Chapter 3. Accurate and timely alert systems: heat–health warning systems

Summary

Heat–health alert or warning systems are a key component of HHAPs, as they inform local populations and stakeholders about the health risks associated with heat. They thereby raise awareness and ensure timely activation of prevention measures and emergency protocols. Several European countries have a fully operational heat–health warning system in place as part of their HHAPs, and have been able to extend the lead times of their forecasts.

The majority of heat–health warning systems are developed and managed by national meteorological services and information is passed to the HHAP lead body to take action. Effort has also been invested in improving warning dissemination and understanding among stakeholders to improve timely response. A formal evaluation of the warning system should be carried out on a regular basis to improve uptake and efficiency of warning systems and of the HHAP as a whole. The evaluation should include both process and outcome indicators: forecast performance and warning thresholds, dissemination, awareness among stakeholders and modulation of actions based on warning levels.

Key messages

- Heat–health warning systems are a key component of HHAPs.
- Heat–health warnings need to be based on the temperature–health association (defining the temperature threshold for issuing warnings in a way that accounts for changing vulnerability patterns in health outcomes).
- Response measures and actions need to be varied according to the warning level.
- Understanding of warnings by different stakeholders and vulnerable groups is crucial, and dissemination of warning bulletins needs to be targeted.
- Evaluation of warning systems needs to be carried out regularly.

3.1 Introduction: the nature of heat–health warning systems

The WHO Regional Office for Europe's guidance on HHAPs published in 2008 stressed the key role of heat–health warning systems in serving as information tools to identify and predict weather conditions that may adversely affect health in a specific geographical setting (Matthies et al., 2008). This chapter gives a brief overview of the nature of heat–health warning systems; presents the results of a recent survey carried out by WHO on heat–health warning system implementation in countries; and gives insight into innovative aspects, research gaps and future perspectives. Key aspects of warning system development for HHAPs are discussed in detail in the WMO/WHO (2015) joint publication *Heatwaves and health: guidance on warning-system development*.

3.1.1 Elements of heat–health warning systems

Heat–health warning systems in the context of HHAPs should take into account the effects of temperature and other weather parameters on a specific population, using evidence from the epidemiological literature related to the location of interest and defining response-specific thresholds. When this is not possible, meteorological definitions of a heat-wave can be used – for example, percentiles (90th, 95th, 99th) of the temperature indicator variable or bioclimatic indices that are assumed to be the threshold above which heat becomes a risk factor for health. Forecast data can then be used to predict risk-related weather conditions and alert decision-makers, who can implement a range of preventive actions, as defined in each HHAP, with the aim of reducing the health impact of hot weather and heat-waves.

Key aspects of a heat–health warning system, as noted in both WHO and WMO/WHO guidance (Matthies et al., 2008; WMO & WHO, 2015), are:

- accurate forecasts of temperature and weather parameters;
- identification of risk conditions for health (scientifically sound threshold levels);
- graded levels of alert/warning;
- a definition of an information network for dissemination of alerts;
- timely communication of warnings and public health recommendations, produced jointly by the agencies involved (weather and public health services), in a user-friendly manner.

Heat–health warning systems have been developed using various exposure indices of heat stress. These range from single meteorological variables – usually temperature parameters (such as mean, minimum and maximum) – to bioclimatic indices of different complexity, which combine a number of parameters such as temperature, humidity, wind speed and solar radiation to represent the perceived temperature or human-heat budget models (models based on adult physiological characteristics) (WMO & WHO, 2015). A combination of indices and approaches have been developed across Europe to set thresholds (Matthies et al., 2008; Lowe, Ebi & Forsberg, 2011; Bittner et al., 2014; WMO & WHO, 2015; Casanueva et al., 2019).

Several studies have compared indices and their performance (Hajat et al., 2010; Zhang et al., 2012; Burgstall et al., 2019), but the choice of the index ultimately depends on the purpose of the warning and the public health measures put in place in the local context. The key aspect in the context of an HHAP is to ensure that warning systems accurately identify days with a high health risk and are used to drive specific prevention measures and emergency actions (Matthies et al., 2008; WMO & WHO, 2015). A multisectoral approach is essential in the warning system design phase, as weather forecasters and modellers need to know:

- what the health sector and emergency services need in terms of lead time of a forecast;
- when the forecast run has to come out in order for them to activate response measures;
- what each warning level should include (such as intensity of heat, persistency and seasonality).

Exchange of information and know-how on the different components by all sectors are also vital.

As noted in the 2008 WHO guidance, warning levels should be set to take into account local health risks, warning system characteristics (lead times, persistency) and the interventions triggered when warnings are issued (Matthies et al., 2008). Warning levels are currently set very differently across Europe (Lowe, Ebi & Forsberg, 2011; Casanueva et al., 2019). They are denoted either with a colour scale (green, yellow, orange, red) as for other national alert systems – as for extreme weather, flooding, forest fires and natural hazards – or numerically (0, 1, 2, 3, 4).

How levels of warning can modulate actions by different stakeholder groups is illustrated in Table 2, which sets out an example from the *Heatwave plan for England*, published each year by Public Health England on behalf of the National Health Service (NHS) and Department of Health and Social Care, and the Local Government Association (PHE, 2020). It shows activities modulated by level of risk for specific stakeholder groups at different levels; these are intended to guide the development of local preparedness and response measures, tailored around local organizational frameworks. This approach can also be extended to include indications and responses for vulnerable groups by different stakeholders.

Table 2. Example of preparedness and response actions modulated by warning level

Stakeholder group	LEVEL 0 Long-term planning (All year)	LEVEL 1 Heat-wave and summer preparedness programme (1 June–15 September)	LEVEL 2 Heat-wave is forecast: alert and readiness (60% risk of heat-wave in the next 2–3 days)	LEVEL 3 Heat-wave action (Temperature thresholds reached in one or more regions)	LEVEL 4 Major incident: emergency response (Declared by central government in the event of severe or prolonged heat-wave affecting sectors other than health)
National level: **NHS England, Public Health England, Department of Health and Social Care, Met Office, other government departments**	Cooperate with partner agencies to prepare for and mitigate the impact of heat-waves. Improve resilience of vulnerable communities and individuals. Ensure local programmes that include housing, environmental and infrastructure improvements are set up. Engage with communities and the voluntary sector. Update and revise Public Health Outcomes Framework indicators.	Work with other agencies to coordinate heat-wave plans. Raise awareness and maximize dissemination. Ensure care homes and hospitals engage in preparing for heat-waves. Engage with communities and the voluntary sector. Ensure institutions are aware of heat-wave guidance. Ensure organizers of mass events consider heat risks.	Met Office: send a Level 2 alert to a list of organizations and Category 1 responders. Central government departments: disseminate information through their networks and front-line communication systems. The Department of Health and Social Care: disseminate alert information to other government departments and briefs ministers. NHS England: take action to prepare for a heat-wave. Public Health England: disseminate advice to the public and health care professionals. Public Health England: monitor syndromic and mortality surveillance.	Met Office: send a Level 3 alert, as with Level 2. Central government departments: disseminate information, as with Level 2. Met Office: continue to monitor and forecast temperatures in each area, giving details on duration, intensity and geographical extent. NHS England: muster mutual aid when requested by local services. Public Health England: monitor syndromic and mortality surveillance and produce a weekly report for inclusion within a daily heat-wave output.	Central government: implement national emergency response arrangements. Responses involve: • national government departments • executive agencies • public sector bodies, including the health sector • the voluntary sector. Public Health England: monitor syndromic and mortality surveillance and produce a weekly report for inclusion within a daily heat-wave output
Professional staff	Develop systems to identify and improve resilience of high-risk individuals. Request an housing health and safety rating system assessment from environmental health experts for clients at particular risk. Encourage walking and cycling in urban areas.	Identify high-risk individuals and raise awareness of heat-related risks and prevention among carers. Include heat–health risk in care records and consider changes in care plans.	Check that high-risk individuals have visitor/phone call arrangements in place. Reconfirm key public health messages to clients. Check clients' room temperature if visiting.	Visit/phone high-risk individuals. Reconfirm key public health messages to clients. Advise carers to contact a GP if they have concerns about clients' health.	Continue actions as per Level 3 unless advised differently.

Table 2 contd

Stakeholder group	LEVEL 0 Long-term planning	LEVEL 1 Heat-wave and summer preparedness programme	LEVEL 2 Heat-wave is forecast: alert and readiness	LEVEL 3 Heat-wave action	LEVEL 4 Major incident: emergency response
Care homes and hospitals	Establish long-term preparedness plans. Initiate environmental improvements. Prepare business continuity plans. Raise awareness among partners and staff on health impacts.	Ensure continuity plans are in place. Identify/create cooling rooms. Install thermometers where vulnerable individuals spend more time.	Undertake indoor temperature measurement for all areas where patients reside. Ensure cool areas are below 26 °C. Review and prioritize vulnerable individuals. Ensure sufficient cold water and ice are available. Consider weighing clients regularly to identify dehydration. Reschedule physiotherapy to cooler hours of the day. Ensure sufficient staffing. Communicate alerts to staff and make sure that they are aware of heat-wave plans. Implement business continuity plans.	Activate plans to maintain business continuity – including a possible surge in demand. Measure indoor temperatures for all areas where patients reside. Ensure staff are trained on heat response. Monitor vulnerable individuals closely. Reduce internal temperatures. Ensure discharge planning takes home temperatures and support into account.	Continue actions as per Level 3 unless advised differently.
Community groups	Develop a community emergency plan to support vulnerable neighbours. Carry out impact assessments on community venues. Support subjects at risk.	Trigger the development of a community emergency plan. Help raise awareness about health risks.	Check up on at-risk individuals. Consult weather forecasts and warnings and act accordingly. Keep stocked up with food and medications. Monitor ambient room temperatures.	Activate community emergency plans. Check on those you know are at risk.	Continue actions as per Level 3 unless advised differently.
Individuals	Improve shading and cooling. Install insulation to reduce indoor heat. Identify cool areas inside the house.	Acquire information on health risks. Look out for vulnerable relatives and neighbours.	Check weather forecasts and warnings. Check ambient room temperatures where disabled or vulnerable individuals reside. Look out for vulnerable relatives and neighbours.	Follow key public health messages. Check on those you know are at risk.	Continue actions as per Level 3 unless advised differently.

Source: adapted from PHE (2020).

3.1.2 Forecast models and lead times

In terms of weather forecast models, a recent review of heat–health warning systems in Europe provided an update on models used, lead time, temporal and spatial resolution of models and lead bodies in charge (Casanueva et al., 2019). The WMO/WHO (2015) publication *Heatwaves and health: guidance on warning-system development* provides details of forecast models and methodologies developed around the world to define heat–health warning systems.

The spatial resolution of models goes from under 2 km to 16 km, depending on whether they are regional/national downscaled or local models or European scale models. Models are heterogeneous across Europe and mostly reflect national meteorological service availability and the best compromise between forecast predictive power, spatial coverage needed and timeliness of forecast run for HHAP purposes. In several countries a combination of forecast models is used: regional models that have a finer spatial resolution to capture geographical differences in a more accurate manner for forecasting the short term (1–7 days) and ensemble models, such as ECMWF, for longer lead times or as a complementary tool. A crucial aspect is that the accuracy of meteorological forecasts should be part of the design of a heat–health warning system (WMO & WHO, 2015), as well as the scope of the forecast and its use for public health warning and response measures. It is worth noting there is a trade-off between lead time and model accuracy: as a rule of thumb, as lead times are extended, forecast accuracy is reduced – especially as it moves from short time frames into medium-range forecasts (two weeks to a month).

The lead time is crucial for the health sector to be prepared to cope when a heat-wave is coming and to ensure that prevention and emergency measures are in place and operational if and when populations are affected. Different measures require different timings for preparation and becoming operational: heat–health warning systems and HHAPs should consider this when defining warning levels. Furthermore, considering the short lag between exposure to extreme heat and worsening of health conditions and even fatality, the process of warning notifications should be timely (Díaz, Linares & Tobías, 2006; Lowe, Ebi & Forsberg, 2011). Lead times for notifying of extreme heat risks, as previously reported in other reviews or surveys (Lowe, Ebi & Forsberg, 2011; Bittner et al., 2014), are between two and eight days.

Moreover, in the last 10–15 years great efforts and advances have been made in weather and climate modelling and forecasting the subseasonal-to-seasonal time range, which corresponds to forecasts beyond two weeks but less than a season (typically 3–4 months) (Brunet et al., 2010; Vitart, 2014). In essence, the main advantage here is that the gap between short-term and medium- to long-term forecasting has been filled, thus providing skilful forecasts of extreme weather risks that can inform decisions in different sectors – including health. Forecast information at different timescales with different lead times is relevant for different decision-makers and for planning of prevention and response measures in the context of HHAPs. An example is the "Ready-Set-Go" concept, using forecasts from the weather to the seasonal scale, proposed by the Red Cross/Red Crescent Climate Centre and the International Research Institute for Climate and Society for application in heat prevention (Vitart & Brown, 2019):

- Ready: seasonal and subseasonal forecasts are used to update contingency plans, train volunteers and enable early warning systems;
- Set: submonthly forecasts are used to alert volunteers and warn communities;
- Go: weather forecasts are used to activate volunteers, distribute instructions to communities and evacuate.

3.2 Status of heat–health warning systems

A first comprehensive review of heat–health warning systems across Europe (Lowe, Ebi & Forsberg, 2011) found that 12 countries had a warning system in place (Belgium, France, Germany, Hungary, Italy, Netherlands, North Macedonia, Portugal, Romania, Spain and Switzerland, and the United Kingdom). The review provides information on exposure variables considered, threshold levels and forecast lead times, as well as geographical coverage (national, regional) and lead bodies. A survey carried out a few years later (Bittner et al., 2014) showed a slight increase to 16 in the number of countries with an operational heat–health warning system as part of their HHAP (Austria, Belgium, Croatia, England (United Kingdom), France, Germany, Hungary, Italy, Luxembourg, Monaco, North Macedonia, Netherlands, Portugal, Spain and Switzerland). A more recent study also identified 16 heat–health warning systems through a review of the literature, a web search and a questionnaire (Casanueva et al., 2019).

WHO's 2019 survey of heat–health action planning also comprised a series of questions on warning systems (Table 3).

The survey results show that heat–health warnings systems are the core element of HHAPs most widely considered to be "fully implemented", with 16 countries responding that a warning system is in place – fully or partly implemented.

Heat–health warning systems are typically operational between May and September, while a review of the system and updates (such as modelling and dissemination network), if carried out, is done in the remaining months. The majority of the alert systems are developed and managed by national meteorological services, which are also in charge of issuing the heat warning and informing the agency leading the health response (75% national public health agency or ministry of health, 19% regional health agency, 6% national environmental agency). Collaborative processes for setting up warning systems and defining thresholds

Table 3. Questions on heat–health warning systems in the WHO survey

Question	Summary of answers by responding countries with national HHAPs
Which agency issues meteorological heat warnings?	• 13: meteorological agencies • 4: others
How many days in advance are heat warnings sent to the agency in charge of the health response?	• Between one and five days in advance
Which agency leads the health response to heat?	• 12: national public health agency or ministry of health • 3: regional health agency • 1: environment agency
How many alert levels are there and when are they are triggered?	• Starting from baseline (0 – no alert) level, an additional 2–5 levels, with different criteria for activation including simple measurement of maximum daily temperature or meteorological indices
How many days in advance is the heat alert issued to the public?	• Between one and five days in advance
How many days in advance is the heat alert issued to key stakeholders (hospitals, nursing homes, etc.)?	• Same as to the general public

and warning levels should be promoted between meteorological and health services and other key institutions involved in the HHAP, to better tailor warnings around its scope and use. Warnings are disseminated through information networks comprising the general public and operational stakeholders (health authorities, social services, hospitals, nursing homes, municipalities, emergency services, GPs, vulnerable groups and so on).

Dissemination of warnings is another crucial aspect for the effectiveness of HHAPs. The WMO/WHO 2015 guidance illustrates the various factors to consider when communicating heat–health warnings with a focus on warning contents, the use of appropriate language for each audience and the effective dissemination of warnings to all users. Details on communication can be found in Chapter 4.

3.3 Innovations and future perspectives

3.3.1 Increasing lead times, seasonal forecasts and future climate impacts

The issue of extending lead times of weather forecasts and the use of subseasonal or seasonal climate models is of great importance for public health response planning and management before the summer season. Use of monthly and seasonal probabilistic forecasts may assist public health administrators in decision-making in the preparatory phase and during the summer season. To improve preparedness and response, institutions involved in HHAPs can use monthly and seasonal probabilistic forecasts, requesting information (maps and data) on temperature trends and the likelihood of above- or below-average temperatures (minimum, mean, maximum, heat-wave days) or other variables (pressure and precipitation). These can give an indication of how the season will compare to the average climate, giving health services and all actors involved in HHAPs the opportunity to undertake better planning and resource allocation in advance (WMO & WHO, 2015; Lowe et al., 2016).

The trade-off is that the longer the lead time, the lower the skill (measure of the accuracy and/or degree of association between predicted value and observed value) of forecasts; this makes probabilistic forecasting less reliable for public health services. With seasonal modelling skill constantly improving (especially in latitudes where heat-waves are an issue for health such as the Mediterranean (Vitart, 2014)) and better interdisciplinary communication, collaboration and knowledge bases, however, the utility of these forecasts is not only understood but also appreciated by stakeholders and responders. The availability of seasonal forecast products to all users has been greatly improved recently through the C3S Climate Data Store platform (see Box 1 in Chapter 1) – an example of the multimodel system that combines different model forecasts into one, giving more reliable and accurate forecasts.

Seasonal time series availability and improved seasonal climate-prediction products offer the opportunity to develop heat–health warnings at longer monthly and seasonal timescales (WMO & WHO, 2015). A few recent studies have looked at the possibility of using these forecasts to develop seasonal health warning models using mortality data. For example, Lowe et al. (2016) used apparent temperature forecasts at different lead times (from one day to three months) to produce subseasonal (1–18 days) and seasonal (1–3 months) probabilistic mortality forecasts at a regional level for Europe. For some areas of Europe, excess mortality was detected with some certainty even at monthly scales. As expected, however, as lead times became longer, the skill of the mortality forecast decreased considerably.

Lastly, the C3S European health service (ECMWF, 2020) has defined a series of exposure indicators related to health impacts. Among the indicators available on the Copernicus platform are future projections of the number of heat-wave days, based on both standardized and HHAP specific heat-wave definitions, with different climate change scenarios. This is a useful tool for public health and environmental stakeholders involved in planning adaptation policies to anticipate future risks associated with heat-waves.

3.3.2 Information tools to improve dissemination

Since the set-up of HHAPs and heat–health warning systems, great effort has been focused on improving dissemination of information and the utility of the advice provided. Communicating risks and giving behavioural advice is considered a key element of the effectiveness of an HHAP, as noted in the 2008 WHO guidance (Matthies et al., 2008). Recent years have seen a shift from traditional communication tools such as television, radio and newspaper-based information to web and social media (Facebook, Twitter) sites, and alternative means of communication such as heat warning-dedicated mobile applications, infographics and videos (discussed in more detail in Chapter 4). These tools extend the dissemination of warnings and improve population awareness of health-related risks and prevention measures to adopt. They also assist with timely delivery of information to the general public and to stakeholders who have to activate response and emergency measures. Box 3 gives an example of a mobile application that provides personalized heat–health risks, recommendations and information on cooling spaces within a city.

Box 3. Extreme Temperature Alerts for Europe (EXTREMA): an emergency notification system for extreme temperatures

The EXTREMA project, funded by the European Commission, has created an innovative mobile application for the public and an administration web service dashboard for local municipalities. It aims to increase citizen awareness and reduce their exposure to heat risk, as well as supporting local authorities with implementation of HHAPs. The mobile application aims to inform individuals of their heat–health risk (no/low/increased/high risk), taking into account the user's profile characteristics (age, presence of chronic disease associated with a greater risk during heat-waves, use of medication), in real time.

The mobile application uses satellite thermal images and numerical weather predictions, alongside a set of predefined thresholds from published epidemiological evidence, to estimate heat–health risks at each location. It also provides health recommendations and information on cooling centres or spaces managed by each city authority (such as community centres, parks or hospitals if necessary), as well as routing directions. It supports multiple profiles, allowing users to check on family members (children and elderly people) at multiple locations.

Through the web dashboard city authorities can manage information on cooling centres, such as updating opening hours, adding new centres or providing other relevant information (entrance fee, contacts, capacity). The dashboard also provides current and previous day alerts (based on severe weather information from the Network of European Meteorological Services) and real-time maps of the extreme temperature hazard in the city, with a spatial resolution of 1 × 1 km, updated every five minutes. It thus helps city authorities to manage their response actions better during extreme heat events. EXTREMA is currently operational in Athens, Greece; Mallorca, Spain; Milan, Italy; Paris, France; and Rotterdam, Netherlands.

Source: National Observatory of Athens (2020).

3.3.4 Warning messages and systems customized for vulnerable subgroups

In recent years, with the identification of diverse vulnerable groups, customized warning messages with advice on what to do during a heat-wave have been issued with alerts during heat-waves to ensure a customized response (Price et al., 2018; PHE, 2020). Automated phone warning systems have recently been introduced as an alternative way of communicating warnings to vulnerable subgroups and improving coverage. A recent study conducted in Montreal, Canada, issued warnings via automated telephone calls and gave heat protection messages (Mehiriz et al., 2018). The study also carried out an evaluation of the system – results suggest an improvement in individual adaptation to heat and a reduction in the use of health services by subjects included in the study. Use of tools like this can improve dissemination to vulnerable subgroups, while reducing costs.

Such systems should be promoted within HHAPs to ensure a better response, especially among the most vulnerable subgroups. Furthermore, ad hoc heat–health warning systems for vulnerable subgroups are being developed. For example, Morabito et al. (2019) developed a heat–health warning system for outdoor workers, taking into account personalized local heat stress risk, based on workers' characteristics and the outdoor working work environment. The warning system provides weekly and monthly forecasts.

3.3.5 Integration with other environmental exposures

Several extreme weather and environmental exposures that have a negative impact on health occur concurrently, and often affect the same set of vulnerable subgroups. They are dealt with separately, however, often duplicating actions that could be combined. For instance, in some cases separate warning systems are managed by the same or other environmental agencies; different prevention plans are in place; time is spent identifying vulnerable groups, which may be the same – such as elderly people with pre-existing cardiorespiratory diseases; and surveillance and evaluation are done independently. Better cooperation and intersectoral collaboration are needed in devising multi-exposure systems. The core components of such systems should follow HHAPs with alert systems, prevention and response measures, surveillance of health effects and evaluation (Linares et al., 2020).

In recent years, the epidemiological evidence on the synergistic effects of temperatures and air pollution has become more consolidated (Chen et al., 2017; Li et al., 2017; Analitis et al., 2018; Scortichini et al., 2018a), showing an increase in health effects when both temperatures and levels of ozone or particulate matter smaller than about 10 µm in diameter (PM_{10}) are high. Weather conditions such as stable atmospheric circulation regimes in summer are associated with high temperatures and the build-up of air pollutants. Several countries (Belgium, Hungary, Italy, North Macedonia, Portugal, Switzerland and the United Kingdom) account for air quality in HHAPs either by formally including air pollution alerts or by providing advice related to both heat and air pollution, as briefly described in the Lowe, Ebi & Forsberg (2011) survey and reviews.

3.3.6 Evaluations and updates of heat–health warning systems within HHAPs

To date, information on formal evaluations of European heat–health warning system and HHAP effectiveness is limited (Toloo et al., 2013; Martinez et al., 2019). As noted in the 2008 WHO guidance, evaluation of the plan as a whole, as well as its components, is important to support decision-makers in selecting the most appropriate measures and improving heat plan effectiveness (Matthies et al., 2008). Heat–health warning systems should also be evaluated in both process and outcome indicators (WHO Regional Office for Europe, 2011; WMO & WHO, 2015). It is important that the evaluation process is formally defined and that results are written up and disseminated to core participants in the warning system and HHAP. Evaluations will help build confidence in the system and improve the knowledge base among the different stakeholders.

Key aspects to consider when evaluating the effectiveness of a warning system, as described in the WMO/WHO 2015 guidance, are simplicity, acceptability, timeliness, sensitivity and specificity (Table 4). In terms of process evaluation of warning systems, all the operational phases should be evaluated to assess whether implementation has been achieved successfully and what can be improved. This should include warning dissemination and reaching all relevant institutions (coverage and timing), the quality of information provided (levels of warnings, bulletins) and understanding the system and how it is considered useful to the relevant stakeholders.

How actions are modulated based on warning levels and the specific actions required at each level of warning by stakeholders is another crucial aspect that affects the effectiveness of HHAPs. Questionnaires and face-to-face seminars have been carried out to assess perception of risk, level of awareness and understanding of warning systems, alongside potential changes in response modes during heat-waves by health and social services (Matthies et al., 2008; Abrahamson et al., 2009; Matthies & Menne, 2009; Toloo et al., 2013; Wolf et al., 2014; Takahashi et al., 2015; Price et al., 2018; Vu, Rutherford & Phung, 2019). To date, response to and knowledge of risk and response measures and adaptation among the general public and stakeholders is heterogeneous. A recent systematic review underlines the need for further research in different contexts to assess the effectiveness of the different components of HHAPs and their formal uptake, to improve response (Vu, Rutherford & Phung, 2019).

Outcome evaluation, on the other hand, entails the assessment of measurable impacts. This should be done routinely to monitor and improve model performance and keep track of potential changes in population response. Model performance in terms of meteorological forecasts and warning levels (sensitivity, specificity, hit and miss rates) should be carried out on a regular basis. It should also consider the health outcome data (mortality, morbidity) on which the warning system model is based, to assess whether health impacts (excess deaths, increases in ER visits, calls to emergency and health services) change when warnings are correct or when forecast are wrong and a warning might be missed.

Table 4. Criteria for evaluating a heat–health warning system

Criterion	Description/factors to consider
Simplicity of the warning system and its operation	• Operational system (data required to issue a warning and institutions involved) • Management (time spent issuing warnings and maintaining the system)
Acceptability by stakeholders	• Collaboration between agencies • Participation of institutions and stakeholders • Completeness of response
Timeliness of issuing warnings	• Adequacy of timeliness of warnings for different response measures
Sensitivity of warnings	• Ability of a warning forecast system to identify warning days (how often a forecast was correct in issuing a warning compared to observed meteorological and/or health data)
Specificity of warnings	• Ability of a warning forecast to identify non-warning days, thereby keeping false-positives to a minimum

Source: adapted from WMO & WHO (2015).

Several studies have examined changes in health effects relative to risk estimates or quantified the change in excess mortality and morbidity during extreme events over time (Bassil & Cole, 2010; Benmarhnia et al., 2016; de'Donato et al., 2018; Weinberger et al., 2018; Martínez-Solanas & Basagaña, 2019). These mostly focus on mortality as health outcome because mortality data are more robust and are collected routinely in a timely manner, and the evidence on health effect estimates is more consistent in the literature. A quasi-experimental approach has recently been adopted to assess changes in heat-related mortality in response to the introduction of heat plans in Montreal, Canada, and the Republic of Korea (Benmarhnia et al., 2016; Heo et al., 2019).

Outcome evaluation has generally been carried out more in terms of the HHAP as a whole and not just the warning itself; this is discussed in more detail in Chapter 9. This exercise is also useful when considering potential modifications to warning system thresholds or response measures associated with warning level actions over time. A study conducted in Italy showed a greater reduction in heat-related deaths for extreme temperatures when Level 2 and Level 3 warnings are issued, compared to Level 1 pre-alert days (de'Donato et al., 2018). The authors suggest that public health prevention and response measures during pre-alert conditions are less stringent and may be adopted with less attention; they therefore need to be revised and improved. Research from Adelaide, Australia, considered changes in both morbidity (ambulance calls and ER visits) and mortality effects in two summers: before and after the introduction of a warning system and prevention plan (Nitschke et al., 2016). The study showed a reduction in morbidity outcomes, while mortality remained unvaried.

Intermediate benefits such as behavioural changes at the individual or community levels are also important. These provide useful insight into the effectiveness of measures and warnings in changing population perception of risk, knowledge and measures adopted. Community questionnaires have been carried out on the perception of heat-waves, warning systems and prevention measures (Sheridan, 2007; White-Newsome et al., 2011; Nitschke et al., 2013; 2017; Vu, Rutherford & Phung, 2019). A recent review of heat–health prevention measures and adaptation among elderly people reported that further action was needed to translate knowledge/warnings into heat-adaptive behaviours (Vu, Rutherford & Phung, 2019). Although knowledge of the heat warnings was widespread, changes in behaviour or knowledge of what to do were less common (Sheridan, 2007; White-Newsome et al., 2011). Perception of risk among vulnerable subgroups and stakeholders is reported in detail in Chapter 4.

Finally, economic evaluations using cost–benefit analyses are also an important aspect of evaluating a warning system. Studies have estimated that heat–health warning systems are highly cost-effective, with the benefits in terms of lives saved outweighing the running costs (Ebi et al., 2004; Chiabai, Spadaro & Neumann, 2018). The costs and benefits of a warning system provide policy-makers with an economic perspective of the HHAP; this enables them to plan funding and resources formally for it in a systematic way, thus ensuring its continuity and improvement over time by the core bodies involved.

Another issue that not been formally addressed in HHAPs to date is updating warning systems in relation to organizational changes, new forecast models and warning thresholds – in response to climate change (rising temperatures) and changes in population response (adaptation and vulnerability) (Hess & Ebi, 2016). When and how often this should be done is far from simple. Responses to WHO's 2019 survey of heat–health action planning show that while around 60% of respondents stated that they update the national HHAP every year or every 2–5 years, it is not clear what the update entails, or whether a formal process is in place. A limited number of countries stated that they had updated or were in the process of updating thresholds since the initial set-up of the warning system.

Several studies have shown a change in the temperature–mortality association (Guo et al., 2014; de'Donato et al., 2015; Scortichini et al., 2018b) in recent years, in response to the introduction of HHAPs or changing temperatures. These are suggestive of a shift in the curve and potential variation (rise/decline) of the threshold. On the other hand, if the curve has shifted, showing some acclimatization or adaptation – potentially also thanks to HHAPs and measures in place – if thresholds are changed (increased) and prevention is no longer carried out at lower temperatures, the mortality impact might rise again. Fluctuations in the temperature–mortality association over time and factors affecting these dynamics should be considered when updating and revisiting warnings.

Future estimates of the impact on mortality in the light of climate change have given an idea of the potential added health impact (Martinez et al., 2016; Kendrovski et al., 2017; Guo et al., 2018; Vicedo-Cabrera et al., 2018). Furthermore, the ageing of the European population and rising levels of noncommunicable diseases and comorbidities are likely to increase the pool of vulnerable individuals, thus also influencing temperature–mortality response and threshold levels (Wolf et al., 2014; Martinez et al., 2019). The iterative management approach suggested by Hess & Ebi (2016) could be a useful system when planning the monitoring and evaluation of warnings, taking into account the dynamics.

3.4 Conclusion

Heat–health warning systems are a key component of HHAPs, as they inform local populations and stakeholders about the health risks associated with heat. They thereby raise awareness and ensure timely activation of prevention measures and emergency protocols. Threshold levels should be based on health risks and not only on meteorological conditions. The 2019 WHO survey showed a progressive increase in the number of European countries with a fully operational heat–health warning system as part of their HHAPs.

Efforts have been made to enhance alert systems (with better forecasts and longer lead times) and to improve dissemination and communication. Formal evaluations of warning systems, including both process and outcome indicators, should be carried out on a regular basis to improve the effectiveness of warnings.

References[1]

Abrahamson V, Wolf J, Lorenzoni I, Fenn B, Kovats S, Wilkinson P et al. (2009). Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK. J Public Health (Oxf). 31(1):119–26. doi:10.1093/pubmed/fdn102.

Analitis A, de'Donato F, Scortichini M, Lanki T, Basagaña X, Ballester F et al. (2018). Synergistic effects of ambient temperature and air pollution on health in Europe: results from the PHASE project. Int J Environ Res Public Health. 15(9):1856. doi:10.3390/ijerph15091856.

Bassil KL, Cole DC (2010). Effectiveness of public health interventions in reducing morbidity and mortality during heat episodes: a structured review. Int J Environ Res Public Health. 7(3):991–1001. doi:10.3390/ijerph7030991.

Benmarhnia T, Bailey Z, Kaiser D, Auger N, King N, Kaufman JS (2016). A difference-in-differences approach to assess the effect of a heat action plan on heat-related mortality, and differences in effectiveness according to sex, age, and socioeconomic status (Montreal, Quebec). Environ Health Perspect. 124(11):1694–9. doi:10.1289/EHP203.

[1] All URLs accessed 7–8 September 2020.

Bittner MI, Matthies EF, Dalbokova D, Menne B (2014). Are European countries prepared for the next big heat-wave? Eur J Public Health. 24(4):615–9. doi:10.1093/eurpub/ckt121.

Brunet G, Shapiro M Hoskins, B, Moncrieff M Dole, R, Kiladis GN et al. (2010). Collaboration of the weather and climate communities to advance subseasonal-to-seasonal prediction. B Am Meteorol Soc. 91(10):1397–1406. doi:10.1175/2010BAMS3013.1.

Burgstall A, Casanueva A, Kotlarski S, Schwierz C (2019). Heat warnings in Switzerland: reassessing the choice of the current heat stress index. Int J Environ Res Public Health. 16(15):2684. doi:10.3390/ijerph16152684.

Casanueva A, Burgstall A, Kotlarski S, Messeri A, Morabito M, Flouris AD et al. (2019). Overview of existing heat–health warning systems in Europe. Int J Environ Res Public Health. 16(15):2657. doi:10.3390/ijerph16152657.

Chen F, Fan Z, Qiao Z, Cui Y, Zhang M, Zhao X, Li X (2017). Does temperature modify the effect of PM_{10} on mortality? A systematic review and meta-analysis. Environ Pollut. 224:326–35. doi:10.1016/J.ENVPOL.2017.02.012.

Chiabai A, Spadaro JV, Neumann MB (2018). Valuing deaths or years of life lost? Economic benefits of avoided mortality from early heat warning systems. Mitig Adapt Strateg Glob Chang. 23(7):1159–76. doi:10.1007/s11027-017-9778-4.

de'Donato F, Leone M, Scortichini M, De Sario M, Katsouyanni K, Lanki T et al. (2015). Changes in the effect of heat on mortality in the last 20 years in nine European cities. Results from the PHASE project. Int J Environ Res Public Health. 12(12):15567–83. doi:10.3390/ijerph121215006.

de'Donato F, Scortichini M, De Sario M, de Martino A, Michelozzi P (2018). Temporal variation in the effect of heat and the role of the Italian heat prevention plan. Public Health. 161:154–62. doi:10.1016/j.puhe.2018.03.030.

Díaz J, Linares C, Tobías A. (2006). Impact of extreme temperatures on daily mortality in Madrid (Spain) among the 45–64 age-group. Int J Biometeorol. 50(6):342–8. doi:10.1007/s00484-006-0033-z.

Ebi KL, Teisberg TJ, Kalkstein LS, Robinson L, Weiher RF (2004). Heat watch/warning systems save lives: estimated costs and benefits for Philadelphia 1995–98. Bull Am Meteorol Soc. 85(8):1067–73. doi:10.1175/BAMS-85-8-1067.

ECMWF (2020). European health service. In: Climate Change Service [website]. Reading: European Centre for Medium-Range Weather Forecasts (https://climate.copernicus.eu/european-health-service).

Guo Y, Gasparrini A, Li S, Sera F, Vicedo-Cabrera AM, de Sousa Zanotti Stagliorio Coelho M et al. (2018). Quantifying excess deaths related to heatwaves under climate change scenarios: a multicountry time series modelling study. PLoS Med. 15(7):1–17. doi:10.1371/journal.pmed.1002629.

Guo Y, Gasparrini A, Armstrong B, Li S, Tawatsupa B, Tobías A et al. (2014). Global variation in the effects of ambient temperature on mortality: a systematic evaluation. Epidemiology. 25(6):781–9. doi:10.1097/EDE.0000000000000165.

Hajat S, Sheridan SC, Allen MJ, Pascal M, Laaidi K, Yagouti A et al. (2010). Heat–health warning systems: a comparison of the predictive capacity of different approaches to identifying dangerously hot days, Am J Public Health. 100(6):1137–44. doi:10.2105/AJPH.2009.169748.

Heo S, Nori-Sarma A, Lee K, Benmarhnia T, Dominici F, Bell ML (2019). The use of a quasi-experimental study on the mortality effect of a heat wave warning system in Korea. Int J Environ Res Public Health. 16(12):2245. doi:10.3390/ijerph16122245.

Hess JJ, Ebi KL (2016). Iterative management of heat early warning systems in a changing climate. Ann N Y Acad Sci. 1382(1):21–30. doi:10.1111/nyas.13258.

Kendrovski V, Baccini M, Martinez G, Wolf T, Paunovic E, Menne B (2017). Quantifying projected heat mortality impacts under 21st-century warming conditions for selected European countries. Int J Environ Res Public Health. 14(7):729. doi:10.3390/ijerph14070729.

Li J, Woodward A, Hou XY, Zhu T, Zhang J, Brown H et al. (2017). Modification of the effects of air pollutants on mortality by temperature: a systematic review and meta-analysis. Sci Total Environ. 575:1556–70. doi:10.1016/j.scitotenv.2016.10.070.

Linares C, Martinez GS, Kendrovski V, Díaz J (2020). A new integrative perspective on early warning systems for health in the context of climate change. Environ Res. 187:109623. doi:10.1016/j.envres.2020.109623.

Lowe D, Ebi KL, Forsberg B (2011). Heatwave early warning systems and adaptation advice to reduce human health consequences of heatwaves. Int J Environ Res Public Health. 8(12):4623–48. doi:10.3390/ijerph8124623.

Lowe R, García-Díez M, Ballester J, Creswick J, Robine JM, Herrmann FR et al. (2016). Evaluation of an early-warning system for heat wave-related mortality in Europe: implications for sub-seasonal to seasonal forecasting and climate services. Int J Environ Res Public Health. 13(2):206. doi:10.3390/ijerph13020206.

Martínez-Solanas È, Basagaña X (2019). Temporal changes in temperature-related mortality in Spain and effect of the implementation of a heat health prevention plan. Environ Res. 169:102–13. doi:10.1016/j.envres.2018.11.006.

Martinez GS, Baccini M, De Ridder K, Hooyberghs H, Lefebvre W, Kendrovski V et al. (2016). Projected heat-related mortality under climate change in the metropolitan area of Skopje. BMC Public Health. 16(1):407. doi:10.1186/s12889-016-3077-y.

Martinez GS, Linares C, Ayuso A, Kendrovski V, Boeckmann M, Díaz J (2019). Heat–health action plans in Europe: challenges ahead and how to tackle them. Environ Res. 176:108548. doi:10.1016/j.envres.2019.108548.

Matthies F, Bickler G, Cardeñosa N, Hales S, editors (2008). Heat–health action plans. Copenhagen: WHO Regional Office for Europe (https://www.euro.who.int/en/publications/abstracts/heathealth-action-plans).

Matthies F, Menne B (2009). Prevention and management of health hazards related to heatwaves. Int J Circumpolar Health. 68(1):8–12. doi:10.3402/ijch.v68i1.18293.

Mehiriz K, Gosselin P, Tardif I, Lemieux MA (2018). The effect of an automated phone warning and health advisory system on adaptation to high heat episodes and health services use in vulnerable groups-evidence from a randomized controlled study. Int J Environ Res Public Health. 15(8):1581. doi:10.3390/ijerph15081581.

Morabito M, Messeri A, Noti P, Casanueva A, Crisci A, Kotlarski S et al. (2019). An occupational heat–health warning system for Europe: The HEAT-SHIELD platform. Int J Environ Res Public Health. 16(16):2890. doi:10.3390/ijerph16162890.

National Observatory of Athens (2020). EXTREMA [website]. Athens: National Observatory of Athens (http://extrema.space/).

Nitschke M, Hansen A, Bi P, Pisaniello D, Newbury J, Kitson A et al. (2013). Risk factors, health effects and behaviour in older people during extreme heat: a survey in South Australia. Int J Environ Res Public Health. 10(12):6721–33. doi:10.3390/ijerph10126721.

Nitschke M, Krackowizer A, Hansen AL, Bi P, Tucker GR (2017). Heat health messages: a randomized controlled trial of a preventative messages tool in the older population of south Australia. Int J Environ Res Public Health. 14(9):992. doi:10.3390/ijerph14090992.

Nitschke M, Tucker G, Hansen A, Williams S, Zhang Y, Bi P (2016). Evaluation of a heat warning system in Adelaide, South Australia, using case-series analysis. BMJ Open. 6(7):e012125. doi:10.1136/bmjopen-2016-012125.

Price K, Benmarhnia T, Gaudet J, Kaiser D, Sadoine ML, Perron S et al. (2018). The Montreal heat response plan: evaluation of its implementation towards healthcare professionals and vulnerable populations. Can J Public Health. 109(1):108–16. doi:10.17269/s41997-018-0020-2.

PHE (2020). Heatwave plan for England: protecting health and reducing harm from severe heat and heatwaves. London: Public Health England (https://www.gov.uk/government/publications/heatwave-plan-for-england).

Scortichini M, De Sario M, de'Donato F, Davoli M, Michelozzi P, Stafoggia M (2018a). Short-term effects of heat on mortality and effect modification by air pollution in 25 Italian cities. Int J Environ Res Public Health. 15(8):1771. doi:10.3390/ijerph15081771.

Scortichini M, de'Donato F, De Sario M, Leone M, Åström C, Ballester F et al. (2018b). The inter-annual variability of heat-related mortality in nine European cities (1990–2010). Environ Health. 17(1):66. doi:10.1186/S12940-018-0411-0.

Sheridan SC (2007). A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness, Int J Biometeorol. 52(1):3–15. doi:10.1007/s00484-006-0052-9.

Takahashi N, Nakao R, Ueda K, Ono M, Kondo M, Honda Y et al. (2015). Community trial on heat-related illness prevention behaviors and knowledge for the elderly. Int J Environ Res Public Health. 12(3):3188–214. doi:10.3390/ijerph120303188.

Toloo G, FitzGerald G, Aitken P, Verrall K, Tong S (2013). Evaluating the effectiveness of heat warning systems: systematic review of epidemiological evidence. Int J Public Health. 58(5):667–81. doi:10.1007/s00038-013-0465-2.

Vicedo-Cabrera AM, Guo Y, Sera F, Huber V, Schleussner CF, Mitchell D et al. (2018). Temperature-related mortality impacts under and beyond Paris Agreement climate change scenarios. Clim Change. 150(3–4):391–402. doi:10.1007/s10584-018-2274-3.

Vitart F (2014). Evolution of ECMWF sub-seasonal forecast skill scores. Q J R Meteorol Soc. 140(683):1889–99. doi:10.1002/qj.2256.

Vitart F, Brown A (2019). S2S forecasting: towards seamless prediction. WMO Bulletin. 68(1) (https://public.wmo.int/en/resources/bulletin/s2s-forecasting-towards-seamless-prediction).

Vu A, Rutherford S, Phung D (2019). Heat health prevention measures and adaptation in older populations – a systematic review. Int J Environ Res Public Health. 16(22):4370. doi:10.3390/ijerph16224370.

Weinberger KR, Zanobetti A, Schwartz J, Wellenius GA (2018). Effectiveness of national weather service heat alerts in preventing mortality in 20 US cities. Environ Int. 116:30–8. doi:10.1016/j.envint.2018.03.028.

White-Newsome JL, Sánchez BN, Parker EA, Dvonch JT, Zhang Z, O'Neill MS (2011). Assessing heat-adaptive behaviors among older, urban-dwelling adults. Maturitas. 70(1):85–91. doi:10.1016/j.maturitas.2011.06.015.

WHO Regional Office for Europe (2011). Public health advice on preventing health effects of heat: new and updated information for different audiences. Copenhagen: WHO Regional Office for Europe (https://www.euro.who.int/en/health-topics/environment-and-health/Climate-change/publications/2011/public-health-advice-on-preventing-health-effects-of-heat.-new-and-updated-information-for-different-audiences).

WMO, WHO (2015). Heatwaves and health: guidance on warning-system development. Geneva: World Meteorological Organization (https://www.who.int/globalchange/publications/heatwaves-health-guidance/en/).

Wolf T, Martinez GS, Cheong HK, Williams E, Menne B (2014). Protecting health from climate change in the WHO European Region. Int J Environ Res Public Health. 11(6):6265–80. doi:10.3390/ijerph110606265.

Zhang K, Rood RB, Michailidis G, Oswald EM, Schwartz JD, Zanobetti A et al. (2012). Comparing exposure metrics for classifying "dangerous heat" in heat wave and health warning systems. Environ Int. 46:23–9. doi:10.1016/j.envint.2012.05.001.