

APPLICATION OF FUZZY LOGIC FOR MONITORING OF APPEARANCE OF HEAT WAVES IN LARGE TOWNS

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Abstract: In the paper are introduced some results of the influence of cooling effect of vegetation on the climate in large towns. The results have been acquired from measurement of some meteorological variables in selected parts of large town and from application of fuzzy models on the prediction of maximum day temperature. Great motivation of the paper is not only course of maximum temperature in standard days but especially the more dramatic situations as is appearance of Heat Waves. Besides the selection of relevant variables and the design of knowledge based system (with application) is performed an approximation operation for knowledge based system function taking into account the conditions throughout the city.

Keywords: extreme temperatures; measurement on selected segment of large town; computations by a knowledge network; complex system; heat waves in large towns.

1 Introduction

Though the most of days in summer months in large towns are standard days some days with Heat Waves (HWs) are very danger. Where is the origin of concepts Heat Wave and Heat Island? The initial signals have appeared in the field of Healthcare, e.g. [17]. It was discovered that in hot days died more people than in standard conditions. However only in some hot places and only somewhere. The attention of Healthcare research was concentrated in most on large towns in “warm” countries. [16], [18]. As a principal reason of higher mortality was confirmed the sharp increase of temperature of air and long duration of maximal temperature. It was formed thousands of temperature maps of the type – Fig. 1, [15]. Conclusions from these maps were very urgent for some towns, e.g., for Madrid, Rio de Janiero but also for New York, [19], [20].

The research started to solve problems of Heat Waves in towns. There were proposed the following causes of appearance of Heat Waves:

- Insufficient ventilation of towns (architecture).
- Small portion of vegetation in towns (architecture).
- Poor state of vegetation (municipalities).
- Strong solar radiation (physics).
- Greenhouse effect (globalization).
- Insufficient albedo (physics).
- Strong anthropogenic effects (transport, industry, globalization).

Already these several factors have prompted discussion about proper fields of solution of given problem:

- Weakening of influence of solar radiation (shading of Sun, modification of weather (cloud seeding), and others.
- Training of population (with motivation – “How there are living people in Dubai or in Qatar where ordinary temperature is around 50°C ?”).
- Adaptation of town structure. (However, it is available only in limits.)
- Restrictions of anthropogenic activities in towns (especially restrictions in transport and industry).

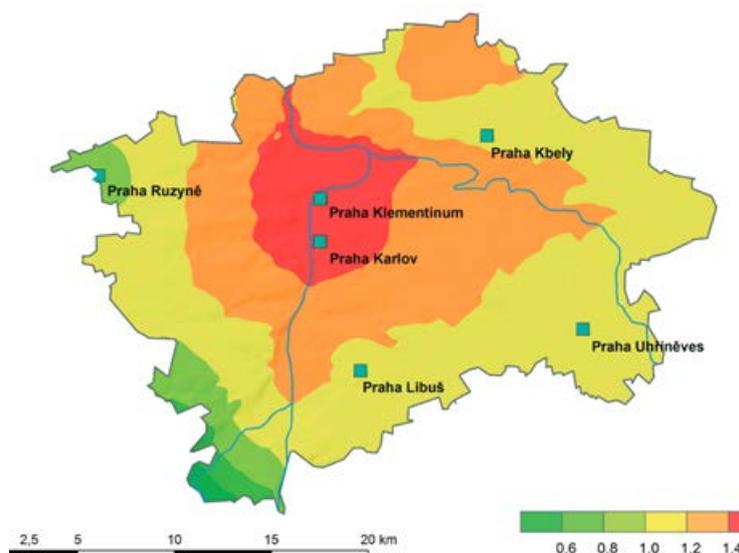


Figure 1: Heat Island in Prague (Source [11]).

- Support of cooling effect of vegetation in towns. (Comparing with previous named changes is relatively free field.)

All the introduced interventions are exacting as well in research as in realization. Nowadays is hard to decide which of them will have priority.

A few words to organization of the paper: Section 2 contains a short list of related works. In Section 3 there is described the used method for investigation of the influence of cooling effect of vegetation on coming of Heat Wave: selection of relevant variables, measurement, synthesis of an associated fuzzy logic based system with its deployment and results. Section 4 contains description of one approach to monitoring of appearance of Heat Waves in large towns.

2 Related Works

Problems of Heat Waves, Heat Islands and defending strategies are included in works [10], [18], [19] [20], [22]. Main works from this list are [10] where is described an evolution of Heat Waves in Southeastern Australia, [18] summarizing experience with HWs in Madrid in season 1986-1997 and [22] with one of the first attempts to model HW. Discussion of relation between anthropogenic heat flux and global climate changes is in [12] and [21]. Sources [16], [19] and [20] contain approaches to defending strategies against HW.

Energy flows through ecosystems that are candidates for HW evolution and their monitoring were investigated, e.g., in [1], [4], [7]. Special and new types of ecosystem models (e.g., CMD, SED + EMA) are introduced in [5], [7] and [14]. There is seen that these models with their results are absolutely passing through HW investigation.

Problems and introduction to theory of complex systems are, e.g., in [2], [3]. Mathematical background needed for this paper is in [6], [8], [9], [13], [22].

3 Investigation of the Influence of Cooling Effect of Vegetation on Coming Heat Wave

The first what has been attacked by research were places where was a clear increase in temperatures against the surrounding area, e.g., parking places, stadiums and roofs of houses. With regard to initial field of interest (Healthcare) seem to be these efforts of research foolish. Who will be living in parking place or in stadium? However – sometimes is needed to visit parking place to take a car or to go to football. And even more urgent is the problem of a hot roof. (However, there was discovered local and partial solution – green roofs.) Nevertheless let us turn back to the whole context of the town. Influence these mentioned localities on Heat Wave? We have to add that yes but we do not know which and how strong. And here starts a classical approach: Measurement in selected places in town and the synthesis of the model.

The first measurement stations have been situated in campus CTU in Prague denoted in Fig. 2 by red contour as a first Reference Segment of Town (RST). There were measured the following quantities:



Figure 2: Locality of measurement in CTU in Prague campus – red contour.

Time [hour, minute, day], Temperature [°C] and Humidity [%] in distances 0.3m, 1m, 2m from the surface of the terrain, Coming Sun radiation [W/m²], Reflected Sun radiation [W/m²], Velocity of the wind (in determined direction) [m/sec]. (All values of quantities were related to time.)

In further there were considered the following factors related to RST: Quality of the surface, Type of vegetation, Density of vegetation, Buildings, Reflection areas, Surface of roads and paths, Weather, Precipitation in previous days, Tree irrigation.

After evaluation of the influence of these quantities and factors on the difference between maximum temperature T_{max} and temperature in 8.00 morning $T(8.00)$ in the day was formed a knowledge based (fuzzy logic) model with 20 input variables (with fuzzy values in vector \mathbf{w}) and linguistic variable $\mathbf{C}(T_{max} - T(8.00))$ with fuzzy values ($\mathbf{C1}$, $\mathbf{C2}$, $\mathbf{C3}$) covering the difference ($T_{max} - T(8.00)$). The knowledge based network computes the function

$$\mathbf{C}(T_{max} - T(8.00)) = \mathbf{f}(\lambda, \mathbf{w}, \mathbf{A}), \tag{1}$$

where

- $\mathbf{C}(T_{max} - T(8.00))$ is a fuzzy set $\{(\mathbf{C1}, \mu(\mathbf{C1})), (\mathbf{C2}, \mu(\mathbf{C2})), (\mathbf{C3}, \mu(\mathbf{C3}))\}$ covering the difference ($T_{max} - T(8.00)$),
- λ is a vector of quotient of importance,
- \mathbf{w} is a vector of fuzzy set of inputs related to elements of fuzzy set $\mathbf{C}(T_{max} - T(8.00))$.

$$\mathbf{w} = (\{(\mathbf{Concrete}, \mu(\mathbf{Concrete})), (\mathbf{Grass}, \mu(\mathbf{Grass})), \dots, (\mathbf{Strong\ wind}, \mu(\mathbf{Strong\ wind}))\}_{\mathbf{C1}},$$

$$\{(\mathbf{Concrete}, \mu(\mathbf{Concrete})), (\mathbf{Grass}, \mu(\mathbf{Grass})), \dots, (\mathbf{Strong\ wind}, \mu(\mathbf{Strong\ wind}))\}_{\mathbf{C2}},$$

$$\{(\mathbf{Concrete}, \mu(\mathbf{Concrete})), (\mathbf{Grass}, \mu(\mathbf{Grass})), \dots, (\mathbf{Strong\ wind}, \mu(\mathbf{Strong\ wind}))\}_{\mathbf{C3}}).$$
- \mathbf{A}, \mathbf{B} are observation fuzzy sets related to a situation in the selected observation day,
- $\mu(x)$ is a value of point membership function for an element x .

(Inference module for function (1) was based on *fuzzy composition rule* [6]) In Table 1 there are introduced input and output variables with their fuzzy representation. Representations are introduced for 100% fulfillment of the semantic content of the variable. (The course of all membership functions is considered as linear one.)

Note (Legend for Table 1 and Table 2). “Related to RST” denotes “Related to a Relevant Segment of Town.” Variables (in left column) are defined in the interval $\langle 0, 1 \rangle$. If there is not completely fulfilled the content of variable, e.g., if in previous 2 weeks has been raining for 2 days the quantification of variable **Dry previous period** was less than 1, e.g., 0.2.

In Table 2 are expert apriori fuzzy values for individual variables from Table 1 related to outputs $\mathbf{C1}, \dots, \mathbf{C6}$. For example – variable **High density of vegetation** contributes to output $\mathbf{C3}$ with value 0.6 (from the interval $\langle 0, 1 \rangle$).

Table 1: Fuzzyfication of variables: 100% represents the word expression in the corresponding row

Related to RST	Word expression for 100% fulfillment of the semantic content of the variable.
Concrete	There is no cover of surface other than concrete.
Grass	There is no cover of surface other than grass.
Bushes	There is no cover of surface other than bushes.
Oaks	In vegetation dominate oaks.
Spruces	In vegetation dominate spruces.
Poplars	In vegetation dominate poplars.
High density of vegetation	For each 4 m ² – one tree.
Panel houses	For each 200 m ² – one panel house.
Family houses	For each 200 m ² – four family houses.
Reflection buildings	For each 200 m ² – one reflection building.
Asphalt roads	For each 100 m ² – one asphalt road (wideness 10 m).
Park paths	For each 100 m ² – 5 park paths (wideness 3 m).
Strong solar radiation	1000 W/m ²
Dry previous period	In previous 2 weeks (or more) has not been raining.
Moist temporary period	It past 5 days (or more) has been raining continuously.
Weather now – clear	There was none cloudiness for 6 last hours.
T(8.00) is high	It was measured $T(8.00) \geq 22^{\circ}\text{C}$.
High albedo	50 %.
Sufficient irrigation of vegetation	Each tree is irrigated by 10 liters of water per day.
Strong wind	It was measured average velocity of wind 15 m/sec/day.
C1 – temperature difference	$(T_{\max} - T(8.00)) \geq 10^{\circ}\text{C}$.
C2 – temperature difference	$(T_{\max} - T(8.00)) \geq 20^{\circ}\text{C}$.
C3 – temperature difference	$(T(8.00) - T_{\max}) \geq 1^{\circ}\text{C}$.

Results of computation from such a type of model are here:

A.

In column **A** there are values of point membership functions $\{(\mathbf{Concrete}, \mu(\mathbf{Concrete})), (\mathbf{Grass}, \mu(\mathbf{Grass})), \dots, (\mathbf{Strong\ wind}, \mu(\mathbf{Strong\ wind}))\}$ related to a measured data in part of town named Dejvice and in the selected observation day. (In our case 19.6.2017).

$$\begin{aligned}
 \mathbf{C1} - \text{temperature difference} & \quad (T_{\max} - T(8.00)) \geq 10^{\circ}\text{C}. \\
 \mathbf{C2} - \text{temperature difference} & \quad (T_{\max} - T(8.00)) \geq 20^{\circ}\text{C}. \\
 \mathbf{C3} - \text{temperature difference} & \quad (T(8.00) - T_{\max}) \geq 1^{\circ}\text{C}.
 \end{aligned}$$

Computed results: **C1:** Temperature T_{\max} increases for 10°C or more (comparing with $T(8.00)$) with weight 0.9. **C2:** Temperature T_{\max} increases for 20°C or more (comparing with $T(8.00)$) with weight 0.9. **C3:** Temperature T_{\max} decreases for 1°C or more (comparing with $T(8.00)$) with weight 0.5.

Resulting difference of temperature $(T_{\max} - T(8.00))$ was computed using fuzzy average rule:

$$(T_{\max} - T(8.00)) = (\mu(\mathbf{C1}) \cdot \mathbf{C1} + \mu(\mathbf{C2}) \cdot \mathbf{C2} + \mu(\mathbf{C3}) \cdot \mathbf{C3}) / (\mu(\mathbf{C1}) + \mu(\mathbf{C2}) + \mu(\mathbf{C3})) = (9 + 18 - 0.5) / 2.3 = 11.14^{\circ}\text{C}$$

For $T(8.00) = 22.4^{\circ}\text{C}$ is means $T_{\max} = 33.54^{\circ}\text{C}$. The measured value (in day 19.6.2017, 15:50, in 2 m) was $T_{\max} = 32.5^{\circ}\text{C}$.

Though the results of knowledge based system has to be taken rather as qualitative facts the computation precision of computation does not exceed error 3.5% from measured values.

B.

In column **B** there are values of point membership functions $\{(\mathbf{Concrete}, \mu(\mathbf{Concrete})), (\mathbf{Grass}, \mu(\mathbf{Grass})), \dots, (\mathbf{Strong\ wind}, \mu(\mathbf{Strong\ wind}))\}$ related to a part of town with *large portion of vegetation* and with simulated observation conditions day as in case **A**. Case **B** illustrates the *influence of cooling effect* of vegetation.

$$\begin{aligned}
 \mathbf{C4} - \text{temperature difference} & \quad (T_{\max} - T(8.00)) \geq 1^{\circ}\text{C}. \\
 \mathbf{C5} - \text{temperature difference} & \quad (T_{\max} - T(8.00)) \geq 5^{\circ}\text{C}. \\
 \mathbf{C6} - \text{temperature difference} & \quad (T(8.00) - T_{\max}) \geq 10^{\circ}\text{C}.
 \end{aligned}$$

Table 2: Expert estimations of influences of individual inputs to outputs

Related to RST	C1	C2	C3	A	C4	C5	C6	B
Concrete	0.5	0.3	0.05	0.5	0.5	0.3	0.1	0.2
Grass	0.2	0.1	0.8	0.1	0.2	0.1	0.8	0.8
Bushes	0.2	0.1	0.5	0.3	0.2	0.1	0.5	0.7
Oaks	0.0	0.0	0.8	0.1	0.0	0.0	0.9	0.8
Spruces	0.05	0.0	0.4	0.2	0.05	0.0	0.6	0.5
Poplars	0.1	0.0	0.5	0.1	0.1	0.0	0.5	0.4
High density of vegetation	0.0	0.0	0.6	0.5	0.0	0.0	0.9	0.8
Panel houses	0.8	0.5	0.0	0.3	0.8	0.5	0.1	0.4
Family houses	0.5	0.3	0.0	0.0	0.5	0.3	0.3	0.0
Reflection buildings	0.3	0.1	0.0	0.8	0.3	0.1	0.4	0.0
Asphalt roads	0.9	0.8	0.0	0.5	0.5	0.4	0.0	0.1
Park paths	0.1	0.05	0.5	0.5	0.1	0.05	0.6	0.8
Strong solar radiation	0.6	0.5	0.0	0.4	0.3	0.4	0.0	0.4
Dry previous period	0.7	0.6	0.0	0.6	0.4	0.4	0.0	0.6
Moist temporary period	0.0	0.0	0.3	0.2	0.0	0.0	0.7	0.2
Weather now – clear	0.1	0.1	0.0	0.6	0.1	0.1	0.2	0.6
T(8.00) is high	1.0	0.8	0.0	0.9	0.3	0.2	0.3	0.9
High albedo	0.1	0.1	0.2	0.5	0.1	0.1	0.2	0.5
Sufficient irrigation of vegetation	0.3	0.4	0.6	0.5	0.3	0.4	0.3	0.4
Strong wind	0.0	0.0	0.2	0.1	0.0	0.0	0.2	0.1

Computed results: **C4**: Temperature T_{max} increases for 1°C or more (comparing with T(8.00)) with weight 0.9. **C5**: Temperature T_{max} increases for 5°C or more (comparing with T(8.00)) with weight 0.9. **C6**: Temperature T_{max} decreases for 10°C or more (comparing with T(8.00)) with weight 0.5.

Resulting difference of temperature ($T_{max} - T(8.00)$) was computed using fuzzy average rule:

$$(T_{max} - T(8.00)) = (\mu(C4) \cdot C4 + \mu(C5) \cdot C5 + \mu(C6) \cdot C6) / (\mu(C4) + \mu(C5) + \mu(C6)) = (0.4 + 2 - 8) / 1.6 = -3.5^\circ C$$

For $T(8.00) = 22.4^\circ C$ is means $T_{max} = 18.9^\circ C$.

The knowledge based system with set up values w_A in Table 2 is possible to use for fragment of large town that is similar one to Dejvice in Prague. It is the part of town with average portion of vegetation and with average influence of vegetation cooling effect. The knowledge based system with set up values w_B in Table 2 is possible to use for fragment of large town that has more vegetation then in case **A**.

In order to tune the introduced model for the whole town and extend its applicability for other towns it is necessary to repeat measurement in sufficient number of reference segments.

4 Monitoring of Appearance of Heat Waves in Large Towns

4.1 Description and definitions of some Heat Waves

There is no standard definition of a heat wave. We introduce only 4 of them:

- In the Netherlands, a heat wave is defined as a period of at least 5 consecutive days in which the maximum temperature (measured in locality De Bilt) exceeds 25°C, provided that on at least 3 days in this period the maximum temperature in De Bilt exceeds 30°C. This definition of a heat wave is also used in Belgium and Luxembourg.
- In Denmark, a national heat wave (*hedebløge*) is defined as a period of at least 3 consecutive days of which period the average maximum temperature across more than fifty percent of the country exceeds 28°C – the Danish Meteorological Institute further defines a “warmth wave” (*varmebløge*) when the same criteria are met for a 25°C temperature, while in Sweden, a heat wave is defined as at least 5 days in a row with a daily high exceeding 25°C.
- In the United States, a heat wave is usually defined as a period of at least two or more days of excessively hot weather. In the Northeast, a heat wave is typically defined as three consecutive days where the temperature reaches or exceeds 32.2°C, but not always as this ties in with humidity levels to determine a heat

index threshold Heat storms occur when the temperature reaches 37.8°C for three or more consecutive days over a wide area (tens of thousands of square miles).

- In Adelaide, South Australia, a heat wave is defined as five consecutive days at or above 35°C, or three consecutive days at or over 40°C. The Australian Bureau of Meteorology defines a heat wave as “three days or more of maximum and minimum temperatures that are unusual for the location”.

4.2 Detection of possible appearance of Heat Waves as an emergent situation

We will now return to our system to calculate maximum temperatures. The system has been tuned for the Dejvice-Prague area. Similar measurements and debugging would have to be done for all Prague parts, but this cannot be done in a short time. But even if we have all the parts of the town measured, it is possible to predict appearance of HW using a classical information technology derived from the measurement only indirectly.

(As described above, it is possible to configure s_1, \dots, s_{20} values for the maximum temperature T_{\max} (e.g., 38°C). However, for the HW description we still need duration of maximum temperature and this fact our knowledge model does not include.)

If we do not want to describe the cases measured at other workplaces, we can use a more global approach that includes both the maximum temperature and the duration of the heat wave. This approach is based on the theory of complex systems and the detection of emergent situations. HW is considered as an emergent situation (EMS). In works [2, 3, 4] was presented a theory for which is not place here.

In brief: we model a possibility of appearance of the EMS by means of extension of the ground set X of the matroid and one of its basis $B \in BM, M = \langle X, BM \rangle$ that we have built on a complex system compartment – in our case – of a large city segment. Computation goes from estimation of consequences of EMS to the number of elements of matroid basis. The extension of the number of elements of the matroid given by Ramsey numbers includes the case of extension of matroid basis by at least one new element.

At first a few words about equations for the detection of EMS:

$$\Delta H_P(B + 1) = (u/c)H_{COM}(B). \tag{2}$$

Equation (2) describes the so called contribution to power of the emergent phenomenon $\Delta H_P(B + 1)$ depended on number of elements that are “responsible” for the emergent phenomena. Equation (3) describes the same contribution to power expressed in measurable variables related to this phenomenon. The measure of complexity $H_{COM}(B)$ in equation (2) was considered and verified as the number of elements of matroid basis $\#B$ and quotient $(u/c) \in \langle 0, 1 \rangle$ represents “intelligence” of the self organizing process that executed the emergent phenomenon. Operating with equation (3) we obtain contribution to power released by emergent phenomenon in some level of the description estimated by quantities of external variables (symptoms) $s_i, i = 1, \dots, n$ for emergent ($s_{i,em}$) and for nominal ($s_{i,nom}$) situations:

$$\Delta H_P(B + 1) = \left(\sum_{i=1}^n \omega_i (s_{i,em}/s_{i,nom})^2 \right)^{1/2}, \quad \text{for } i = 1, \dots, n, \tag{3}$$

where ω_i are quotients of importance. The contribution to power of emergent phenomenon results in a dimensionless real number expressed here in % (for example, contribution for 20 % is calculated as $(120/100) = 1.2$). In order to use expression (2) for computation of the number of matroid basis is necessary to set up the quotient (u/c) . The discussion around this quotient was done in works [2, 3] and for our case of HW is $(u/c) = 0.3$.

A basic rule for the detection of an emergent situation (derived in [2, 3]) is the following one:

$$\text{IF } (\#E \geq \min \Delta f(\text{RN})) \Rightarrow (\text{PAES}), \tag{4}$$

where E is a set that extends matroid $\langle X, BM \rangle$ and contains at least one element e extending some basis B , from BM . The number $\min \Delta f(\text{RN})$ is a minimal difference between further and actual Ramsey number. PAES denotes “a possible appearance of an emergent situation”.

Let us now rewrite knowledge about HW quoted at the beginning of this Section in the context of this paper. Variables that represent power of emergent phenomenon are:

T_{\max} ... maximum temperature in an ordinary day,

D_{\max} ... duration of temperature higher or equal to 80% T_{\max} of day maximum temperature in the day.

By means of this two variables we form one critical *symptom* that characterizes the power of emergent phenomenon:

$$s = T_{\max} \cdot D_{\max} [\text{°C} \cdot \text{hours}]. \tag{5}$$

With respect to the description of HW is considered:

$T_{\max,em} = 32^{\circ}\text{C}$, $T_{\max,nom} = 25^{\circ}\text{C}$, $D_{\max,em} = 3 \text{ days} = 36 \text{ hours}$, $D_{\max,nom} = 10 \text{ hours}$.
 $s_{em} = 32 \cdot 36 = 1152 [^{\circ}\text{C} \cdot \text{hours}]$, $s_{nom} = 25 \cdot 10 = 250 [^{\circ}\text{C} \cdot \text{hours}]$.

Contribution to the power of emergent phenomenon:

$$\Delta H_P(\mathbf{B} + \mathbf{1}) = (32 \cdot 36) / (25 \cdot 10) = 4.6,$$

and for $(u/c) = 0.3$

$$\#\mathbf{B} = \Delta H_P(\mathbf{B} + \mathbf{1}) / (u/c) = 15.3 \approx 16.$$

It leads to matroid with $R(16, 3) = \#\mathbf{X} \geq 79$ elements.

$$\mathbf{B} + \mathbf{1} = 17, \quad R(17, 3) \geq 92.$$

Applying (4) we acquire condition for the detection of possible appearance of HW:

$$\min \Delta f(\text{RN}) = 92 - 79 = 13.$$

Note. For determination of $R(16, 3)$ and $R(17, 3)$ there was used tables from [9].

Note. There are considered only “minimal” Ramsey numbers for $Y = 3$. For higher Y we find larger Ramsey numbers, e.g., $R(16, 6) \geq 434$ and $R(17, 6) \geq 548$ – however the most dangerous for our case are Ramsey numbers for $Y = 3$.

The computed difference of Ramsey numbers corresponds to changes of fuzzy values of inputs to which they are needed to converge for the appearance of HW. If we consider as a reference state from which we calculate the contribution ΔRN the set up of \mathbf{w}_A and observation set \mathbf{A} , for the observation day 19.6.2017, we may compute changes of values of elements from \mathbf{A} with regard to this day according to the following relations:

$$\Delta \text{RN} / \text{RN} \approx (\Delta \mu(s_1), \dots, \Delta \mu(s_n)) / (\mu(s_1), \dots, \mu(s_n)) \tag{6}$$

$$\Delta \text{RN} / \text{RN} = 13 / 79 = 0.1645. \tag{7}$$

In Table 3 are introduced values of changes $\Delta \mu(s_i)$ of inputs that contribute to increasing of temperature T_{\max} , their new values respect to appearance of HW and their interpretation regarding their semantics from Table 1.

Table 3: Conditions for HW possible appearance

Related to RST	$\Delta \mu(s_n)$	$\mu(s_i)_{HW}$	Interpretation of $\mu(s_i)_{HW}$
Concrete	0.083	0.583	Nearly 60% of surface is covered by concrete.
Panel houses	0.05	0.35	In each 571 m ² is one panel house.
Reflection buildings	0.13	0.93	In each 215 m ² is one reflection building.
Asphalt roads	0.083	0.583	For each 172 m ² one asphalt road (wideness 10 m).
Strong solar radiation	0.066	0.465	465 W/m ²
Dry previous period	0.098	0.698	In 10 last days has not been raining.
T(8.00) is high	0.148	1	Temperature in 8.00 a.m. was higher of equal 22°C
High albedo	0.083	0.583	29%

5 Conclusion

In the proposed paper was introduced a knowledge based system for modeling ecological situations in large towns. The selection of relevant variables and methodology of the investigation were supervised by experts from fields of ecology and meteorology. The main motivation of the paper was investigation of appearance of Heat Waves in large towns. The results acquired from knowledge based system that has been associated with a typical segment of town Prague continued in the detection of possible appearance of Heat Wave in a segment of town. The development of knowledge based system is a classical application of fuzzy logic. For the part of the detection of appearance of Heat Waves was used the method developed for the detection of emergent situation in complex systems. The paper contains illustrative examples and looks friendly for potential users of the introduced methods.

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References

- [1] Baldocchi, D.D., Vogel, C.A.: Seasonal variation of energy and water vapor exchange rates above and below a boreal jack pine forest canopy. *Journal of Geophysical Research* **102**, 28939–28951 (1997)
- [2] Bila, J.: Emergent Phenomena in Complex Systems and their Detection. *International Journal of Enhanced Research in Science Technology and Engineering* **6**(12), 40–53 (2017)
- [3] Bila, J.: Emergent Phenomena in Natural Complex Systems. In: A. Synaiei et al., (eds.). *Proceedings of Interdisciplinary Symposium of Complex Systems – ISCS 2014*, no. 8 in Emergence, Computation and Complex Systems, pp. 89–100. Springer-Verlag, Berlin, Heidelberg, (2014)
- [4] Bila, J., Pokorný, J., Jura, J., Bukovsky, I.: Qualitative Modeling and Monitoring of Selected Ecosystem Functions. *Ecological Modelling* **222**(19), 3640–3650 (2011)
- [5] Bila, J., Novak, M., Pokorný, J.: Smart Region as a complex system and some notes to its design. In: *Smart Cities Symposium Prague (SCSP)*, pp. 31–35. IEEE Press, New York (2015)
- [6] Leitch, R., Shen, Q.: Fuzzy Qualitative Simulation. *IEEE Trans. on Syst., Man and Cybernet.* **23**(4), 1038–1061 (1993)
- [7] Elzinga, C.L. Salzer, D.W., Willoughby, J.W., Gibbs, J.P.: *Monitoring Plant and Animal Populations*. Blackwell Science, Massachusetts (2001)
- [8] Oxley, J.G.: *Matroid Theory*, Reprinted Edition. Oxford Science Publications, Oxford (2001)
- [9] Weinstein, W.: Ramsey Number. A Wolfram Web Resource. <http://mathworld.wolfram.com/RamseyNumber.html> (2004) [Online; accessed 17-May-2004]
- [10] Parker, T.J., Berry, G.J., Reeder, M.J.: The influence of tropical cyclones on heatwaves in southeastern Australia. *Geophys. Res. Lett.* **40**, 6264–6270 (2013)
- [11] http://copernicus.gov.cz/documents/19/42686/05-Tepeln%C3BD%_ostrov_Praha_Moravcik.pdf [Online; accessed 05-June-2018]
- [12] Flanner, M.G.: Integrating anthropogenic heat flux with global climate models. *Geophys. Res. Lett.* **36**(2), L02801 (2009)
- [13] Jura, J., Novak, M.: Analysis of the hydrometeorological data using the Fractal dimension estimation. In: *Proceedings of 21st International Conference on Process Control (PC)*, 2017, pp. 137–142. Strbske Pleso, Slovakia (2017)
- [14] Odum, H.T.: Explanation of ecological relationships with energy systems concepts. *Ecological Modelling* **158**(3), 201–2011 (2002)
- [15] Roth, M., Oke, T.R., Emery, W.J.: Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. *International Journal of Remote Sensing* **10**(11), 1699–1720 (1989)
- [16] Changnon, S.A., Kunkel, K.E.Jr., Reinke, B.C.: Impacts and responses to the 1995 heat wave: A call to action. *Bulletin of the American Meteorological Society* **77**(7), 1497–1506 (1996)
- [17] Buechley, R. W., Van Bruggen, J., Trippi, L. E.: Heat island = death island? *Environmental Research* **5**(1), 85–92 (1972)
- [18] Diaz, J., Jordan, A., Garcia, R., Lopez, C., Alberdi, J., Hernandez, E., Otero, A.: Heat waves in Madrid 1986/1997: effects on the health of the elderly. *International Archives of Occupational and Environmental Health* **75**(3), 163–170 (2017)
- [19] *Reducing Urban Heat Islands: Compendium of Strategies | Heat Island Effect | US EPA*. Environmental Protection Agency, n.d. Web. (2014)
- [20] Rosenfeld, A.H., et al.: Cool communities: strategies for heat island mitigation and smog reduction. *Energy and Buildings* **28**(1), 51–62 (1998)
- [21] Parker, D.E.: Climate: Large-scale warming is not urban. *Nature* **432**(290), (2004)
- [22] Myrup, L.O.: A Numerical Model of the Urban Heat Island. *Journal of Applied Meteorology* **8**, 908–918 (1969)