

Feasibility Study of the Dew Point Evaporative Cooling System for UK & EU Building Air Conditioning

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ABSTRACT: This paper investigated the feasibility of the dew point evaporative cooling for air conditioning of buildings in the UK/EU regions. The issues involved include analyses of the UK and EU weather conditions, investigation of availability of water for dew point cooling, and assessment of cooling capacity of the system over various regions of UK and EU countries. It is concluded that the dew point system is suitable for most regions of the UK/EU countries, particularly Portugal, Spain, France, German, Hungary, Poland and Romania. It is unsuitable for some regions in Italy, such as Venice and Rome, where the air is too humid to be dealt with using the system. Lower humidity results in higher difference between the dry bulb and dew point of the air, which benefits to the system in terms of the enhancing its cooling performance. Tap water has a suitable temperature to feed the system for cooling and its consumption rate is in the range 2 to 2.5 litre/kWh output. The cooling output of the system ranges from 1.6 to 5.2 W per m³/h air flow rate, depending on the region where the system applies. For a 100 m² of buildings with 30W/m² cooling load, the required air volume flow rate varies with its application location and is in the range 700 to 1700 m³/h. This building consumes 50 to 60 litres of water daily. Compared with mild or humid climates, the dry and hot climates need less air volume flow rate and less water.

Keywords: Dew point; evaporative cooling; feasibility; buildings

NOMENCLATURE

C_p – specific heat of air, kJ/kg.°C;

d – moisture content of air, kg/kg dry air;

h – enthalpy of air, kJ/kg dry air;

M – water consumption rate per kWh cooling output, litre/kWh;

M_{daily} – daily water consumption for the selected building, litre/day;

Q – Cooling capacity of the dew point system, W;

Q_p – cooling output of 1 m³/h of supply air, W;

Q_{p1} – cooling output of 1 m³/h of supply air for removing internal sensible load, W;

Q_{p2} – cooling output of 1 m³/h of supply air for removing fresh air load, W;

t – temperature of air, °C;

V – air volume flow rate, m³/h;

V_{target} – air volume flow rate for the target building, m³/h;

ρ – air density, 1.2kg/m³;

ρ_w – density of water, 1 litre/kg;

η_d – dew point effectiveness;

Subscripts

1 – intake air;

2 – supply air;

3 – discharged air

dp – dew point

1. INTRODUCTION

In the UK/EU, energy use in buildings accounts for approximately 40% of its total primary energy consumptions, respectively. It contributes to similar proportions of the national total carbon emissions. Of this, HVAC (heating, ventilation and air conditioning) systems consume approximately 50% of the building energy [1]. Reducing energy consumption of HVAC systems is therefore important in terms of controlling national carbon emissions.

In recent years, frequent summer warm spells, improved insulation of buildings, and growth of indoor facilities have led to an increased requirement for air conditioning of the indoor environment. The conventional mechanical compression air conditioning systems consume huge amount of electrical energy that is largely dependent upon fossil fuel. This mode of air conditioning is, therefore, neither sustainable nor environment-friendly. Evaporative cooling utilizes the latent heat of water evaporation, a natural energy existing in the atmosphere, to perform air conditioning of buildings, and is therefore a potential replacement of existing systems. However, evaporative cooling has encountered several technical difficulties that impede its wide application. Direct evaporative cooling adds moisture to room air which causes unpleasant thermal comfort [2]. Indirect evaporative cooling lowers air temperature and avoids adding moisture to the air, but it limits the temperature of supply air to some degrees above the wet bulb of the outdoor air, which is too high to perform air conditioning of buildings [2, 3].

The dew point (evaporative) cooling breaks the limit of wet bulb, and allows the supply air to be cooled to a level below the wet bulb and above the dew point of the outdoor air [4, 5]. A new type of polygonal exchanger for dew point cooling has been recently developed, which allows an enhanced dew point effectiveness of up to 85 to 90% to be achieved [6]. Advance on dew point cooling technology opens up the

opportunity for wide application of evaporative cooling for air conditioning of buildings in UK/EU. However, prior to real application of the technology, a feasibility study is needed to identify potential difficulties involved and develop solutions for problem solving.

This paper reported the feasibility study of the dew point evaporative cooling for air conditioning of buildings in the UK/EU. The main issues involved in this investigation include:

1. Analyses of the UK and EU weather data, particularly dry & wet bulb and dew point temperatures of outdoor air across whole period of summer season.
2. Investigation of the availability of water for dew point cooling, particularly water temperature, water requirement and water supply.
3. Assessment of the cooling capacities of the dew point system in UK/EU ranges.

As a result of the investigation, the most prominent factors that affect the performance of dew point cooling for air conditioning of UK/EU buildings were identified, and the availability of the system in various climate ranges of the EU was analysed. The research is of great help to promote the application of the dew point system in the Europe, and thus has obvious benefits to the UK and EU in terms of reduced greenhouse gas and pollutant emissions, increased use of sustainable energy and security of energy supply, growth in economy, improved life quality, as well as enhanced competitiveness of industry.

2. DESCRIPTION OF THE DEW POINT SYSTEM AND EVALUATION OF ITS PERFORMANCE

A polygonal-sheets-stacked heat and mass exchanger was developed by the authors recently to perform dew point cooling of the buildings [6]. The polygonal sheets could be stacked together using guides of the same material, as shown in Figure 1, and one side of each sheet would be coated with a water-

proof material to avoid water penetration. The intake air is brought into the dry channels from the lower part of the right-hand side of the stack. Operation is as follows: The air flows through the channels and is divided into two parts at the other end of the channels: One part of the air stream keeps moving in the same direction and is finally delivered to the space where cooling is required, and the other part of the air stream is diverted into the adjacent wet channels where the surfaces are wetted by water. The wet channels allow heat to be absorbed through the channel walls by vaporising the water on the surfaces. The air in the wet channels flows in a reverse direction and is finally discharged to atmosphere from the upper part of the right side of the stack. In this design, the dry channels contain both product and working air, and the wet channels take only working air, a division of the intake air. Because of the heat transfer between the dry-channels and their adjacent wet-channels, the product air in the dry channels will be cooled and the working air in the wet channels will be humidified and heated.

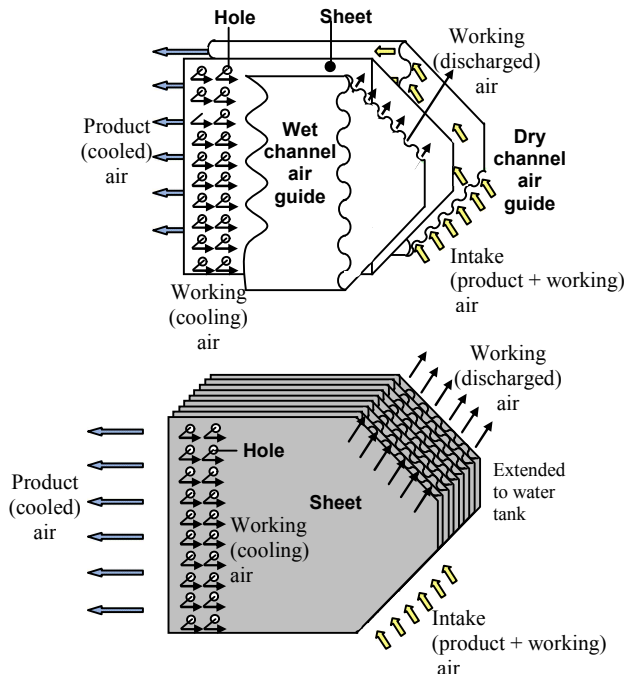


Figure 1. The polygonal stack exchanger configuration

The air treatment process can be illustrated in a Psychrometric Chart, as shown in Figure

2. In the dry channels, the air transfers heat to the adjacent wet channels, and is cooled from state 1 to 2, with no moisture added into the air. Part of the air is delivered to room space for cooling of the space. The remaining air flows into the adjacent wet channel, where it firstly becomes saturated due to absorbing moisture reserved on the channel surface, and then continues to absorb sensible heat and moisture due to heat transfer between the dry and wet channels, which contributes to evaporation of water on the wet surface. The air is finally discharged to the atmosphere at the saturated and hot air streams, defined as state 3.

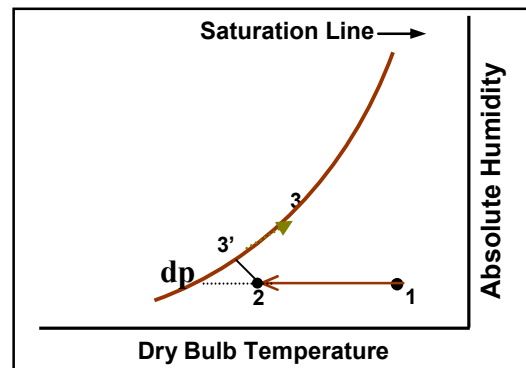


Figure 2. Psychrometric indication of the heat and moisture transfer in a dew point evaporative cooling system

Based on the above analyses, the performance of the dew point system can be evaluated using the methods.

The cooling capacity of the dew point system can be calculated as follows:

$$Q = \rho V_1 (h_1 - h_2) / 3.6 \quad (1)$$

The relationship between states 1, 2 and 3 can be expressed as follows:

$$h_1 - h_2 = \frac{V_2}{V_1 + V_2} (h_3 - h_2) \quad (2)$$

$$h_2 = h_1 - \eta_{dp} (h_1 - h_{dp}) \quad (3)$$

$$t_2 = t_1 - \eta_{dp} (t_1 - t_{dp}) \quad (4)$$

$$d_2 = d_1 \quad (5)$$

$$h_3 = h_2 + \frac{V_1 + V_2}{V_2} (h_1 - h_2) \quad (6)$$

As long as you obtain the value of h_3 , d_3 and t_3 can be acquired from the Psychrometric Chart

Water consumption per kWh cooling output will be

$$M = 3600 \frac{d_3 - d_1}{\rho_w (h_1 - h_2)} \quad (7)$$

For 1 m³/h of supply air, its cooling potential can be calculated using the following equation:

$$Q_p = C_p \rho (t_1 - t_2) / 3.6 \quad (8)$$

If room temperature is t_r , the cooling energy used for removing internal sensible load can be written as,

$$Q_{p1} = C_p \rho (t_r - t_2) / 3.6 \quad (9)$$

The cooling energy used for removing fresh air load can be written as,

$$Q_{p2} = C_p \rho (t_1 - t_r) / 3.6 \quad (10)$$

3. ANALYSES OF THE UK AND EU WEATHER DATA

Weather data relevant to various locations of the UK and other EU countries were analysed. The cooling design temperatures, including dry-bulb, wet-bulb and dew point of the outdoor air, are the major parameters to be considered, which can be acquired from Table 2-19 in CIBSC guide A. The design conditions are based on wet-bulb temperatures which represent extremes of the total sensible plus latent heat of outdoor (0.4% un-guaranteed frequency) [7], as shown in Table 1. This data are used for design of cooling towers, evaporative coolers, and fresh air ventilation systems.

It is found that lower value of relative humidity results in higher value of temperature difference between the dry bulb and dew point temperatures, which is the

thing we expected in terms of full utilization of the benefit of dew point cooling. The relationship between the relative humidity and difference between dry-bulb to dew-point temperature can be presented by a diagram as shown in Figure 3. If the relative humidity is 70%, the temperature difference between dry bulb and dew point will be around 6°C. Assuming the cooling effectiveness is 0.85, a 5.1°C temperature difference between supply air and room space can be achieved, this difference is good enough for performing cooling of the buildings.

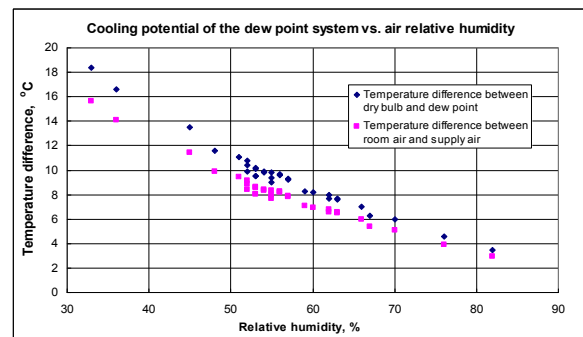


Figure 3. Cooling potential of the dew point system against air relative humidity

For most regions of the Europe, the air relative humidity is below 70%, and therefore dew point cooling is suitable for use in cooling of buildings. The drier the air in the region, the better the performance of the dew point cooling system will be. The ideal regions for this application are Portugal, Spain, France, Germany, Hungary, Poland and Romania where the climate remains dry and hot in summer season. Other countries including Denmark, Norway, Netherlands, Switzerland, Sweden and UK, are also suitable for this application, but the performance of the dew point system is lower, due to relatively lower temperature difference between the dry bulb and dew point. In some regions of Italy, like Venice and Rome, dew point cooling is unsuitable for use, as the outdoor air relative humidities in these regions are as high as 76 to 82%, which leaves very small room for utilizing the benefit of the dew point cooling, i.e.,

temperature difference between the dry bulb and dew point.

4. AVAILABILITY OF WATER SOURCE, TEMPERATURE LEVEL AND VOLUME CONSUMPTION

Owing to its instantaneous supply and ease of connection, tap water is the most convenient medium used for the dew point system. To assess its availability, tap water temperature and volume consumption rate are the most concerns which need to be taken into careful consideration.

Ideally, tap water temperature should be lower than dew point of the atmosphere, which allows an effective cooling to be achieved when system is in operation. Since tap water is delivered from the water source through the pipe services, and the pipes are embedded at the level of 50 to 100cm below the ground, the water temperature will eventually reach the soil temperature at the same depth level. The data of soil temperature under the 100cm below the ground are shown in Table 2 [8].

It is seen that tap water temperature is about the same or slightly lower than the dew point of the atmosphere above the earth. This allows dew point cooling to be performed in an effective way. In terms of water volume consumption, a calculation can be made based on the following assumptions (1) discharged-to-total-air ratio is 0.5; and (2) dew point effectiveness is 0.85. The calculation yields the water consumption rates in various regions of the whole range of Europe, as shown in Table 2. In most regions of Europe, water consumption rates are in the range of 2 to 2.5 litre/kWh. However, Norway has less water need which is from 1.28 to 1.5 litre/kWh. The reason for this is due to its relatively lower temperatures, including dry-bulb, wet-bulb and dew point which lead to less water need for cooling.

5. COOLING POTENTIAL AND AIR FLOW RATE SCALE OF THE DEW POINT COOLING SYSTEM

Cooling potential of the dew point system can be calculated by eqs 1 to 9, which gave cooling outputs of the system in various regions of the Europe. The calculation also yielded the amount of cooling energy used for removing internal load and fresh air load. All calculations are made based on 1m³/h air volume flow rate and the results are shown in Figure 4. It is found that the cooling output varies with the region where the system applies and in the range of 1.8 to 5.2 W per m³/h air-flow-rate. In mild climate ranges like the UK, Norway and Denmark, or humid ranges like Venice and Rome, the cooling output is relatively low, and is mainly used to remove internal sensible load. However, in hot and dry climate ranges like Spain, Romania, Portugal and German, the cooling output is much higher and large percentage of the output is used to remove fresh air load.

For a 100 m² of building with 30W/m² cooling load and 8 h daily operation hours, its cooling requirement is 3,000 W, and the required volume flow rate can be calculated as follows:

$$V_{target} = \frac{3000}{Q_p} \quad (11)$$

The daily water consumption can be written as,

$$M_{daily} = 24M \quad (12)$$

Table 2 also presents the required volume flow rate for 100m² of building with 30W/m² cooling load. For mild or humid climate regions, the required volume flow rates are relatively higher, which reaches a value up to 1400 to 1700 m³/h. However, in dry and hot climate regions, the volume flow rates are smaller, which are in the range 700 to 1200m³/h. If the building is in operation for 8 hours a day, the daily water consumption of the dew point system will be in the range 50 to 60 litre.

6. CONCLUSION

The dew point evaporative cooling system is suitable for most regions of the UK/EU countries, particularly Portugal, Spain, France, Germany, Hungary, Poland and Romania, where hot and dry climate conditions are the common cases. It is also suitable for mild climate regions like Denmark, Norway, Netherlands, Switzerland, Sweden and UK, but presents a low performance for cooling. The investigation indicates that the system is unsuitable for some regions in Italy, such as Venice, where the air is too humid to be dealt with using this system.

Lower value of relative humidity results in higher value of temperature difference between the dry bulb and dew point temperatures, and higher cooling performance of the dew point system. If air is at a relative humidity of 70% or below, the dew point system could be used for cooling of the buildings.

Tap water can be easily used to support cooling of the dew point system. Its temperature is about the same and slightly lower than the dew point of the ambient air, which ensures the effectiveness of cooling. The water consumption rate varies with the region where the system applies, but is usually in the range 2 to 2.5 litre/kWh output. The dry and hot climate regions need more water supply; but mild or humid climate regions need less, particularly cities in Norway.

The cooling output of the dew point system varies with the region where the system applies, but is usually in the range 1.6 to 5.2 W per m³/h air-flow. In mild climate regions like the UK, Norway and Denmark, or humid ranges like Venice and Rome, the cooling output is relatively low, and is mainly used to remove internal sensible load. In hot and dry climate regions like Spain, Romania, Portugal and Germany, the cooling output is much higher and large percentage of the output is used to remove fresh air load.

For a 100 m² of building with 30W/m² cooling load, the required air volume flow rate varies with region where the building is, and is in the range 700 to 1700 m³/h. In mild or humid climate regions, the air volume flow rates requires a higher value ranging from 1400 to 1700 m³/h. In dry and hot climate ranges, the volume flow rate could be as low as 700 to 1200m³/h. If the building is in operation for 8 hours a day, the daily water consumption of the system will be in the range 50 to 60 litres.

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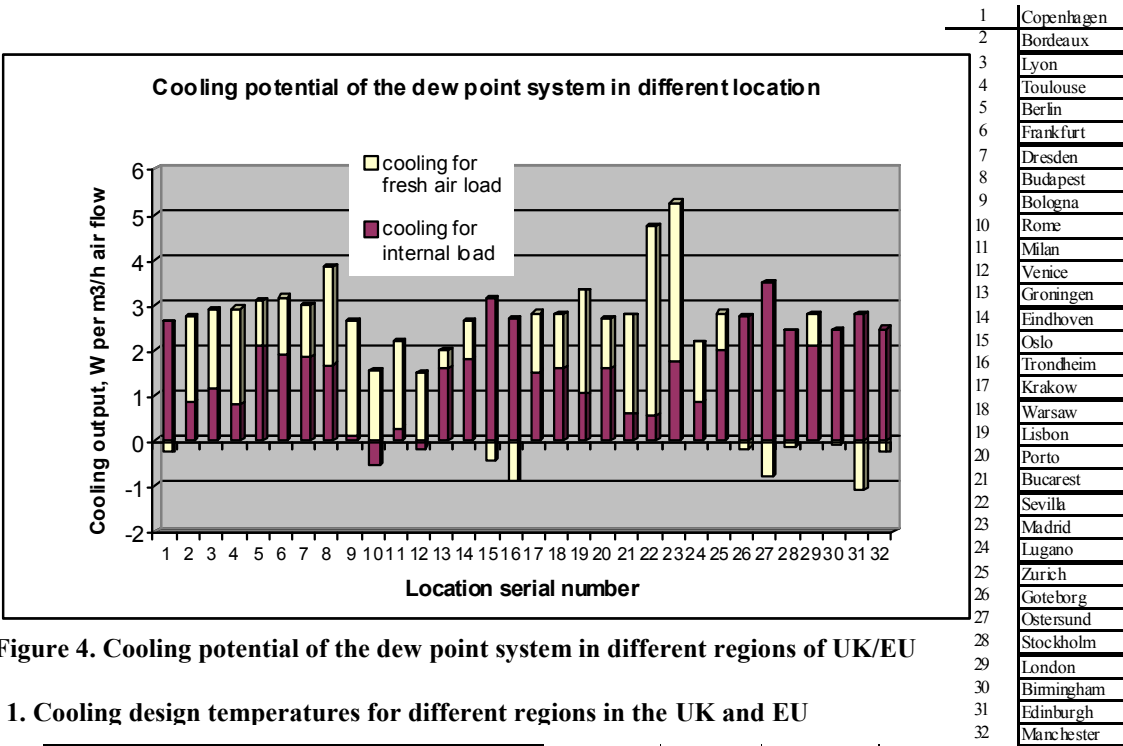


Table 1. Cooling design temperatures for different regions in the UK and EU

Country	City	Dry-bulb, °C	Wet-bulb, °C	Dew point, °C	Relative humidity, %	Difference between dry and dew point, °C	Difference between dry and wet bulb, °C
Denmark	Copenhagen	23.2	18.2	15	60	8.2	5
France	Bordeaux	29.6	23	20	56	9.6	6.6
	Lyon	29.1	22.2	19	53	10.1	6.9
	Toulouse	30.2	23	20	53	10.2	7.2
	Berlin	27	20.1	16.2	52	10.8	6.9
German	Frankfurt	27.8	20.5	16.7	51	11.1	7.3
	Dresden	27.4	20.1	17	52	10.4	7.3
	Budapest	30.5	21.4	17	45	13.5	9.1
Italy	Bologna	31.6	24.9	22.4	57	9.2	6.7
	Rome	28.6	26.1	25.1	82	3.5	2.5
	Milan	29.7	24.2	22	63	7.7	5.5
	Venice	28.4	25.1	23.8	76	4.6	3.3
Netherlands	Groningen	25.2	20.6	18.2	66	7	4.6
	Eindhoven	26.5	20.3	17.2	57	9.3	6.2
Norway	Oslo	22.7	16.6	13.2	53	9.5	6.1
	Trondheim	21.3	17.4	15	67	6.3	3.9
Poland	Krakow	27.9	21.2	18	54	9.9	6.7
	Warsaw	27.6	21	17.8	54	9.8	6.6
Portugal	Lisbon	30.8	22.7	19.2	48	11.6	8.1
	Porto	27.2	20.8	17.8	55	9.4	6.4
Romania	Bucarest	30.5	23.6	20.8	56	9.7	6.9
Spain	Sevilla	36.4	24.6	19.8	36	16.6	11.8
	Madrid	34.4	21.9	16	33	18.4	12.5
Switzerland	Lugano	27.9	22.6	20.3	63	7.6	5.3
	Zurich	26.5	19.7	16.6	52	9.9	6.8
Sweden	Goteborg	23.5	17.7	14.5	55	9	5.8
	Ostersund	21.7	15.9	12.2	53	9.5	5.8
	Stockholm	23.6	18.4	15.6	62	8	5.2
	London	26	19.6	16.2	55	9.8	6.4
UK	Birmingham	23.8	18.5	15.5	59	8.3	5.3
	Edinburgh	20.8	17.2	14.8	70	6	3.6
	Manchester	23.2	18.3	15.5	62	7.7	4.9

Table 2. Water temperature, consumption and air flow rate in different regions around the UK and EU

Country	City	Water consumption rate, litre/kWh	Tap water temperature, %	Volume flow rate for 100m ² building, m ³ /h	Daily water consumption for the targeted building, litre
Denmark	Copenhagen	2.050773994	15	1278.463571	49.21857585
France	Bordeaux	2.194652406	18.9	1092.020967	52.67165775
	Lyon	2.194652406	19.1	1037.960523	52.67165775
	Toulouse	2.194652406	19.4	1027.784439	52.67165775
German	Berlin	2.427149321	15.4	970.6853038	58.25158371
	Frankfurt	2.310160428	16.1	944.4505659	55.44385027
	Dresden	2.117647059	13.6	1008.019354	50.82352941
Hungary	Budapest	2.223529412	15.6	776.5482431	53.36470588
Italy	Bologna	2.362848297	20.6	1139.500139	56.70835913
	Rome	2.541176471	21	2995.257509	60.98823529
	Milan	2.220946915	20.6	1361.480686	53.30272597
	Venice	2.310160428	19.3	2279.000279	55.44385027
Netherlands	Groningen	2.220946915	13.7	1497.628754	53.30272597
	Eindhoven	2.273418314	14.5	1127.24745	54.56203953
Norway	Oslo	1.469387755	8.6	1103.515924	35.26530612
	Trondheim	1.281733746	8.2	1664.031949	30.76160991
Poland	Krakow	2.117647059	13.3	1058.929422	50.82352941
	Warsaw	2.277469478	13.9	1069.734825	54.65926748
Portugal	Lisbon	2.272596844	20.7	903.7414898	54.54232425
	Porto	2.137815126	17.9	1115.255455	51.30756303
Romania	Bucarest	2.321266968	17.3	1080.763019	55.71040724
	Sevilla	2.366782007	20.6	631.5301977	56.80276817
Spain	Madrid	2.184520124	15.8	569.7500696	52.42848297
Switzerland	Lugano	2.192387543	18.8	1379.394905	52.61730104
	Zurich	2.310160428	17.1	1058.929422	55.44385027
Sweden	Goteborg	2.075294118	10.4	1164.822365	49.80705882
	Ostersund	2.097087379	8.1	1103.515924	50.33009709
	Stockholm	2.117647059	10.8	1310.42516	50.82352941
UK	London	2.216602529	14.7	1069.734825	53.19846069
	Birmingham	2.192387543	10.9	1263.060395	52.61730104
	Edinburgh	2.299159664	12.03	1747.233547	55.17983193
	Manchester	2.117647059	13.7	1361.480686	50.82352941