

Predicted Heat Strain (PHS)

User Guide



Version 1: August 2016

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1 Overview

1.1 Purpose

The purpose of this document is to provide a practical overview and a step-by-step application of the Predicted heat strain (PHS) mobile phone application. This includes a demonstration of how PHS may be used to analyse methods of reducing or managing thermal risk associated with a task or environment.

Heat strain risk evaluation within sites has historically received limited focus, with limitations in site risk analysis or management frequently identified through the auditing process (largely due to the level of complexity associated with detailed analysis). PHS and this accompanying user guide seek to encourage a higher degree of heat strain risk evaluation through providing an interactive, simple and user friendly risk analysis tool.

1.2 Scope

This user guide is limited to the application of PHS for the analysis of predicted heat strain.

2 Background

2.1 Predicted heat strain

A number of techniques currently exist for the evaluation of thermal responses in humans. Many of these are based on heat exchange modelling and complex algorithms. The inherent complexity of these evaluation methods has resulted in a limited capacity for practical application by occupational health personnel. To increase the ability of occupational health personnel to assess and analyse thermal environments and risks, a 'user friendly' mobile phone application, was developed to assist with evaluating the impact of thermal environments on health.

PHS analyses and interprets thermal risk using calculations of predicted heat strain. The programme applies predicted heat strain formulae outlined in *ISO Standard 7933:2004 Ergonomics of the thermal environment* (ISO 7933), to provide a graphical illustration and summary of predicted heat strain based on user entered data.

The heat balance equation used by PHS is displayed below. The formula is comprised of several complex algorithms and component calculations, hence the advantage of the PHS app in simplifying the evaluation process.

$$E_{\text{req}} = M - W - C_{\text{res}} - E_{\text{res}} - C - R - S_{\text{eq}},^i$$

Where:

E_{req} is the required evaporative heat flow,

M is the metabolic rate,

W is the effective mechanical power,

C_{res} is the respiratory convective heat flow,

E_{res} is the respiratory evaporative heat flow,

C is convective heat flow,

R is radiative heat flow, and

S_{eq} is the body heat storage for increase of core temperature associated with the metabolic rate.ⁱⁱ

In evaluating thermal risk, PHS interprets a number of user-defined environmental and task parameters and through algorithms within the above formula, determines the predicted core temperature for an individual or similar exposure group (SEG) working under defined conditions.

PHS provides the following interpretive data:

- Predicted heat strain summaries for specified parameters/ scenarios
- Predicted heat strain graphs for specified parameters/ scenarios
- One, two and / or three work phase analyses
- Predicted water loss values
- Custom reports based on summary information and graphs (which can be emailed)

As stated, PHS was primarily developed to increase the ability of occupational health personnel to critically assess and analyse factors contributing to thermal strain and risk. Through modelling predicted heat strain in work environments and tasks, users are able to alter various parameters (e.g. air velocity, air temperature, rest cycles, etc.) to determine the resulting effect on employee thermal strain.

Rather than simply classifying a work task or environment as 'unsuitable' due to air temperature or other factors, personnel are encouraged to determine how. By utilising control measures influencing parameters of PHS (e.g. fans, air conditioning, radiant heat shielding, frequency of rest breaks, etc), contributors to heat strain may be reduced or controlled. This will enable steps to reduce risk to as low as reasonably practicable and work may continue through the application of practical solutions.

In addition to PHS, the application provides predictive information regarding water loss. Within summary information and graphs, values for predicted water loss over time are provided. These values provide information that may assist in reducing the risk of dehydration as employees can be provided with task-specific fluid intake guidance and values may indicate when the use of electrolyte supplements or re-hydrating products is required.

Note: that predicted water loss values are still under review and as such should not be used as definitive dehydration risk criteria.

2.2 Ranges of Validity

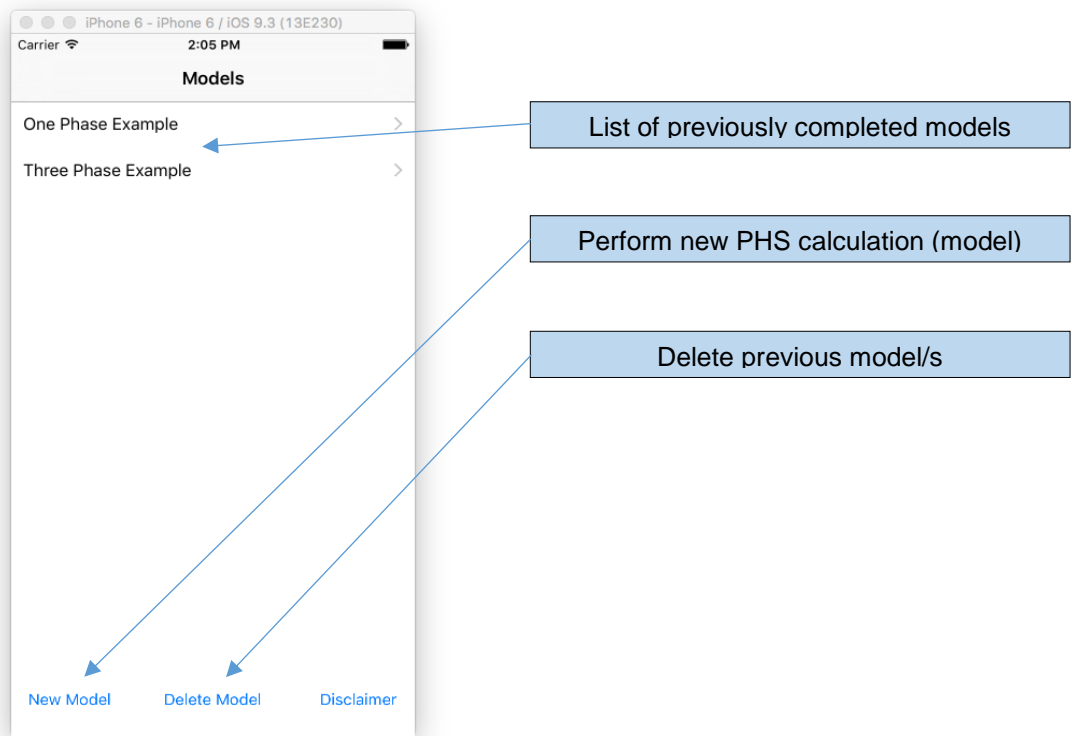
The program is based on algorithms used in ISO 7933 which were validated on a database including 747 lab experiments and 366 field experiments, from 8 research institutions. Table 1. gives the ranges of conditions for which the Predicted Heat Strain Model can be considered to be validatedⁱⁱⁱ.

Table 1. Ranges of validity of the PHS Model.

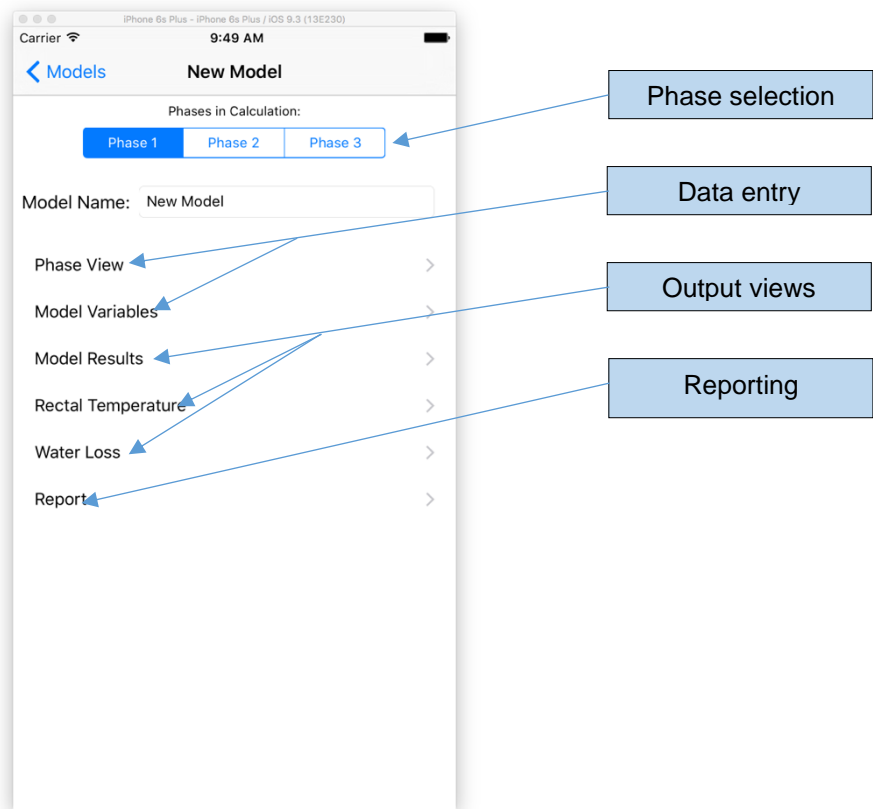
| Parameters | Minimum | Maximum |
|------------------------|---------|---------|
| t_a °C | 15 | 50 |
| p_a kPa | 0 | 4.5 |
| $t_r - t$ °C | 0 | 60 |
| v_a ms ⁻¹ | 0 | 3 |
| M W | 100 | 450 |
| I_{cl} clo | 0.1 | 1.0 |

3 PHS iOS Application

3.1 Start Screen / Model List Screen



3.2 New Model Screen



3.3 Application functions

Phase Selection:

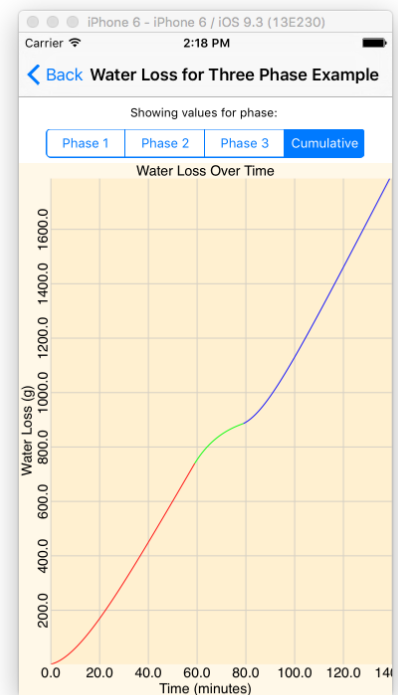
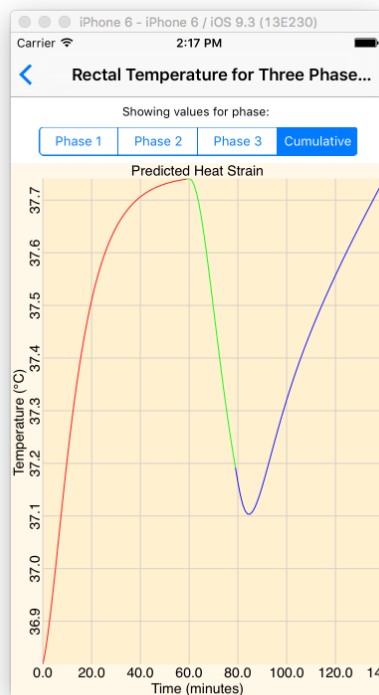
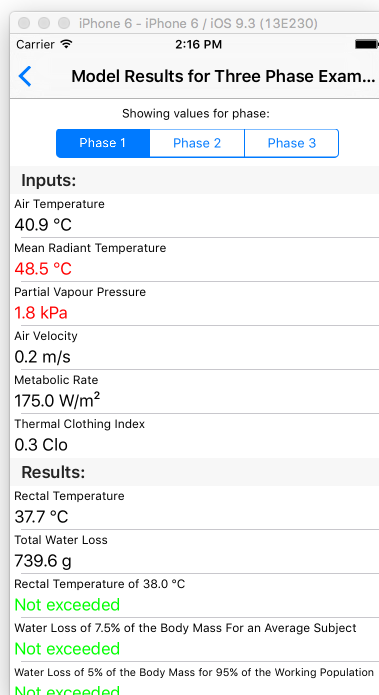
- Allows for the analysis of between one and three work phases (i.e. between one and three separate tasks and/or rest breaks undertaken by an individual or SEG during a work period).
- Each phase represents a change in task or environment. For example, a worker in phase one may spend 30 minutes working in 30°C, phase two rest for 10 minutes in 20°C and phase three working again in 30°C for 20 minutes.

Phase View and Model Variables:

- Allows user to enter data required to perform the PHS calculations.

Output views:

- Provides three options for displaying calculated information, including;
 - **Model results**— characteristics of the individual and environment used in the analysis and results of end temperature, water loss and time to exceed 38°C (for phase selected).
 - **Rectal temperature graph** – graphical display of temperature increase for number of phases analysed.
 - **Water loss graph** – graphical display of water loss over time for number of phases analysed.



Report:

- Reports – provides user ability to email a copy of the summary results information and graphs of predicted heat strain and water loss for analysed phases, individually or combined.

Data entry:

The first screenshot shows the 'Three Phase Example' screen at 2:20 PM. It has a 'Back' button and three phase tabs: 'Phase 1' (selected), 'Phase 2', and 'Phase 3'. Below the tabs, it says 'Showing values for phase:'. The form contains several input fields with their current values: Duration (60.00 minutes), Metabolic Rate (175 - Arm and trunk work), Acclimatised (Yes), Can Drink Freely (Yes), Posture (Standing), Static Clothing Index (0.30 - Underpants, T-shirt, shorts, li...), Air Temperature (40.90 °C), Globe Temperature (45.30 °C), Mean Radiant Temperature (0.00 °C), Relative Humidity (22.60 %), and Parital Vapour Pressure (empty). The second screenshot shows the same screen at 2:21 PM, but the 'Subject's Height' and 'Subject's Weight' fields are visible at the top, with values 1.80 m and 75.00 kg respectively. The rest of the form is the same as the first screenshot.

- Allows for the entry of parameters used to determine PHS.
- Values are entered in each phase (depending on the number of phases analysed). Model variables (individual characteristics of height and weight) are pre-set to 1.8 metre height and 75kg weight. These parameters were used to validate the application against Annex F in ISO 7933^{iv}.
- Each parameter field has defined value limits therefore outside the data ranges are automatically identified by the application. Users are notified when entered values lie outside the acceptable range but the programme will still provide a calculation.
- Note that whilst the toggle fields are pre-populated with values, it is possible to type in site specific data for a calculation into the “New Value” box.

The screenshot shows the 'Metabolic Rate' screen at 3:19 PM. It has a 'Back' button and the title 'Metabolic Rate'. It displays a list of metabolic rate options: '90 - Light manual work', '115 - Arm work', '145 - Sustained hand and arm work', '175 - Arm and trunk work' (which is highlighted), '200 - Intense arm and trunk work', and '230 - Very intense activity'. Below the list, there is a 'New Value:' label and a text input field containing '175.00'.

- Data entry will be further discussed in the step-by-step guide.

4 Application of PHS

4.1 Step-by-step guide

Prior to utilising PHS, users require a thorough understanding of the task being analysed (eg. duration, level of physical exertion, frequency of breaks etc) and the thermal parameters of the environment the task is performed in (eg. air and globe temperature, air velocity, humidity etc).

Employee input should be sought to provide accurate knowledge of task details. Accurate monitoring data should be used to determine environmental parameters.

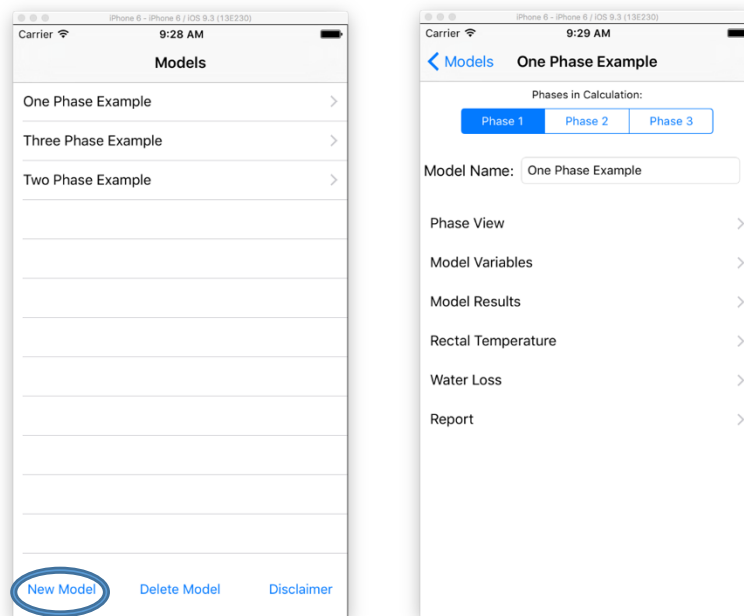
Single Phase Analysis

Single phase analysis involves using the PHS application to assess the predicted heat strain associated with a single activity or period of work. A step-by-step example of a single phase analysis using PHS is outlined below.

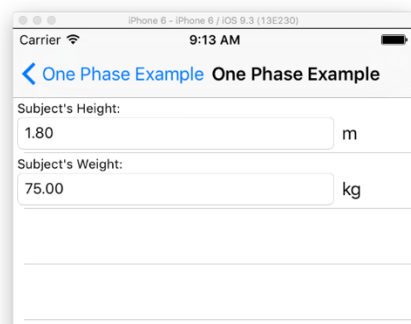
A 1.8m, 90kg vehicle maintainer is working for 60 minutes in the mine pit where the air temperature is 37°C, globe temperature is 37°C, humidity is 65% and air velocity is 0.1ms⁻¹. The maintainer is working mainly in a crouched position performing sustained hand and arm work. The maintainer is acclimatised, can drink freely and is wearing normal work clothing (long trousers, long sleeve shirt, boots, socks, underwear).

Step:

1. Press the 'New Model' on the Models screen to begin a new analysis. Give the new model a name on the next screen and select Phase 1 at the top.



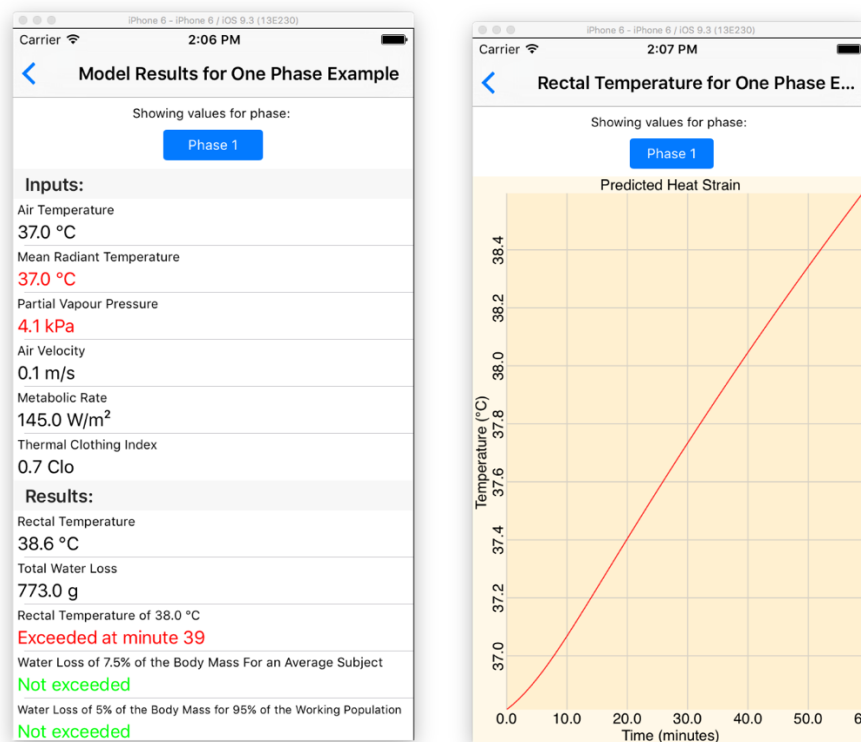
2. Select 'Model Variables' and update the model variables to reflect those of the individual (in the case of a SEG normative population height and weight values should be used).



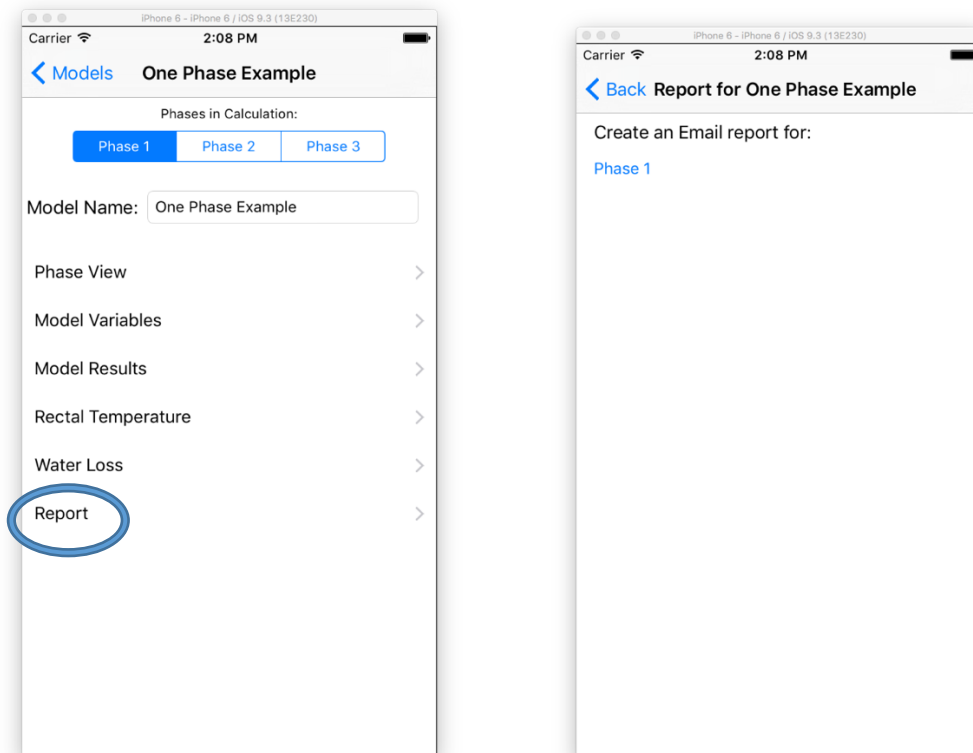
3. Select 'Phase View' and enter relevant data into the Phase 1 variables listed on the screen. Note that 'Metabolic Rate', 'Acclimatised', 'Can Drink Freely', 'Posture' and 'Clothing Index' values are selected from toggle lists.

4. When all data is entered, go back to the previous screen and select the Model Results button. After computing phase data PHS will determine mean radiant temperature and partial vapour pressure (using previously entered values), which are required for the PHS equation discussed in Section 2.

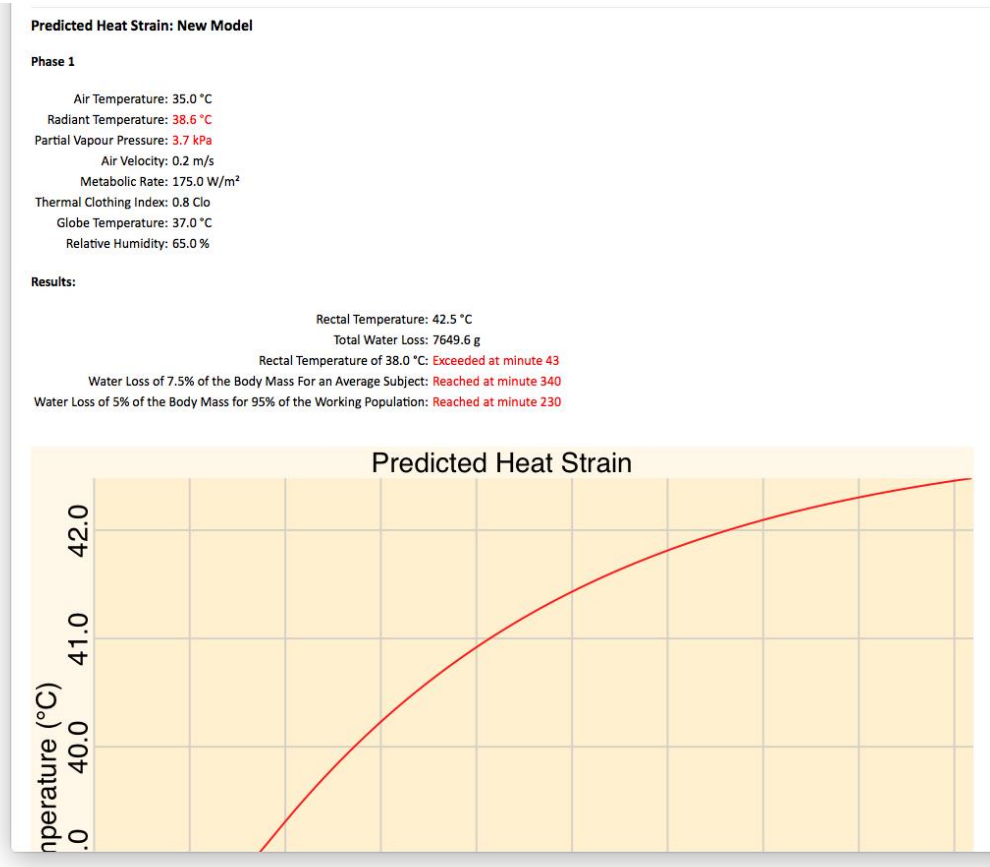
5. As discussed, output information may be displayed in two methods (model results or graphs).



6. Results may be emailed by using the Report button on the model's screen.



7. Once the report has been emailed you can save graphs as .PNG image files by write clicking on the graph within the email body and selecting 'Save'.



Output methods are used to evaluate thermal strain and risk. As the model and report outputs display, the maintainer in the above example is predicted to exceed 38°C after 43 minutes of work in the pit. And as displayed in the graph and report output options, the maintainers body temperature is expected to further increase for the remaining 18 minutes of work; reaching approximately 38.5°C after 60 minutes.

This information may be used as a general guide only to determine how long similar employees (ie. mine pit maintenance personnel, drill and blast crews etc) are recommended to spend working in similar conditions before alternating task or environment. This information can also be used to indicate where control measures may be required to reduce thermal stress risk for personnel required to work in similar conditions (eg. using mobile fans, shade stands etc). PHS can then be used to model the effects of these measures on thermal strain and thus provide a cost-analysis method and encourage a solutions-based approach to thermal stress risk assessment and management.

Multiple Phase Analysis

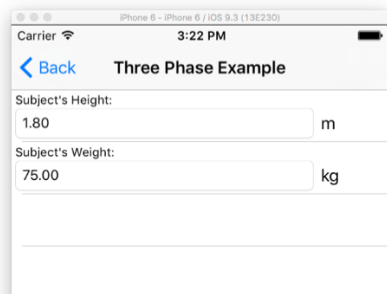
Multiple phase analysis involves using PHS to analyse thermal strain across two to three work periods that may differ in environmental conditions, task requirements and / or duration. Multiple phase analysis may be used to determine the effect of work breaks on heat strain and provides an indication of changes and the thermal risk across a work period (ie. situations where task and environment may change though heat strain may continue to increase).

A step-by-step example of a two-phase analysis using PHS is outlined below.

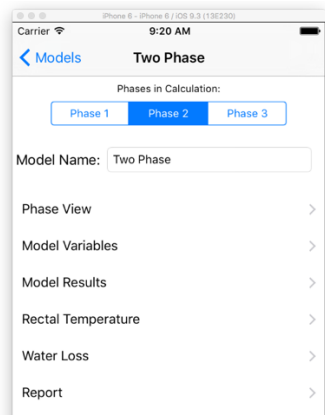
Continuing from the example used in the single phase analysis – After working in the mine pit for 60 minutes the maintenance employee begins to escort a vehicle to the maintenance workshop using an air conditioned light vehicle where the air temperature is 22°C, globe temperature is 22°C, humidity is 40% and air velocity is 0.4ms⁻¹. The maintainer is sitting during the escort, performing minimal physical work and is able to drink freely. The escort takes 30 minutes.

Step:

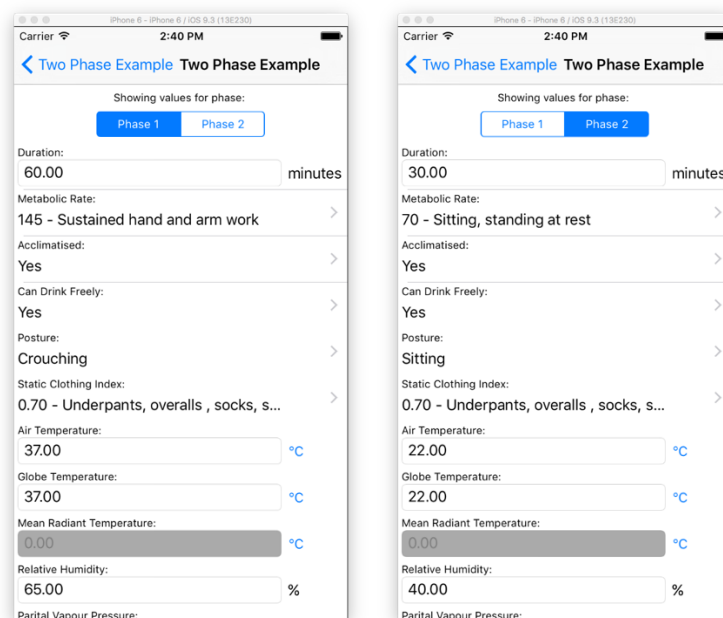
1. Model variables do not require updating (if using a new employee or SEG however they would be updated as per step one of the single phase analysis).



2. Two or three phase analysis is enabled by clicking on the appropriate phase number at the top of the New Model Screen and giving the model an appropriate name.

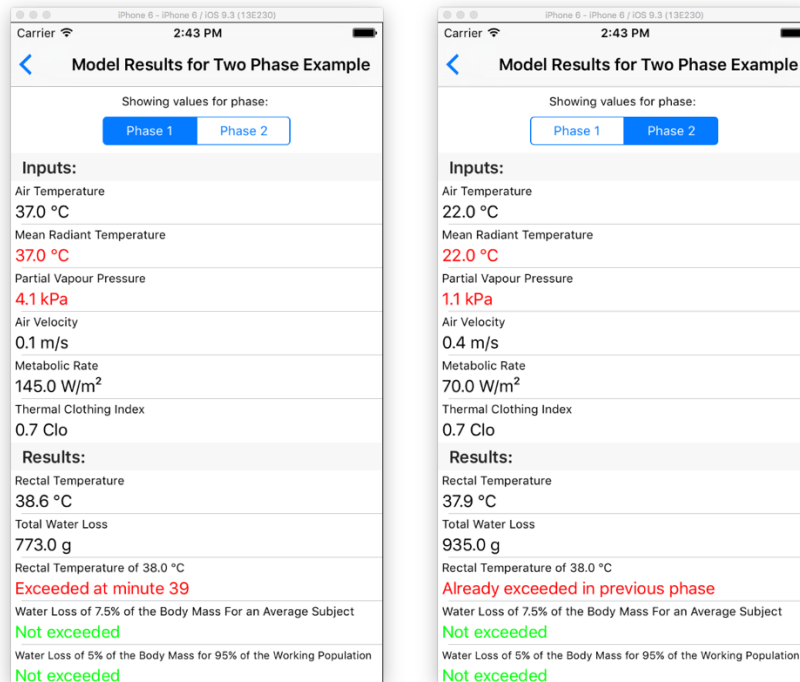


3. In the Phase View screen, relevant data is entered for each phase by selecting it from the buttons at the top of the screen.



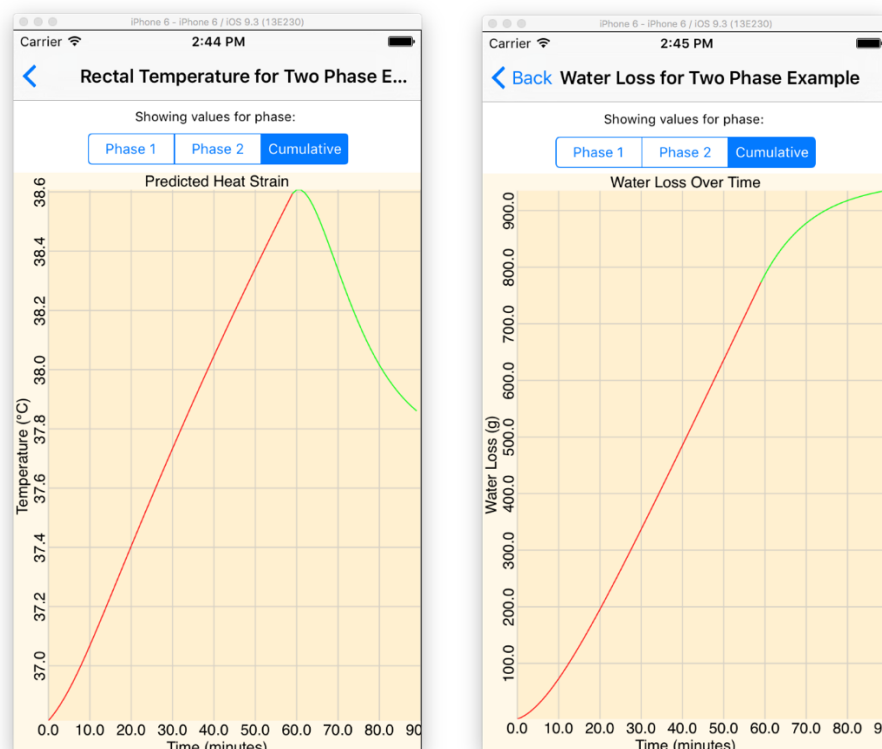
4. Again after entering data, go back to the previous screen and select the Model Results button. As in the single phase analysis, mean radiant temperature and partial vapour pressure values will be calculated by PHS.

- Output methods may now be selected as per single phase analysis. However, in two or three phase analysis users are able to view information for each phase. Output information may be emailed as a report by phase or for all phases.



Note: if the selected phase is a cooling phase, the message in red (shown on the right image above) will be dependent on whether the previous phase was exceeded. If so it will indicate that the rectal temperature was “Already Exceeded in Previous Phase”.

- Users may view the graphical representations of PHS and predicted water loss for the analysed phases to identify the effect of different phase parameters on PHS and potential water loss.



- Pressing the 'Report' button users may email the results of an individual phase or the combined results (see step 7 in the Single Phase Analysis).

As in single phase analysis, output methods are used to evaluate thermal strain and risk. Where a single phase analysis provides information limited to one task or environment, two or three phase analysis allows users to observe the effects of multiple work or environmental conditions on heat strain.

As shown in step 7, the second phase of work when the maintainer is travelling in the air conditioned vehicle resulted in a predicted decrease in core body temperature, with the maintainer's core body temperature predicted to decrease below 38°C after 20 minutes in the vehicle.

This information may be used to determine recommended duration of rest periods or recommendations for modifying environmental or work parameters (e.g. fans, air conditioning etc) to ensure thermal risk is as low as reasonably practicable.

4.2 Control measure modelling

Control measure modelling using PHS involves analysing the heat strain for a particular scenario (e.g. maintenance work in the mine pit) then modifying task or environmental parameters to determine the effect on PHS. Modifying task or environmental parameters allows health personnel to assess the impact various control measures will have on PHS and consequently the risk associated with a task.

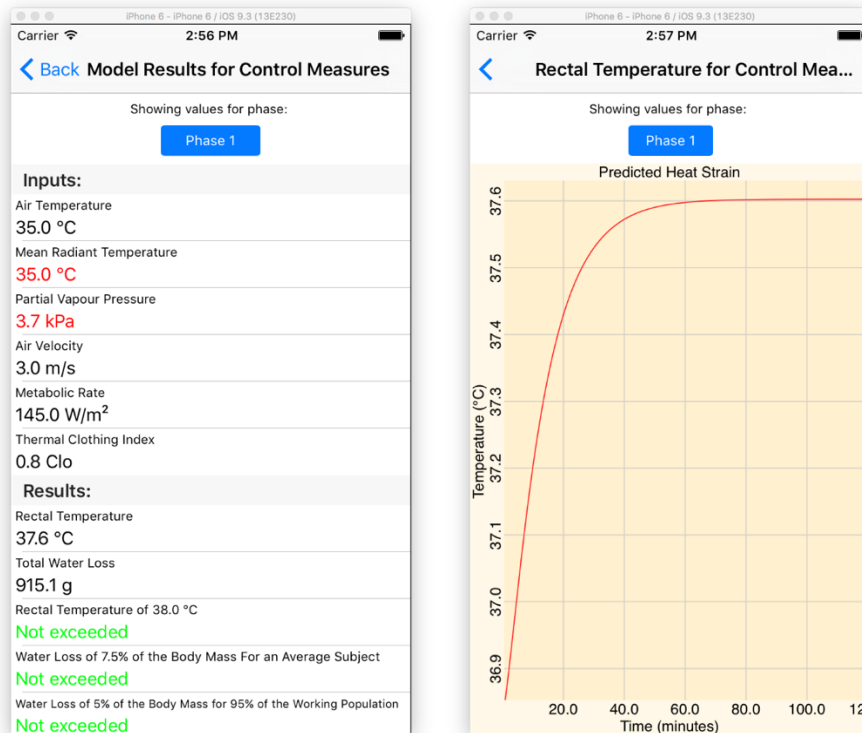
To demonstrate, a scenario and several potential control measure impact models are illustrated below:

Scenario one – no controls:



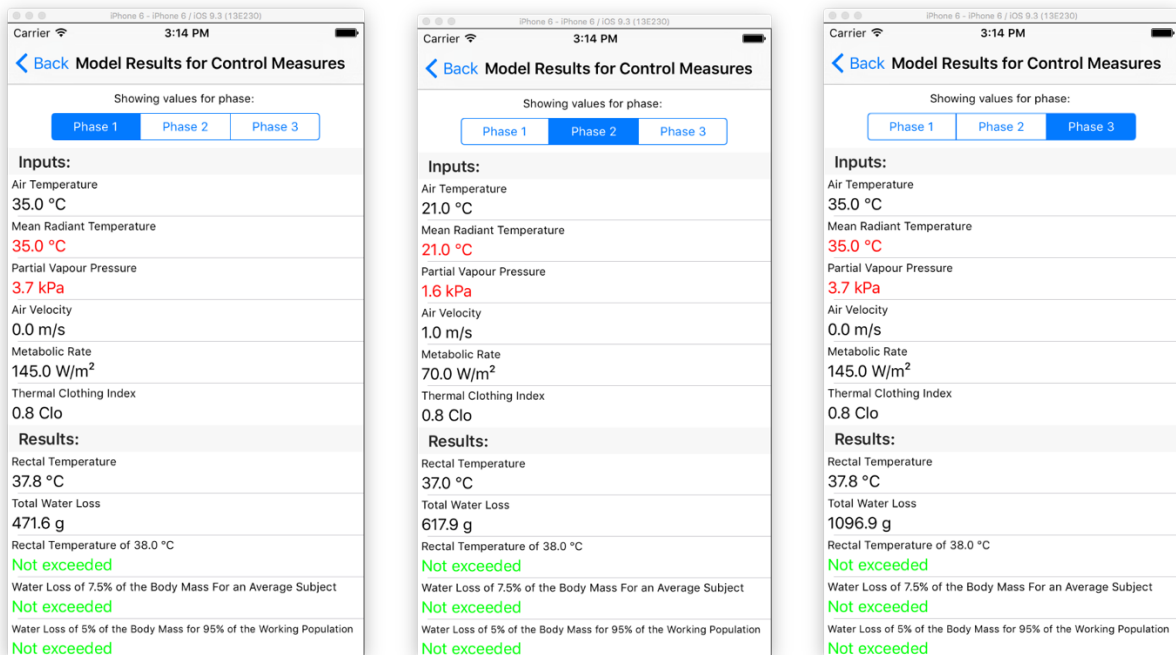
As shown in scenario one, the employee will exceed 38°C after 47 minutes in the current task and environmental conditions. Core body temperature is expected to increase for the two hours of work to a peak of 39.6°C.

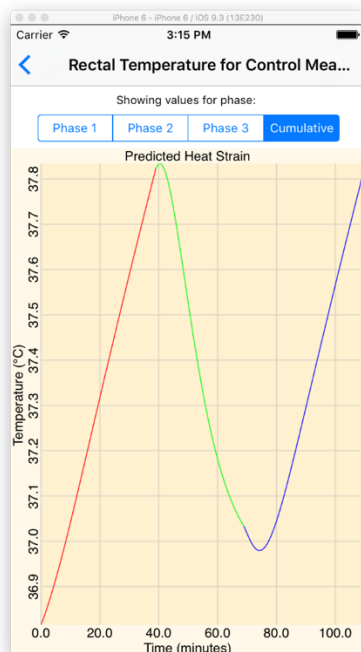
Scenario two – using an industrial fan to increase air velocity to 3 m/s:



As shown in scenario two, 38°C is not exceeded during the work period. Due to the effect of higher air velocity the subsequent improvement in evaporative cooling, the employee's core body temperature is expected to reach heat exchange equilibrium at 37.6°C after approximately 60 minutes of work.

Scenario three – using a work-rest cycle:





As shown in scenario three, 38°C is not exceeded during the work period. Due to the work-rest cycle, the employee's core body temperature remains below 38°C for the duration of work – however, the modified environmental conditions during the rest period (reflecting an air conditioned room) were required to facilitate a decrease in core body temperature.

It is preferred that work-rest cycles be used as the last option in controlling heat strain and thermal risk. As with all administrative control measures, work-rest cycles are dependent upon personal behaviour, support and reinforcement. Whereas, engineered control measures such as heat shielding barriers, industrial fan systems, and industrial cooling systems rely on a low degree of personal involvement to effectively control risk. These work/rest cycle estimates assume a fit healthy individual and hence should always be used as a guide only.

5 Interpretation guide

5.1 Interpreting results

All thermal indices have some limitations in terms of their ability to comprehensively predict human responses to the thermal environment. It is important to note that PHS cannot definitively account for all the variables associated with individuals, the environment and in general, heat stress risk assessment. This mobile application should only be used as an evaluative tool, **not to determine safe/unsafe limits**. Health personnel should always use professional judgement when drawing conclusions from PHS analysis.

Various individual factors such as illness, physiological characteristics, medications, tolerance thresholds and susceptibilities are not components of the PHS analysis. These factors may contribute significantly to individual risk and must be considered (beyond the limitations of heat transfer equations or modelling) when evaluating thermal risk associated with a task or environment.

Other references may provide users with more comprehensive heat stress guidance. This will include potential contributing factors that PHS may not incorporate into the result calculation (i.e. individual factors listed above), and should be referred to when interpreting PHS results to determine physiological and environmental limits for heat stress.

ⁱ ISO 7933 (2004). *Ergonomics of the thermal environment - Analytical determination and interpretation of heat stress using calculation of the predicted heat strain*. International Organisation for Standardisation, Geneva.

ⁱⁱ Parsons, K., Human Thermal Environments. (2003). 2nd Ed. Taylor & Francis Group. London

ⁱⁱⁱ ISO 7933 (2004). Op. cit.

^{iv} ISO 7933 (2004). Op. cit.