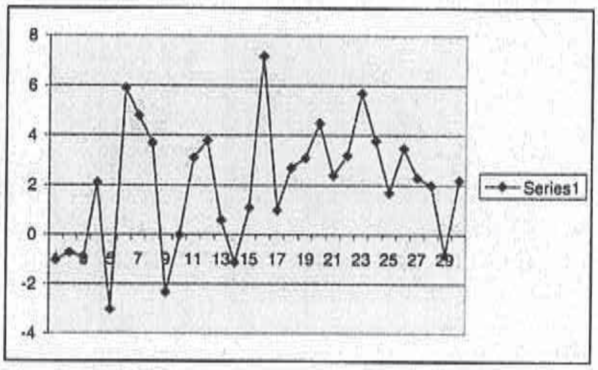


Figure 148. Gradient of temperature variation during measurement period 1.4.-30.4.2000.

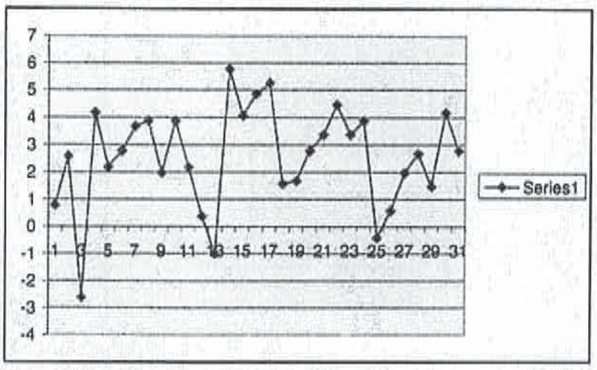


Figure 149. Gradient of temperature variation during measurement period 1.5.-31.5.2000.

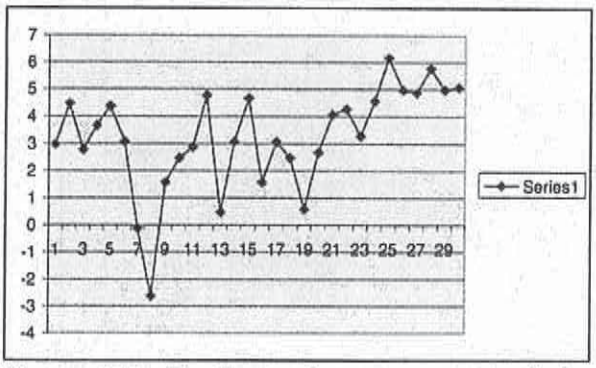


Figure 150. Gradient of temperature variation during measurement period 1.6.-30.6.2000.

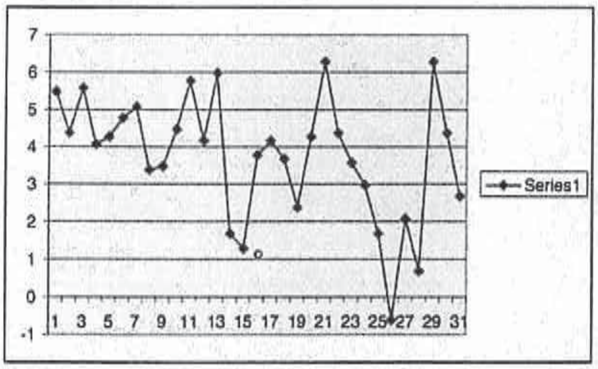


Figure 151. Gradient of temperature variation during measurement period 1.7.-31.7.2000.

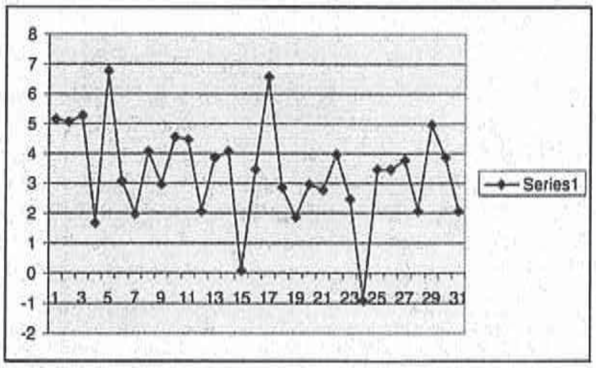


Figure 152. Gradient of temperature variation during measurement period 1.8.-31.8.2000.

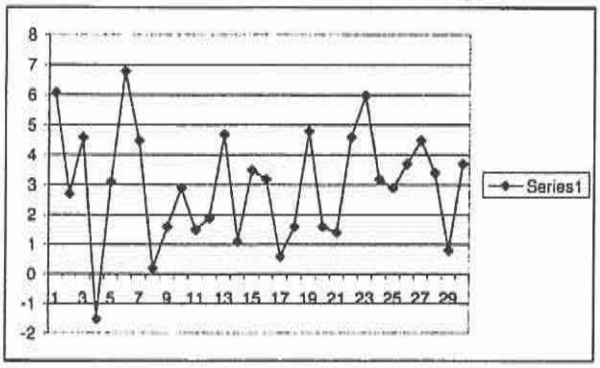


Figure 153. Gradient of temperature variation during measurement period 1.9.-30.9.2000.

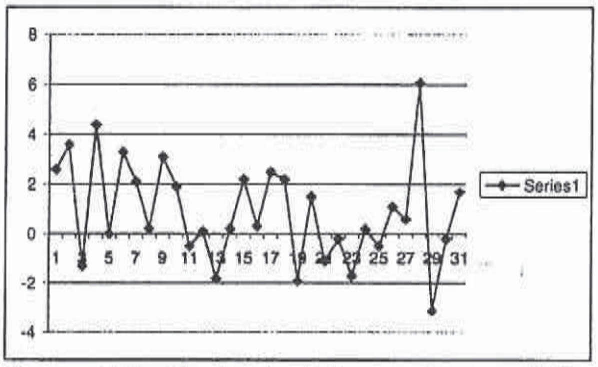


Figure 154. Gradient of temperature variation during measurement period 1.10.-31.10.2000.

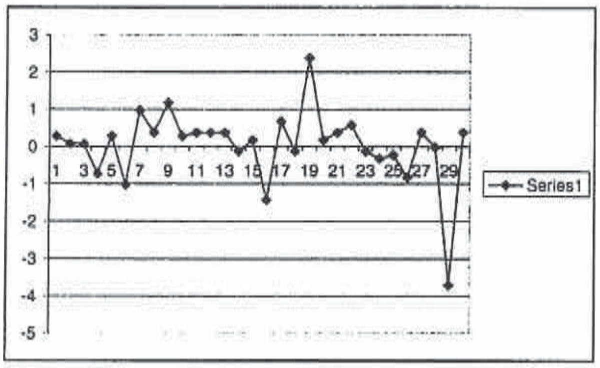


Figure 155. Gradient of temperature variation during measurement period 1.11.-30.11.2000.

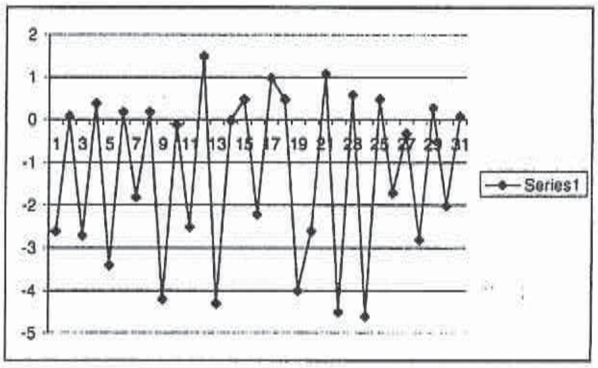


Figure 156. Gradient of temperature variation during measurement period 1.12.-31.12.2000.

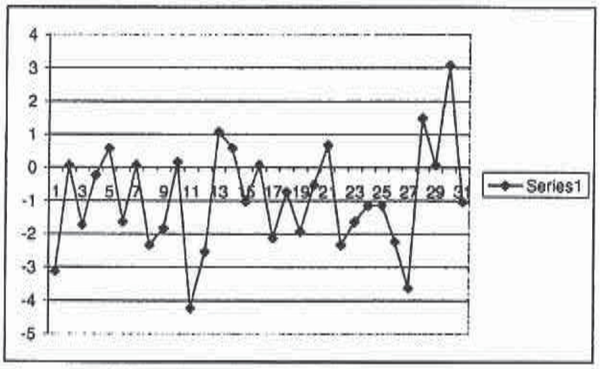


Figure 157. Gradient of temperature variation during measurement period 1.1.-31.1.2001.

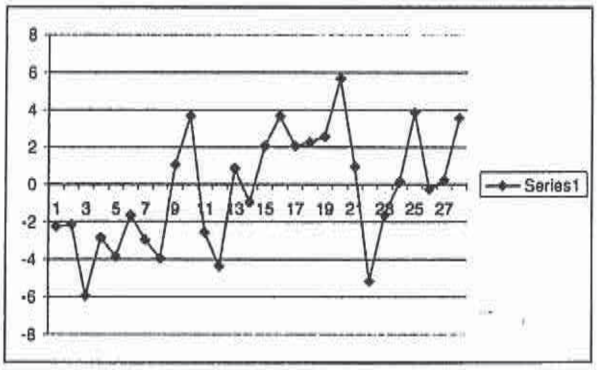


Figure 158. Gradient of temperature variation during measurement period 1.2.-28.2.2001.

4.4.5 Measuring point E

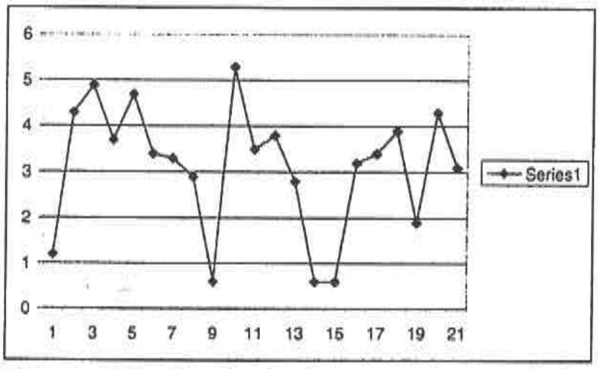


Figure 159. Gradient of temperature variation during measurement period 11.5.-31.5.1999.

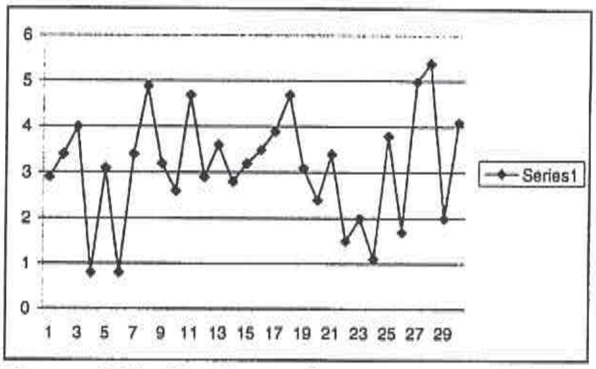


Figure 160. Gradient of temperature variation during measurement period 1.6.-30.6.1999.

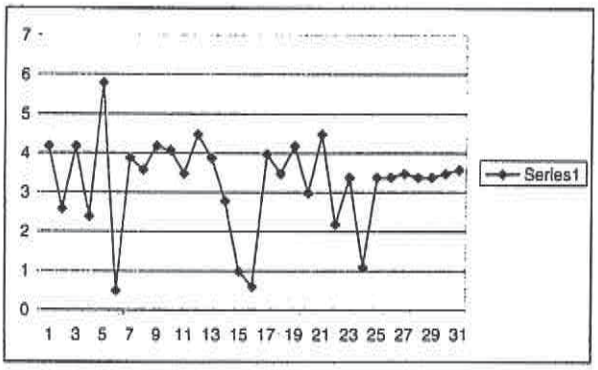


Figure 161. Gradient of temperature variation during measurement period 1.7.-31.7.1999.

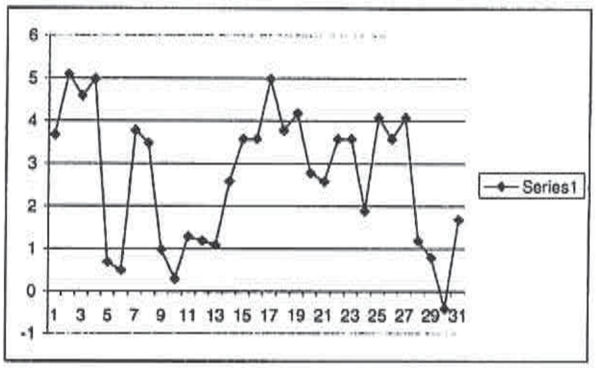


Figure 162. Gradient of temperature variation during measurement period 1.8.-31.8.1999.

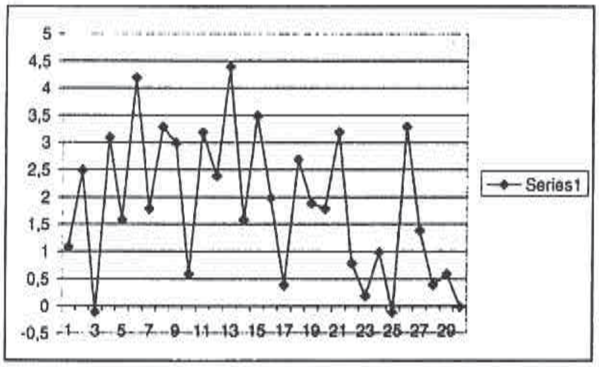


Figure 163. Gradient of temperature variation during measurement period 1.9.-30.9.1999.

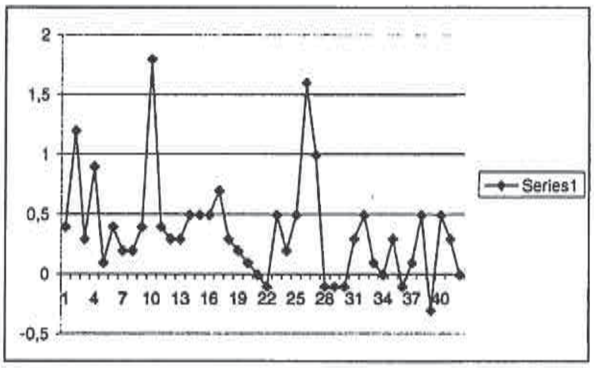


Figure 164. Gradient of temperature variation during measurement period 20.10.-30.11.1999.

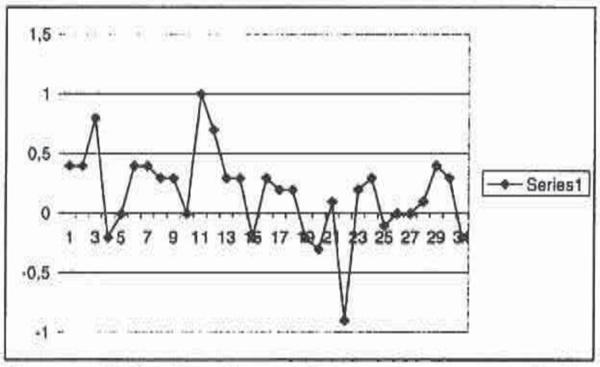


Figure 165. Gradient of temperature variation during measurement period 1.12.-31.12.1999.

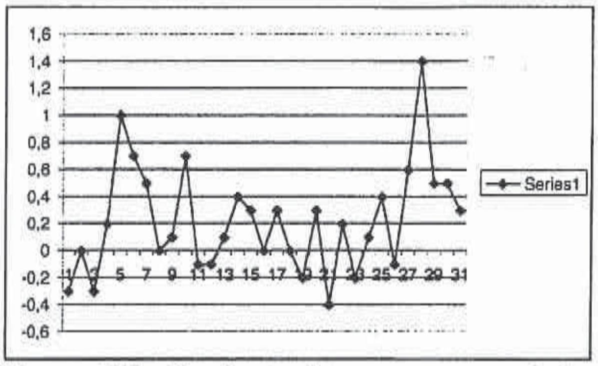


Figure 166. Gradient of temperature variation during measurement period 1.1.-31.1.2000.

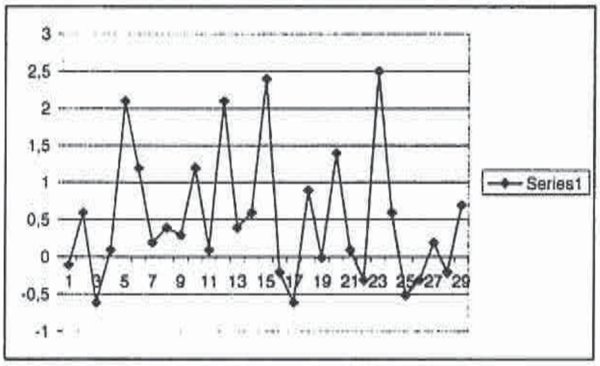


Figure 167. Gradient of temperature variation during measurement period 1.2.-29.2.2000.

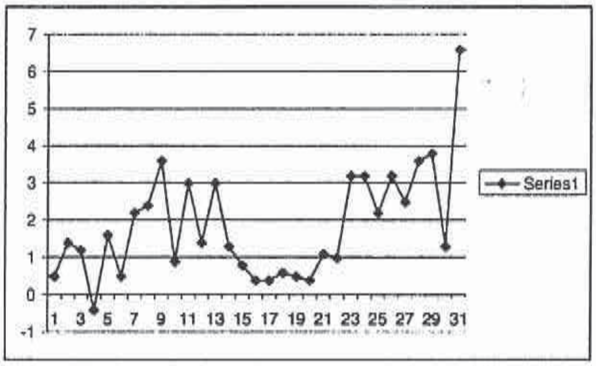


Figure 168. Gradient of temperature variation during measurement period 1.3.-31.3.2000.

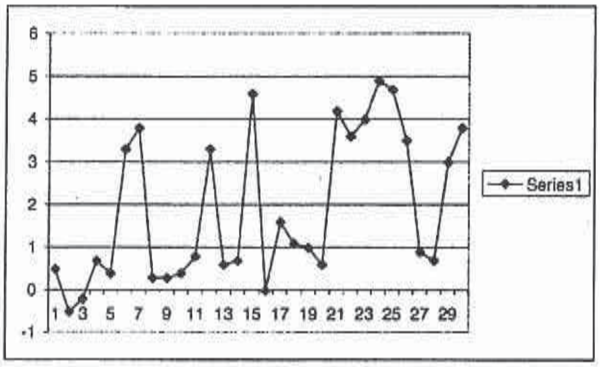


Figure 169. Gradient of temperature variation during measurement period 1.4.-30.4.2000.

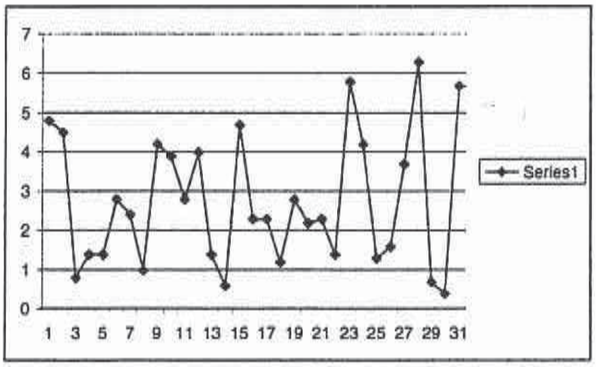


Figure 170. Gradient of temperature variation during measurement period 1.5.-31.5.2000.

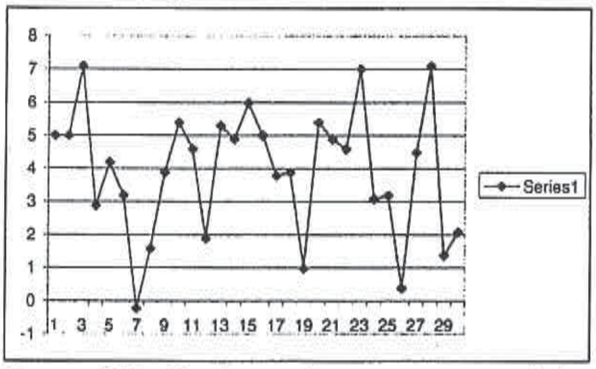


Figure 171. Gradient of temperature variation during measurement period 1.6.-30.6.2000.

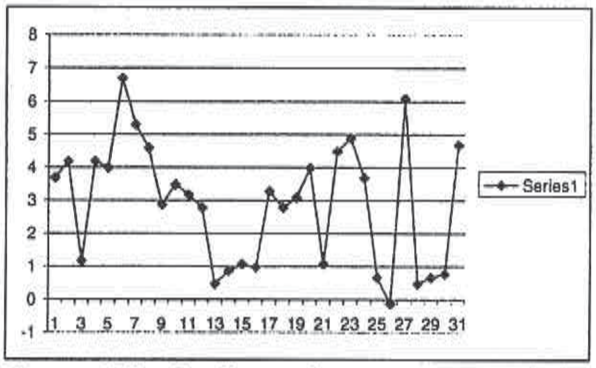


Figure 172. Gradient of temperature variation during measurement period 1.7.-31.7.2000.

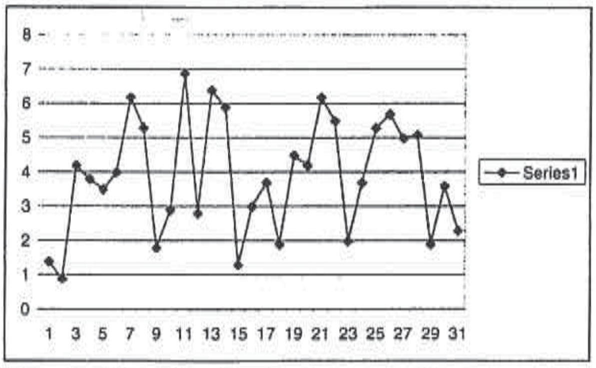


Figure 173. Gradient of temperature variation during measurement period 1.8.-31.8.2000.

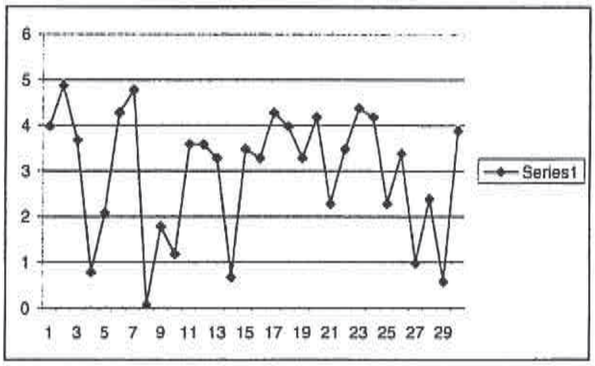


Figure 174. Gradient of temperature variation during measurement period 1.9.-30.9.2000.

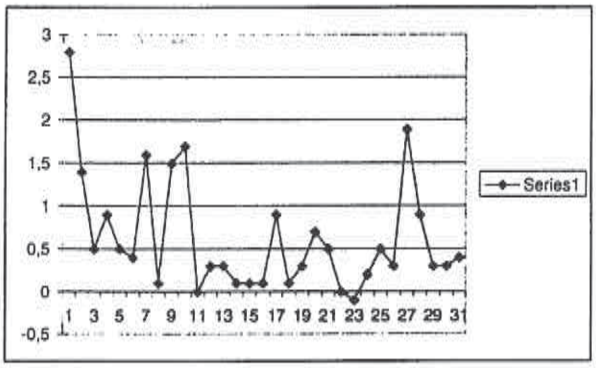


Figure 175. Gradient of temperature variation during measurement period 1.10.-31.10.2000.

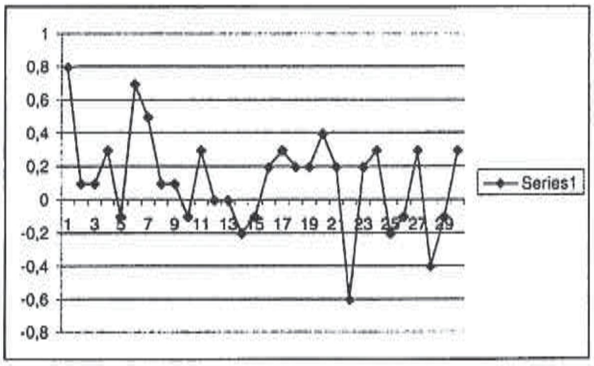


Figure 176. Gradient of temperature variation during measurement period 1.11.-30.11.2000.

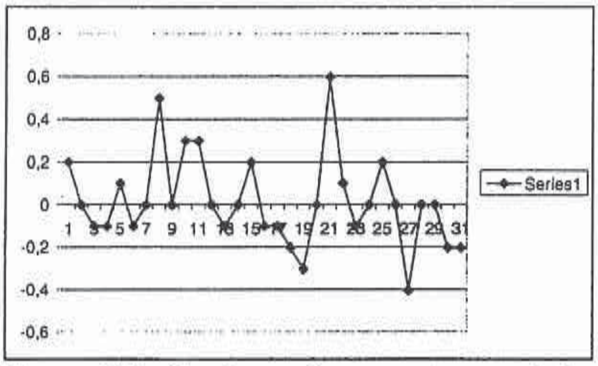


Figure 177. Gradient of temperature variation during measurement period 1.12.-31.12.2000.

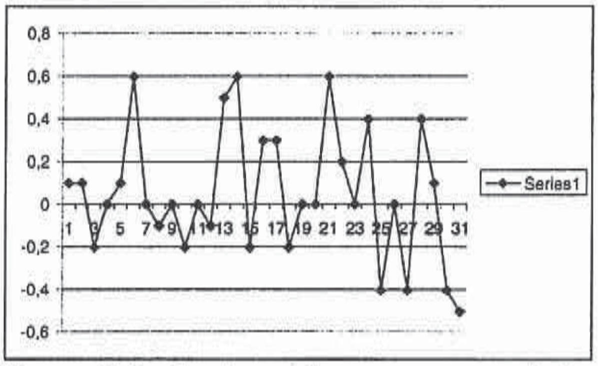


Figure 178. Gradient of temperature variation during measurement period 1.1.-31.1.2001.

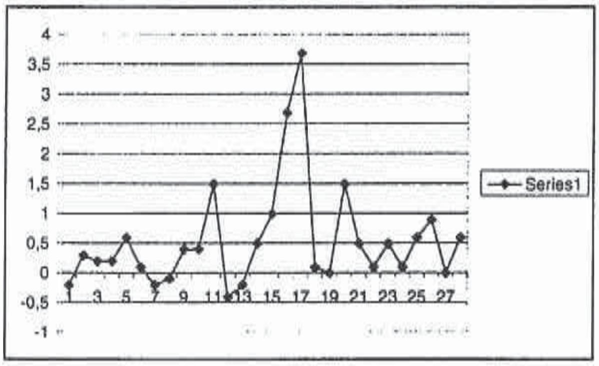


Figure 179. Gradient of temperature variation during measurement period 1.2.-28.2.2001.

4.5 Freeze/thaw -cycling of marble

The number of freeze/thaw -cycles occurred on marble surfaces was calculated from the data dealing with the daily variation of temperature presented in chapter 4.3. In this case freeze/thaw -cycle was defined as a day during which the maximum temperature was higher than +0.3°C and the minimum temperature lower than -0.3°C. The number of such days in every month, i.e. the number of freeze/thaw -cycles, on outer (OUT) and inner (IN) surfaces of each measuring slab is presented in Table 1.

Table 1. The number of freeze/thaw -cycles on marble surfaces.

month/year	slab A		slab B		slab C		slab D		slab E	
	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN
5/1999	x	x	x	x	x	x	1 [7)]	1 [7)]	4 [7)]	2 [7)]
6/1999	0	0	0	0	0	0	0	0	0	0
7/1999	0	0	x	x	0	0	0	0	0	0
8/1999	0	0	x	x	0	0	0	0	0	0
9/1999	0	0	x	x	0	0	0	0	0	0
10/1999	1	0	x	x	4 [4)]	3 [4)]	1	1	1 [8)]	1 [8)]
11/1999	7	5	x	x	x	x	10	9	7	5
12/1999	14	13	x	x	x	x	23	21	15	13
1/2000	4 [1)]	4 [1)]	x	x	x	x	16	15	13	14
2/2000	x	x	x	x	x	x	8	3	12	11
3/2000	16 [2)]	14 [2)]	x	x	x	x	1	0	25	23
4/2000	5	2	14 [3)]	8 [3)]	10 [5)]	8 [5)]	0	0	5	4
5/2000	0	0	4	3	0 [6)]	0 [6)]	1	1	1	0
6/2000	0	0	0	0	0	0	0	0	0	0
7/2000	0	0	0	0	0	0	0	0	0	0
8/2000	0	0	0	0	0	0	0	0	0	0
9/2000	0	0	1	0	1	0	0	0	0	0
10/2000	2	1	4	3	4	3	2	2	3	2
11/2000	2	0	7	5	6	4	1	1	3	3
12/2000	7	6	1	2	2	2	11	11	5	5
1/2001	21	20	0	0	5	7	9	8	10	11
2/2001	19	20	2	2	1	7	9	10	12	13

x = no results available
1) → 11.1.2000 2) 7.3.2000 → 3) 29.3.2000 → 4) → 20.10.1999
5) 29.3.-12.4.2000 6) 17.5.2000 → 7) 11.5.1999 → 8) 20.10.1999 →

4.6 Humidity gradient over the marble slab

The gradient of relative humidity over the marble slabs was studied by using the maximum and minimum relative humidities observed daily in outdoor air above the slab and inside the ventilation slot behind the slab. The results from measuring points D and E are shown as pictures presented below, Figs. 180-222. There are four curves in every picture. They are coded with numbers 1-4, and they have the following meaning:

Series 1	maximum relative humidity in outdoor air
Series 2	minimum relative humidity in outdoor air
Series 3	maximum relative humidity in ventilation slot
Series 4	minimum relative humidity in ventilation slot

4.6.1 Measuring point D

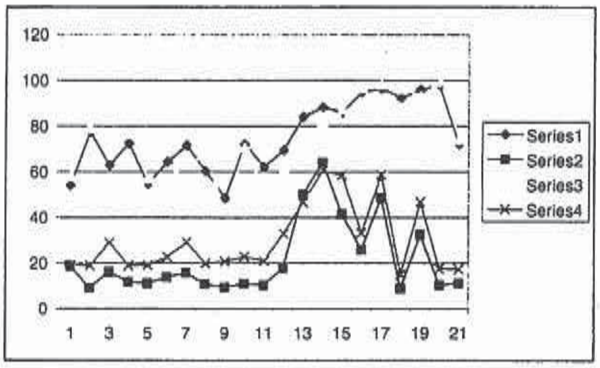


Figure 180. Daily variation of relative humidity during measuring period 11.5.-31.5.1999.

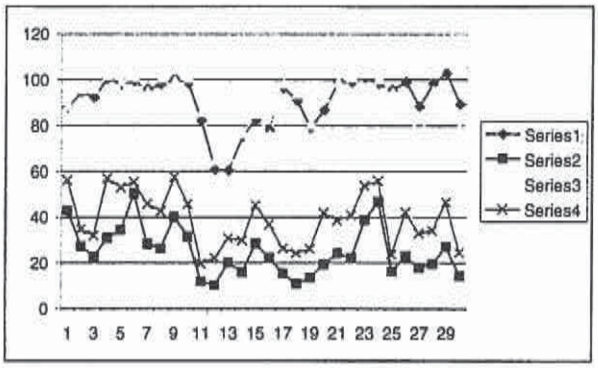


Figure 181. Daily variation of relative humidity during measuring period 1.6.-30.6.1999.

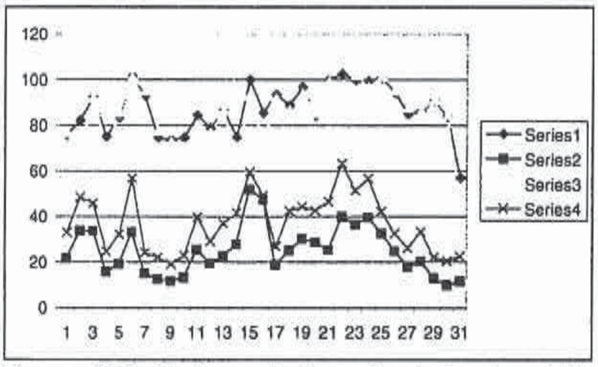


Figure 182. Daily variation of relative humidity during measuring period 1.7.-31.7.1999.

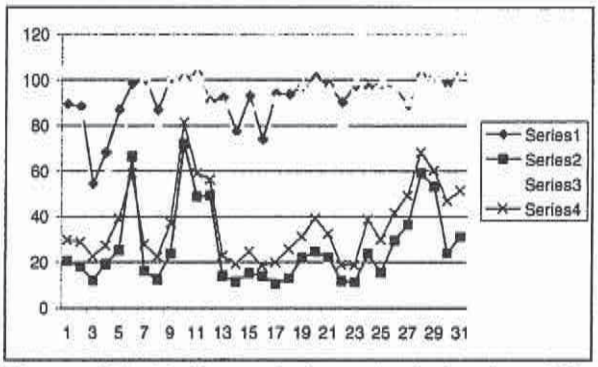


Figure 183. Daily variation of relative humidity during measuring period 1.8.-31.8.1999.

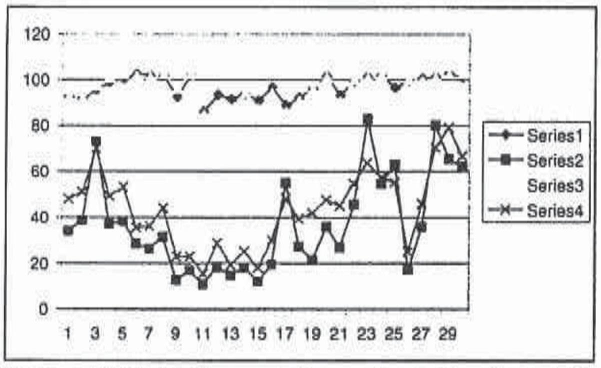


Figure 184. Daily variation of relative humidity during measuring period 1.9.-30.9.1999.

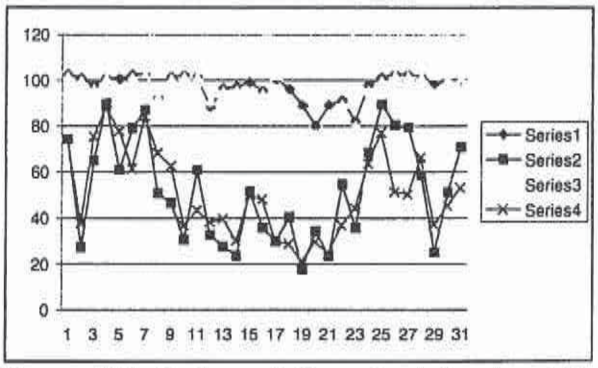


Figure 185. Daily variation of relative humidity during measuring period 1.10.-31.10.1999.

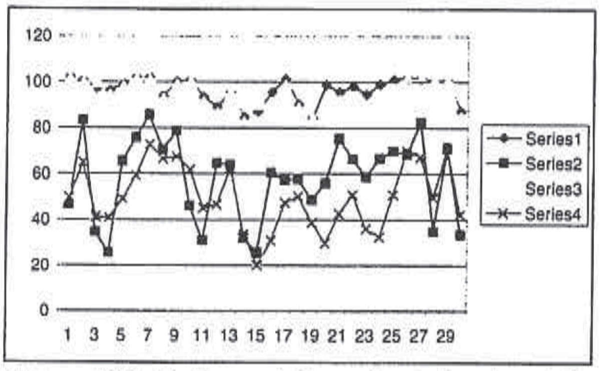


Figure 186. Daily variation of relative humidity during measuring period 1.11.-30.11.1999.

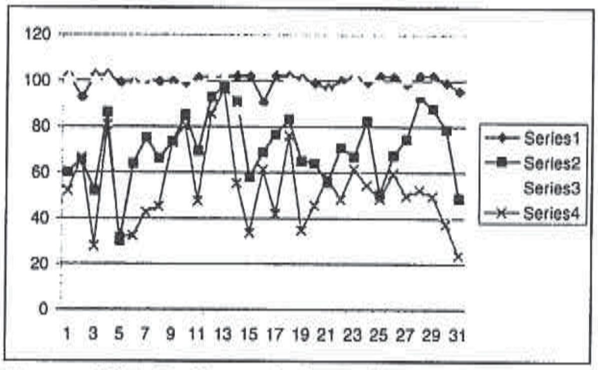


Figure 187. Daily variation of relative humidity during measuring period 1.12.-31.12.1999.

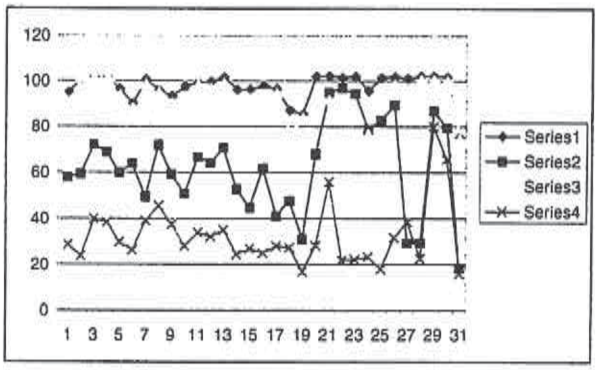


Figure 188. Daily variation of relative humidity during measuring period 1.1.-31.1.2000.

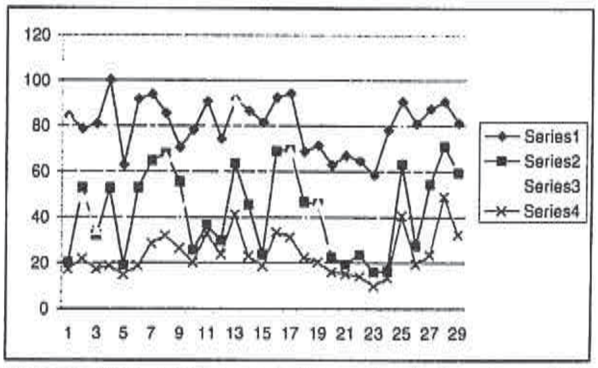


Figure 189. Daily variation of relative humidity during measuring period 1.2.-29.2.2000.

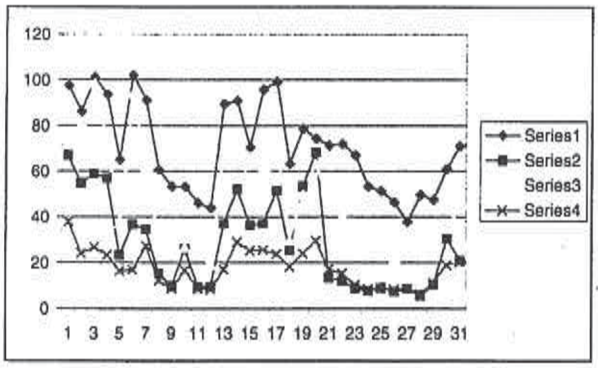


Figure 190. Daily variation of relative humidity during measuring period 1.3.-31.3.2000.

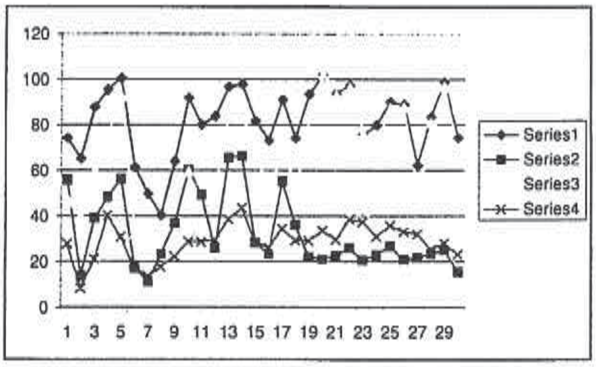


Figure 191. Daily variation of relative humidity during measuring period 1.4.-30.4.2000.

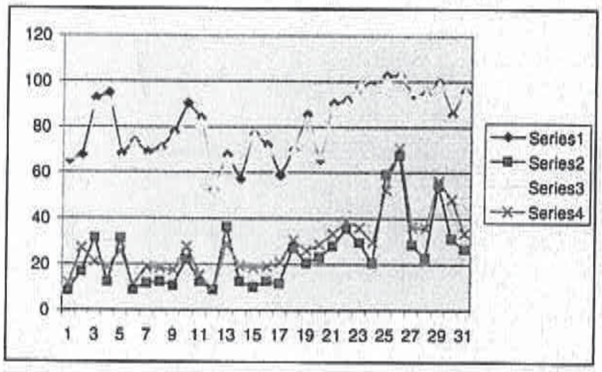


Figure 192. Daily variation of relative humidity during measuring period 1.5.-31.5.2000.

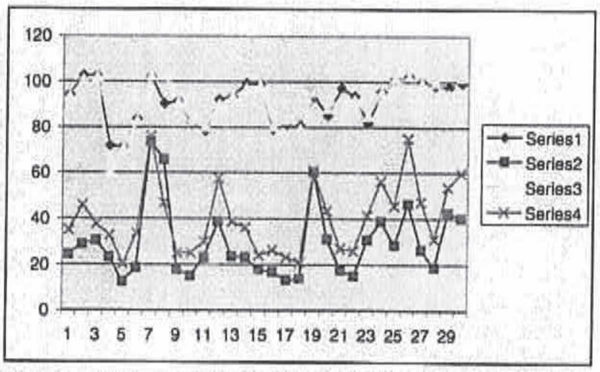


Figure 193. Daily variation of relative humidity during measuring period 1.6.-30.6.2000.

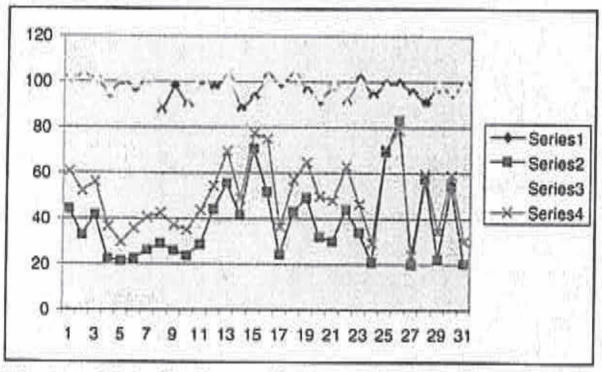


Figure 194. Daily variation of relative humidity during measuring period 1.7.-31.7.2000.

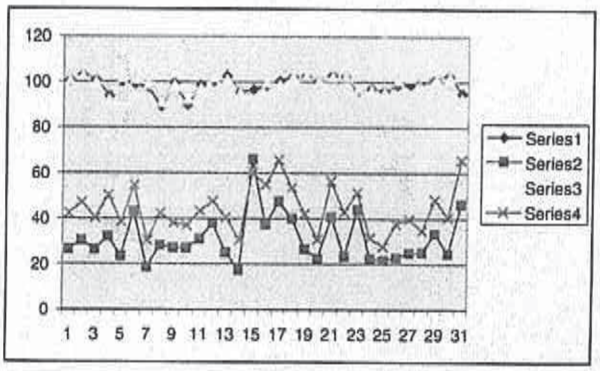


Figure 195. Daily variation of relative humidity during measuring period 1.8.-31.8.2000.

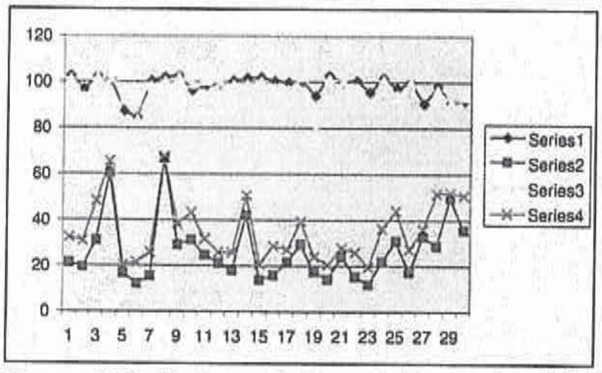


Figure 196. Daily variation of relative humidity during measuring period 1.9.-30.9.2000.

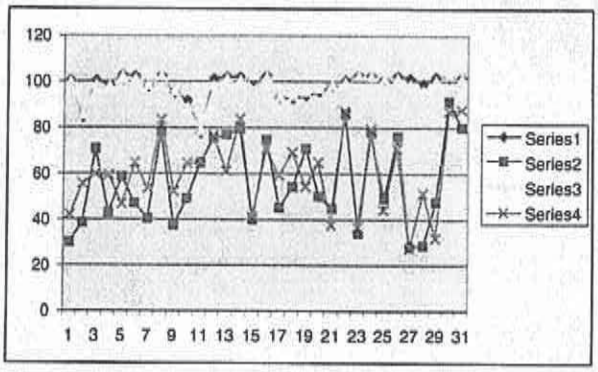


Figure 197. Daily variation of relative humidity during measuring period 1.10.-31.10.2000.

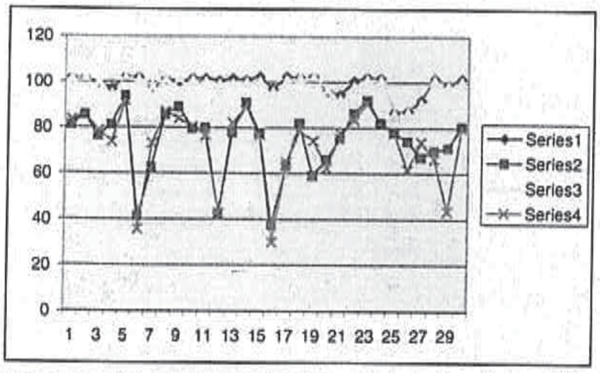


Figure 198. Daily variation of relative humidity during measuring period 1.11.-30.11.2000.

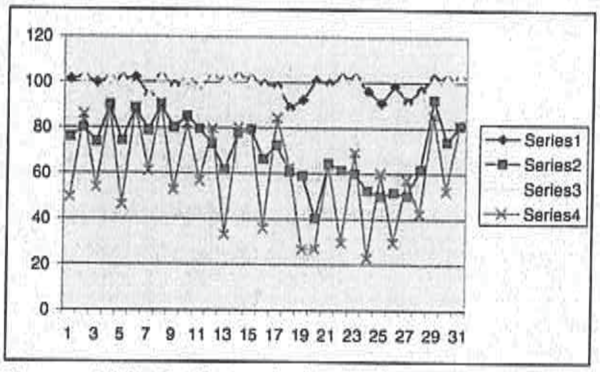


Figure 199. Daily variation of relative humidity during measuring period 1.12.-31.12.2000.

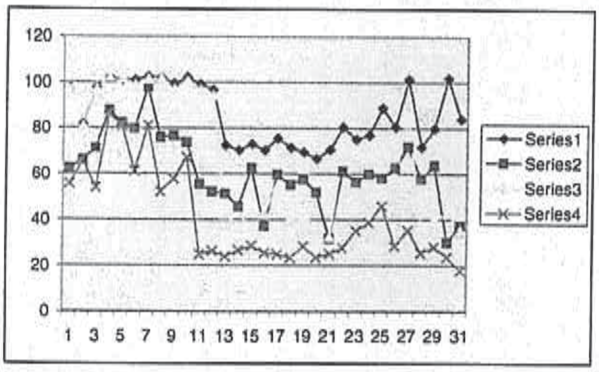


Figure 200. Daily variation of relative humidity during measuring period 1.1.-31.1.2001.

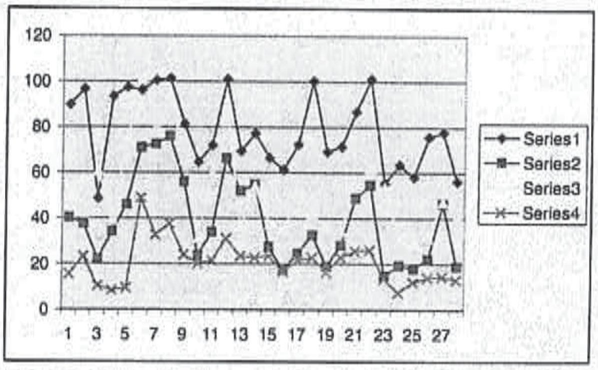


Figure 201. Daily variation of relative humidity during measuring period 1.2.-28.2.2001.

4.6.2 Measuring point E

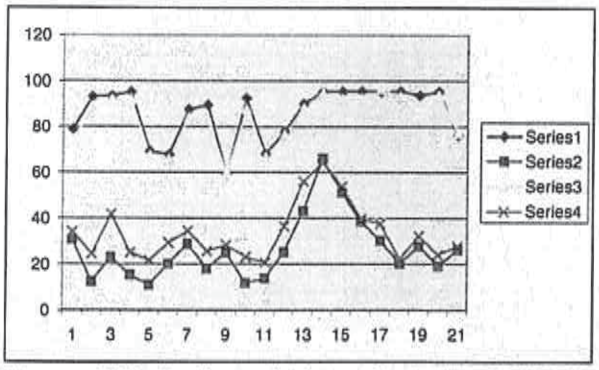


Figure 202. Daily variation of relative humidity during measuring period 11.5.-31.5.1999.

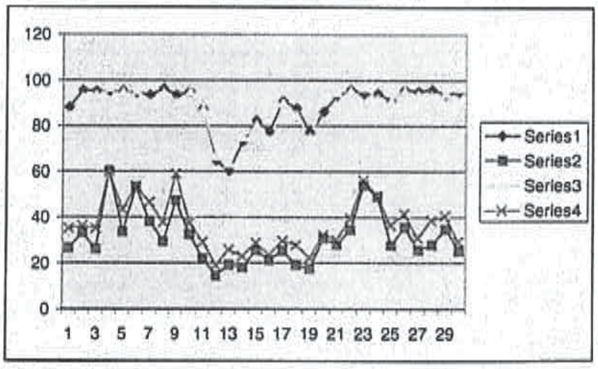


Figure 203. Daily variation of relative humidity during measuring period 1.6.-30.6.1999.

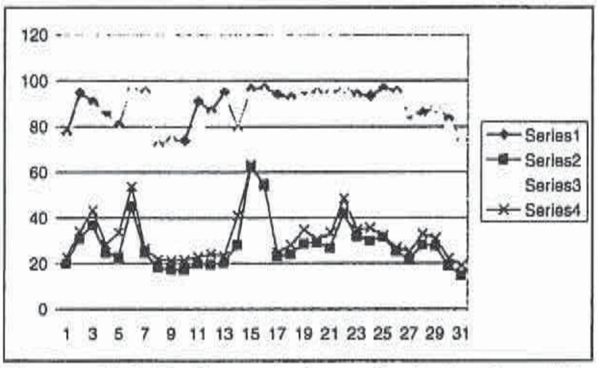


Figure 204. Daily variation of relative humidity during measuring period 1.7.-31.7.1999.

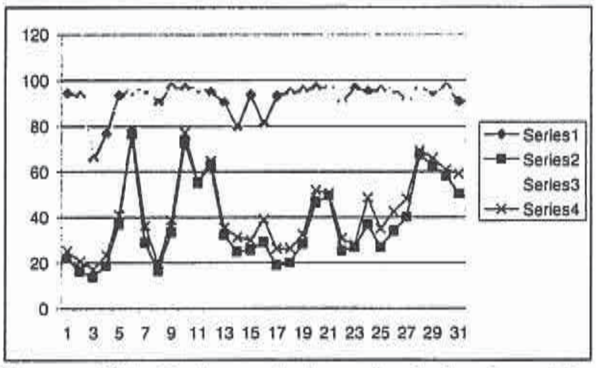


Figure 205. Daily variation of relative humidity during measuring period 1.8.-31.8.1999.

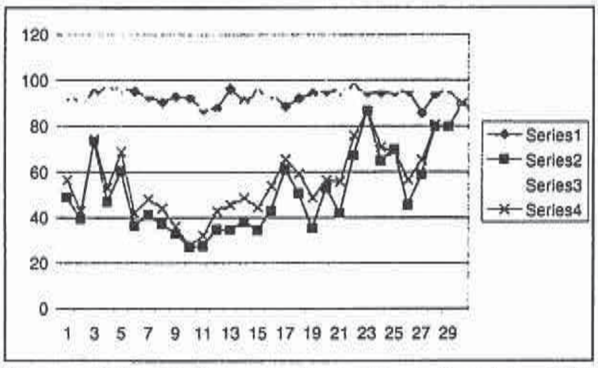


Figure 206. Daily variation of relative humidity during measuring period 1.9.-30.9.1999.

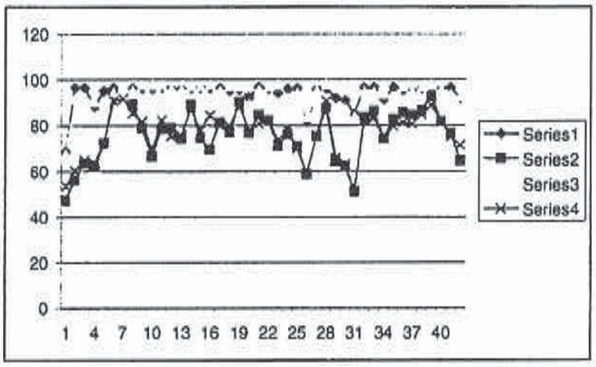


Figure 207. Daily variation of relative humidity during measuring period 20.10.-30.11.1999.

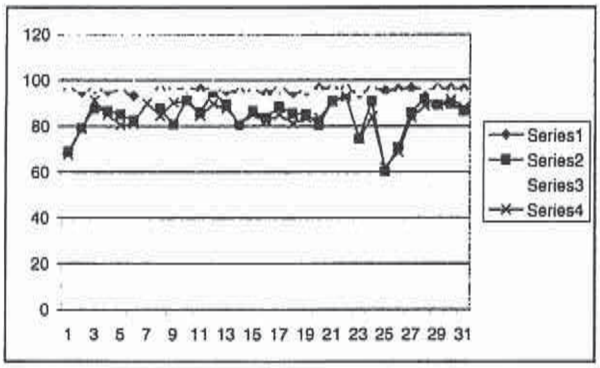


Figure 208. Daily variation of relative humidity during measuring period 1.12.-31.12.1999.

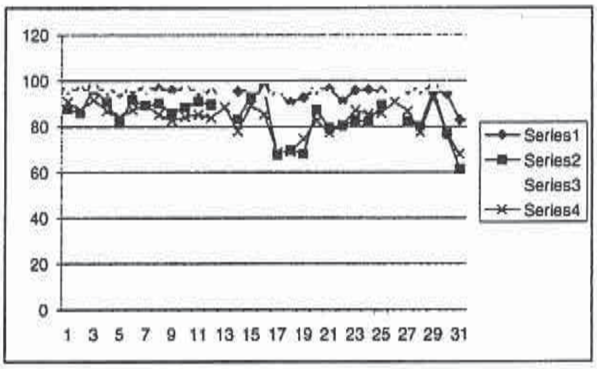


Figure 209. Daily variation of relative humidity during measuring period 1.1.-31.1.2000.

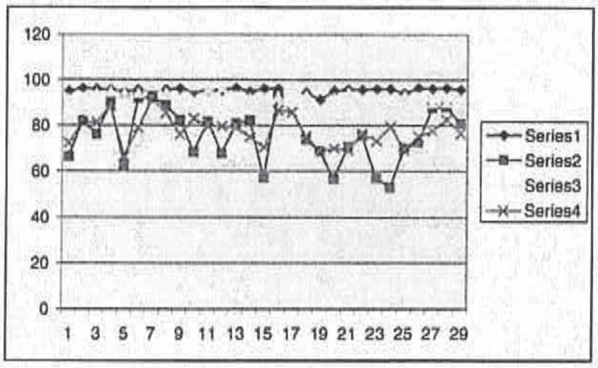


Figure 210. Daily variation of relative humidity during measuring period 1.2.-29.2.2000.

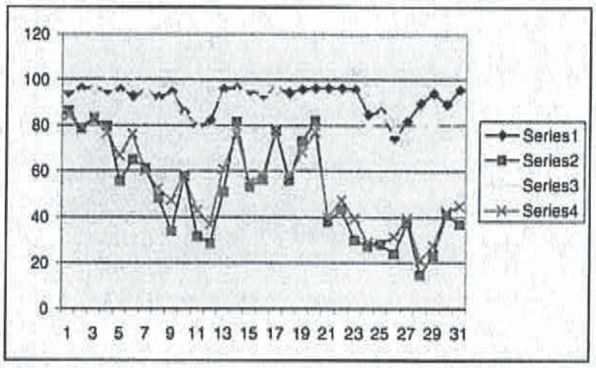


Figure 211. Daily variation of relative humidity during measuring period 1.3.-31.3.2000.

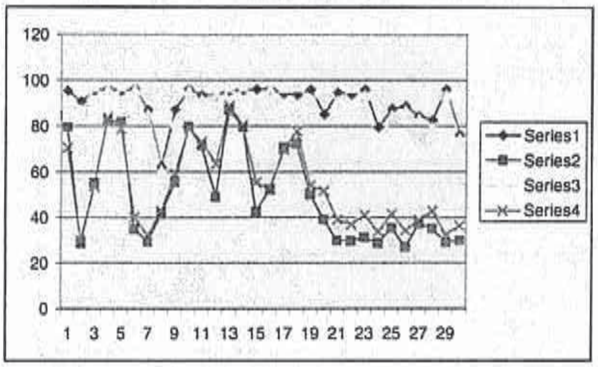


Figure 212. Daily variation of relative humidity during measuring period 1.4.-30.4.2000.

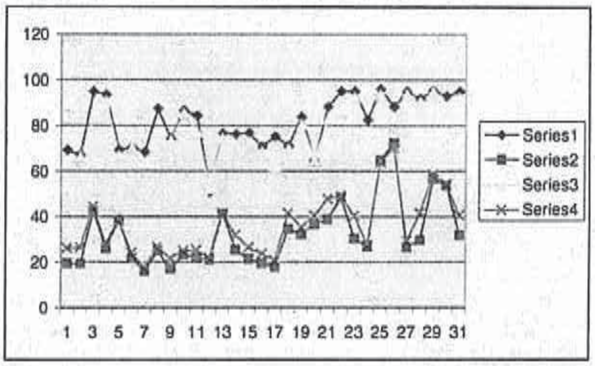


Figure 213. Daily variation of relative humidity during measuring period 1.5.-31.5.2000.

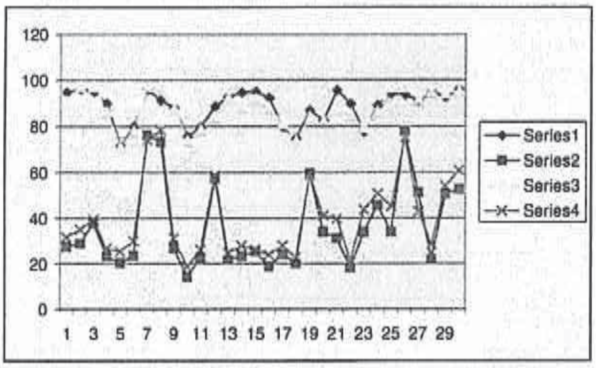


Figure 214. Daily variation of relative humidity during measuring period 1.6.-30.6.2000.

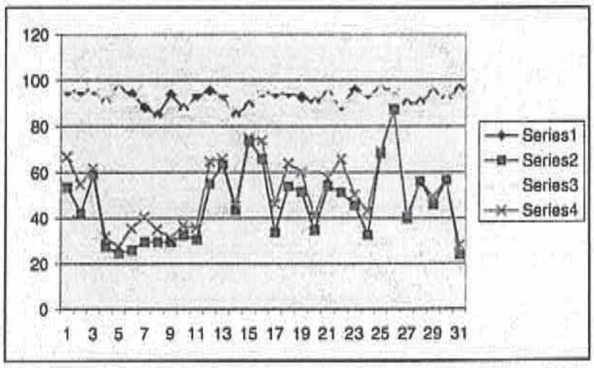


Figure 215. Daily variation of relative humidity during measuring period 1.7.-31.7.2000.

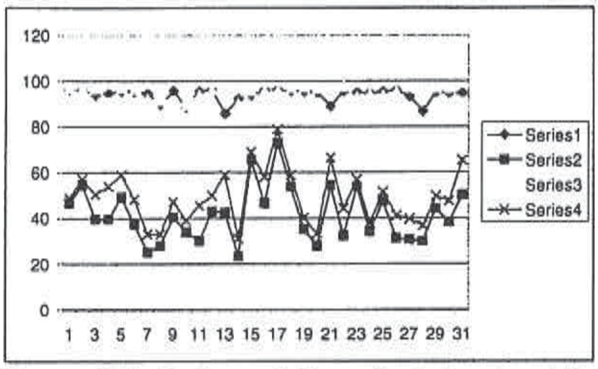


Figure 216. Daily variation of relative humidity during measuring period 1.8.-31.8.2000.

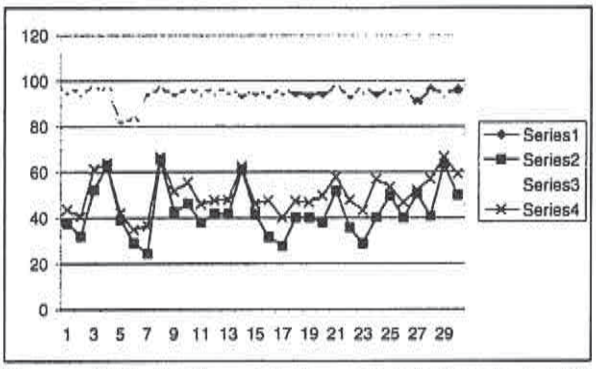


Figure 217. Daily variation of relative humidity during measuring period 1.9.-30.9.2000.

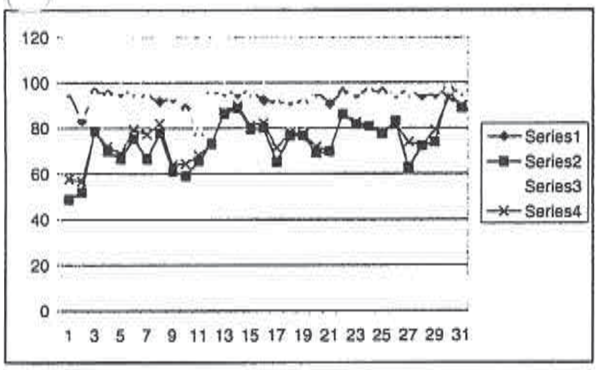


Figure 218. Daily variation of relative humidity during measuring period 1.10.-31.10.2000.

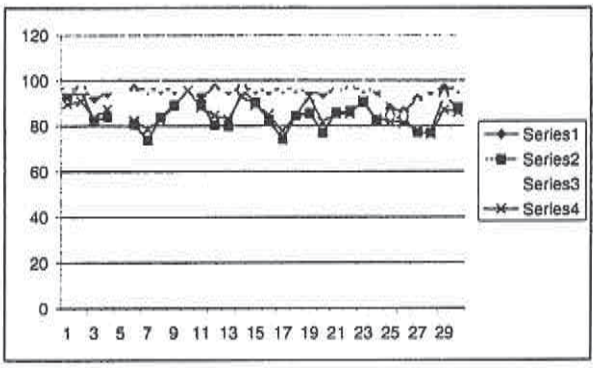


Figure 219. Daily variation of relative humidity during measuring period 1.11.-30.11.2000.

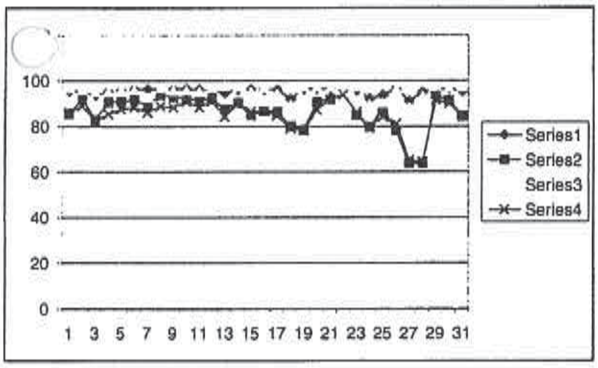


Figure 220. Daily variation of relative humidity during measuring period 1.12.-31.12.2000.

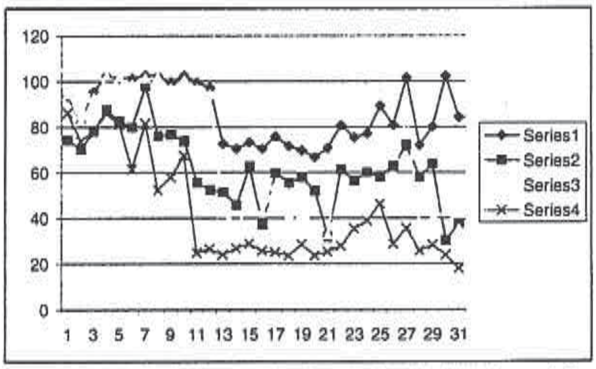


Figure 221. Daily variation of relative humidity during measuring period 1.1.-31.1.2001.

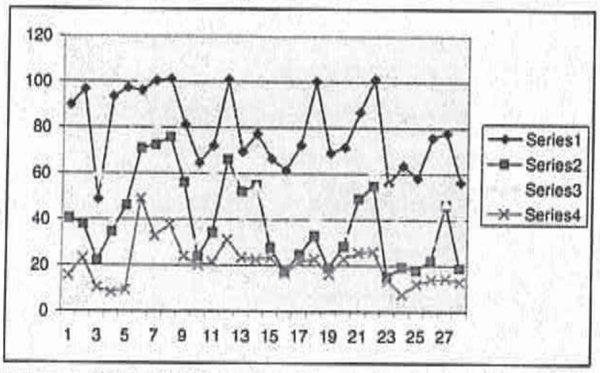


Figure 222. Daily variation of relative humidity during measuring period 1.2.-28.2.2001.

4.7 Acidity of rain water

Finnish Environment Institute has a measurement station at Nupuri, Espoo, about 20 km northwest from Finlandia Hall, where pH of rain water is continuously monitored. Monthly averages from the year 1999 are presented in Table 2.

Table 2. Acidity of rain water at Nupuri measurement station in 1999.

month	pH
January	4.30
February	4.80
March	4.89
April	5.32
May	*
June	*
July	5.34
August	*
September	4.93
October	5.06
November	4.98
December	4.63

* result abandoned due to contamination

The weighted pH-average of the year 1999 was 4.80. It was calculated from the monthly averages by weighting the values with the monthly depths of rainfall. The results from the year 2000 were not available by the time of reporting.

4.8 Weather conditions

4.8.1 Temperature and humidity

Daily maximum and minimum temperatures and corresponding relative humidities in Helsinki area are presented in Figs. 223-266 according to the data of Finnish Meteorological Institute. In the figures Series 1 represents the maximum values and Series 2 the minimum values.

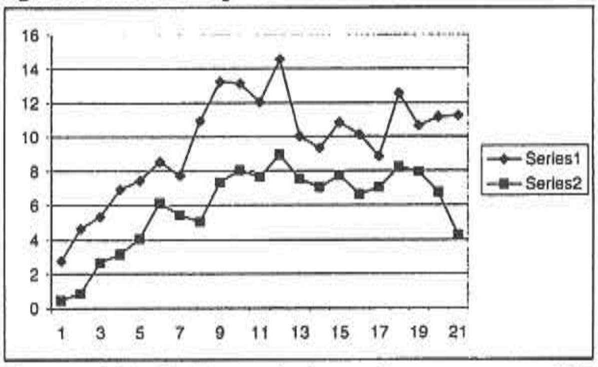


Figure 223. Daily variation of temperature (°C) in Helsinki during measurement period 11.5.-31.5.1999.

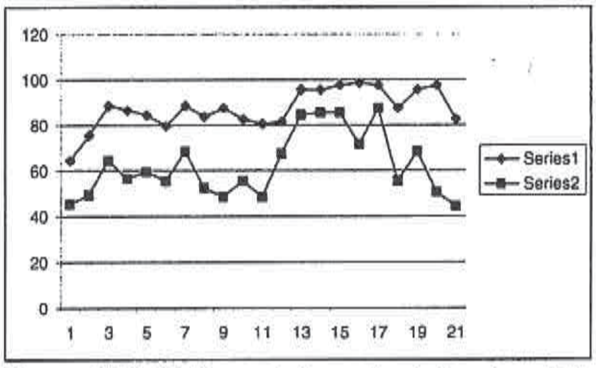


Figure 224. Daily variation of relative humidity (%) in Helsinki during measurement period 11.5.-31.5.1999.

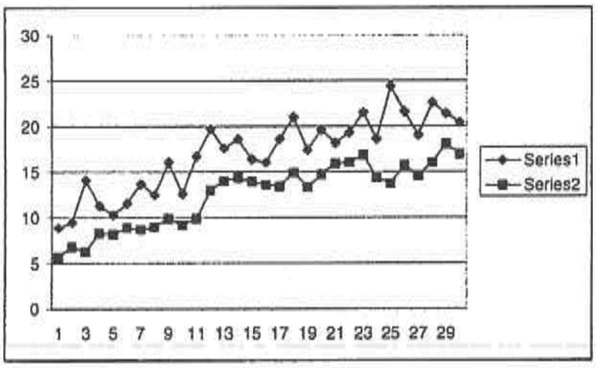


Figure 225. Daily variation of temperature (°C) in Helsinki during measurement period 1.6.-30.6.1999.

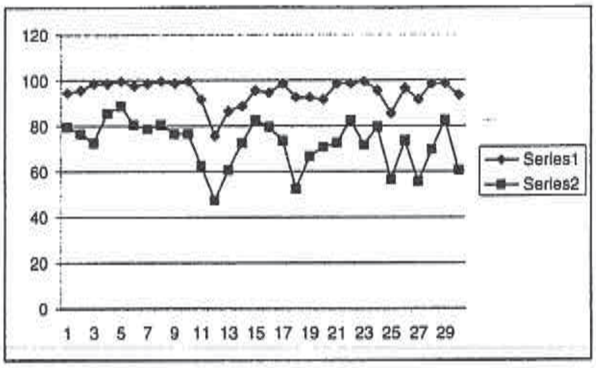


Figure 226. Daily variation of relative humidity (%) in Helsinki during measurement period 1.6.-30.6.1999.

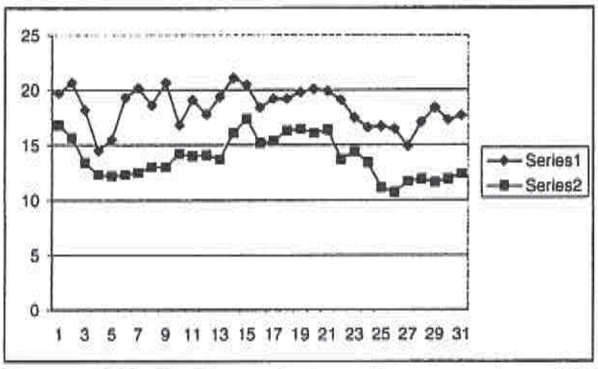


Figure 227. Daily variation of temperature (°C) in Helsinki during measurement period 1.7.-31.7.1999.

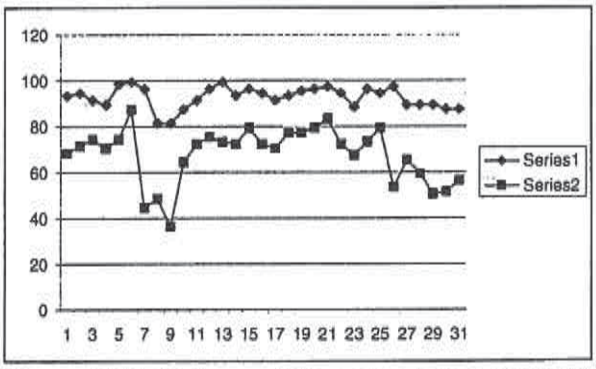


Figure 228. Daily variation of relative humidity (%) in Helsinki during measurement period 1.7.-31.7.1999.

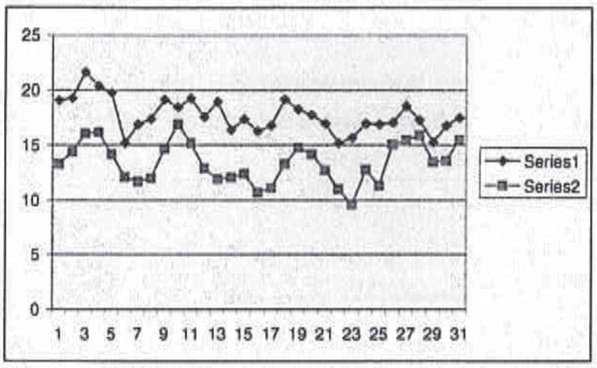


Figure 229. Daily variation of temperature (°C) in Helsinki during measurement period 1.8.-31.8.1999.

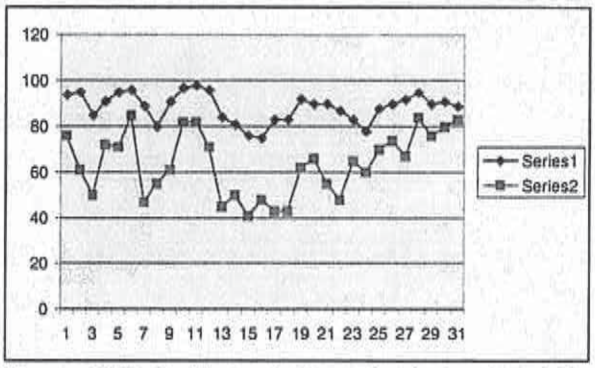


Figure 230. Daily variation of relative humidity (%) in Helsinki during measurement period 1.8.-31.8.1999.

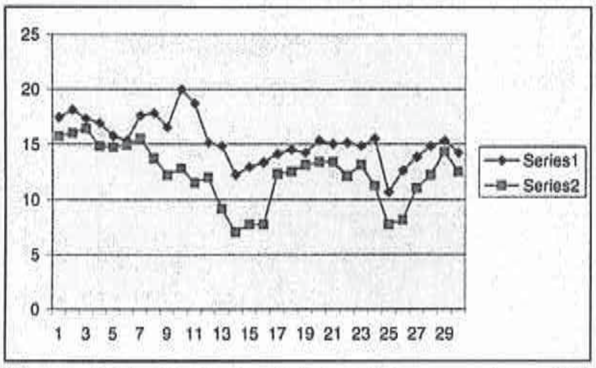


Figure 231. Daily variation of temperature (°C) in Helsinki during measurement period 1.9.-30.9.1999.

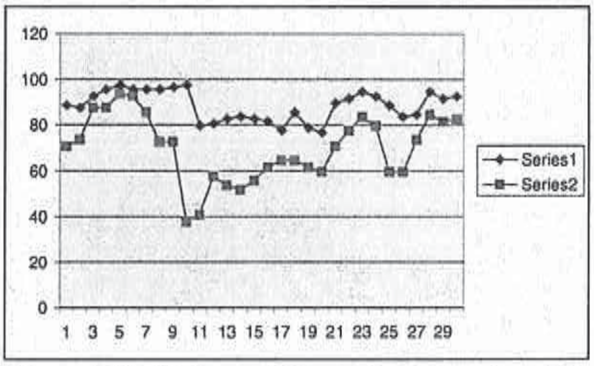


Figure 232. Daily variation of relative humidity (%) in Helsinki during measurement period 1.9.-30.9.1999.

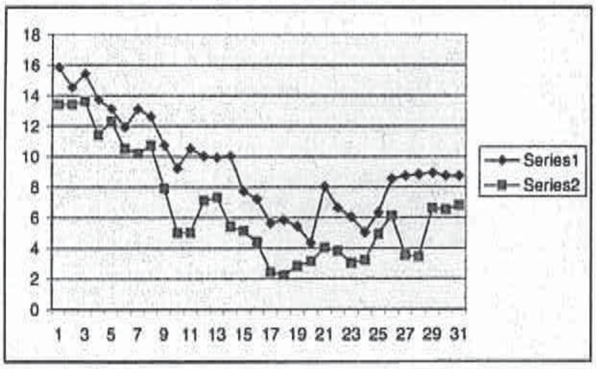


Figure 233. Daily variation of temperature (°C) in Helsinki during measurement period 1.10.-31.10.1999.

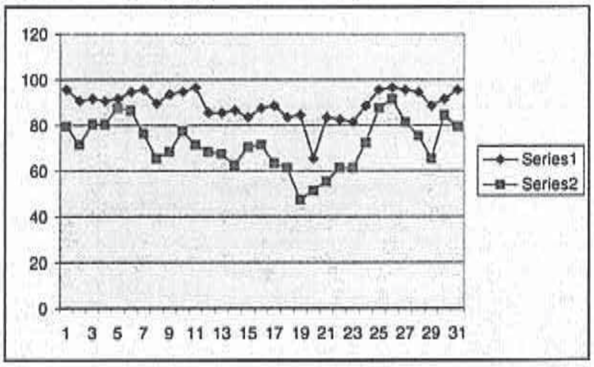


Figure 234. Daily variation of relative humidity (%) in Helsinki during measurement period 1.10.-31.10.1999.

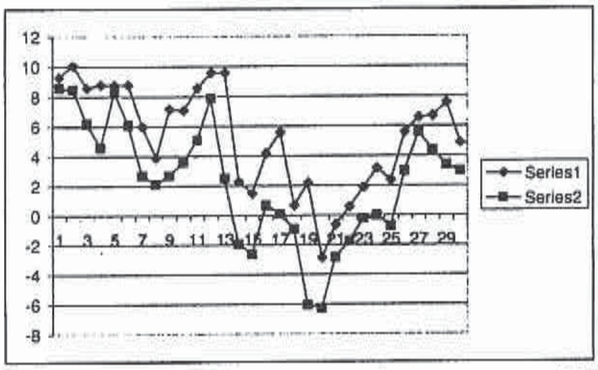


Figure 235. Daily variation of temperature (°C) in Helsinki during measurement period 1.11.-30.11.1999.

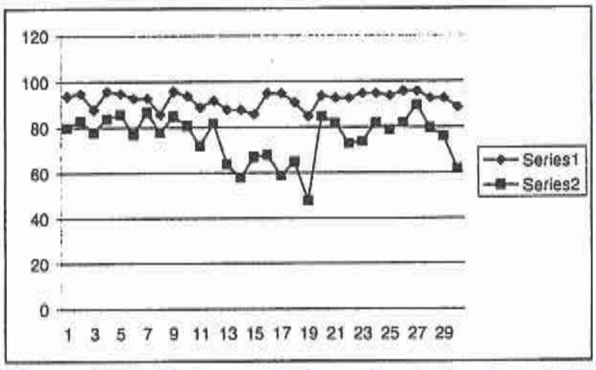


Figure 236. Daily variation of relative humidity (%) in Helsinki during measurement period 1.11.-30.11.1999.

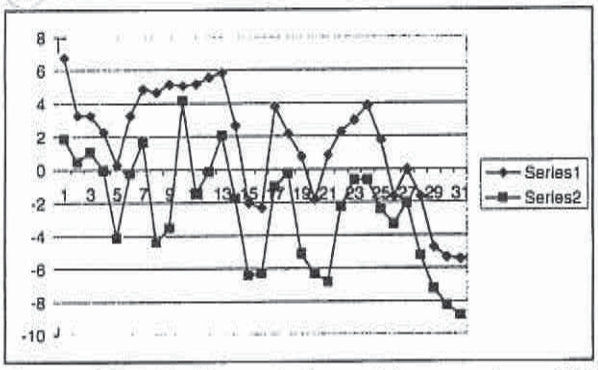


Figure 237. Daily variation of temperature (°C) in Helsinki during measurement period 1.12.-31.12.1999.

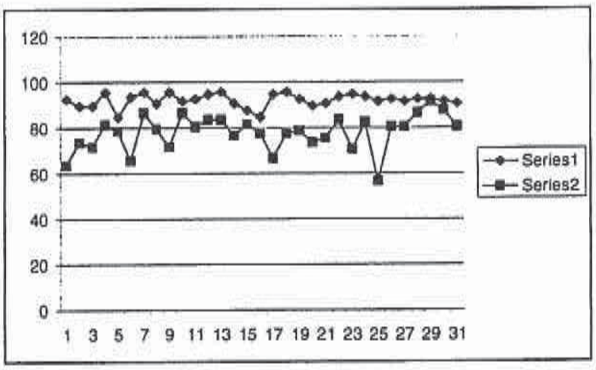


Figure 238. Daily variation of relative humidity (%) in Helsinki during measurement period 1.12.-31.12.1999.

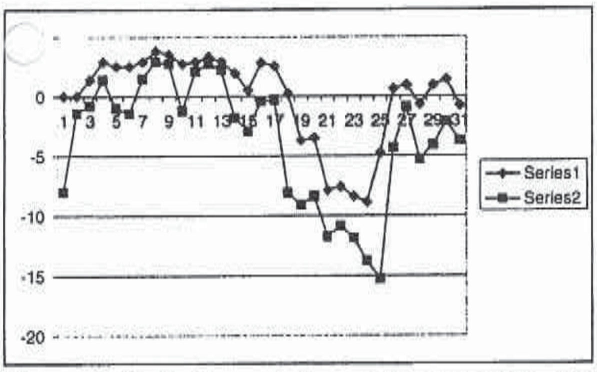


Figure 239. Daily variation of temperature (°C) in Helsinki during measurement period 1.1.-31.1.2000.

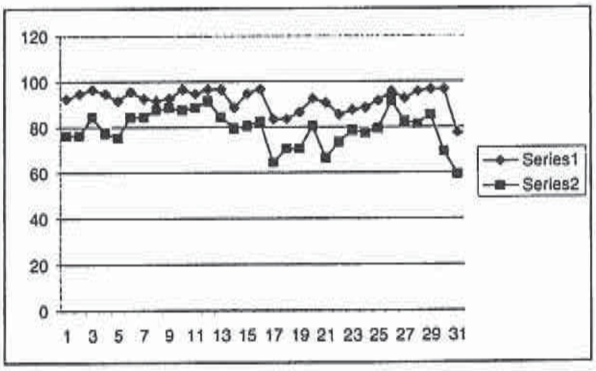


Figure 240. Daily variation of relative humidity (%) in Helsinki during measurement period 1.1.-31.1.2000.

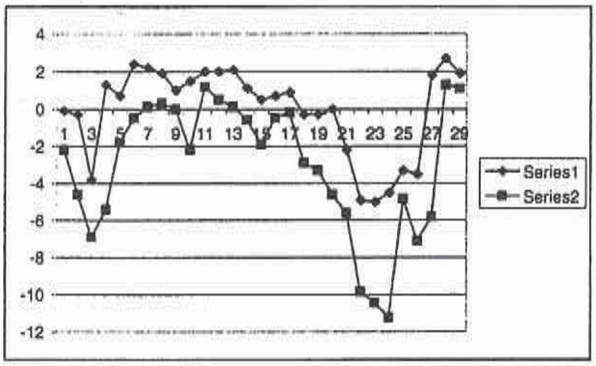


Figure 241. Daily variation of temperature (°C) in Helsinki during measurement period 1.2.-29.2.2000.

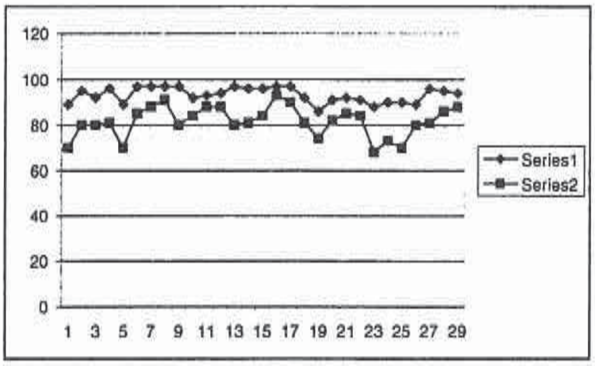


Figure 242. Daily variation of relative humidity (%) in Helsinki during measurement period 1.2.-29.2.2000.

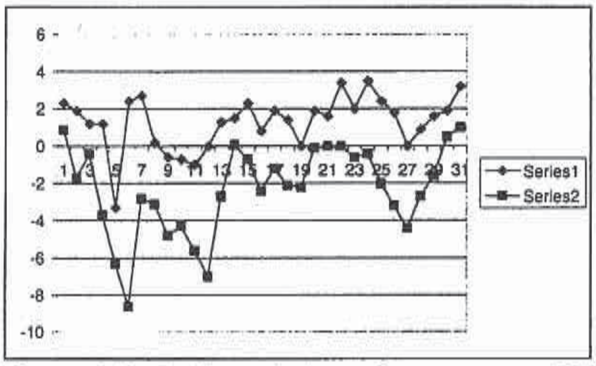


Figure 243. Daily variation of temperature (°C) in Helsinki during measurement period 1.3.-31.3.2000.

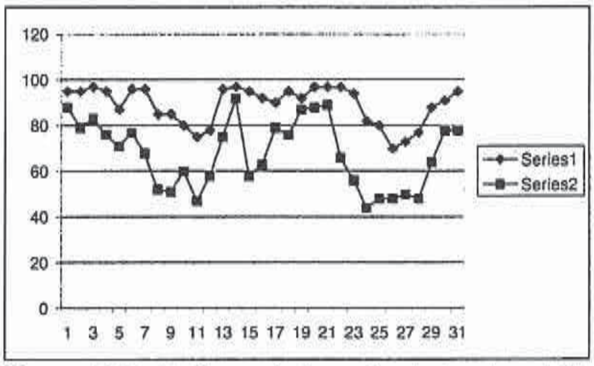


Figure 244. Daily variation of relative humidity (%) in Helsinki during measurement period 1.3.-31.3.2000.

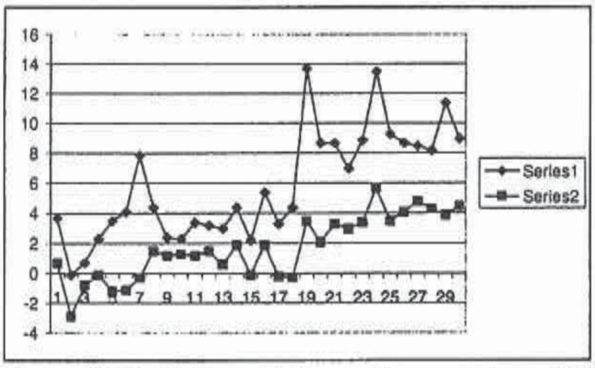


Figure 245. Daily variation of temperature (°C) in Helsinki during measurement period 1.4.-30.4.2000.

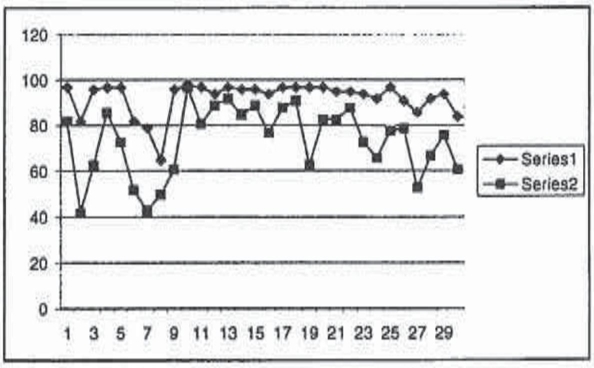


Figure 246. Daily variation of relative humidity (%) in Helsinki during measurement period 1.4.-30.4.2000.

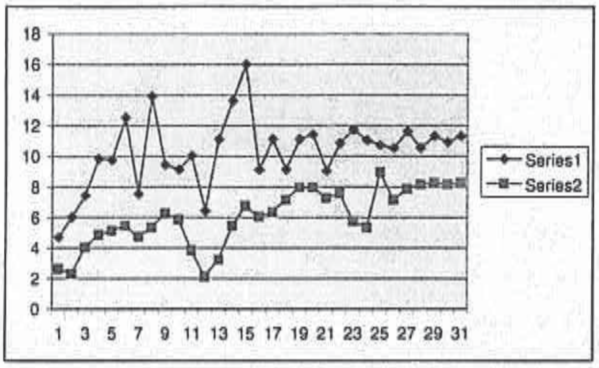


Figure 247. Daily variation of temperature (°C) in Helsinki during measurement period 1.5.-31.5.2000.

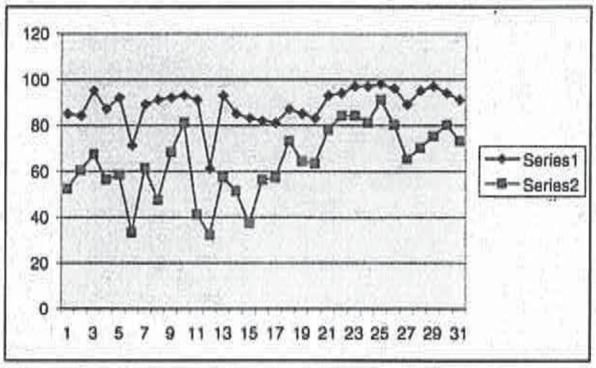


Figure 248. Daily variation of relative humidity (%) in Helsinki during measurement period 1.5.-31.5.2000.

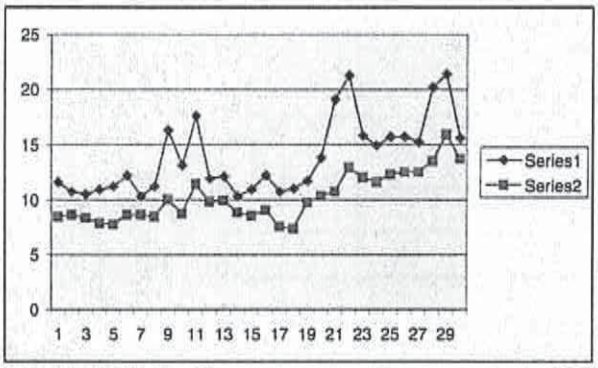


Figure 249. Daily variation of temperature (°C) in Helsinki during measurement period 1.6.-30.6.2000.

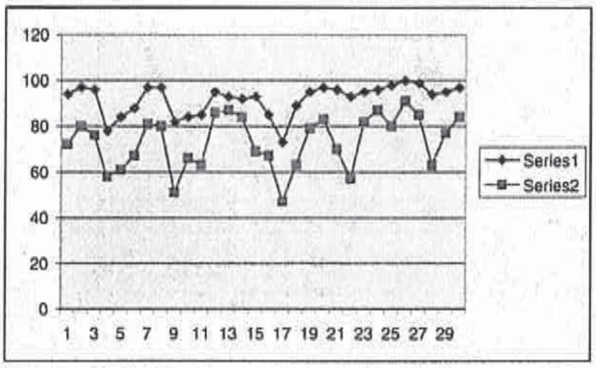


Figure 250. Daily variation of relative humidity (%) in Helsinki during measurement period 1.6.-30.6.2000.

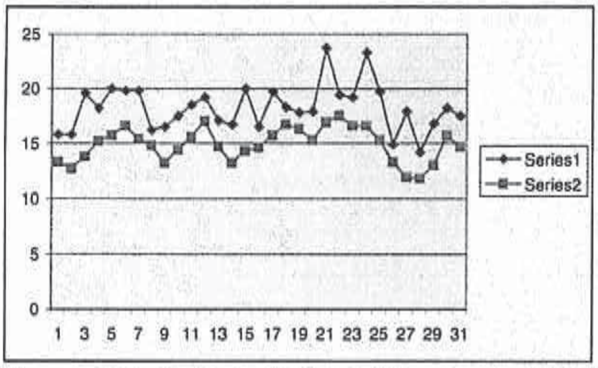


Figure 251. Daily variation of temperature (°C) in Helsinki during measurement period 1.7.-31.7.2000.

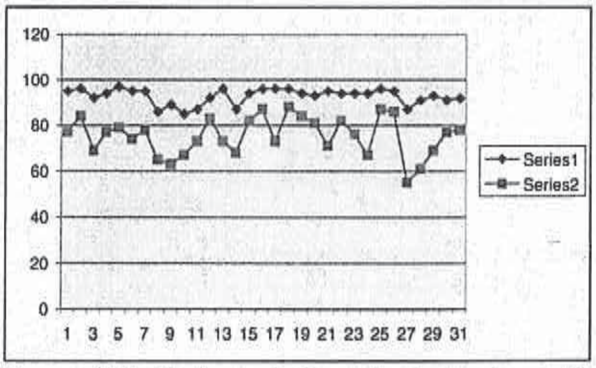


Figure 252. Daily variation of relative humidity (%) in Helsinki during measurement period 1.7.-31.7.2000.

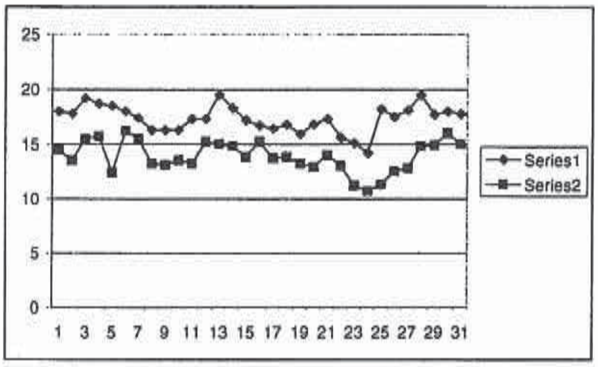


Figure 253. Daily variation of temperature (°C) in Helsinki during measurement period 1.8.-31.8.2000.

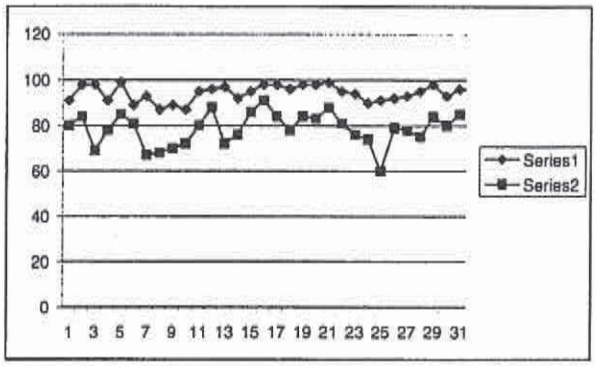


Figure 254. Daily variation of relative humidity (%) in Helsinki during measurement period 1.8.-31.8.2000.

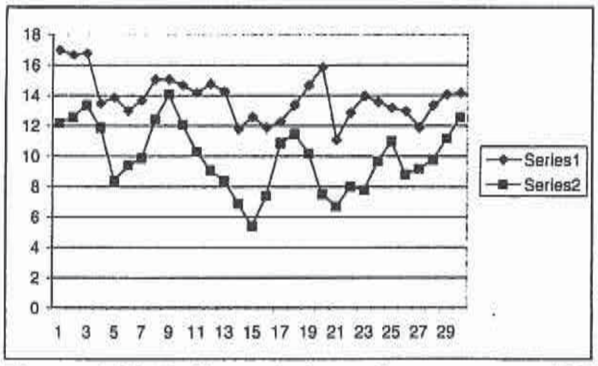


Figure 255. Daily variation of temperature (°C) in Helsinki during measurement period 1.9.-30.9.2000.

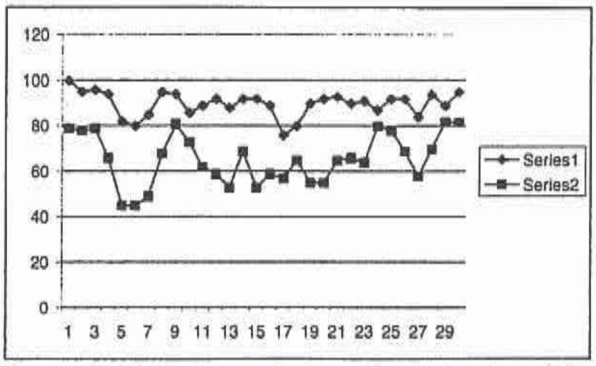


Figure 256. Daily variation of relative humidity (%) in Helsinki during measurement period 1.9.-30.9.2000.

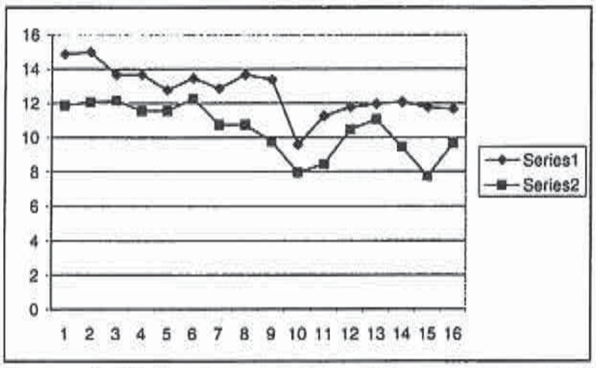


Figure 257. Daily variation of temperature (°C) in Helsinki during measurement period 1.10.-16.10.2000.

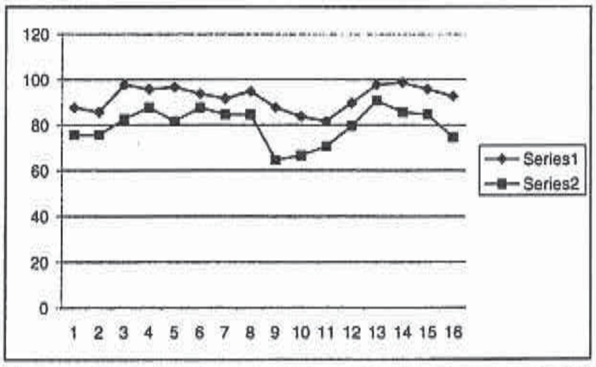


Figure 258. Daily variation of relative humidity (%) in Helsinki during measurement period 1.10.-16.10.2000.

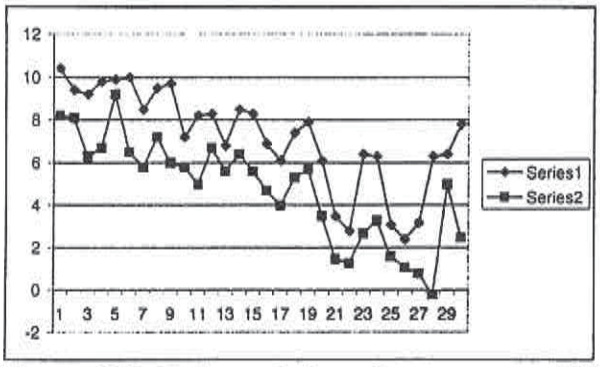


Figure 259. Daily variation of temperature (°C) in Helsinki during measurement period 1.11.-30.11.2000.

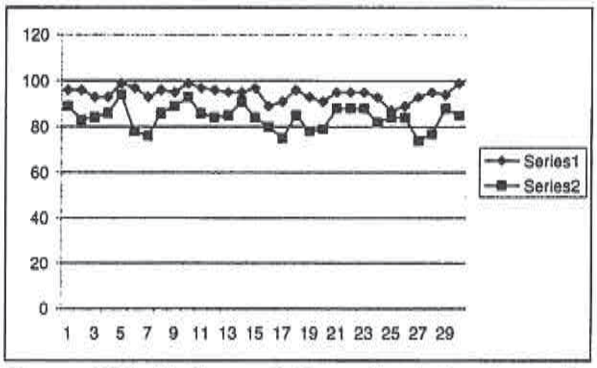


Figure 260. Daily variation of relative humidity (%) in Helsinki during measurement period 1.11.-30.11.2000.

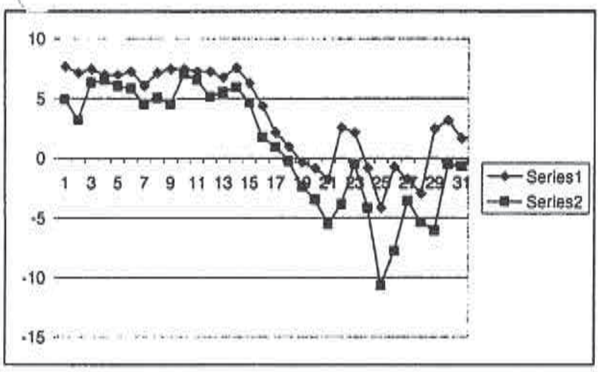


Figure 261. Daily variation of temperature (°C) in Helsinki during measurement period 1.12.-31.12.2000.

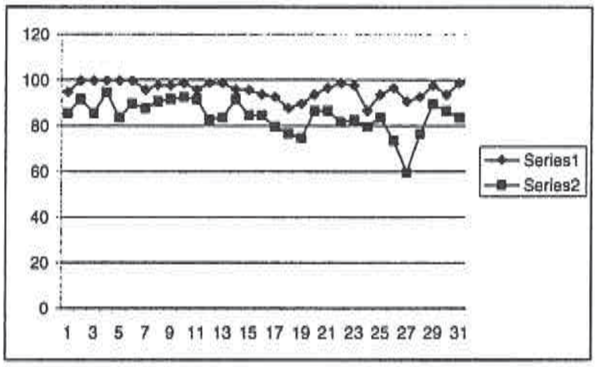


Figure 262. Daily variation of relative humidity (%) in Helsinki during measurement period 1.12.-31.12.2000.

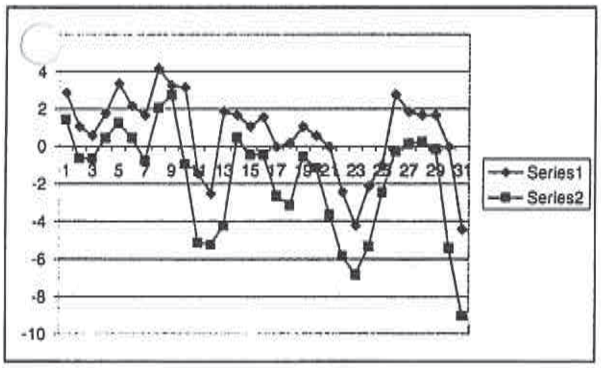


Figure 263. Daily variation of temperature (°C) in Helsinki during measurement period 1.1.-31.1.2001.

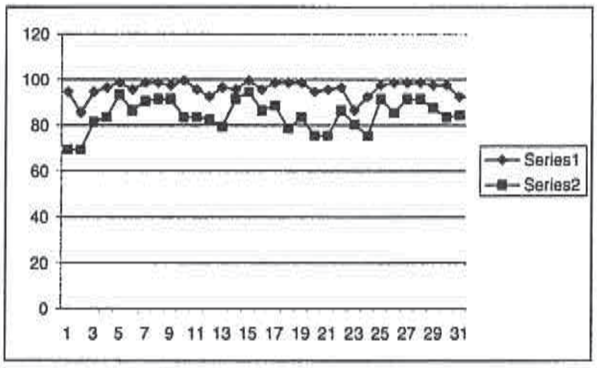


Figure 264. Daily variation of relative humidity (%) in Helsinki during measurement period 1.1.-31.1.2001.

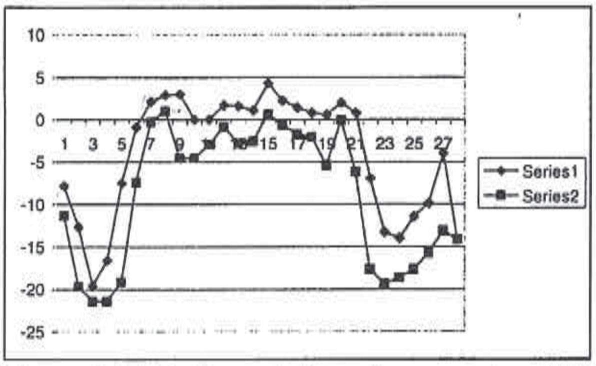


Figure 265. Daily variation of temperature (°C) in Helsinki during measurement period 1.2.-28.2.2001.

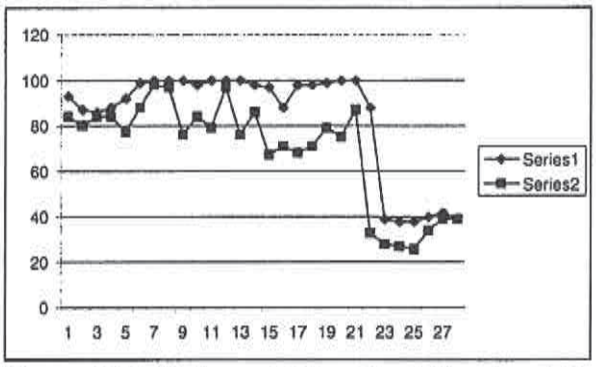


Figure 266. Daily variation of relative humidity (%) in Helsinki during measurement period 1.2.-28.2.2001.

4.8.2 Rainfall and sunshine

Daily rainfall and amount of sunshine in Helsinki area are presented in Figs. 267-310 according to the data of Finnish Meteorological Institute.

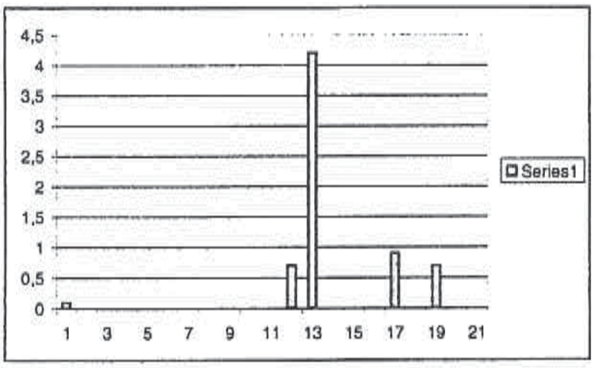


Figure 267. Daily rainfall (mm) in Helsinki during measurement period 11.5.-31.5.1999.

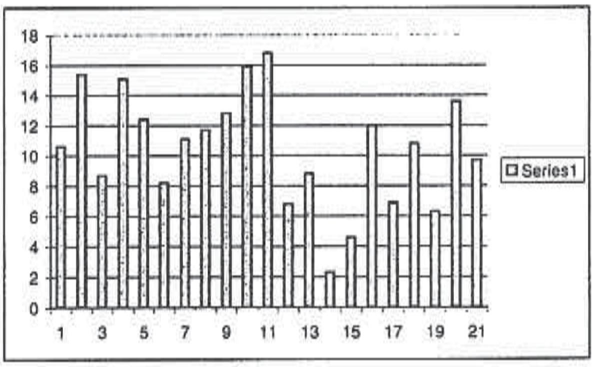


Figure 268. Daily amount of sunshine (h) in Helsinki during measurement period 11.5.-31.5.1999.

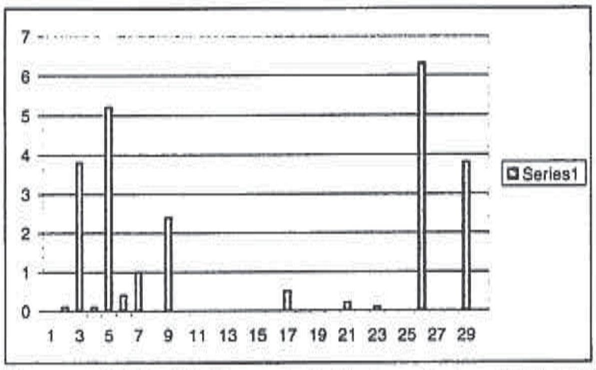


Figure 269. Daily rainfall (mm) in Helsinki during measurement period 1.6.-30.6.1999.

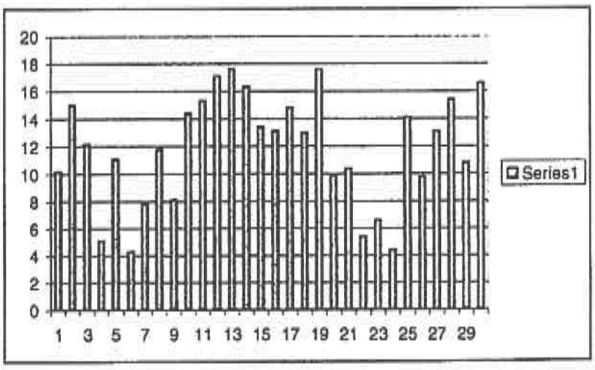


Figure 270. Daily amount of sunshine (h) in Helsinki during measurement period 1.6.-30.6.1999.

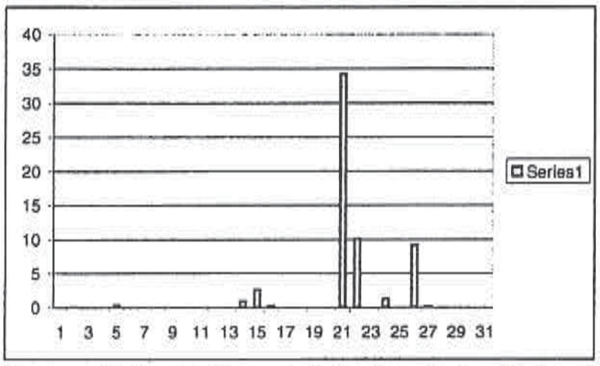


Figure 271. Daily rainfall (mm) in Helsinki during measurement period 1.7.-31.7.1999.

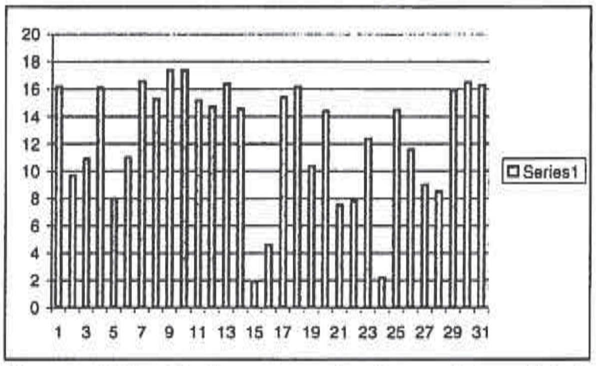


Figure 272. Daily amount of sunshine (h) in Helsinki during measurement period 1.7.-31.7.1999.

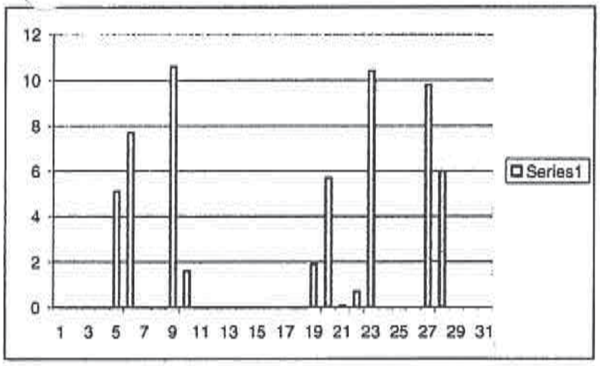


Figure 273. Daily rainfall (mm) in Helsinki during measurement period 1.8.-31.8.1999.

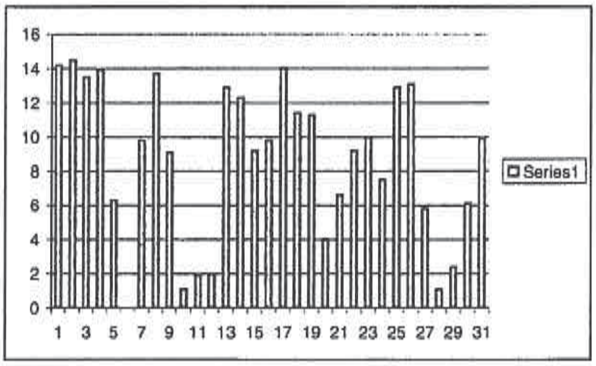


Figure 274. Daily amount of sunshine (h) in Helsinki during measurement period 1.8.-31.8.1999.

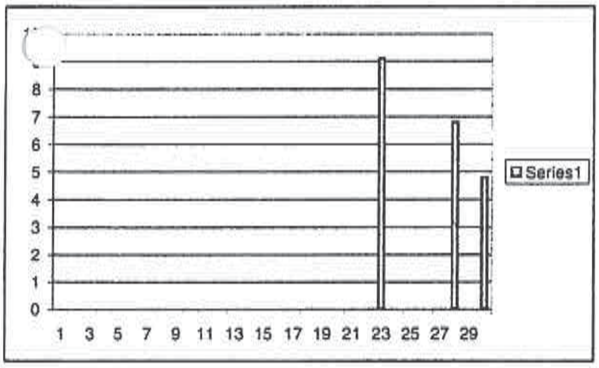


Figure 275. Daily rainfall (mm) in Helsinki during measurement period 1.9.-30.9.1999.

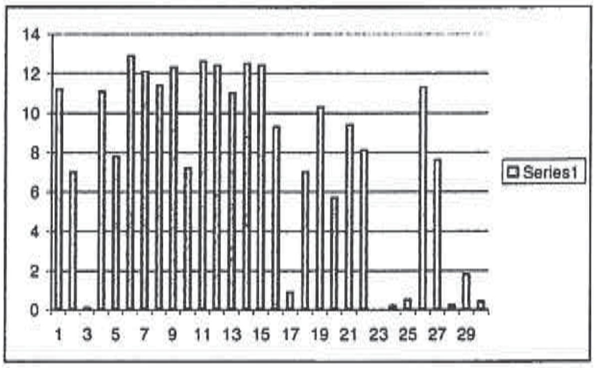


Figure 276. Daily amount of sunshine (h) in Helsinki during measurement period 1.9.-30.9.1999.

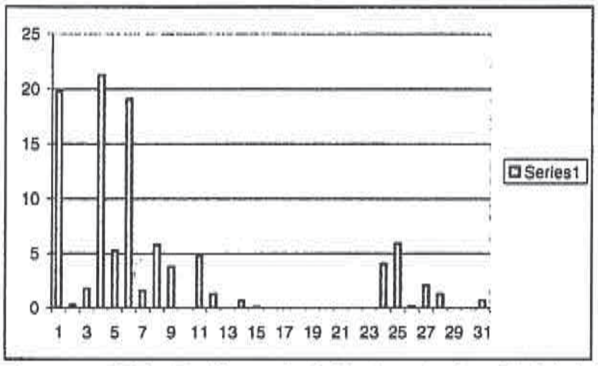


Figure 277. Daily rainfall (mm) in Helsinki during measurement period 1.10.-31.10.1999.

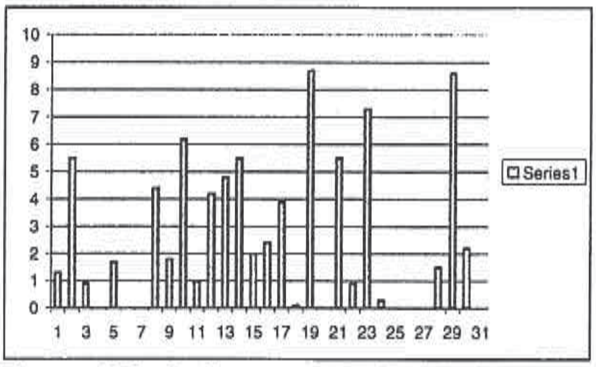


Figure 278. Daily amount of sunshine (h) in Helsinki during measurement period 1.10.-31.10.1999.

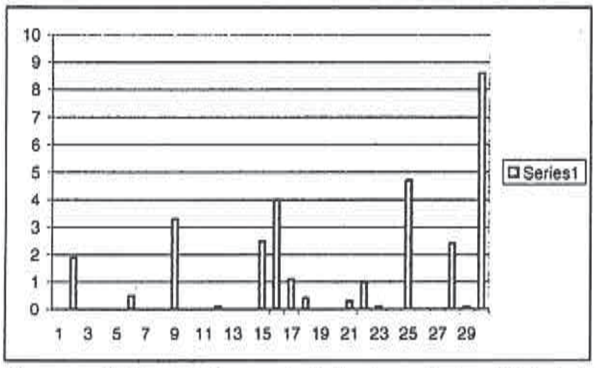


Figure 279. Daily rainfall (mm) in Helsinki during measurement period 1.11.-30.11.1999.

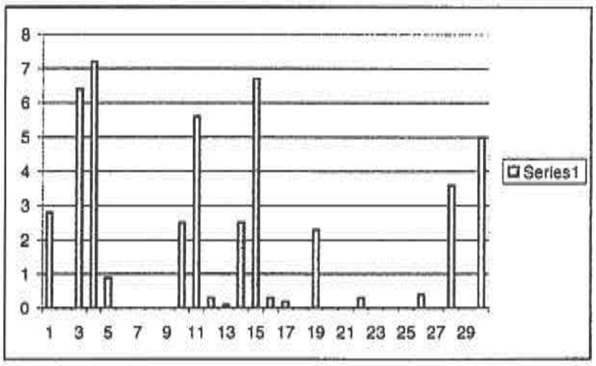


Figure 280. Daily amount of sunshine (h) in Helsinki during measurement period 1.11.-30.11.1999.

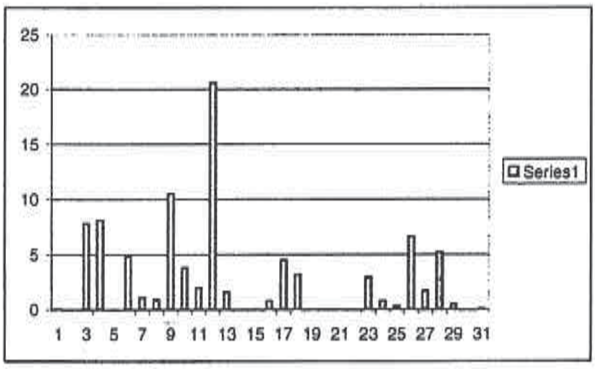


Figure 281. Daily rainfall (mm) in Helsinki during measurement period 1.12.-31.12.1999.

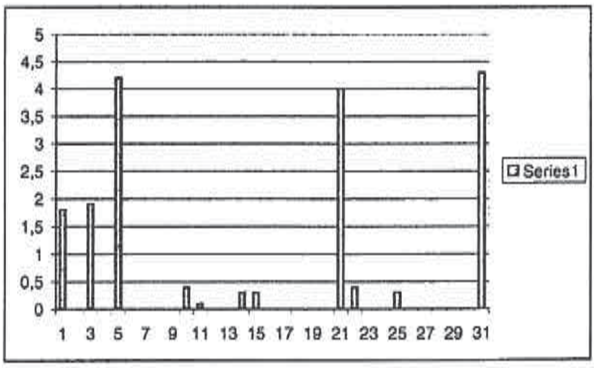


Figure 282. Daily amount of sunshine (h) in Helsinki during measurement period 1.12.-31.12.1999.

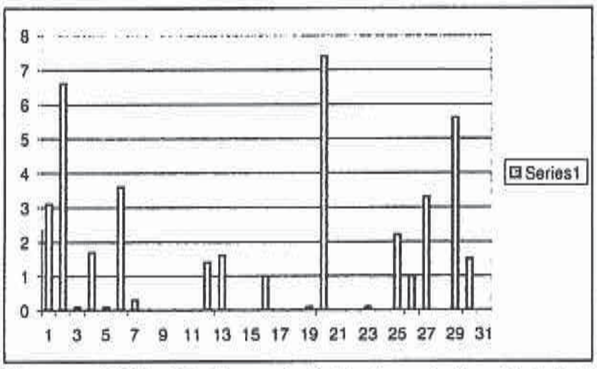


Figure 283. Daily rainfall (mm) in Helsinki during measurement period 1.1.-31.1.2000.

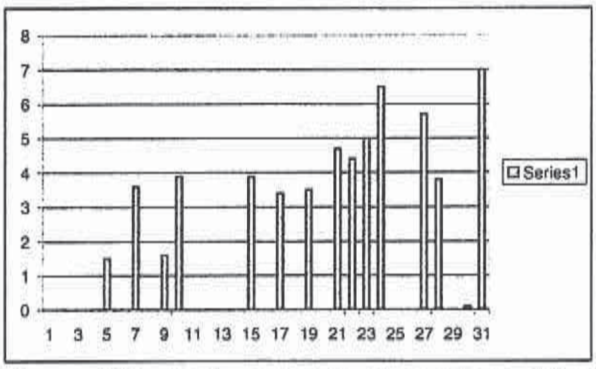


Figure 284. Daily amount of sunshine (h) in Helsinki during measurement period 1.1.-31.1.2000.

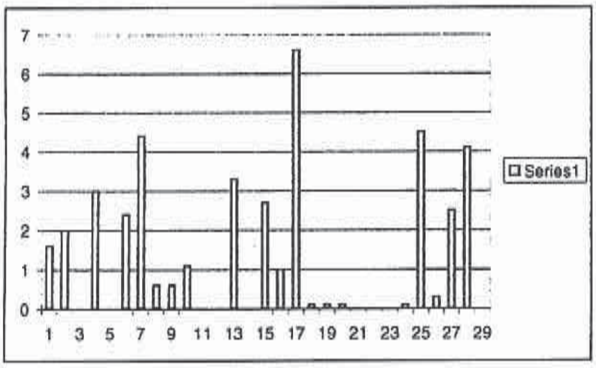


Figure 285. Daily rainfall (mm) in Helsinki during measurement period 1.2.-29.2.2000.

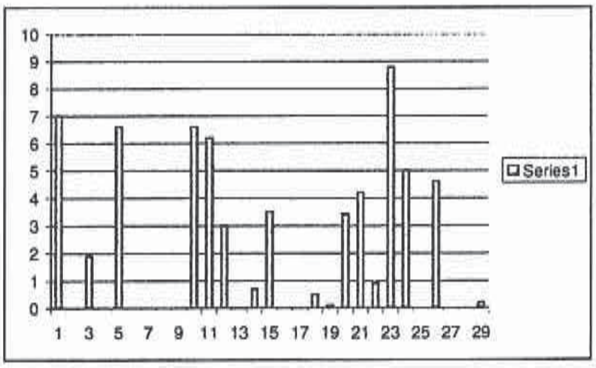


Figure 286. Daily amount of sunshine (h) in Helsinki during measurement period 1.2.-29.2.2000.

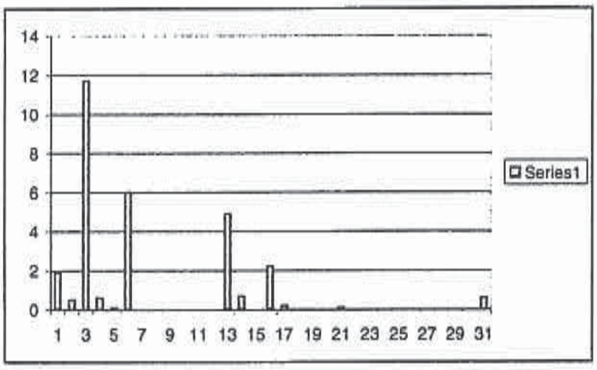


Figure 287. Daily rainfall (mm) in Helsinki during measurement period 1.3.-31.3.2000.

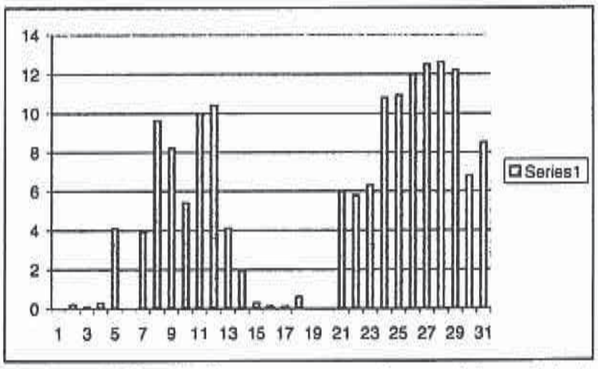


Figure 288. Daily amount of sunshine (h) in Helsinki during measurement period 1.3.-31.3.2000.

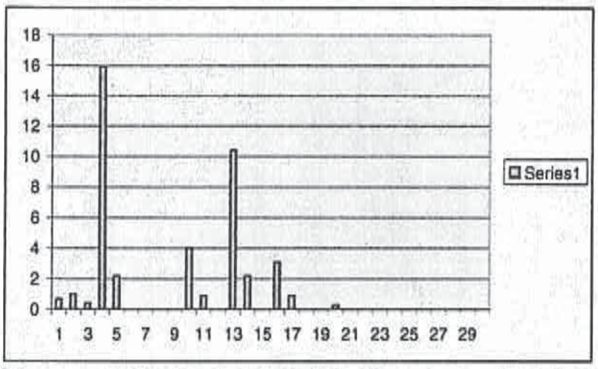


Figure 289. Daily rainfall (mm) in Helsinki during measurement period 1.4.-30.4.2000.

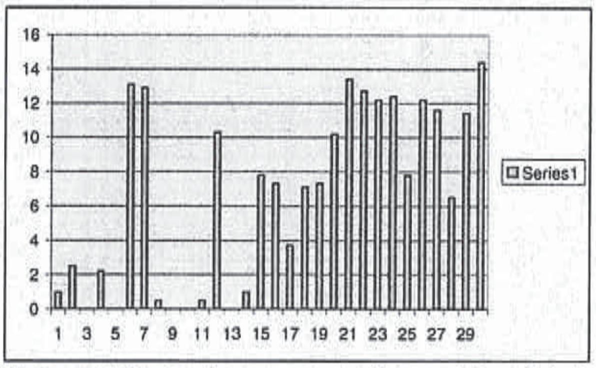


Figure 290. Daily amount of sunshine (h) in Helsinki during measurement period 1.4.-30.4.2000.

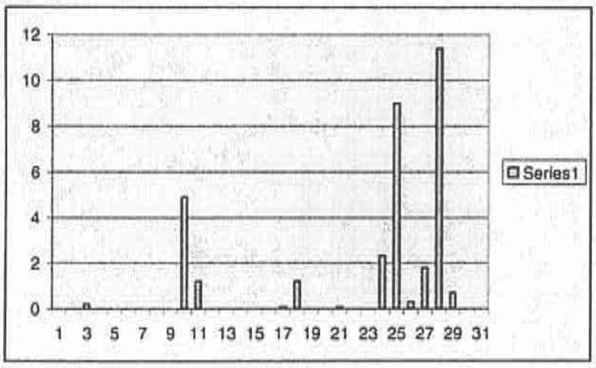


Figure 291. Daily rainfall (mm) in Helsinki during measurement period 1.5.-31.5.2000.

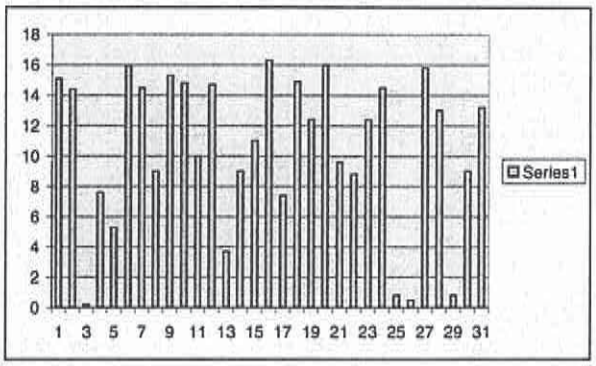


Figure 292. Daily amount of sunshine (h) in Helsinki during measurement period 1.5.-31.5.2000.

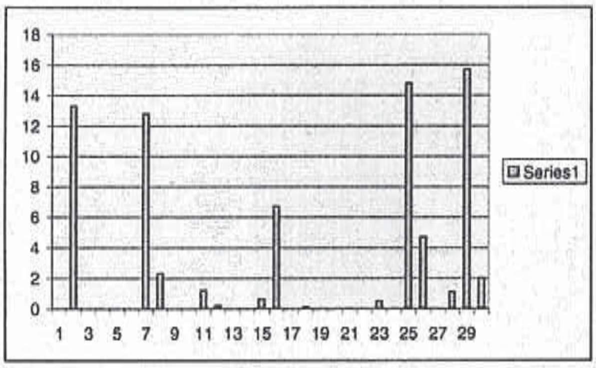


Figure 293. Daily rainfall (mm) in Helsinki during measurement period 1.6.-30.6.2000.

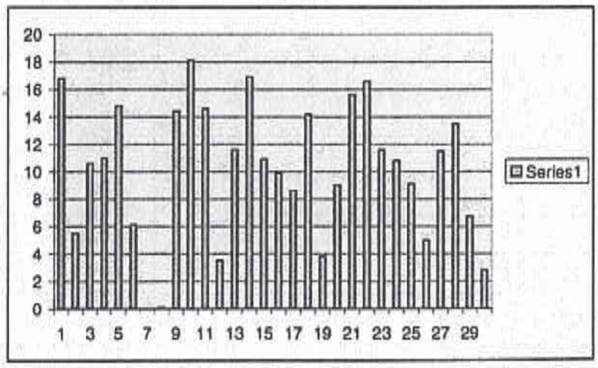


Figure 294. Daily amount of sunshine (h) in Helsinki during measurement period 1.6.-30.6.2000.

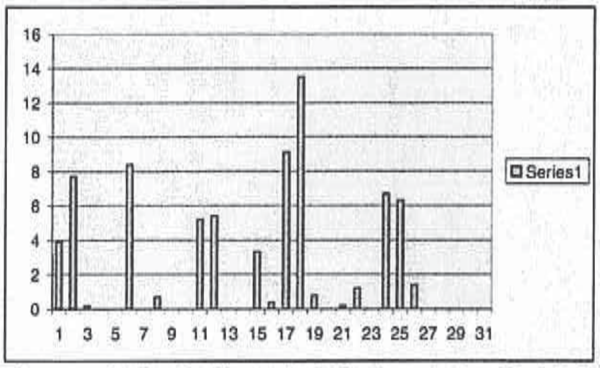


Figure 295. Daily rainfall (mm) in Helsinki during measurement period 1.7.-31.7.2000.

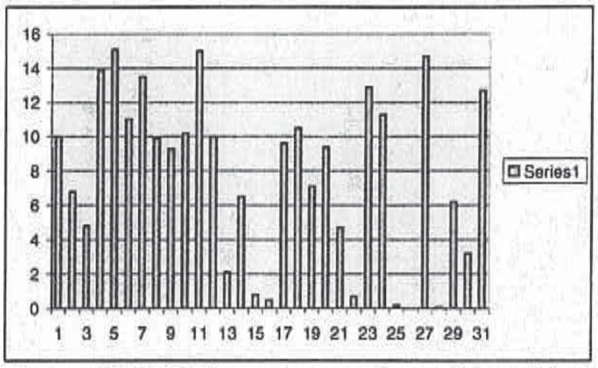


Figure 296. Daily amount of sunshine (h) in Helsinki during measurement period 1.7.-31.7.2000.

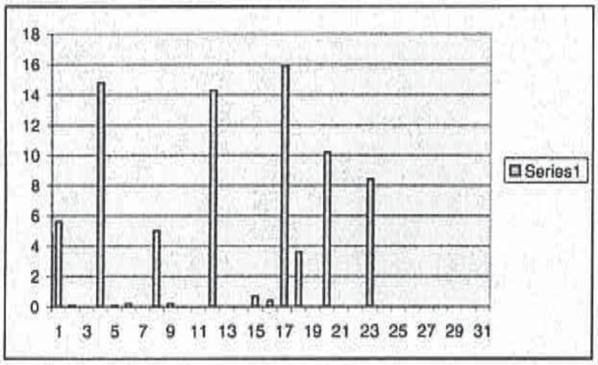


Figure 297. Daily rainfall (mm) in Helsinki during measurement period 1.8.-31.8.2000.

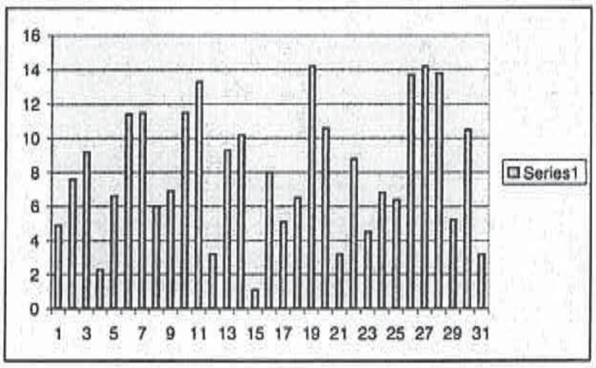


Figure 298. Daily amount of sunshine (h) in Helsinki during measurement period 1.8.-31.8.2000.

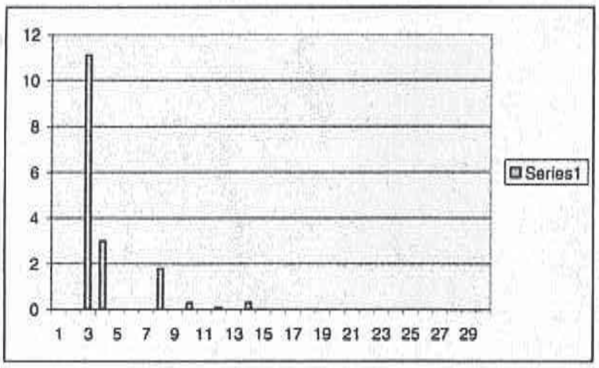


Figure 299. Daily rainfall (mm) in Helsinki during measurement period 1.9.-30.9.2000.

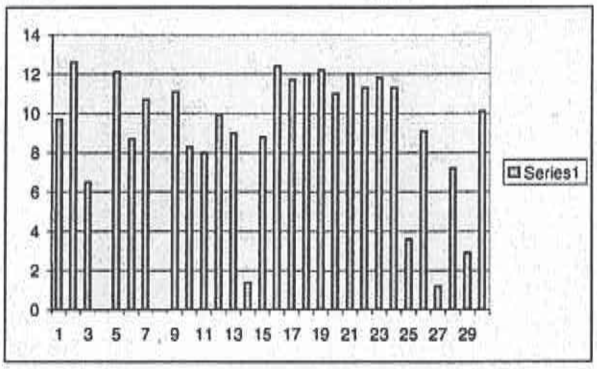


Figure 300. Daily amount of sunshine (h) in Helsinki during measurement period 1.9.-30.9.2000.

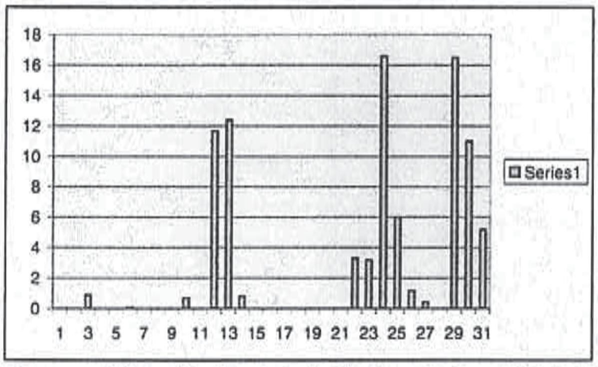


Figure 301. Daily rainfall (mm) in Helsinki during measurement period 1.10.-31.10.2000.

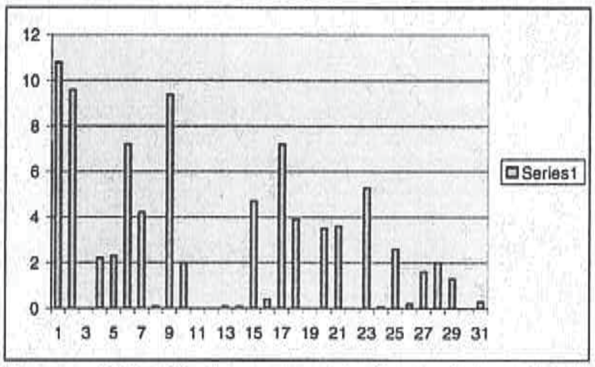


Figure 302. Daily amount of sunshine (h) in Helsinki during measurement period 1.10.-31.10.2000.

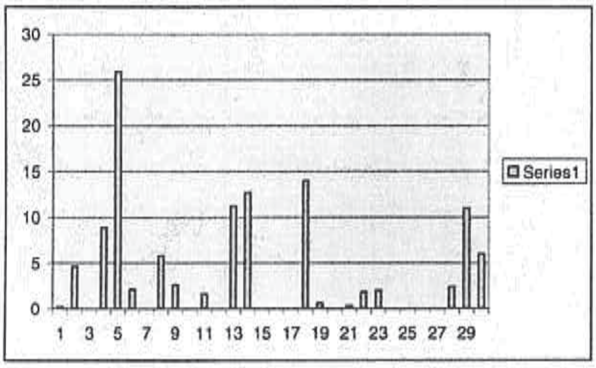


Figure 303. Daily rainfall (mm) in Helsinki during measurement period 1.11.-30.11.2000.

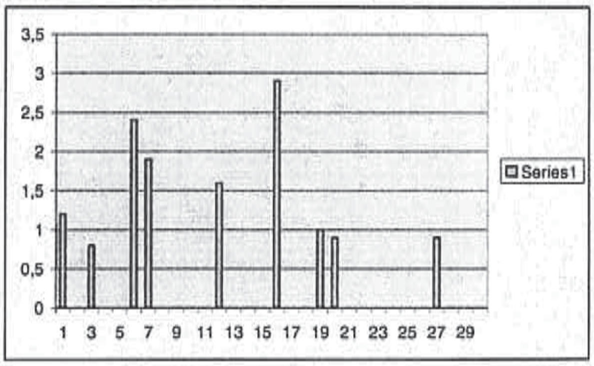


Figure 304. Daily amount of sunshine (h) in Helsinki during measurement period 1.11.-30.11.2000.

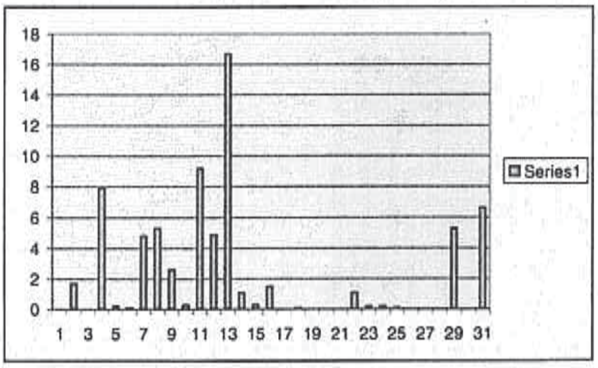


Figure 305. Daily rainfall (mm) in Helsinki during measurement period 1.12.-31.12.2000.

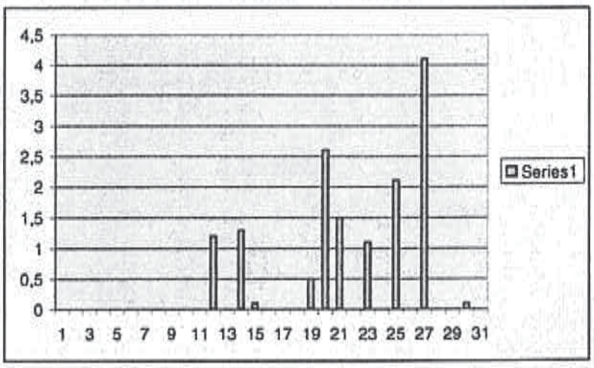


Figure 306. Daily amount of sunshine (h) in Helsinki during measurement period 1.12.-31.12.2000.

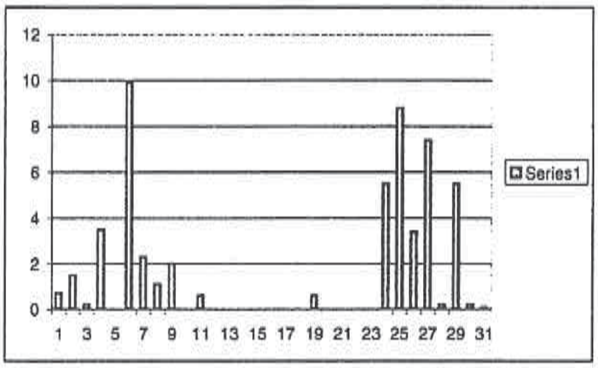


Figure 307. Daily rainfall (mm) in Helsinki during measurement period 1.1.-31.1.2001.

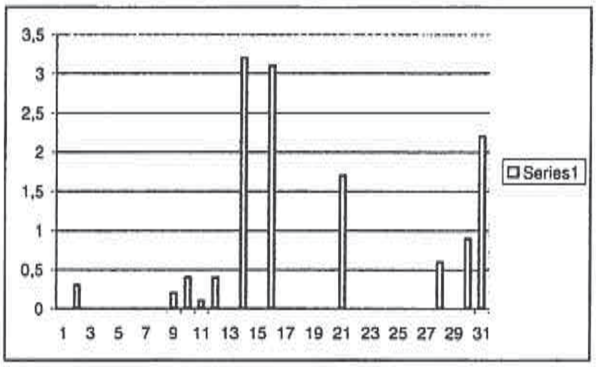


Figure 308. Daily amount of sunshine (h) in Helsinki during measurement period 1.1.-31.1.2001.

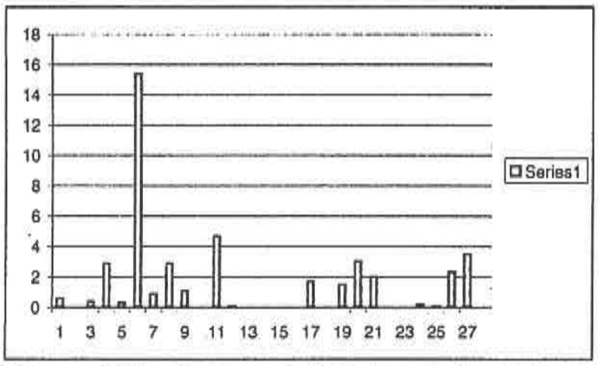


Figure 309. Daily rainfall (mm) in Helsinki during measurement period 1.2.-28.2.2001.

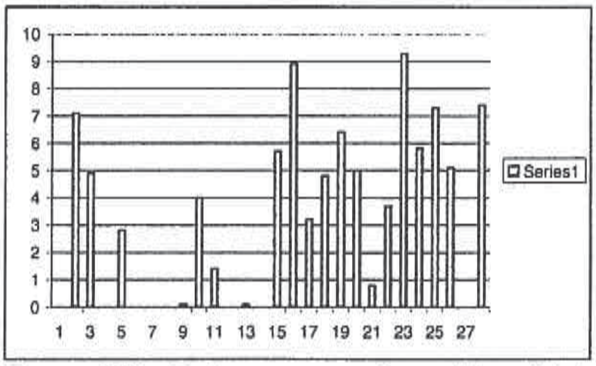


Figure 310. Daily amount of sunshine (h) in Helsinki during measurement period 1.2.-28.2.2001.

5 DISCUSSION

5.1 Temperature gradient

According to the temperature data recorded it seems that in general the temperature of the inner surface of marble slabs was higher than that of the outer surface. Especially this was the case on western and northern walls, where the inner surface temperature was 1-2°C higher than the corresponding outer surface temperature. Only during the warmest season of the year, June-August, the temperatures were almost the same on both sides of the slabs. The outer surface temperature was occasionally even higher.

On eastern walls the outer surface temperature was usually higher than the inner surface temperature during summer time. The temperature difference varied between 1-4°C. A similar trend was observed in the warmest days of autumn, but then the temperature difference was only about 1°C in favour of the outer surface. For the rest of the year the inner surface was a little warmer than the outer surface.

Measurement results from southern walls resembled those from eastern walls. During summer time and during the warmest days of autumn the outer surface was warmer, but otherwise the temperature was higher on the inner surface. The temperature differencies during summer and autumn were approximately as high as on eastern walls, but during winter the inner surface was about 1°C and during spring even 1-5°C warmer than the outer surface. However, the results from the measuring point A, which was also on southern wall, were different from those presented above. At that point the inner surface temperature was always 1-2°C, during summer time even 2-4°C, higher than the outer surface temperature. Because the measuring point A located on top of the wall of the tower part of the building, this could be due to "chimney effect". In that case high inner surface temperatures would be a consequence of the effect of warm air rising up from the roof through the ventilation slot.

5.2 Daily variation of temperature

The daily variation of temperature of the marble slabs was substantial. It was most prominent during the warm seasons reflecting the natural weather conditions. In addition to the season the amount of variation depended also on the location of the slab with respect to the cardinal points.

On northern walls the average daily variation of temperature was 10-15°C during summer (June-August), 5-10°C during spring (February-April) and only 2-3°C during winter (November-January). In May and in September it was around 10°C and in October around 5°C. The maximum temperature recorded varied accordingly from 30-35°C in summer to around zero in winter. The minimum temperature varied between 5-10°C in summer, but could be as low as -25°C in winter.

On western walls the average daily variation of temperature varied between 15-20°C during the time period from March to September. In winter, from November to January, the variation was only 1-5°C. Between these two periods, i.e. during February and October, the variation was 5-10°C. The maximum temperature varied from 35-40°C in summer to around zero in mid-winter. The minimum temperature was around 10°C in summer but as low as -25°C in winter.

On eastern walls the average daily variation of temperature varied between 15-20°C in summer (June-August), between 5-10°C in spring (March-April) and between 2-5°C in winter (November-January). During May and September it was 10-15°C and during February and October around 5°C. The maximum temperature varied from 35-40°C in summer to about 5°C in winter. The corresponding minimum temperatures were 10°C and -25°C.

On southern walls the average daily variation of temperature varied between 15-20°C in summer (May-September), between 10-15°C in spring (March-April) and between 5-10°C in winter (October-February). The maximum temperature varied from 35-40°C in summer to about 15°C in winter. The minimum temperature was about 10°C in summer and about -25°C in winter.

On top of the tower wall (measuring point A) the daily variation of temperature during summer and spring was roughly 5°C higher than on southern walls in general. Correspondingly, the maximum temperatures were even 10°C higher than on lower parts of the roof walls. Highest temperatures were measured on the outer surface of black granite slab beside the measuring point A. They were in general 5-10°C higher than the temperatures on the outer surface of the marble slab.

5.3 Gradient of temperature variation

The daily variation of temperature did not occur evenly in the marble slabs. This can be considered to be significant, because uneven stressing of marble could be one of the factors leading to bowing of the slabs.

On northern walls the differencies in the temperature variation between the surfaces were small, and the direction of the gradient changed frequently from one side to another. Most of the time, however, the variation was wider on the outer surface of the slab. Compared to the variation on the inner surface the difference was only 0-1°C.

On western walls the temperature variation was wider on the outer surface of the slab. The difference was noteworthy, 2-4°C, during warm season (April-September), but almost insignificant, 0-1°C, for the rest of the year. In mid-winter the difference between the surfaces in this respect was practically zero.

Also on eastern walls the temperature variation was wider on the outer surface of the slab. The difference was remarkable, 3-4°C, in summer (May-September). During spring (February-April) and late autumn (October) the difference was smaller but clear, 0-2°C. In winter (November-January) the variation was practically equal on both sides of the slab.

On southern walls the temperature variation was wider on the outer surface of the slab except during winter time when the situation was the other way around. In winter (November-February) the difference was 1-2°C, in January even 3-4°C, in favour of the inner surface, but during the rest of the year the difference was 2-3°C, in May-June even 3-4°C, higher on the outer surface. During the turning periods, in October-November on one hand and in March on the other, the direction of the gradient could be either way.

The results from the measuring point A deviated again from the general trend presented for southern walls. Excluding the mid-winter the variation at that point was wider on the inner surface of the slab. The difference was 2-3°C during February-September and 0-2°C during October-December. In March it was 3-4°C and in September even 5°C. In January the variation was 2-3°C wider on the outer surface. The observed behaviour could be a consequence of the "chimney effect" as discussed in chapter 5.1.

5.4 Freeze/thaw -cycling

The number of freeze/thaw -cycles during the whole monitoring period of 22 months was amazingly high. The most reliable results were those from the measuring points D and E as their data covered the time period almost completely. The number of freeze/thaw -cycles defined as presented in chapter 4.5 was around 90 in the point D and even 110 in the point E. In addition, it must be noted that for two whole years the data from two important months, March and April, was missing. These could have meant 20-30 cycles more, so that the total amount of cycles during two years would have been 120-140. Thus the annual amount of freeze/thaw -cycles seems to have been something like 60-70, while the earlier estimate has been about 20.

The definition of the freeze/thaw -cycle used in this study can be criticized for not being strict enough as the temperature limits were set to -0.3°C for freezing and +0.3°C for thawing. Water in marble probably requires lower temperatures in order to freeze, correspondingly higher temperatures in order to melt. Setting the temperature limits further from zero would diminish the amount of freeze/thaw -cycles, even considerably if the limits are set far enough. However, as the threshold values for temperatures are not known, the estimates presented here can be used as long as the limitations connected to the definition are remembered. On the other hand only one cycle per day was calculated in this study as maximum and minimum daily temperatures were used. In reality more than one cycle can occur even in the same day.

The worst directions from the frost resistance point of view seem to be south and east. Considerable amount of data was lacking from northern and western walls. The results would indicate that the amount of cycles has been lower in these directions, though it has been rather high especially on western walls.

The amount of freeze/thaw -cycles seemed to be a little lower on the inner surface of the marble slab than on the outer surface. The difference was about 10%. As this causes a higher stress to the outer surface than to the inner this could be one of the factors contributing to bowing of the slabs.

Only during the three summer months, June-August, no freeze/thaw -cycles were observed. The worst period of time in this respect was naturally that from November to March. It seemed that southern walls were especially stressed during November-January while the others suffered most during February-March. During October some cycles were detected on all walls. Excluding southern walls the situation was the same during April. During May and September some occasional freeze/thaw -cycles were observed on other walls except the southern ones.

5.5 Relative humidity

In general the values of relative humidity were fairly high. During autumn and winter the average relative humidity values were even higher than during spring and summer. This was due to the fact that the daily minimum rose from the value of about 20%, which was typical of summer, to 60-80%, or even higher.

On southern walls there seemed to be a difference between the relative humidity of outdoor air and that of the ventilation slot for the most of the year meaning a humidity gradient over the marble slab. The direction of the gradient was not the same all of the time, however. During summer (May-August) the average relative humidity was higher inside the ventilation slot, though the difference was rather small. It was due to the fact that the minimum value was higher than that of outdoor air and thus the variation of relative humidity was smaller inside. The situation was exactly the other way around during November-December, when the minimum relative humidity inside the ventilation slot was smaller than that of outdoor air meaning wider variation of humidity inside. However, the most remarkable difference was observed during January-April. During that time period both the maximum and the minimum relative humidities were higher in outdoor air than in the ventilation slot. Thus, the conditions were considerably more humid on the outer surface of marble than on the inner surface. Only during September-October the humidity conditions were similar on both sides of the marble slab.

On eastern walls the humidity conditions were much more even than on southern walls. There were no great differencies between the relative humidities of outdoor air and that of the ventilation slot. Only during winter time, from January to March, both the maximum and the minimum relative humidities were higher in outdoor air than in the ventilation slot. Thus, the conditions were considerably more humid on the outer surface of marble than on the inner surface.

The difference in relative humidity between outdoor air and the ventilation slot causes a higher stress on the outer surface of marble than on the inner. Thus, this could be one of the factors contributing to bowing of the slabs.

5.6 Acidity of rain water

The pH-value of rain water varied between 4.3 and 5.3 during 1999 the weighted average being 4.8. The values of the year 2000 were not available, but most probably the situation was very similar to that in 1999. Although the acidity of rain water has diminished, i.e. the pH-value increased, during the last decade it still acts like a weak acid. Thus, it forms a stressing factor to all materials subjected to rain water. Its effect must especially be taken into account when materials like marble which are very reactive in acidic surroundings are considered.

6 CONCLUSIONS

According to the temperature and humidity data recorded the prevailing environmental conditions include several factors that cause stress to the marble facades of Finlandia Hall. The intensity of these factors was not the same everywhere but depended on the cardinal point towards which the walls were directed. It seemed that in general the sum of the stressing factors was highest on southern walls and lowest on northern walls.

The annual variation of temperature is one of the stressing factors. The minimum temperature recorded during the monitoring period was about -25°C on all walls. The corresponding maximum temperature varied from about 35°C on the northern side to about 50°C on top of the southern side of the tower part of the building.

The daily variation of temperature was also considerable. The average variation was highest on southern walls, 15-20°C during summer and 5-10°C during winter time. On northern walls the average variation was lowest varying between 10-15°C during summer and 2-3°C during winter. Occasionally the daily variation could be even twice the average.

Freeze/thaw -cycling caused also stresses to marble and facade structures. According to the results the annual amount of cycles can be as high as 60-70. The freeze/thaw -effect was prominent at least on southern and eastern walls, probably also on western walls.

At least two other stressing factors were observed: variation of humidity and acidity of rain water. During summer and spring the relative humidities, especially the daily minimum values, were varying sharply depending on whether it was raining or not. During colder seasons the humidity conditions were much more even. The pH-value of rain water varied between 4 and 5 creating acidic conditions that can affect the highly reactive marble.

In addition, three factors causing a higher stress on the outer surface of marble than on the inner were observed: the average daily variation of temperature, the number of freeze/thaw -cycles and the relative humidity were higher on the outer surface. The differencies were small, but all of them had a parallel effect. Thus, these could be at least some of the factors contributing to bowing of the slabs.