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URBAN EFFECT ON CLIMATIC ELEMENTS IN FINLAND

by

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Abstract

The effect of urbanization on climatic elements was analyzed by means of climatological observations of two Finnish towns and their surroundings, 1961–1975. Higher temperatures are normally observed within an urban area, although both the town stations are affected by their park settings. In Helsinki the difference between the town centre and its rural environs is 0.5–1.0°C in mean temperature and about 2°C in minimum temperature, while the difference in maximum temperature is slight. In a smaller town, Jyväskylä, the corresponding differences are about half as much. No essential change of the urban effect was found since the 1930s. Relative humidity has an inverse relationship with temperature, but the urban-rural differences are quite small. The differences with regard to cloudiness and precipitation are obscure and the urban effect is doubtful.

1. *Introduction*

The influence of the activities of man on climate in different scales has attracted much attention during recent years. On a limited scale the town provides an example of the modification of natural conditions. The term urban climate is widely used and urban climatology has aroused scientific interest and gained practical importance.

Although densely populated regions represent a minor area, the population is, however, centred in towns, and the urban environment is becoming of more direct concern to a larger number of people. The need for more detailed knowledge of the urban environment has led to numerous studies on urban climate. In addition, most of the longest climatological observation series are from towns; thus the study of climatic changes also involves knowledge of the effect of urbanization on climatic elements.

A well-known study by KRATZER [12] summarizes the features of urban climate revealed in many towns, primarily in Europe. The most extensive survey on urban climate undertaken so far covered London (CHANDLER [2]). It is a combination of both the statistical treatment of fixed stations and the local details by mobile traverse methods. The 1968 WMO Brussels symposium on Urban Climates (WMO [21]), however, can be regarded as a cornerstone of modern urban climatology. The abundant recent literature in this field has been summarized *e.g.* by CHANDLER [4] and OKE [16].

In Finland urban climatological investigations have been made by ALESTALO [1], FÅGELBERG *et al.* [6] and TOMMILA [19]. All of these contain information on temperature conditions for Helsinki. Moreover, a few studies have concentrated on air pollution conditions in Finnish towns.

This study is limited to the climatological effects of towns using the observations of such customary climatological elements as temperature, humidity, cloudiness and precipitation made at fixed stations in two towns and their surrounding areas (Fig. 1). The towns studied represent large and middle-sized towns in Finland, although on a world-wide scale Helsinki (500 000 inhabitants) and Jyväskylä (60 000) may be regarded as middle-sized and small, respectively.

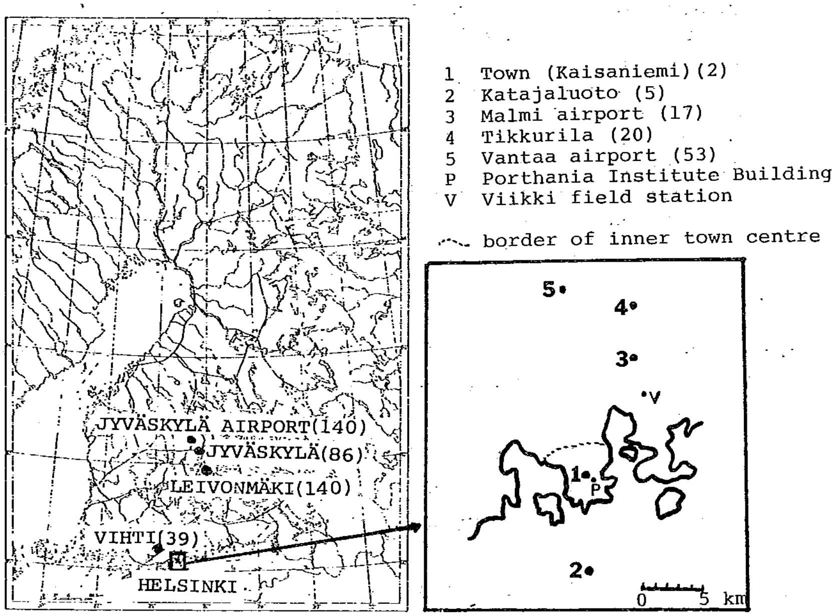

Fig. 1. Meteorological stations in Helsinki and Jyväskylä and in their surroundings. In brackets, the elevation of the station above sea level (m).

Owing to the short simultaneous observation periods the data used in the comparisons are taken primarily from the statistics for the period 1961–1975 (HEINO [8]). In order to determine the change in the effects due to the urban growth some comparisons have also been made using older observations.

As pointed out by LANDSBERG [13] and MUNN [15], for historical reasons towns are located in special topographic settings (coast lines, river valleys, slopes, etc.) and rarely on flat plains; by nature they have a microclimate different from that of the surroundings. The differences are especially great if the comparison stations are located at airports.

These remarks are also valid for this study. In the case of Helsinki it is difficult to separate urban effects from the influence of the sea. Jyväskylä is thus a better place for comparisons, although the differences in the elevation may make comparisons more difficult. In addition to the disturbances due to different topographic settings urban areas are far from uniform. The distribution of built-up areas and parks varies from one town to another. In this study the urban stations are located in parks and the differences shown by these stations certainly underestimate the urban effects.

2. *Temperature*

The thermal modification of the urban atmosphere is usually connected with the »heat island», which has received increasing attention during recent decades. CHANDLER [3] has summarized that the factors leading to the excess heat of towns are changes i) in the thermal characteristics of the surface, ii) in the airflow patterns, iii) in evaporation rates and iv) in heat added by human activities.

The relative importance of these factors varies from town to town and also depends on the time of year and time of day. It has also been demonstrated that the heat island of a town is weaker on Sundays than on other days of the week reflecting the cycle of human activities (MITCHELL [14], MUNN [15]). In addition, the form and intensity of the heat island depend on many other factors (topography, maritimity, etc.) and are on any particular day or night highly modified by atmospheric conditions, especially by wind and cloudiness.

The average temperature differences are presented in Tables 1–3 for Helsinki and Jyväskylä and their surroundings. The location of Helsinki on the coast makes the comparisons with the surrounding (northern) rural areas difficult. The marine influence is strong and affects the temperature at different times of day and year in different ways.

TARAND [18] has determined a quantitative expression of the marine influence on temperature on the Estonian Baltic coast. The annual mean temperature is

Table 1. Differences in monthly and annual mean temperature (°C) between the stations situated in urban and adjoining rural areas, 1961–1975.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
HELSINKI													
Town													
– Katajaluoto	–0.6	0.3	0.9	1.4	2.3	1.9	1.3	0.5	–0.3	–0.6	–0.8	–0.8	0.4
– Malmi airport	1.1	1.1	1.0	0.4	0.0	0.2	0.4	0.5	0.8	0.9	0.9	1.0	0.7
– Tikkurila	1.2	1.1	0.9	0.3	–0.2	0.1	0.3	0.6	0.9	1.0	1.1	1.2	0.7
– Vantaa airport	1.2	1.1	0.9	0.4	–0.2	0.0	0.3	0.5	1.0	1.1	1.3	1.3	0.7
– Vihti	2.0	1.9	1.8	0.7	0.1	0.5	1.0	1.4	1.6	1.5	1.6	1.7	1.3
JYVÄSKYLÄ													
Town													
– Airport	0.6	0.7	0.9	0.8	0.8	0.7	0.6	0.7	0.8	0.7	0.7	0.5	0.7
– Leivonmäki	0.5	0.4	0.4	0.5	0.4	0.7	0.7	0.7	0.6	0.5	0.4	0.4	0.5

0.2°C higher on the coast than at a distance of 1 km inland. In the course of the year the difference varies between 0.5°C (January) and –0.3°C (May). At a distance of more than 1 km the influence of the sea becomes weaker. On the northern coast of the Gulf of Finland, VAAJAMA [20] has shown the coastal temperature advection to extend 5–8 km inland from the coast line.

With regard to annual mean temperature (Table 1) the sea has a cooling effect on the averages for Kaisaniemi, and to a lessen degree on the averages of the adjoining stations, too. Taking into account the differences in the elevation and the local character of the observation sites, too, an estimate of between 0.6 and 0.8°C may be used on the strength of the annual heat island in Helsinki. Based on the observations for the period 1947–49 TOMMILA [19] arrived at 0.6°C as a corresponding estimate.

The highest values in the annual course of difference is observed in autumn and winter, when the sea has a warming influence on the Helsinki area. Thus the differences in Table 1, mostly over 1°C, are overestimations and the pure urban effect may be about 1°C, at least in mid-winter. In spring and summer the influence of the cold sea with sea breezes causes the observed differences to be around 0°C, while the urban effect may be about 0.5°C. The urban effect can best be seen in mid-winter and late summer, when land and sea areas are equally warm.

In Jyväskylä the influence of water bodies is rather small. Considering the differences in distance and elevation (Fig. 1), the warming effect of the town seems to be about 0.4°C without any noteworthy seasonal variation.

A closer examination of the diurnal variation of the effect of the town reveals that the urban-rural temperature difference is generally greatest by night and

Table 2. Differences in mean daily maximum temperatures (°C) between the stations situated in urban and adjoining rural areas, 1961–1975.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
HELSINKI													
Town													
– Katajaluoto	−0.3	0.4	1.3	2.4	3.3	2.9	2.3	1.6	0.8	0.1	−0.5	−0.6	1.1
– Malmi airport	0.7	0.4	0.1	−0.4	−0.9	−0.7	−0.4	−0.3	0.0	0.2	0.6	0.6	0.0
– Tikkurila	0.9	0.4	−0.1	−0.6	−1.4	−1.2	−0.9	−0.7	−0.1	0.2	0.9	0.9	−0.2
– Vantaa airport	1.0	0.6	0.1	−0.6	−1.5	−1.2	−0.8	−0.5	0.1	0.5	1.1	1.1	0.0
– Vihti	1.2	0.5	−0.3	−0.7	−1.6	−1.3	−0.8	−0.5	0.1	0.5	1.3	1.1	−0.1
JYVÄSKYLÄ													
Town													
– Airport	0.4	0.5	0.7	0.7	0.5	0.5	0.7	0.6	0.6	0.5	0.6	0.4	0.5
– Leivonmäki	0.5	0.4	0.4	0.4	0.3	0.6	0.6	0.4	0.3	0.3	0.4	0.5	0.3

Table 3. Differences in mean daily minimum temperatures (°C) between the stations situated in urban and adjoining rural areas, 1961–1975.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
HELSINKI													
Town													
– Katajaluoto	−1.0	0.2	0.8	0.5	0.7	0.1	0.0	−0.8	−1.3	−1.4	−1.2	−1.3	−0.4
– Malmi airport	1.8	1.9	2.0	1.3	1.8	2.0	1.8	1.7	1.7	1.4	1.3	1.5	1.7
– Tikkurila	2.0	1.4	2.0	1.4	2.0	2.8	2.4	2.3	2.2	1.7	1.3	1.6	1.9
– Vantaa airport	1.6	1.5	1.5	1.3	1.6	1.8	1.9	1.7	1.9	1.6	1.5	1.6	1.6
– Vihti	3.5	3.8	4.2	2.4	3.4	4.8	4.5	4.3	3.5	2.6	2.3	2.6	3.5
JYVÄSKYLÄ													
Town													
– Airport	1.2	1.3	1.5	1.1	1.3	1.3	1.3	1.4	1.1	1.1	1.1	1.1	1.2
– Leivonmäki	0.5	0.4	0.3	0.5	0.6	1.2	1.0	0.9	0.6	0.7	0.5	0.5	0.6

smallest by day. This is in connection with the diurnal course of wind and turbulence, which are normally at their maximum by day and tend to suppress local differences. Thus the maximum and minimum heat-island intensities can be studied using the minimum and maximum temperatures, respectively.

The differences in daily maximum temperatures between urban and suburban sites (Table 2) are less easily interpreted. Keeping in mind the warming or cooling influence of the sea in different seasons, the urban effect on maximum temperature can be considered small in Helsinki. However, in late autumn, when the sea and the coast are equally warm at the time of maximum temperature, a warming amounting to a few tenths of a degree is evident. In winter the difference seems to be a bit greater. In the summer months it is more difficult to make such estimations. The opposite sign of the town-country difference, however, is primarily due to the cooling influence of the sea (*cf.* the difference between Kaisaniemi and Katajaluoto).

In Jyväskylä the urban effect is again more evident in the absence of disturbing effects. Because of the elevation differences a heat island of only a few tenths of a degree is present the year round, too.

The figures for minimum temperatures (Table 3) contain the greatest urban-rural differences. In summer the intensity of the Helsinki heat island is about 2°C, which is most clearly observed when the sea and the coast are equally warm (June–July). In winter the urban effect seems to be somewhat smaller. The minimum temperatures are higher at both Vantaa airport and at Malmi airport than in Tikkurila which is a more natural place. This may be due to the asphalt runways. On the other hand, the exceptionally low minimum temperatures in Vihti are due to topographic conditions.

In Jyväskylä the intensity of the nocturnal heat island is about 1°C, but it may be caused partly by lake Päijänne, south of town. The higher minimum temperatures in Leivonmäki compared with the airport are due to the south-north distance (KOLKKI [11]).

The urban effect depends especially on the severity of the winter. This is clearly reflected e.g. in the figures for January 1968 and 1975, the coldest and warmest January months during the period 1961–1975. The following mean urban-rural differences were recorded in the Helsinki region during these months:

	January 1968			January 1975		
	mean	maximum	minimum	mean	maximum	minimum
Town – Katajaluoto	–0.1°C	–0.7°C	0.0°C	–0.5°C	–0.2°C	–0.9°C
– Malmi airport	1.9	1.2	3.2	0.7	0.4	0.8
– Tikkurila	1.9	1.5	3.2	0.7	0.6	0.9
– Vantaa airport	1.8	1.6	2.2	1.0	0.8	1.4
– Vihti	3.3	2.1	5.7	1.1	0.7	1.8

In addition to increased artificial heat output the great urban-rural contrasts were also emphasized by weak, northerly winds in January 1968, while strong, southerly winds were prevailing in January 1975.

The values in Tables 2 and 3 are based on the extreme values for the whole day.

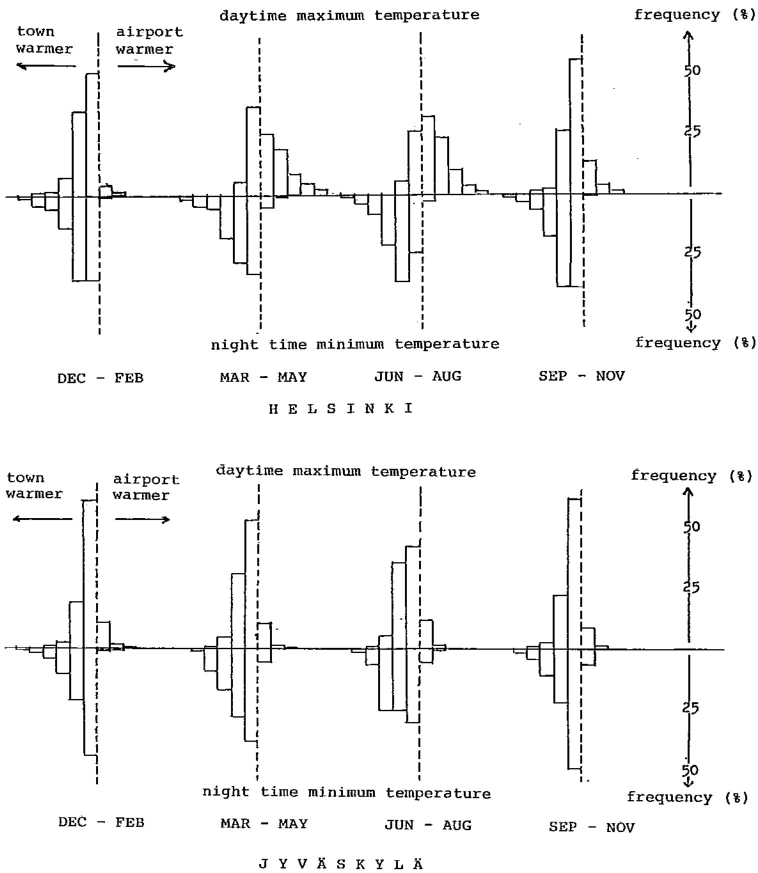

Fig. 2. Frequency distribution of the difference in daytime (8–20:00) maximum temperature and night time (20–8:00) minimum temperature between town and airport stations in Helsinki and Jyväskylä, 1961–1970 (class size 1°C) [7].

The maximum temperature, however, does not necessarily mean the highest daytime temperature and the minimum temperature the lowest night time temperature, especially in winter. For instance, over 60 per cent of the maximum temperatures in December occur at night (20–8:00) at Finnish airports (HEINO [7]).

Separate maximum and minimum temperatures for daytime and night time are presented in Fig. 2. The main features of Tables 2 and 3 are, of course, included in the figure. Again the differences in the elevation (both airports are about 50 m higher than the urban station) must be taken into account and the zero-difference lines moved 0.3°C to the left.

The most frequent difference between the town and airport is around 0.5°C for both daytime maximum and night time minimum temperatures. The airport is very rarely warmer than the town except in the case of the spring and summer maximum temperatures in Helsinki, as was already shown in Table 2. Differences of up to 5°C are quite common in these cases, and by day the town may be over 7°C colder than the airport. In Jyväskylä the corresponding difference seldom exceeds 3°C. Normally the town, however, is warmer than the airport by day, but the differences are generally below 4°C and the highest recording differences are about 6°C.

The night time minimum temperatures are distinctly higher in the towns than at the airports outside them. Differences of up to 6°C, in extreme cases up to 9°C, occur during dry, calm and clear nights. On the other hand the night time minimum temperature may also be higher at airports than in towns. In Helsinki this is due to the cold sea in spring and early summer. The other occasions on which the airport is warmer than the town may be explained by local and temporal differences in weather.

The conclusion to be drawn from the figures for maximum and minimum temperatures is also valid for the diurnal variation in temperature. Owing primarily to the higher night temperatures the diurnal range of the urban temperature is restricted compared with the temperatures of the surrounding countryside. The average diurnal range is typically about 1°C smaller in Finnish towns than in the neighbouring airports, but the difference may exceed 3°C in the towns near the coast in summer (HEINO [7]).

The gradual decrease in the difference of mean daily maximum and minimum temperatures by about 1°C from the 1880s in the Helsinki centre also supports the urban effect on temperature.

The influence of the heat island is also reflected in other average figures. The average annual number of frost days, for instance, is about 10 per cent less in the centre of Jyväskylä than in the surrounding stations. In towns the last freezing temperatures are on average earlier in spring and the first freezing temperatures later in autumn than in the surrounding areas. The growing season is generally longer in towns, too.

The urban heat island has been investigated for a number of towns using the mobile observation technique in order to determine local details of variations in the heat-island intensity. Many of these studies have been summarized by CHANDLER [4]. In Finland two such studies have been made for Helsinki.

By studying three cold, calm winter nights FÅGELBERG *et al.* [6] found separate heat islands in densely populated suburbs in addition to the heat island in the central parts of Helsinki. The warmest area was in the centre of town (to the

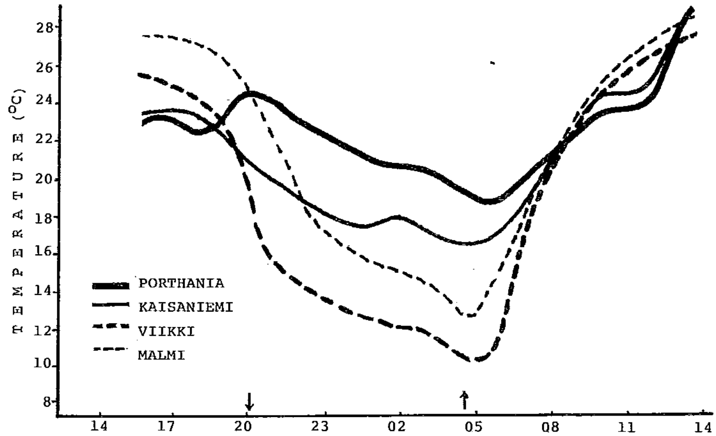

Fig. 3. The diurnal variation of temperature at the rooftop level of the Porthania Institute Building (25 m above street level) and at the Viikki field station 15–16 August 1973 [1] supplemented with the corresponding graphs from the Kaisaniemi and Malmi stations (*cf.* Fig. 1). The arrows show the times of sunset and sunrise.

south of Kaisaniemi) and the coldest in the Viikki field area (*cf.* Fig. 1). The extreme difference amounted to as much as 13°C.

Comparative figures for the temperature in Helsinki have been published by ALESTALO [1]. The area studied comprised a central urban route and a route extending to the northermost parts of Helsinki (near Tikkurila and Vantaa airport). Averaged over 22 horizontal »soundings» (6–16 March 1973) the built-up areas of the town centre were 0 – 0.5°C warmer by night than the park areas and about 1°C warmer than the areas outside the inner city. During the daytime no systematic differences were observed. The strongest heat-island conditions occurred on 11–12 March and the extreme difference observed was 9°C. The park and coastal areas were then found to be 1–2°C colder than the built-up areas.

ALESTALO also studied the intensity of the heat island of Helsinki on a clear, calm summer night (15–16 August 1973). The main features of the summer night heat island were similar to winter conditions, the maximum difference amounting to as much as 10°C. The park areas were again colder than the built-up areas, but the differences (3–4°C) were greater than in winter. The diurnal variation in temperature in the town centre and surrounding sites is illustrated in Fig. 3.

The graph observed in Viikki represents the conditions on an open field about 10 km from the town centre. The course of the corresponding graph from a nearby fixed station at Malmi airport is quite similar. The other two graphs from nearby urban locations also resemble each other. The fixed stations, however, are seen to represent less extreme temperature conditions in Helsinki.

The town centre nearer the sea is cooler by day, but after sunset the surrounding rural surfaces, which have smaller thermal capacity, soon become colder due to radiation. The intensity of the urban heat-island is greatest at sunrise. Soon after sunrise the intensity of the heat island decreases and coalesces to the cold coastal belt, which is emphasized by the sea wind in the forenoon hours.

In order to determine the changes in urban effects on temperature, the differences in annual mean temperature and mean daily extreme temperatures in the

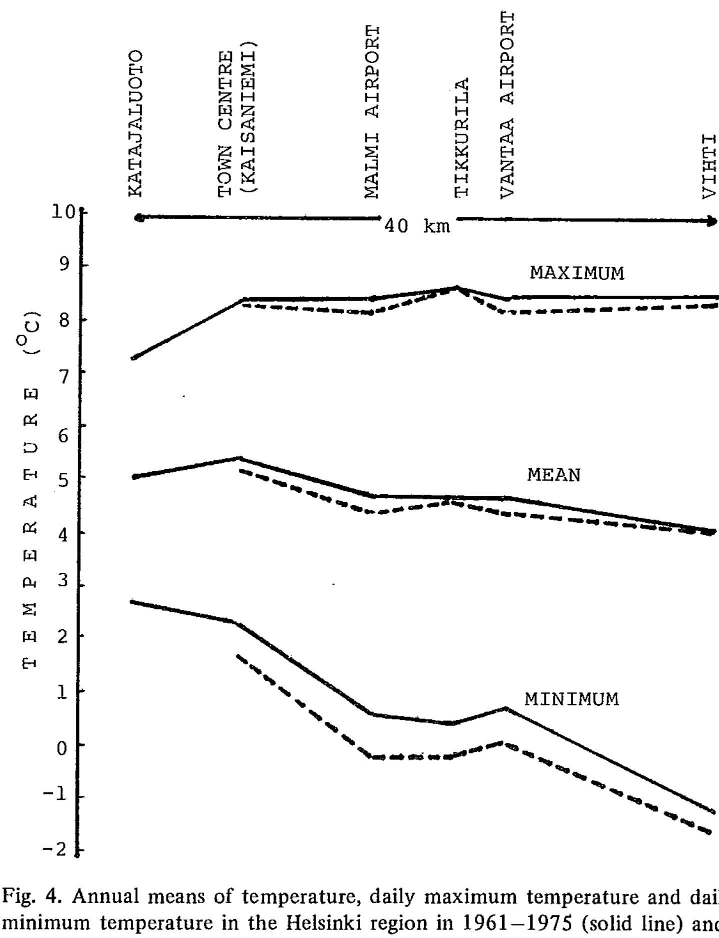

Fig. 4. Annual means of temperature, daily maximum temperature and daily minimum temperature in the Helsinki region in 1961–1975 (solid line) and in 1931–1960 (dashed line). The site change of Kaisaniemi station has been taken into account (see the text).

Helsinki region are presented graphically in Fig. 4 for the periods 1961–1975 and 1931–1960 (KOLKKI [11]). The effect of the built-up central parts of Helsinki on temperature is clearly seen in every curve and is not explained solely by the influence of the sea, as stated earlier.

In considering the changes from the period 1931–1960 to the period 1961–1975, moving the urban station from the yard of the Finnish Meteorological Institute to Kaisaniemi park nearby at the end of 1961 must be taken into account. According to the simultaneous 5-year observations, the present site is 0.2°C colder in mean temperatures and 0.6°C in minimum temperatures, while no difference was found for maximum temperature (KOLKKI, unpublished data). These figures also show the differences between built-up and park areas inside the town.

No significant changes can be found between the normal period and the last 15-year period. Thus the urban effect in Helsinki has remained practically the same in recent decades. This corresponds well with the urban growth of Helsinki, because most of the city centre was built before the 1930s.

A comparison in Jyväskylä and its surroundings is not possible until the 1950s. No effect of urbanization was found due to the fact that the changes in the urban area have also been quite small during the comparison period. The difference between the town and airport stations was even found to decrease slightly from the 1960s, which may be due to the extension of the urban heat-island in the downwind direction as in many other towns (*cf.* CHANDLER [4]). SOLANTIE [17] has found this phenomena in Finland, too, by studying the changes of the growing season temperatures between the periods 1931–1960 and 1961–1975.

3. *Humidity*

The effects of urban areas on humidity are usually explained by surface differences. Urban air is supposed to be drier than rural air, because most of the urban surfaces are dry and impervious and evaporation is small in the absence of vegetation. Moreover, a smaller part of the precipitation is available for moistening the air by direct evaporation, while the rest is drained off.

CHANDLER [2] has studied the differences in relative humidity in London and found them to be quite small, except when the heat islands are marked. On calm, clear nights the relative humidity differences between urban and rural locations may, according to traverses, amount to 20 per cent.

It is difficult to make humidity comparisons between Finnish towns and their surroundings, because any differences are affected by the sea or inland waters. Moreover, in some stations no humidity observations have been made. The higher urban temperature is primarily reflected in the relative humidity (Table 4).

Table 4. Differences in relative humidity (%) (mean of observations at 8, 14 and 20:00 local time) between the stations situated in urban and adjoining rural areas, 1961–1975.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
HELSINKI													
Town													
– Katajaluoto	−1	−2	−5	−7	−15	−17	−13	−9	−4	−2	−2	−1	−7
– Malmi airport	−2	−2	−1	1	2	2	1	−1	−2	−2	−2	−2	−1
– Vantaa airport	−3	−2	0	2	4	4	3	1	−2	−2	−4	−3	−1
JYVÄSKYLÄ													
Town													
– Airport	−2	−4	−4	−1	0	2	1	1	0	−2	−3	−2	−1

On an annual basis, the relative humidity is only slightly lower in the towns than at the neighbouring airport stations. The difference is greatest in winter, when the heat island of the town is most marked. Because night time humidities are missing in the comparisons in Table 4, opposing differences prevail in late spring and in summer, but the proximity of the sea and inland waters also have an influence on the difference. The estimate of the influence of the Baltic Sea on relative humidity inland from the coast line (TARAND [18]) indicate that if the Helsinki peninsula were uninhabited, it would be moister than the present town, especially in summer.

The decrease in relative humidity in Helsinki from the beginning of this century by 5 per cent may support the urban effect on humidity, because the corresponding temperature figures do not completely explain this decrease in relative humidity. On the other hand, there have been significant changes in the instrumentation and methods for making humidity observations.

4. *Cloudiness*

A consequence of the heat island is increased thermal convection over towns. The updraft, together with water vapour and condensation nuclei released by combustion processes, faciliates increased cloud formation over towns (LANDSBERG [13]).

The comparisons of cloudiness in the London area suggest a tendency for clouds to develop over the town, but the average annual excess is only 1–2 per cent (CHANDLER [2]). Contrasts are greatest in summer and least marked in winter.

The subjective nature of cloud observations together with the maritime

Table 5. Differences in mean cloudiness (%) (mean of observations at 8,14 and 20:00 local time) between the stations situated in urban and adjoining rural areas, 1961–1975.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
HELSINKI													
Town													
– Katajaluoto	−4	−2	−2	−2	−3	−4	−4	−3	−4	−4	−3	−2	−3
– Malmi airport	0	2	2	1	1	3	2	3	3	1	1	3	2
– Tikkurila	−1	1	2	2	2	2	1	2	2	0	0	1	1
– Vantaa airport	−1	0	1	0	−1	1	0	2	1	0	0	2	0
– Vihti	−3	−2	−1	−3	−4	−3	−6	−6	−4	−4	−2	−2	−4
JYVÄSKYLÄ													
Town													
– Airport	−3	−5	−8	−7	−8	−9	−7	−5	−5	−5	−2	−3	−5
– Leivonmäki	−3	−5	−4	−4	−3	−3	−2	−1	−1	−5	−3	−3	−3

influences result in uninterpreted features in the urban-rural differences (Table 5). In the Helsinki region the town centre seems to be somewhat more cloudy than the adjoining land areas. The figures for other regions on the Gulf of Finland exhibit features similar to those for the Helsinki region. Thus the differences of Table 5 are not necessarily of urban origin. Clear opposite differences prevail, on the other hand, in Jyväskylä.

5. *Precipitation*

The increased probability of rainfall in towns is a natural consequence of i) increased pollution with additional condensation and freezing nuclei, ii) more active turbulence because of increased surface roughness, and iii) increased thermal convection resulting from higher temperature (CHANDLER [3]). Supposedly as a result of these influences a number of towns and their downwind areas have been noted to have greater amounts of precipitation and more rain days and thunderstorms than the countryside around them.

Urban-produced increases in precipitation, especially downwind of certain towns, were first reported in Europe (KRATZER [12]), but most of the recent studies concern American towns and are summarized by CHANGNON [5]. The increase in urban precipitation is around 10 per cent, but some analyses have shown considerably larger increases in isolated cases.

However, the effects of urban environments upon the amount of precipitation and related weather phenomena are difficult to show with the station network

Table 6. Differences in monthly and annual mean precipitation (%) between the stations situated in urban and adjoining rural areas, 1961–1975.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
HELSINKI													
Town													
– Katajaluoto	70	79	45	14	3	19	4	15	21	14	29	41	25
– Malmi airport	–5	–6	–3	–5	–11	–6	–15	–1	1	–5	–11	–9	–6
– Tikkurila	–12	–6	–6	–7	–14	0	–21	–7	3	–9	–9	–12	–8
– Vantaa airport	2	10	7	–5	–9	–16	–23	–8	6	0	–7	0	–4
– Vihti	11	10	7	0	–6	11	–29	–13	9	0	5	14	0
JYVÄSKYLÄ													
Town													
– Airport	2	6	15	8	5	12	16	–2	4	5	2	0	5
– Leivonmäki	–7	–8	–3	–2	–2	17	12	–6	–1	–9	–9	–9	–2

available in this study. The influence of the sea and topography is primarily seen in the differences of precipitation in the Helsinki region (Table 6).

The mean annual precipitation is a few per cent higher at the rural stations than at the urban station, while the precipitation at the sea station is distinctly lower. Seasonally, the differences are greatest in summer, owing to the convective rains of the inland areas. The figures for stations on the Gulf of Finland with similar locations in relation to the coast line exhibit features like those for the Helsinki region. Thus the effect of the town is doubtful.

In Jyväskylä the present urban effect on precipitation is doubtful, too. The smaller amount of precipitation at the airport is at least partly due to the smaller catch of the rain gauges at an open airport field, while the observation sites in the other stations are more sheltered.

Comparisons with the latest normal period, 1931–1960 (HELIMÄKI [9]), show a decrease in annual precipitation by 7 per cent in the centre of Helsinki, while no such change occurred in Tikkurila and an increase of 18 per cent occurred in Vihti. These changes, however, are among the regional changes observed in Finland between these two consecutive periods.

In Jyväskylä the increase in annual precipitation was 15 per cent in the urban station, while the increase in the other stations studied was 1–2 per cent. The increase in town may be due to urbanization, although changes in the observation site might also explain the increase.

The frequencies of days with different weather phenomena can also be considered in evaluating urban effects on precipitation. Due to the lack of comparable observations only the synoptic stations in the Helsinki region can be used.

Table 7. Differences in mean annual number of days with different weather phenomena in and around Helsinki, 1961–1975.

	rain	sleet	snow	thunderstorm	hail
HELSINKI					
Town					
– Katajaluoto	30	11	16	2	4
– Malmi airport	13	5	–2	2	4
– Vantaa airport	2	4	–14	–1	4

The mean annual number of days with different forms of precipitation (Table 7) does not correspond well to the figures for precipitation (Table 6). Days with rain or sleet are, as expected, more numerous in the town centre, while snowfall is observed more often in the surrounding land stations.

A number of studies (*e.g.* CHANDLER [2], CHANGNON [5], KRATZER [12]) show that the number of thunderstorms and hail storms is greater over the town than over the suburbs. According to Table 7 it is impossible to be sure about the relationship between the number of thunderstorm days and the urban area. The average annual number of hail days, on the other hand, was 6 in the town centre in 1961–1975, while the corresponding number was 2 in the other stations. These figures may at first sight support the studies mentioned above, but knowing the diversity of the practises in observing weather phenomena, it is rash to claim the significance of these figures, too.

6. *Other elements*

The depth of the snow is highly dependent on the observation site. The differences between the town and the surrounding areas therefore contain variable features. The values of mean snow depth are primarily reflections of the precipitation amounts and are less a reflection of urban controls. The mean annual number of snow cover days in the town stations, on the other hand, is about 10 per cent less than in the surrounding country areas (HEINO [8]).

Wind conditions in urban areas differ in many respects from the natural and generally smoother surfaces of the surrounding areas. It is, however, impossible to demonstrate the changes in wind conditions in Finnish towns, owing to the lack of comparable, reliable wind data (HUOVILA [10]). CHANDLER [2] has made an extensive study of the wind field over London and found the urban effect on winds to be quite small, a reduction in wind speed of about 5 per cent.

Radiation observations are not made at the urban stations in Finland, and this prevents study of this primary climatic element. In general it is known that the depletion of global radiation over most major cities is on average about 15 per cent of that received at a clean rural site (LANDSBERG [13]). Because urban albedos are generally decreased and the components of long-wave radiation also tend to offset each other, urban-rural differences of the net all-wave radiation are small showing a slight urban deficit by comparison to the rural area (OKE [16]).

7. *Summary*

Although the results of this study may be insufficient to draw concrete generalizations, the main characteristics of the urban climate in Finland and the magnitude of urban effects on climatic elements are estimated as follows:

Element	Compared with rural environs
Temperature	
annual mean	0.4 – 0.8°C more
annual daily maximum	0.1 – 0.2°C more
annual daily minimum	ca. 1°C more
diurnal range	ca. 1°C less
minimum on suitable clear, calm nights	over 10°C more
number of frost days	ca. 10 % less
Relative humidity	some percents less
Cloudiness	unclear
Precipitation	possibly more
Snow cover days	ca. 10 % less

Owing to the nature of the different climatic elements and the station network of this study, quantitative expressions can be given only for temperature, which, however, may be the most important of the climatic elements in urban climatology. Many differences between urban and rural sites are due more or less directly to the urban heat-island.

The above estimates generally refer to long-term averages, and in different weather situations or locations the values may vary considerably. The urban-rural contrasts, however, are so great on clear, calm nights in all seasons that weather forecasts, at least local forecasts, should note this fact.

Because the urban climate is a function of the mesoscale topography of the region, the location of the urban stations and the comparison stations is especially important in urban climatological studies. In addition to a denser network of stations or registered instruments, a more detailed study of climate in Finnish towns should involve horizontal soundings in towns other than Helsinki, too. To measure precipitation, radar could also be used in some Finnish towns.

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