WP4–Human factors simulation in BETs and definition of a related behavioral-based (B-based) resilience metric

T4.2 Simulators application to selected BETs in their current state and by applying current SUOD/SLOD standards mitigation strategies. Interferences assessment between selected SUOD/SLOD through simulation-based approach, with possible overlap of effects and related amplifications. Definition of a set of KPIs for overall resilience evaluation of BE and criteria for their correlation

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Abstract

The Built Environment risk and resilience is highly dependent on the BE users' reactions to the surrounding conditions. In fact, such reactions can drastically modify the exposure aspect of risk by modifying the way the built environment users are exposed to the environmental conditions that impose a stress on them, also depending on their individual vulnerability (e.g. motion speed and other fragilities in motion, health status). For that, simulation methods can be useful to determine the intensity and the extent at which the built environment users are exposed to a significant hazard. Moreover, reasoning on urban unit archetypes, as the ones established in previous steps of the project, are effective to robustly access and determine potential recurring conditions. Then, to evaluate their resilience capacity time and area-weighted UTCI and AQI values are estimated to evaluate the severity of the BE user's exposure, then these are associated to their corresponding sweat rate (connected to the water loss) and health affection rate probability, and finally normalized by the total area of the BE analysed, to correlate it to its intrinsic properties. This was applied to the worst performing climate of the Italian context on every established built environment typology. Results obtain suggests that, under certain circumstances on an outdoor open space, a toddler exposed for just less than 3 hours (~4% water loss on body weight) can reach a dehydration risk state; and, an exposure for 1-hour to very low concentrations of NO_2 can increase the mortality probability by approximately 1%.

Keywords

Urban archetypes; Heat stress; Air quality; Individual vulnerability; Health risk.

Approvals

Role	Name	Partner	Date
Coordinator	Enrico Quagliarini	UNIVPM	

Revision versions

Revision	Date	Short summary of modifications	Name	Partner
0.1	30.11.2021	Revision of results according to the BET simulations update	Juan Diego Blanco Cadena	POLIMI

Summary

1. Introduction: People behavior boosting SLOD risk resilience

According to a behavioural-based perspective, the Built Environment (BE) risk and resilience is highly dependent on the BE users' reactions to the surrounding conditions (Krüger et al. 2017; Choi et al. 2019). In fact, such reactions can drastically modify the exposure aspect of risk by modifying the way the BE user's are exposed to the environmental conditions that impose a stress on them also depending on their individual vulnerability (e.g. motion speed and other fragilities in motion, health status) (Villagràn De León 2006; Bosina and Weidmann 2017; Luo et al. 2018).

However, given the way that SLODs unfold, BE users do not always perceive the stress action that such continuous or prevalent effects have on them, reducing their actual responsivity to hazard arousal (Cori et al. 2020)[1]. Therefore, simulation methods can be useful to determine the intensity and the extent at which the BE users are exposed to a significant hazard (de Nazelle et al. 2009; Yıldız and Çağdaş 2020). Moreover, reasoning on urban unit archetypes, as the BE Typologies (BET) established in D3.2.1, could be more effective than testing single scenarios since their recurring conditions are more feasible to assess (Bernardini et al. 2021).

To reduce the exposure aspect of risk, there shall be strategies to educate or to guide people to behave in a certain manner to avoid their presence on the urban areas that are more vulnerable to the effects of intense hazards (see D.5.1.1). However, to estimate and monitor the efficacy of such strategies, it is necessary to utilize quantitative KPIs. For the SLODs of interest (i.e. increasing temperatures and air pollution), after analysing literature (D.2.2.1 and D.2.2.2), the most applicable KPIs were selected as Universal Thermal Climate Index (UTCI) for thermal stress, and Air Quality Index (AQI) for pollutants danger (Mintz 2006; Bröde et al. 2009).

In order to evaluate the behaviour-based resilience of the BET, it will be associated to the hazard relief brought by the characteristics of the BET, and the possibility that BE users have to access to their benefits. In particular, such resilience would be evaluated in terms of the selected KPIs (UTCI and AQI) throughout time.

For instance, UTCI has been closely linked to the hourly sweat rates (as physiological response) that people could have (Broede et al. 2013) when exposed to a certain category of heat stress (Błażejczyk et al. 2010). It allows to estimate the potential amount of water loss in an hour given the heat stress imposed to the BE user. This, enables designers to acknowledge the risk that BE users could have, by considering that losing water, by means of sweat, that represents more than 4% of body weight could result in initial symptoms of dehydration (Błażejczyk et al. 2014).

On the other hand, specific or quantifiable air pollution burden on health is more complicated. In fact, current methods are more dedicated to estimate the air pollution increments to recorded deaths, hospital entries, and respiratory disease cases. Also, their impact are normally measured on Disability-Adjusted Life Years (DALYs) and Years of Life Lost (YLLs) (Devleesschauwer et al. 2014). However, for a more granular analysis, increments on pollutants concentrations (hourly, daily or yearly) have been attributed to the probability of health affection, reporting symptoms, lung function decrease, asthma, hospital entry and mortality (Dockery and Pope 1994). In specific, it has been more granularly documented for particulate matter such as PM10 and PM2.5 (Dockery and Pope 1994; Martuzzi et al. 2006).

[1] https://climatecommunication.yale.edu/publications/public-perceptions-of-the-health-risks-of-extreme-heat-across-us-states-counties-and-neighborhoods/ (last access: 30/06/2021)

Therefore, the use of health-related, time and behavioural dependant KPIs have been chosen to be utilized, to be then normalized by the area of affection and the total area of the BE studied. Time and area-weighted UTCI and AQI values are estimated to evaluate the severity of the BE user's exposure, then these are associated to their corresponding sweat rate (connected to the water loss) and health affection rate probability, and finally normalized by the total area of the BE analysed, to correlate it to its intrinsic properties.

2. Methodology

Combining the results obtained from the hazard + vulnerability analysis and the hazard + exposure estimate made on the studied area (D.4.1), it is possible to account for the intensity and duration of heat stress and air pollution distress.

Then, the behavioral-based resilience capacity of the urban unit within the BE can be estimated and compared based on the time and area-weighted effect on health of such stress. In this way, Hazard, Vulnerability and exposure are combined to fully account for SLODs risk. Computing the amount of time that a person would be exposed to a certain degree of stress intensity, and the total probable burden that this will have on BE users (see Figure 1).

Therefore, the resilience capacity of the BE is expressed indirectly by the low level of health burden, or the difference on health burden after a mitigation strategy is applied.

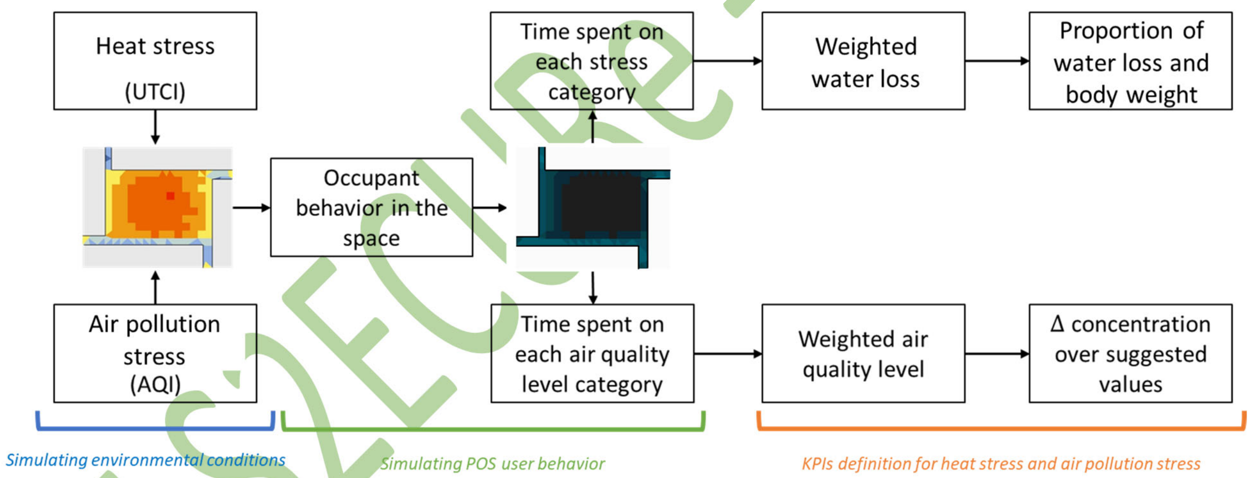


Figure 1 – Schema of the process for handling the SLOD KPIs, utilizing both UTCI and AQI as the main indicators and then weighted on the time a BE user can be exposed.

This analysis has been analyzed on the worst performing climates according to the result obtained from applying the method described in D4.1.1 on the BETs for heat stress and air quality distress. That is, those climates were the BETs reported high UTCI and AQI values within the outdoor space.

2.1 Granular time dependent heat stress affection on health

Compute the amount of water loss (Equation 1), based on the sweat rate associated to a UTCI-heat stress category, for every time-step. Then, the total water loss of a singular individual present in the BE is compared to hypothetical body weight to see if they are at a significant risk or not (WLR) (the larger the water loss/body weight rate, the larger the risk, Equation 2).

Equation 1

$$water\ loss = \sum_{i=0}^{n} Sweat\ rate_i \cdot t_i$$

Equation 2

$$WLR = \frac{water\ loss}{body\ weight}$$

A summary of the allocated sweat rate provided by Błażejczyk et al. (2010 and 2014) by UTCI category is presented in Table 1.

To define the behavioral based KPI for the simulation according to a rapid-to-apply approach, Equation 1 and Equation 2are applied in respect of the area of the BET characterized to be assessed by considering Outdoor Only (OO) and Prevalent Outdoor (PO) users' conditions. For OO, according to a conservative approach to risk assessment, it is considered that users can also move in locally critical conditions of UTCI, so their possible averaged water loss in a tipological BE (BET) $WL_{BET,OO}$ [g/h] to UTCI conditions will be expressed according to Equation 3in terms of probability of permanence for transient behaviors (Cheunga and Jim 2019):

Equation 3

$$WL_{BET,OO} = \frac{\sum_{a=0}^{n}(Sweat\ rate_a \cdot (t_{a,crit} \cdot A_a \cdot\ prob_a)}{\sum_{a=0}^{n} A_a}$$

where *a* is the area characterized by a given UTCI conditions (and so with a given sweat rate), and which dimension in surface term is A_a [m²], while $prob_a$ is the transient acceptable temperature range probability depending on the UTCI (Cheunga and Jim 2019). Equation 3[2] considers the critical exposure time of 15 minutes ($t_{a,crit}$) which is congruent with the transient behavior as well as with the maximum time to cross the BETs at about 1-1.5m/s of speed. Then, the water loss risk can depend on the individual conditions given the age classes considered in the BET (related to social vulnerability), according to D4.1.1 and D3.2.3 (toddlers, children, young adults, adults, elderly). Then, a specific water loss risk WLR_{age} can be calculated for each age class[3], thus according to the average /range of body weight for the specific age class, according to Equation 4.

Equation 4

$$WLR_{age} = \frac{WL_{BET,OO}}{body\ weight_{age}}$$

In particular, $body\ weight_{age}$ [g] data can be associated with statistical anthropometric measurements depending on the specific Country in which the analysis is performed. Due to the lack of completeness of available data for the Italian case study, data from USA statistics are preliminary adopted in this work[4] (Table 2).

[2] This calculation has been included in the behavioral simulator for SLOD to SUOD analysis, developed in WP4- D4.1.1
[3] according to national statistics, e.g. for Italy: https://www.nature.com/articles/1601314
[4] Vital and Health Statistics Series 11, Number 252 October 2012 (cdc.gov)

Table 1 - Sweat rate allocation by UTCI heat stress category, re-elaborated from Błażejczyk et al. (2010 and 2014). [a] Undefined. For this work, interpolation values are utilized, using the start and end values of the range as boundary values.

UTCI [ºC]	Stress category	Sweat rate [g/h]	Interpolation methods for simulation and estimation
>46	Extreme heat stress	>650	$sweate\ rate = 650$
38 – 46	Very strong heat stress	200 – 650 [a]	$sweate\ rate(UTCI) = \begin{cases} \frac{225 \cdot UTCI - 5800}{7}, 46 \geq UTCI > 32 \\ \frac{100 \cdot UTCI - 2600}{3}, 32 \geq UTCI > 26 \end{cases}$
32 – 38	Strong heat stress	>200 [a]	
26 – 32	Moderate heat stress	0-200 [a]	
9 – 26	No thermal stress	0	$sweate\ rate = 0$

Table 2 – Preliminary assumptions on mean body weight[kg] according to the age classes adopted in WP3, and related standard deviation values, according to USA statistics *(Vital and Health Statistics Series 11, Number 252 October 2012 (cdc.gov). *: data do not include the weight of the adult moving with the child.*

Age class (years)	Mean body weight – MALE (st. Dev) [kg]	Mean body weight – FEMALE (st. Dev) [kg]
Toddlers TU (0-4)*	11 (4)	11 (4)
Parent-assisted children PC (5-14)*	40 (14)	40 (14)
Young autonomous users YA(15-18)	77 (4)	65 (2)
Adult users AU (20-69)	89 (3)	76 (1)
Elderly EU (70+)	83 (4)	70 (5)

2.2 Granular pollution burden on health

Motivated by the lack of information on all air pollutant types, the interest on making the methodology robust, and given that there is no direct link between short-term exposures of air pollutants and health burden, a slightly different approach was considered.

Hence, the granular pollution burden is estimated as the increased probability of health affections (reporting symptoms, lung function decrease, asthma, hospital entry and mortality) as presented by Dockery and Pope (1994) for PM10 and for other pollutants (e.g.PM2.5, O3, NO2) reported by Atkinson et al. (2013). Likewise, the relative risk (RR) for PM10 and O3 as presented by Martuzzi et al. (2006). Such probability growth or RR are assigned according to the calculated increment of the pollutant concentration ($\Delta_{pollutant}$) to which an individual is exposed; and in this work, it was dediced to be compared to the maximum suggested concentration for an acceptable air quality.

Thus, as for the heatwave-related risk assessment, a simpliied methodology is adopted to assess the concentration to which an individual could be exposed within the BE $AQI_{BET,crit}$. $AQI_{BET,crit}$ is estimated by considering t_{crit} [minutes] as the time of critical exposure (e.g., for OO, 15 minutes) and the area-weighted average of AQI, for each AQI conditions called a within the BET (

Equation 5). In case of analysis on the users' path or presence over the time in the outdoor areas of the BET, t_{crit} will be equal to the permancence time in each of the areas a, and so it will be different for each of the areas (second line in

Equation 5). Then, this value is reconverted to the concentration values of the pollutant of interest (which generated the displayed AQI) to directly obtain the percentual change in probability, or the total ammount of RR, of health burden (see Equation 7**Errore. L'origine riferimento non è stata trovata.** and **Errore. L'origine riferimento non è stata trovata.**) (Dockery and Pope 1994; Martuzzi et al. 2006; Atkinson et al. 2013). To report the type of health burden and the extent, it can be allocated and estimated complemented by what has been reported by World Health Organization (2021) (see Table 3 and Table 4).

Equation 5

$$AQI_{BET,crit} = \begin{cases} \frac{\sum_{a=0}^{n}(A_a \cdot AQI_a)}{\sum_{a=0}^{n} A_a} \; if \; t_{0,crit} = t_{1,crit} = \cdots = t_{n,crit} \\ \frac{\sum_{a=0}^{n}(A_a \cdot AQI_a \cdot t_{a,crit})}{\sum_{a=0}^{n} A_a \cdot t_{a,crit}} \end{cases}$$

Equation 6

$$Concentration_{AQI} = \frac{(AQI_{BET,crit} - I_{Lo}) \cdot (BP_{Hi} - BP_{Lo})}{I_{Hi} - I_{Lo}} + BP_{Lo}$$

Where, referring to the suggested values already presented in D2.2.2 (Table 2 (Mintz 2006)):

I_{Hi}: the reference AQI value corresponding to BP_{Hi}
I_{LO}: the reference AQI value corresponding to BP_{Lo}
BP_{Hi}: the breakpoint that is greater than or equal to $Concentration_{AQI}$
BP_{Lo}: the breakpoint that is less than or equal to $Concentration_{AQI}$

Equation 7

$$\Delta_{pollutant} = Concentration_{AQI} - Concentration_{suggested}$$

Equation 8

$$short\ term\ pollution\ risk_i = \left(\frac{\Delta_{pollutant}}{10}\right) \cdot (RR_i - 1)$$

Where:

i: mortality, hospital admissions (cardiovascular), hospital admissions (respiratory) or symptoms relative risk for the specific pollutant type studied

Table 3 – Type of air pollutants, their associated health affection and the suggested concentration to mitigate such affections, based on World Health Organization (2021), Mintz (2006) *and US EPA (2018). Sensitive groups can be [a] elderly, [b] children and toddlers, [c] people with health affections (asthma, cardiovascular and respiratory defficiency).*

Pollutant	Health burden type	Suggested Concentration	Critical Concentration for sensitive groups	Critical concentration for everyone
PM10	Acute lower respiratory infections, cardiovascular disease, chronic	15 μg/m³ annual mean 45 μg/m³ 24-hour mean	145 μg/m³ 24-hour mean[a,b,c]	245 μg/m³ 24-hour mean
PM2.5	obstructive pulmonary disease and lung cancer.	5 μg/m³ annual mean 15 μg/m³ 24-hour mean	40 μg/m³ 24-hour mean[a,b,c]	65 μg/m³ 24-hour mean
O3	Asthma morbidity and mortality. Together with reduced lung function and lung diseases.	100 μg/m³, 8-hour daily maximum (for >3 days) 60 μg/m³ 8-hour mean, peak season (for the most polluted 6 month)	80 μg/m³ 8-hour mean[b,c]	105 μg/m³ 8-hour mean

NO2	Asthma, bronchial symptoms, lung inflammation and reduced lung function.	10 µg/m³ annual mean 25 µg/m³ 24-hour mean 100 µg/m³ 1-hour	188 µg/m³ 1-hour[b,c]	2354 µg/m³ 1-hour[a,b,c]

Table 4 – Collection of the population average short term exposure risk variance due to an increase on the air pollutants concentration (Atkinson et al. 2013)*, or from* [a]Dockery and Pope (1994).

	RR per 10 µg/m³			
Pollutant	**Mortality**	**Hospital admissions (cardiovascular)**	**Hospital admissions (respiratory)**	**Symptoms**
PM10	1.0100[a]		1.0080[a]	1.028
PM2.5	1.0123	1.0091	1.0190	
O3	1.0029	1.0089	1.0089	1.0154
NO2	1.0027	1.0015		

For estimating the effect of different pollutants in parallel, equivalent emission methods can be applied (e.g. for PM10, Foresman et al. (2003) has presented a direct method).

3. Results

The worst performing climates in the Italian region according to the result obtained on the BETs for heat stress and air quality distress (See D4.1) were identified as follows:

- Based on UTCI intensity and distribution -> Milan, Lombardy (Cfa - Köppen-Geiger climate type and climate zone E – Italian decree)
- Based on AQI intensity and distribution -> Bolzano, Lombardy (Cfb - Köppen-Geiger climate type and climate zone E – Italian decree)
- Having both high UTCI and AQI intensity distribution in certain BETs -> Milan, Lombardy

Therefore, Milan's climate was analyzed for both UTCI and AQI as it can have critical simultaneous SLODs risk. Its climate data were used to establish and compare the degree of potential impact that every BET could have on the BE users. And also, communicating the degree of exposure within the OO in response to the micro-climate environmental conditions.

The analysis period for Milan was established on the hottest week for the UTCI and the hottest day for the AQI set with .STAT weather file (07/06 to 12/06), within 11 and 16 hours.

3.1 Mapping the BE user movement and exposure

The OO users' displacement are highly influenced by the weather, or the micro-climate of a certain portion of the space. Using the equations provided for UTCI acceptability in D4.1, it was assumed that people would rather concentrate on the areas with a higher percentage of acceptability.

In that context, the acceptability was estimated for a 1-hour exposure time for every BET from the for a 1-hour BE user behavior towards the UTCI value. A summary of the results can be found on Figure 2.

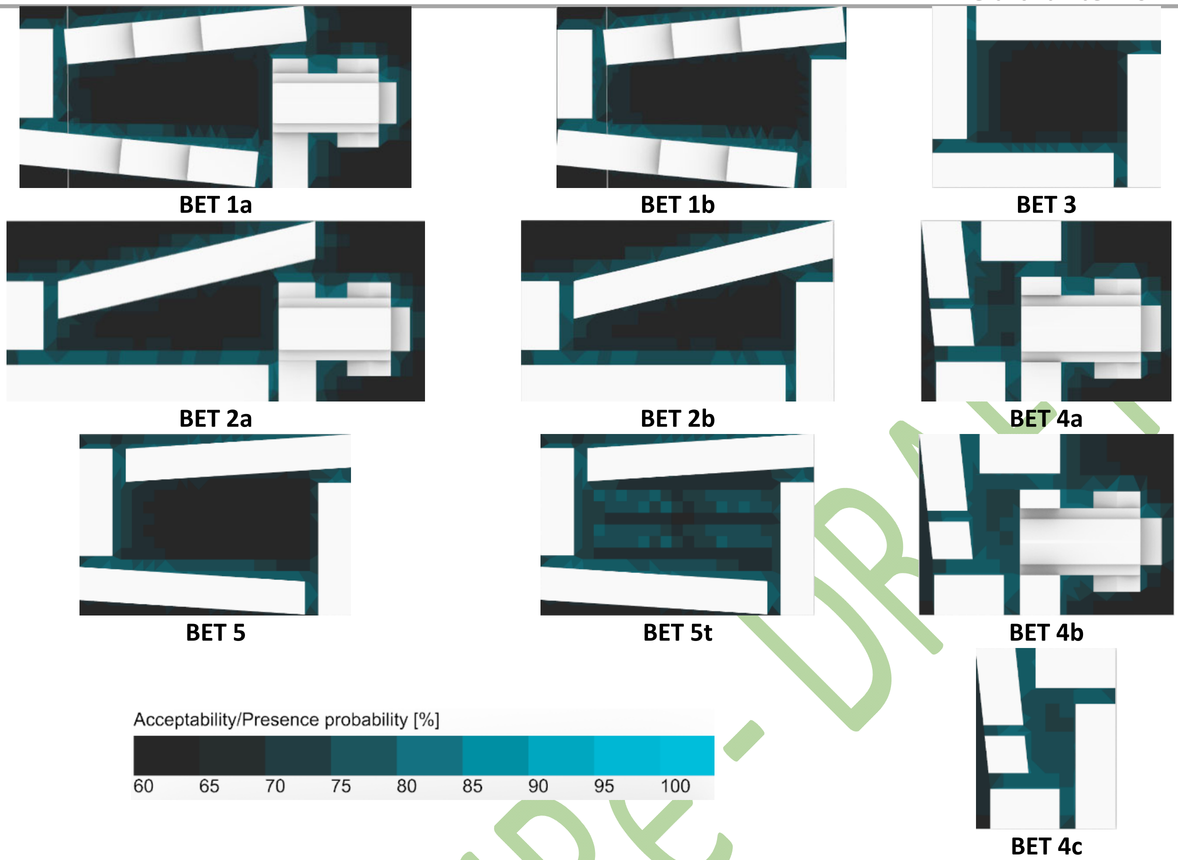
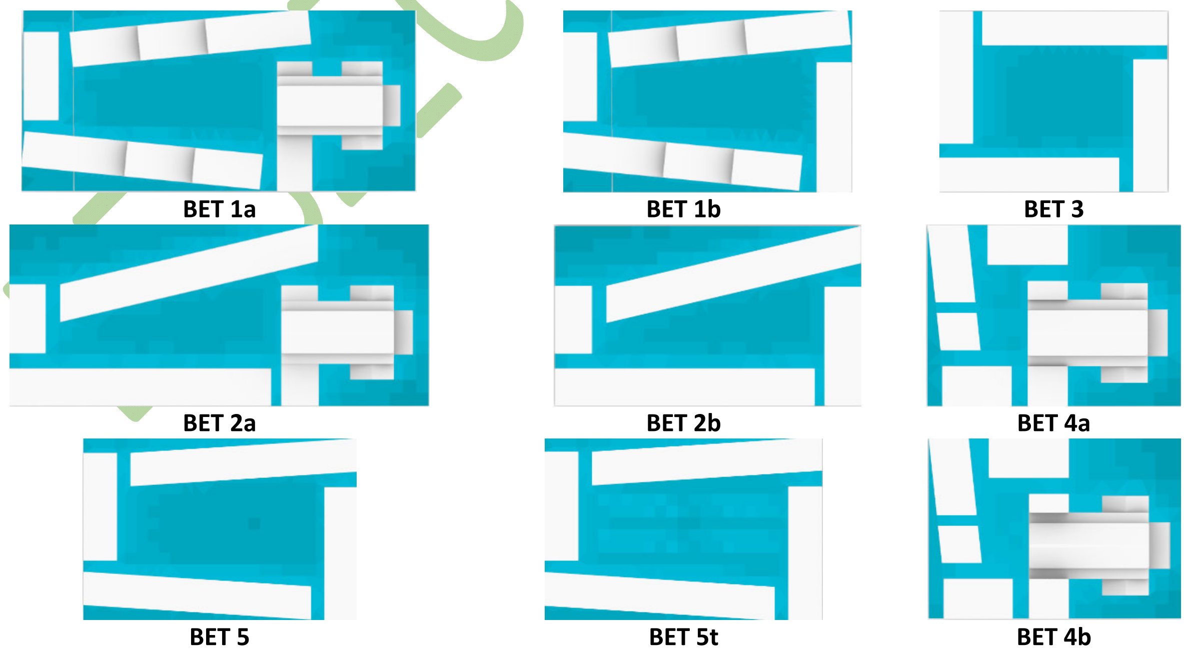


Figure 2 – Results of the computed acceptability and assumed probability of people's presence on the outdoor area based on the UTCI 1-hour behavior response within the constructed BETs for the Italian context subjected to Milan's Climatic conditions.

The acceptability was also estimated for a 1-hour exposure time for every BET, but this time considering a transient BE user behavior towards the UTCI value. A summary of the results can be found on Figure 3.



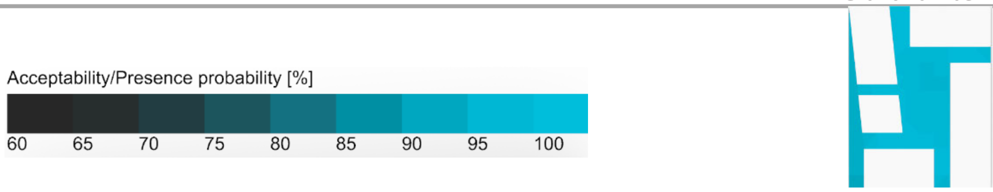


Figure 3 – Results of the computed acceptability and assumed probability of people's presence on the outdoor area based on the UTCI transient behavior within the constructed BETs for the Italian context subjected to Milan's Climatic conditions.

It is interesting to see that on large open spaces, people would rather stay on the edges of such areas, avoiding the potential and direct exposure with solar radiation. The addition of trees on BET 5 + trees increase the probability of people remaining on the middle of the open space, probably providing a more shaded and cooler space to stay on. Smaller piazzas seem to behave better on keeping people within the open OO, as it probably shields them from adverse environmental conditions.

3.2 Heat stress risk evaluation and comparison

Based on the capabilities of Ladybug tools in Grasshopper + Rhinoceros, it was possible to obtain a simplified calculation of the UTCI following the methodology previously described in D4.1. The obtained values (Figure 4) were the base to compute the results obtained for Figure 2 and these were also used to allocate the sweat rate, compute the water loss and the potential water loss risk (Equation 3 and Equation 4).

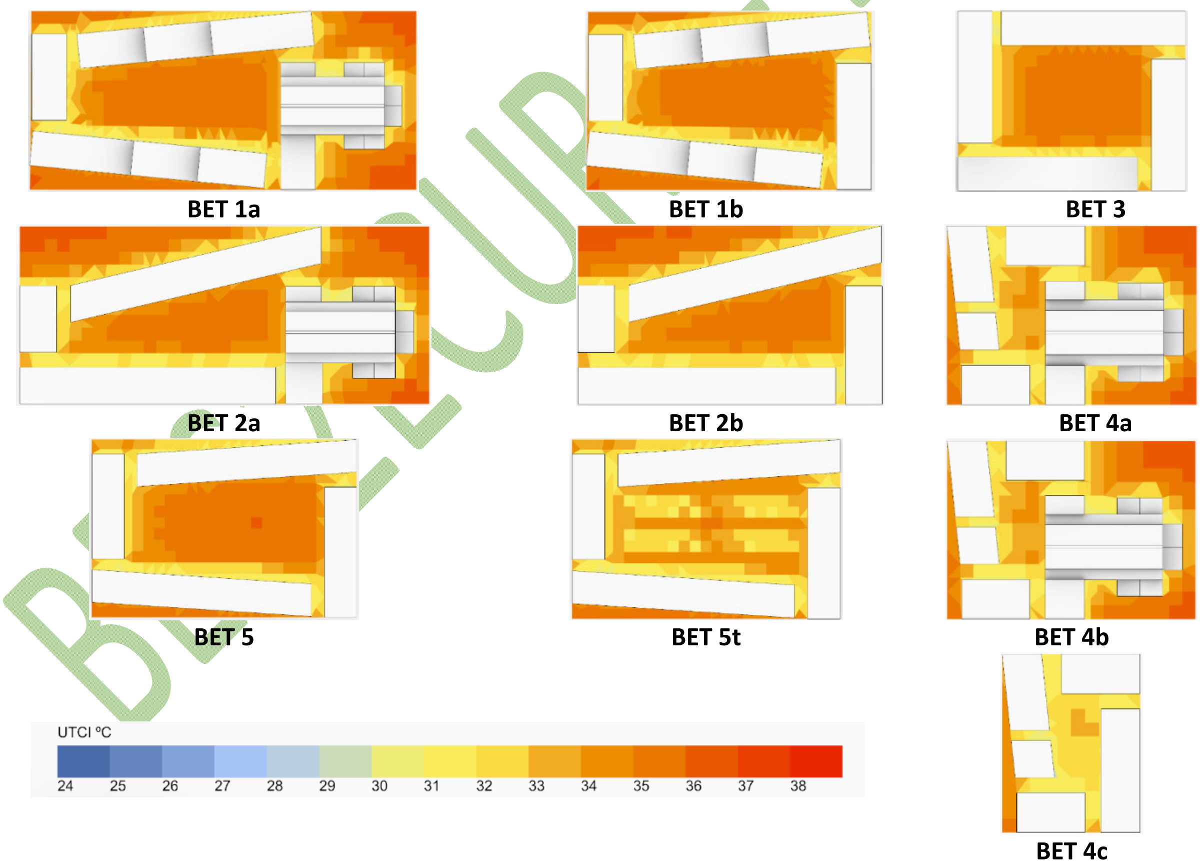


Figure 4 – Results of the computed UTCI representing people's thermal stress outdoor within the constructed BETs for the Italian context subjected to Milan's Climatic conditions.

Then, for the selected period of analysis (i.e. 11-16 in 06/07 to 12/07), the sweat rate was calculated in each point of the analysis grid, then Equation 3 and Equation 4 were used considering a t_{crit} of 1 hour to obtain a unique and normalized heat stress health affection impact risk value for every BET and age class. Such analysis was carried out for the two considered BE user behavior and summarized in Table 5 and Table 6.

Table 5 – Percentage of water loss on body weight given the potential 1-h exposure, 1-hour behavior and perceived thermal stress within the BET, given a certain age class.

Age class	BET 1a	BET1b	BET2a	BET2b	BET3	BET4a	BET4b	BET4c	BET5	BET5t
Male/Female TU	1.54	1.53	1.54	1.53	1.54	1.48	1.44	1.31	1.53	1.42
Male/Female PC	0.42	0.42	0.42	0.42	0.42	0.41	0.4	0.36	0.42	0.39
Male YA	0.22	0.22	0.22	0.22	0.22	0.21	0.21	0.19	0.22	0.2
Female YA	0.26	0.26	0.26	0.26	0.26	0.25	0.24	0.22	0.26	0.24
Male AU	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.16	0.19	0.18
Female AU	0.22	0.22	0.22	0.22	0.22	0.21	0.21	0.19	0.22	0.21
Male EU	0.2	0.2	0.2	0.2	0.2	0.2	0.19	0.17	0.2	0.19
Female EU	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.21	0.24	0.22

Table 6 – Percentage of water loss on body weight given the potential 1-h exposure, transient behavior and perceived thermal stress within the BET, given a certain age class.

Age & gender class	BET1a	BET1b	BET2a	BET2b	BET3	BET4a	BET4b	BET4c	BET5	BET5t
Male/Female TU	2.15	2.13	2.16	2.13	2.16	2.03	1.97	1.72	2.14	1.90
Male/Female PC	0.59	0.59	0.59	0.58	0.59	0.56	0.54	0.47	0.59	0.52
Male YA	0.31	0.3	0.31	0.3	0.31	0.29	0.28	0.25	0.31	0.27
Female YA	0.36	0.36	0.36	0.36	0.37	0.34	0.33	0.29	0.36	0.32
Male AU	0.27	0.26	0.27	0.26	0.27	0.25	0.24	0.21	0.26	0.23
Female AU	0.31	0.31	0.31	0.31	0.31	0.29	0.28	0.25	0.31	0.27
Male EU	0.29	0.28	0.29	0.28	0.29	0.27	0.26	0.23	0.28	0.25
Female EU	0.34	0.34	0.34	0.33	0.34	0.32	0.31	0.27	0.34	0.3

From the results on potential water loss on body weight, it is possible to see how the toddlers are those who are more on risk of dehydration, given their lower weight and their lower capacity to rehydrate. In fact, a toddler exposed on any of the bets is approximately at half of the limit value for dehydration. It will require that a toddler is exposed for less than 3 hours (~4% water loss on body weight) on such averaged conditions to reach a dehydration risk state.

The worst performing BET was BET1a, 2a, 3 followed closely by 1b and 5. Probably due to their high sky vault exposure, thus more direct solar radiation is perceived in the open space. Meanwhile, the best performing BET was BET4c, followed by BET5t with a significant reduction on toddlers' risk (specially comparing BET5 and BET5t).

Finally, it is relevant to note that the behavioral response of both users adopting 1-hour and transient behaviors can generate an average absolute difference of the *WLR* that ranges from 0.05% to 0.62%.

3.3 Air pollution distress risk evaluation and comparison

Based on the capabilities of ENVIMET, it was possible to obtain an estimated value of the pollutants' concentration and distribution (later transformed into AQI) within and around the BETs (see Figure 5), following the methodology previously described in D4.1 (wind speed and direction fixed, 1.9 m/s and 310º from north). Then, an area-weighted AQI was calculated, the corresponding air pollutant concentration was obtained, the difference with the suggested and critical concentration values was computed and the health affection risk increment was determined (

Equation 5, Equation 6, Equation 7 and Equation 8).

Such results were done only for the condition in which the traffic is running within the BETs, in order to obtain the values of the most critical condition as the air pollutants are emitted closer to the BET users (compared to an outside pollutant transportation inwards).

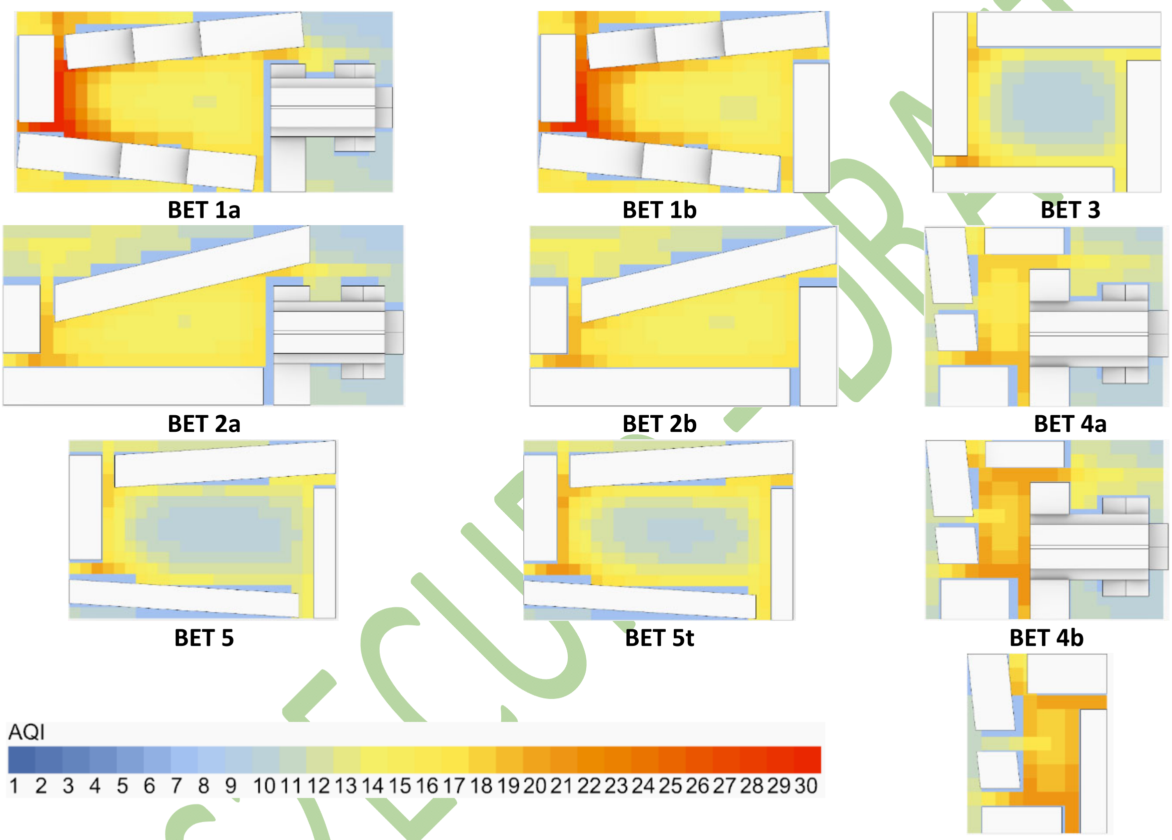


Figure 5 – Results of the computed AQI displaying the air pollution conditions to which people would be exposed when present on the outdoor area within the constructed BETs for the Italian context subjected to Milan's Climatic conditions.

Given that obtained AQI values were found very low, and in order to avoid having negative $\Delta_{\text{pollutant}}$, the values used as suggested were for everyone and was set to 0. Therefore, the exposure is compared to people that are in a rather air-pollutant free environment. Such results are summarized on Table 7and Table 8; allowing also a direct comparison of the impact on risk of the different BE user behaviors (1-hour and transient).

Table 7 – Percentual health risk increment [%] given the potential 1-h exposure to NO2 and the 1-hour user behavior within the BET, given a certain vulnerability/sensibility group compared to a control group with no short-term exposure.

Affections	BET 1a	BET1b	BET2a	BET2b	BET3	BET4a	BET4b	BET4c	BET5	BET5t
Hospital admission with cardiovascular issues	0.30	0.33	0.24	0.27	0.24	0.27	0.30	0.36	0.24	0.27

Mortality	0.54	0.59	0.43	0.48	0.43	0.48	0.54	0.65	0.43	0.48

Table 8 – Percentual health risk increment given the potential 1-h exposure to NO2 and the transient user behavior within the BET, given a certain vulnerability/sensibility group compared to a control group with no short-term exposure.

Affections	BET 1a	BET1b	BET2a	BET2b	BET3	BET4a	BET4b	BET4c	BET5	BET5t
Hospital admission with cardiovascular issues	0.42	0.48	0.36	0.39	0.33	0.36	0.39	0.48	0.33	0.36
Mortality	0.75	0.86	0.65	0.7	0.59	0.65	0.7	0.86	0.59	0.65

The percentual health risk increment found for the different BETs was found to be larger on BET1b and BET4c. Having a larger concentration on the closest leeward side of the buildings to the wind direction (south-west). For NO_2, and for a person that potentially stays on such period for at least an hour within BET1b or BET4c, his possibility of casualty increases by almost 1% compared to some one on a air-pollution free environment.

Meanwhile, the least worst performing BETs were BET3 and BET5. Which present a poorer air quality on the narrow areas of the BE, and a rather good quality towards their center (the most open and exposed to the wind area).

In general terms, it is relevant to note that the behavioral response of both users adopting 1-hour and transient behaviors can generate an average absolute difference, respectively, of 0.27% and 0.09% for hospital admission with cardiovascular issues and mortality probability increase.

4. Discussion

Although Milan climatic and air quality conditions were among the worst performing sites studied, the air pollution related SLOD risk found for the period studied did not show a significant level for the BE users. Differently for the heat stress related SLOD risk, which resulted on a high level specially for toddlers.

The probability of people being in a space are inversely proportional to the heat stress that they perceived. Moreover, the heat stress pressure on the BE users steers people into areas of poor air quality, especially when traffic is present within the BETs. The presence of trees can be helpful to dimmish the risk caused by heat stress by providing shade (Table 5), but can be detrimental for the air pollution exposure (Table 7) by blocking wind flow.

BETs with a large exposure to the sky vault performed better for dispersing/transporting air pollutants, thus better air quality. However, lack direct solar radiation protection to reduce its heat related risk. Meanwhile, those BETs with narrow outdoor spaces or areas (BET4a, BET4b, BET4c) and those with a pronounced slope promote air pollutants staggering (BET1a, BET1b), and those narrows perform better blocking direct solar radiation.

These conditions might be very specific for Milan's climate, or for Milan's climate category (Cfa). As warm temperatures are present with low wind velocities (see Table 4 D.4.1). Moreover, these conditions might vary depending on the most recurrent orientation of the established BETs as this parameter was not taken in consideration (all were oriented either E-W (BET1a, BET1b, BET2a, BET2b, BET3, BET5 and BET5t) or N-S (BET4a, BET4b and BET4c)) for establishing the utilized archetypes(D'Amico et al. 2021).

In addition, the specific values obtained of UTCI and AQI could have been overestimated or underestimated. The UTCI does not consider the Mean radiant temperature variations on the analyzed area (assumed as equal to air temperature), neither for the wind speed (diminished from the 10m measure for urban areas); and, the tree trunk shading potential was ignored. On the other hand, the AQI considered a fix wind speed and direction; and, all pollutant sources were not included as it was considered unfeasible, and no information was available.

Finally, the values obtained for heat-related risk could be worse within the Italian context. Because in this work, the bodyweight of the US population was used, which tends to have the largest prevalence of overweight (Chooi et al. 2019).

5. Conclusions

Repetitive short-term exposures to either increasing temperatures and/or air pollution SLODs can have a great impact on inhabitants. Results for the Italian context, have shown that under certain circumstances on an outdoor open space a toddler exposed for just less than 3 hours (~4% water loss on body weight) can reach a dehydration risk state. Moreover, an exposure for 1-hour to very low concentrations of NO_2 can increase the mortality probability by approximately 1%.

It is important to note that users' behaviors affecting their thermal acceptability of POS conditions can generate a relative increase of risk outcomes between 40 to 45% for both heat and air pollution related risks when passing from a 1-hour to a transient behavior.

The method hereby presented is sufficiently robust to be applied in any other part of the world, as long as the information required is available (geometry, weather, air pollution concentrations and demographics). Also, it can be of great use for public and private entities.

In fact, the identification of outdoor spaces that follow the previously shown geometrical and environmental conditions can lead to timely propose physical, social or educational risk mitigation measures. These have been already studied in D2.2.4 and are further structured and analyzed on D.5.1.1.

6. References

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