Decision Support for Route Planning to Reduce Heat Stress Considering the Time of the Day

January 26, 2017

Heat stress is a serious risk, in particular for certain groups like elderly or patients with multiple sclerosis or heart disease. Developments like the ageing of society, the increasing urbanisation (urban heat island effect) and the climate change are increasing the risk that people are affected by heat stress. One way to reduce those risks is to adapt the everyday behaviour, e.g. by performing purchases in the supermarket or pharmacy in the morning or evening when temperatures are lower.

Therefore we are presenting two different approaches for decision support tools that can help people to adapt their everyday behaviour. At first we're presenting a route planer for pedestrians that can find a route with minimal heat exposure. The second approach we're proposing is a tool that supports the user to select the point in time with a minimal risk of heat stress, considering e.g. the opening hours of a shop. In both cases we are utilizing, among other, remote sensing data of a thermal flight scanner.

Our results are showing that both approaches are able to reduce the heat exposure and therefore can help people to decrease the risk of heat stress in their everyday life.

1 Introduction

Heat is one of several natural hazards our society is faced with today. High temperatures cannot only lead to a discomfort, e.g. because of increased sweating, it can also have serious negative effects on the health.

In numerous studies an increase in both mortality and morbidity has been associated with a high ambient temperature (Basu 2009). For example an excess of mortality during the 2003 heat wave in Europe have been reported for several European countries (Kovats, Wolf, and Menne 2004).

Certain groups are especially vulnerable to heat stress such as older people or people with health problems like high blood pressure, heart, kidney, liver or metabolic diseases (Ebi et al. 2004; Hübler, Klepper, and Peterson 2007). For patients with multiple sclerosis an increased body temperature can lead to a worsening of their symptoms (Davis et al. 2010).

Developments like the ageing of society, the increasing urbanisation and the climate change is making the adaptation to heat stress danger more and more important. For instance due to the tendency that a rising number of people is moving into the cities, the urban heat island effect (UHI) is gaining more importance in the future. Because of the UHI effect an urban area can be 8 °C to 12 °C warmer than the rural areas (Prashad 2014). This is caused by the fact, that urban materials such as asphalt, concrete, and bricks are storing the energy from the sun and releasing it later to their surrounding (Prashad 2014).

There are several steps that can been taken to reduce the risk of heat stress. For instance urban planning measures like more green areas or construction measures like air conditioning or building insulation. Another important step can be the implementation of a heat warning system that enables authorise, hospitals, or retirement homes to take the appropriate actions in time (Ebi et al. 2004).

Additionally, by adapting their everyday behaviour everybody can reduce their risk by themselves. For instance, activities should be performed in the morning or evening when the temperatures are lower.

1.1 Goals

The goal of our work is to help people adapting their everyday behaviour to reduce their heat stress risk. As a use case were looking at everyday actions like go shopping in a supermarket or pharmacy. Those actions usually cannot simply be omitted because there are necessary to challenge the everyday life. Since more and more people are living in cities and do not necessarily own a car, we are focusing on pedestrians.

One possibility to reduce the heat stress is to select the appropriate time to go shopping, because usually in the morning and evening the heat exposure is lower than middays. So, it can make sense to select a shop that is further from the starting point but has longer opening hours.

Another possibility to reduce the heat stress risk is the selection of an appropriate route between the start and the destination. For instance, a longer route with more shadows and green areas can have a lower heat exposure than a shorter route and so that selecting the longer route can reduce the heat stress risk.

1.2 Related Work

Several research projects have considered environmental factors for pedestrian routing in the paste. The AffectRoute routing algorithm proposed by Huang et al. (2014) for instance takes the affective responses to the environment into account, e.g. to find a route that a person considers safer. Sharker, Karimi, and Zgibor (2012) are proposing a method to find a health optimal route, considering several environmental factors like complexity of the walking trail (slope etc.) and weather (only "Good", "Fair" or "Bad"). A method to find a route with a minimal pollution exposure has been proposed by Hasenfratz (2015) in his PhD thesis.

The NaviComf framework for pedestrian routing proposed by Dang, Iwai, Umeda, et al. (2012, 2013), enables to improve the comfort considering environmental factors varying over time. The proposed framework uses a multi-factor cost model for the evaluation of the route and enables them to consider heterogeneous environmental information from multi-modal sensors like air temperature and humidity. To find a optimal route Dang, Iwai, Tobe, et al. (2013) are proposing three different algorithms, a bounded depth-first search algorithm, an adjustable dynamic planning algorithm and a heuristic particle planning algorithm. As a sample application, the authors implemented a routing app for thermal comfort navigation. The meteorological used for this sample application have been collected using a network of 40 micro-climate sensor nodes which detected air temperature and relative humidity.

1.3 Thermal Comfort

To achieve our goals, we need a measure to describe the influence of heat on the human body. In this context, the term thermal comfort plays a key role, which describes climatic conditions consider comfortable, i.e. neither to warm nor to cold.

To describe the influence of the atmospheric environment on the human body it is not sufficient to only take the air temperature into account. Other factors like the humidity, wind speed, sun radiation clothing and physical activity playing an important role as well (Staiger, Laschewski, and Grätz 2011; Hübler, Klepper, and Peterson 2007). Those it's essential to consider a complete heat budget model of the human body to be able to make any reliable statements on the thermal perception and the physiological load on the cardiovascular system (Staiger, Bucher, and Jendritzky 1997). A complete heat budget model of the human body must reach a balance between the internal heat production and environment by exchanging heat, e.g. via sweating (Staiger, Laschewski, and Grätz 2011).

Over time different indices that considers a complete human heat budget model haven been developed like Steadman's heat index (Steadman 1979a, 1979b), the predicted mean vote (PMV) (Fanger 1973), the perceived temperature (Staiger, Bucher, and Jendritzky

1997; Jendritzky, Staiger, et al. 2000) or the universal thermal climate Index UTCI (Jendritzky, Bröde, et al. 2010).

For the examination of the thermal comfort the following meteorological parameters are important: air temperature, vapour pressure, wind velocity and mean radiant temperature of the surroundings (Matzarakis, Mayer, and Iziomon 1999).

Because we only had air temperature and the relative humidity at hand we used Steadman's heat index (Steadman 1979a) and, as a simple comparison measure, the air temperature. To compute an approximation of the heat index we used the formula published by Stull (2011, p. 77).

1.4 Contribution

In this paper we are making contributions to finding a route with minimal heat stress as well as to find a point in time with a minimal heat exposure.

To find a route with minimal heat exposure we are using a different approach then Dang, Iwai, Umeda, et al. (2012, 2013). First of all we didn't have data of a mobile sensor network at hand, instead we're used the remote sensing data of thermal scanner flight as well as the data of weather station. Another contribution is the comparison of different thermal comfort measures like air temperature and heat index. A further difference is the application of static routing algorithm instead of dynamic one as used by Dang, Iwai, Umeda, et al.

Another impotent contribution of this paper is the finding of a point in time with a minimal heat exposure. The approach which we are proposing allows to find a place and a point in time within a given search radius with a minimal heat exposure, considering constrains like the opening hours of the feasible places. Thereby we're taking the heat exposure as well as the distance to the respective places in to account.

2 Minimize Heat Exposure

We are presenting to possible ways how people can be supported to reduce their heat stress risk in their everyday life. First we're presenting an approach to find a route for pedestrian with a minimal heat exposure. On this basis, we show an approach to find a point in time with a minimal heat exposure, for instance to go shopping in a supermarket.

2.1 Finding a Route with Minimal Heat Exposure

2.1.1 Modelling as a Time-Dependent Routing Problem

Finding a route with minimal heat exposure can be modelled as time-dependent routing problem, where the edge weighting function is not static and instead may vary over time. Subsequently, many speed up techniques developed for static routing problems like bi-directional search cannot simply be applied (Delling et al. 2009).

Below, we are representing the road network as undirected graph $G = (V, E, w_d, w_h)$, where V is the set of vertices or nodes (e.g. junctions) and $E \subseteq V \times V$ is the set of edges (e.g. road segments) each connecting a pair of nodes. Furthermore $w_d : E \to \mathbb{R}_{\geq 0}$ and $w_h : E \times T \to \mathbb{R}_{\geq 0}$ are to edge weighting function, at which:

- $w_d(e)$ is the length of the edge e, and
- $w_h(e, t)$ is the heat exposure of edge e at time t.

Hereafter, a path p from node v_0 to node v_k starting a time t_0 is denoted as sequence of edge time pairs $((e_{v_0 v_1}, t_0), (e_{v_1 v_2}, t_1), \ldots, (e_{v_{k-1} v_k}, t_{k-1}))$, where t_i is the time at which node v_i is leaved. The weight of an edge is fixed at the time the traversing of the edge is started (the so-called frozen link model, Orda and Rom 1990). The time t_i can be computed as follows: $t_i := t_{i-1} + t_{walk}(e_{v_{i-1}, v_i})$ where $t_{walk}(e_{v_{i-1}, v_i})$ is the time needed by a pedestrian to traverse the edge e_{v_{i-1}, v_i}. The starting time t_0 is ether given or set to 0.

To compute the weight of a path $w_h(p)$ the following formula can be applied:

$$w_h(p) := \sum_{(e,t) \in p} w_h(e, t). \tag{1}$$

Those means we are looking for the path p^* from a node v to a node u that has the minimal weight of all possible path from v to u. Below, we are using $w_h(p, t)$ to denote the weight of the path p starting at time t.

The time-dependent routing problem is $\mathcal{NP}$-hard, if it is not allowed to wait on a node and the FIFO (first in, first out) property is not fulfilled (Orda and Rom 1990). An edge weighting function $w : E \times T \to \mathbb{R}_{\geq 0}$ stratifies the FIFO or non-passing property if for all edges $e = (u, v) \in E$ and all points in time $t, t' \in T$ with $t \leq t'$ the following in-equation is met (Ahn and Shin 1991):

$$t + w(e, t) \leq w(e, t'). \tag{2}$$

In other words, a weighting function w fulfils the FIFO property if the numerator (change of the edge weight) decreases not faster than the denominator (change in actual time) increases, i.e. the slope of the weighting function is greater or equals to -1 (Kaufman and Smith 1993).

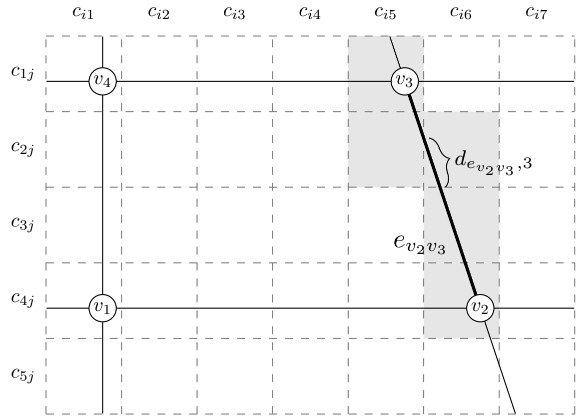


Figure 1: An example for the raster to edge mapping.

Usually, we cannot assume that w_h fulfils the FIFO property, because the function most of the time depends on the air temperature and the air temperature can decrease more than -1 over time. Since, most people are not willing to wait at a node as well, finding a route with a minimal heat exposure is $\mathcal{NP}$-hard. Therefore, hereafter the edge weighting is frozen at the starting time t_0 so that we have static route planning problem and classic algorithms like Dijkstra's algorithm (Dijkstra 1959) can be applied.

2.1.2 The Edge Weighting Function

Above, we described the basic modelling of the routing problem. To find a route with a minimal heat exposure it is key to define the edge weighting function in an appropriated way. Those we need meteorological data (like air temperature and relative humidity) in a sufficient spatial and temporal resolution so we can leverage the variation in that data to find a route with minimal heat exposure. On basis of those meteorological data we can obtain the thermal comfort values as a time-dependent raster $H(t) = (h_{ij}(t))$, where $h_{ij}(t)$ denotes the thermal comfort value in raster cell c_{ij} at time $t \in T$. As we are only interested in heat exposure, we assume that values of h below a certain threshold $h_{comfort}$ (e.g. 20 °C, cf. Jendritzky, Staiger, et al. 2000) are considered comfortable and do not have a negative impact on the health. If the value of raster cell is bellow $h_{comfort}$ it is simply set to that value.

But it is not sufficient to only take the actual thermal comfort value in to account, we also must consider the time a person is exposed to the heat. Below, we assume that the time of exposure is proportional to the length of the edge w_d (following Hasenfratz 2015). Since an edge can cross multiple raster cell we use the value of the intersected raster cell and weighting it with the length of the intersection (see example in figure 1). So finally, we can obtain the weighing function w_h as follows (cf. Hasenfratz 2015):

$$w_h(e,t) := \sum_{c \in Intersec(e)} d_c \cdot h_c(t), \tag{3}$$

where $Intersec(e)$ is the set of raster cells intersected by the edge e, d_c the length of the intersection of e with raster cell c and $h_c(t)$ the value of raster cell c at time t.

2.2 Finding the Optimal Point in Time

Apart from selecting a route with minimal heat exposure the risk of heat stress in the everyday life (e.g. go shopping in a supermarket) can massively be reduced by selecting the appropriate time for this action. That's because usually, the heat exposure is highest at middays and significant lower in the morning or evening.

We are proposing an approach for a decision support tool that can help to find an optimal time for a certain type of location defined by a search criteria, that is within a specified radius. To obtain that goal, we are using three steps:

1. Perform a nearby search originating from a given starting point s (e.g. address or GPS coordinates) to find all locations L that fulfils a certain search criteria (e.g. is supermarket or pharmacy) within a specified radius r (e.g. 500 m).
2. For each location $\ell \in L$ found in step 1, determine the point in time t^* with the lowest heat exposure.
3. Create a ranking of the locations in L based on the minimum heat exposure found in step 2, so that the location with the lowest heat exposure has rank 1, that with second lowest rank 2 and so on.

The steps 1 and 3 are not very complicated, so we are focusing on step 2.

2.2.1 Modelling as a Optimization Problem

If we are search for the optimal point in time for a location ℓ we should consider certain constrains like the opening hours $[t_{open}(\ell), t_{close}(\ell)]$ of a location $\ell \in L$. As the objective function to minimize we are using the heat exposure of the optimal path between the starting point s and a location ℓ as proposed above. Those, finding the point in time with the minimal heat exposure means to minimize the following objective function $h(t, \ell)$:

$$h(\ell, t) = w_h(p^*, t) = \min_{p \in P_{s\ell}} w_h(p, t) = \min_{p \in P_{s\ell}} \sum_{(e,t') \in p} w_h(e, t'), \tag{4}$$

where $P_{s\ell}$ is the set of all possible paths from s to ℓ and $w_h(p,t)$ is the accumulated edge weight of all edges in p at starting time t and w_h is the edge weighting function from equation (3).

Now we can formulate the problem to find a time with minimal heat exposure as a optimization problem with constrains:

$$
\begin{aligned}
&\min_{t\in T} h(\ell, t) && \text{(5a)}\\
&\text{s.t.} \qquad t \geq t_{open}(\ell) - t_{walk}(\ell, t) && \text{(5b)}\\
&\qquad\qquad t \leq t_{close}(\ell) - (t_{walk}(\ell, t) + t_{buff}(\ell)) && \text{(5c)}\\
&\qquad\qquad t \geq t_{earliest} && \text{(5d)}\\
&\qquad\qquad t \leq t_{latest} && \text{(5e)}\\
&\qquad\qquad t \geq t_{now} && \text{(5f)}
\end{aligned}
$$

Note, that the location ℓ is fixed, the selection of the location with lowest heat exposure is performed later in step 3. The objective function (5a) is the one defined in equation (4). The constrains (5b) and (5c) are basically ensuring that the location is arrived within the opening hours. We must ensure that the shop can be reached before it closes, therefore we have to consider the time needed to walk to the location ℓ ($t_{walk}(\ell)$) as well as the time needed perform e.g. the purchase ($t_{buff}(\ell)$). On the other hand, it can make sense to start early in the morning arrive the location ℓ just in time when its opening, so we are subtracting the walking time from the opening time. The constrains (5d) and (5e) are an earliest respectively latest point in time desired by the user and can be omitted. Finally, the last constrain (5f) guarantees, that the optimal point in time is in the future. Another thing to notice is, that the walking time $t_{walk}(\ell, t)$ depends on the starting time t, because conditional on the time a different (properly longer) optimal route can be selected.

2.2.2 Optimization

Now we must find the optimal point in time for each location $\ell \in L$. Since, not necessarily derivations for the objective function $h(\ell, t)$ exits, we have to use optimization method without derivatives like Brent's method (Brent 2002). Brent's method is a procedure for the approximation of local optima within an interval $[x_1, x_2]$, which usually converges faster than the bisection method (Press et al. 1992).

In order to apply Brent's method, we have to transform the constrains (5b) – (5f) to a lower and upper limit of an interval. The constrains (5b), (5d) and (5f) can be easily converted to a lower limit, as follows:

$$t_{lower}(\ell, t) = \max\left\{t_{open}(\ell) - t_{walk}(\ell, t), t_{now}, t_{earliest}\right\}. \tag{6}$$

Alike, we can transform the constrains (5c) and (5e) to an upper limit:

$$t_{upper}(\ell, t) = \min\left\{t_{close}(\ell) - (t_{walk}(\ell, t) + t_{buff}(\ell)), t_{latest}\right\}. \tag{7}$$

It's simple to recognize, that the interval $[t_{lower}(\ell, t), t_{upper}(\ell, t)]$ preserves the constrains from the optimization problem defined above in equation (5).

However, Brent's method can still not be applied, since the lower and upper limit of the interval is depending on the starting time t and therefore not static as required for Brent's method. That's the case because depending on the starting time a different route with minimal heat exposure, can be selected. As solution to avoid this problem we are proposing the introduction of a penalty term:

$$h'(t,\ell) = \begin{cases} h(t,\ell) & \text{if } t_{open}(\ell) - t_{walk}(\ell,t) \leq t \leq t_{close}(\ell) - (t_{walk}(\ell,t) + t_{buff}(\ell)), \\ h(t,\ell) + c & \text{otherwise,} \end{cases} \tag{8}$$

where c is a large constant such that $h(t,\ell) + c$ is never selected as optimal solution, if the constrains are violated. Now, we can use the walking time $t_{walk}^{shortest}(\ell)$ for the shortest route for the lower and upper limit. Finally, we can formulate the optimization problem for Brent's method as follows:

$$\min_{t \in T} h'\ell, t) \tag{9a}$$

$$\text{s.t.} \qquad t \geq \max\left\{t_{open}(\ell) - t_{walk}^{shortest}(\ell), t_{now}, t_{earliest}\right\} \tag{9b}$$

$$t \leq \min\left\{t_{close}(\ell) - \left(t_{walk}^{shortest}(\ell) + t_{buff}(\ell)\right), t_{latest}\right\}. \tag{9c}$$

Now we can use Brent's method to find for each location ℓ the optimal point in time t^*. To avoid, that the Brent optimizer is trapped in a local optimum, its executed several times with different random start points.

3 Evaluation

In the previous section, we gave a short introduction in the theoretical basics of our approach to minimize heat exposure. Below, we are giving a short overview of the data sets we had used, the implementation of our prototype as well as the result of the evaluation.

3.1 Data Sets

3.1.1 Map Data

As map data, we've used the data of the OpenStreetMap (OSM) project (OSMF 2016). Apart from the road network the data set contains for instance points of interest like shops (supermarkets, bakeries, etc.) or amenities (pharmacies, toilets, etc.). Many of them are tagged with useful information e.g. on the accessibility (e.g. `wheelchair=yes`) or their opening hours (e.g. `opening_hours="MoSa 07:00-24:00; Su,PH off"`).

3.1.2 Weather Data

We used two different kind of weather data: the hourly air temperature and relative humidity values of a weather station alongside with to data sets of a thermal scanner flight.

The hourly air temperature and relative humidity values are originating from the weather station of the German Weather Service (Deutscher Wetterdienste, DWD) in Rheinstetten near Karlsruhe (Deutscher Wetterdienst 2016). Because only the hourly values have been available, the intermediate values haven been obtained using linear interpolation of the two adjacent values.

The other kind of data that we've used, have been remote sensing data of a thermal scanner flight provided by the Nachbarschaftsverband Karlsruhe (NVK). The data set consists of two scans, on recorded in the morning and on recorded in the evening of the 26 September 2008. The data are covering an area of $25\,805\,\mathrm{m} \times 39\,555\,\mathrm{m}$ (EW NS) an have a resolution of $5\,161 \times 7\,911$ pixels (pixel size m). The measured surface temperature is in the range of $-1.7\,°\mathrm{C}$ to $18.3\,°\mathrm{C}$ (morning and evening). Before we used the data we rectified them using thin plate splines and cropped them to the same areas as the OSM data. The average surface temperature of the cropped data sets has been $4.18\,°\mathrm{C}$ (morning) respectively $11.24\,°\mathrm{C}$ evening.

3.2 Implementation

3.2.1 Routing

Before we extracted the road network from the OSM data set, we cropped the OSM data set to the evaluated area. Afterwards all ways tagged with `highway`, `railway=platform` or `public_transport=platform` have been extracted.

For the actual implementation of the routing we used the GraphHopper framework for Java (GraphHopper GmbH 2016a; GraphHopper GmbH 2016b). In GraphHopper the edge weighting could be adapted for our needs. Additional the frame work provides implementation of many routing algorithms like Dijkstra's algorithm or the A^* algorithm. Since we are only interested in pedestrian routing, we've used the `FOOT` routing profile predefined in GraphHopper, which e.g. avoids certain highways like motorways.

To compute the edge weights as described above in section 2.1.2 we need to make some assumptions. That's because the weather data that we've used lacked either an appropriate spatial resolution (data of only one weather station) or the required temporal resolution (only two thermal scans have been available). So, we've assumed that the actual spatial variation of the temperature conforms with the spatial variation of the thermal scans (deviation from the mean value). Because for the relative humidity no further data have been available, we assumed that there subject of any spatial variation. For the temporal variation, we've assumed that the temporal variation in the examined area correspond to the temporal variation measure at the weather station in Rheinstetten. Additional we've used the thermal scan recorded in the morning for the time between 00:00 and 11:59 and the scan recorded in the evening for the time between 12:00 and 23:59.

So, we computed the air temperature at time $t \in T$ for the raster cell c_{ij} as follows:

$$T_a(t, c_{ij}) = \begin{cases} T_a^{station}(t) + \delta_{ij}^{morning} & \text{if } 0 \leq t < 12, \\ T_a^{station}(t) + \delta_{ij}^{evening} & \text{if } 12 \leq t < 24, \end{cases} \tag{10}$$

where $T_a^{station}(t)$ is the air temperature measured at the weather station at time t and $\delta_{ij}^{morning}$ respectively $\delta_{ij}^{evening}$ is the deviation of the raster cell c_{ij} from the mean of all raster cells from the morning respectively evening scan.

Using the formula for the air temperature in equation (10) and the formula for the edge weight defined in equation (3) we can now compute the edge weight using the air temperature respectively the Steadman's heat index as measure for thermal comfort. For the computation of the edge weight using the air temperature, the following formula can be applied:

$$w_{T_a}(e, t) = \sum_{c \in Intersec(e)} d_c \cdot T_a(t, c), \tag{11}$$

and respectively for Steadman's heat index:

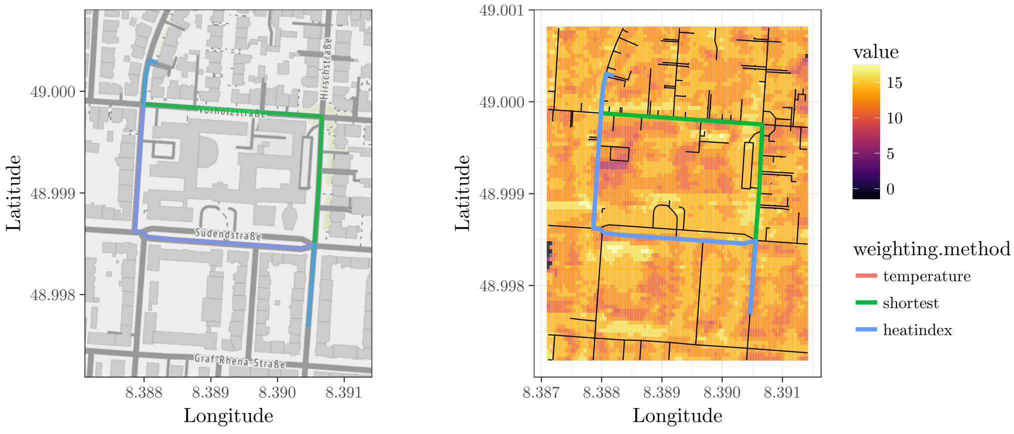
$$w_{HI}(e, t) = \sum_{c \in Intersec(e)} d_c \cdot T_{HI}\left(T_a(t, c), RH(t)\right), \tag{12}$$

where T_{HI} is Steadman's heat index and $RH(t)$ is the relative humidity measured at the weather station at time t. To compute an approximation of Steadman's heat index we used the formula published by Stull (2011, p. 77). Since the heat index is only defined for an air temperature between 20 °C and 50 °C we've used the air temperature as a fallback, if the air temperature was not within that range. Additionally, should be noted that if the air temperature respectively the heat index dropped in a raster cell below a comfort threshold $T_a^{comfort}$ or $T_{HI}^{comfort}$, then that comfort value has been used, because temperature below this threshold are not considered harmful. For both $T_a^{comfort}$ or $T_{HI}^{comfort}$ we used 20 °C as a threshold because temperatures above can cause a light heat stress (Staiger, Laschewski, and Grätz 2011).

3.2.2 Optimal Time

To find an optimal point in time we used the procedure described in section 2.2. As data we used the OSM data as well, because they contain the information necessary, i.e. points of interest with associated opening hours.

For the nearby search, we're using a list of selected OSM tags like `shop=supermarket` or `amenity=pharmacy` as a search criteria. We also only considering locations which have



(a) map

(b) thermal scan (evening)

Figure 2: Routing example: both the *temperature* and the *heatindex* weighting found the same route. (Map tiles by Stamen Design (2017), under CC BY 3.0[1]. Map data by OSMF (2016), under ODbL[2])

opening hours specified (via the `opening_hours` tag). Additionally, only locations which are in a defined radius around the starting point are considered, at this we used the direct distance ("as the crow flies"). To reduce the computation effort a maximum number of results k can be specified.

As optimization algorithm, we used implementation of Brent's method in the Apache Commons Mathematics Library (ASF 2016) with 10 random start points to reduce the risk that only a local optimum is found.

If a shop is not opened over lunch, then for every time window (e.g. 9:00–13:00 and 14:00–18:30) an optimal time is determined and accordingly the solution with lowest heat exposure is used.

3.3 Evaluation

3.3.1 Routing

To evaluate the routing, we've selected 1000 random pairs of start and destinations points form the examined area and 10 random dates from the period of 1 June to 31 August 2015. For each of the start destination pairs and each date we've performed the evaluation at 7:00, 11:00, 15:00, 19:00 and 23:00, so overall we had 50 000 samples. As edge weighting

[2] `http://creativecommons.org/licenses/by/3.0`
[2] `http://www.openstreetmap.org/copyright`

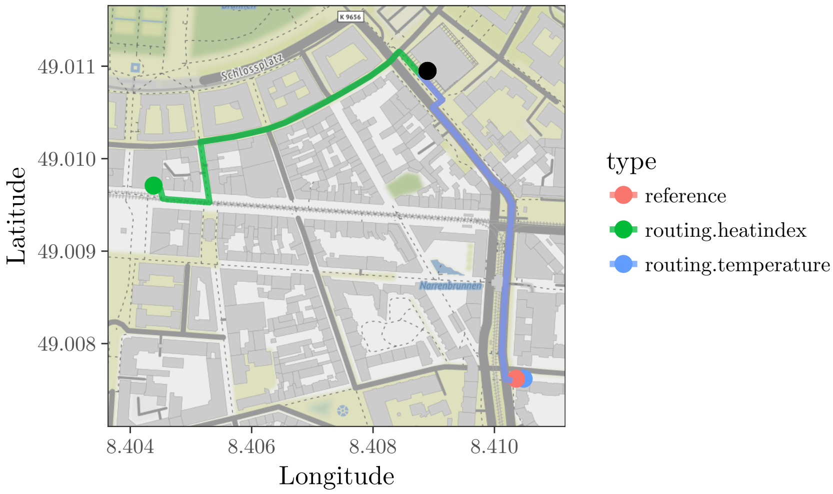


Figure 3: Example for nearby search: In the graphic the starting point (black dot) as well as the locations ranked first by the respective method. (Map tiles by Stamen Design (2017), under CC BY 3.0. Map data by OSMF (2016), under ODbL)

we've used the air temperature (equation (11), *temperature*) and the heat index (12), *heatindex*). For comparison, we computed for each sample the shortest path.

The heat exposure compared to the shortest route could be reduced in 79.70 % (*temperature*) respectively 80.53 % of the cases. In 42.72 % (*temperature*; *heatindex*: 45.11 %) the heat exposure could be reduced by more than 5 % and in 13.81 % (16.07 %) of the cases by more the 10 %. At best the heat exposure could be reduced by up to 25.97 % (*temperature*) respectively 26.17 %. On average the relative heat exposure could be reduce by 2.12 °C (*temperature*) and 2.32 °C (*heatindex*). The relative heat exposure is the edge weight w_{T_a} or w_{HI} of the path normed on the path length w_d and therefore a with the distance weighted average of the heat exposure. In 93.81 % (*heatindex*: 94.11 %) of the cases a longer route was selected. On average the route with minimal heat exposure was 5.59 % (*temperature*) respectively 5.76 % (*heatindex*) longer.

An example can be seen in figure 2. In this example the heat exposure could be reduced by 17.64 % (*temperature*) and 18.76 % (*heatindex*), while at the same time the distance only increased by 0.53 %.

3.3.2 Optimal Time

For the evaluation of optimal time finding procedure we selected 750 random start points. One of the following four search criteria has been assigned to each of the start points at random: supermarket, bakery, chemist or pharmacy. For each of the start points a random start time t_{now} has been selected from the period of 8:00 to 20:00. The radius has been set to 1000 m for all start points and the maximum number of results has been set to 5. Additionally, for all start points a time buffer t_{buff} of 15 minutes has been assumed.

As a reference solution, we've used the closest location found during the nearby search, computed the shortest path from the starting point to this location and evaluated the heat exposure at time t_{now}. The evaluation is performed only for the locations with rank 1, because those have the lowest heat exposure.

The heat exposure could be reduced in 68.43 % (*temperature*) respectively 71.08 % by up to 62.29 % (62.88 %). On average the heat exposure could be reduced by 8.09 % (*temperature*) and 7.73 %. The average increase of the distance was 4.60 % and 4.72 %.

An example can be seen in figure 3. Here the *temperature* weighting selected the same pharmacy and optimal point in time (9:27) as the reference solution. Contrary the *heatindex* routing selected a different pharmacy which is 476.6 m instead of 434.5 m a way from the starting point. Additional the method found a different optimal time (19:39) and those the heat exposure could be reduced by 18.49 %.

4 Conclusion

The results of our evaluation are showing that the approaches proposed in this paper are able to reduce the heat exposure significantly. Those, the recommendations given can help people to adapt their everyday and reduce their personal risk to be affected by heat stress. That the second approach (finding an optimal point in time with minimal heat exposure) can decrease the heat stress risk more strongly is not surprising, since the time of the day has a huge effect on the heat exposure. Since, there are no significant differences between the air temperature and the heat index as a thermal comfort measure, we cannot give any advice in this perspective.

As usually the reduction of heat exposure leads to a longer distance to walk the users should decide based on their personal preferences, i.e. if is user is willing to take longer route to reduce the heat stress risk.

The approach proposed in this paper has some known restrictions and there elimination can be object of future research. First of all, the weather data available had a low spatial and temporal resolution. Utilizing e.g. data from a wireless sensor network can help to improve the data basis and to produce more meaningful results. In that regard, the usage of more complex thermal comfort measure like the UTCI can help to farther improve the reliability of the results. Another restriction is the usage of static routing algorithm instead of dynamic routing method. Using a dynamic routing algorithm as those proposed by Dang, Iwai, Umeda, et al. (2012, 2013) can help to consider the temporal variation more precise.

One very promising extension of our approach to find an optimal time is the consideration from multiple location types (supermarket, pharmacies, ATM, etc.). Thus, the goal is to find a tour with minimal heat exposure that contains exactly one of each location type. Here not only the time and the route with minimal heat exposure should be considered but also, the ordering of the locations.

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