ABI Comfort simulator

User Manual

Jagir R. Hussan

Auckland Bioengineering Institute

March 2019.

Introduction

Climate change is a significant challenge facing humans. On the one hand we need to address the issues that are exacerbating the warming process, and on the other we need to develop lifestyle related products that would help mitigate the effects. Thermophysiological comfort is critical to human performance and is significantly affected by the warming planet. New materials for housing, clothing and protection from harsh elements are being developed. However, significant costs associated with the industrial design and development process stifle equitable development i.e. not all communities have access or are able to afford these technologies, even though the effects of climate change are universal.

Computer simulations may help in reducing these costs and in identifying material suitable for specific applications, and population specific requirements. Development of mathematical models to characterize comfort, the interaction between humans and materials have been an active area of research. Consequently, there are several models in published literature addressing various aspects of thermophysiological comfort. Our experience with implementing some of these models showed that the models and the results in the publications could not always be reproduced. Some issues include typographical errors in the formulae, missing parameters or the need to drill down to publications whose access required subscription, and some old papers used different terminology, units etc. There are a few free tools that are available, however, there isn't an open source software tool that integrates relevant models and enables the study of comfort under various environmental, clothing and radiative heat flux exposure conditions for realistic human geometries and body constitutions.

We believe this gap limits the potential for exploring and developing novel solutions, especially it restricts domain experts who do not have access to such commercial software or have the technical know-how to develop the models into useful software. The *Auckland Bioengineering Institute* (ABI) Comfort Simulator is a user friendly, free, open-source tool that enables the simulation of thermoregulation on realistic human geometries for various environmental, body constitution and metabolic activity levels.

This user manual describes the features of the tool and outlines the steps to setup an experiment, simulate, and visualize it.

Table of Contents

Organising projects

Workspaces

Often files related to experiments are organised in certain folders. Additionally, parameters associated with simulation, visualization etc. may also vary across projects. Users may also connected to multiple servers to perform simulations, in such cases the connection parameters will vary with the server. The notion of workspaces enables the user to collate and store these characteristics, such that all experiments created with respect to a workspace can access these characteristics seamlessly.

Users can select a workspace, associated with a directory, at the time of launching the application. New workspaces can be created by selecting new directories.
Key elements stored within a workspace include:

1. The last successful file operation directory,
2. List of recent projects,
3. Number of simulation time steps per activity record (larger number may increase simulation time),
4. Animation rate,
5. Whether to use a server for simulation ,
6. Uri for accessing the server,
7. Port number for communicating with the server,
8. Whether to use the simplified (65MN) model or full model.

Item 1 and 2 are automatically updated based on the last successful file operation
Items 3,4,5,6,7 can be modified through Help->Preferences option
Item 8 can be modified through the Simulation-> Project To Standard Model option

Experiment setup

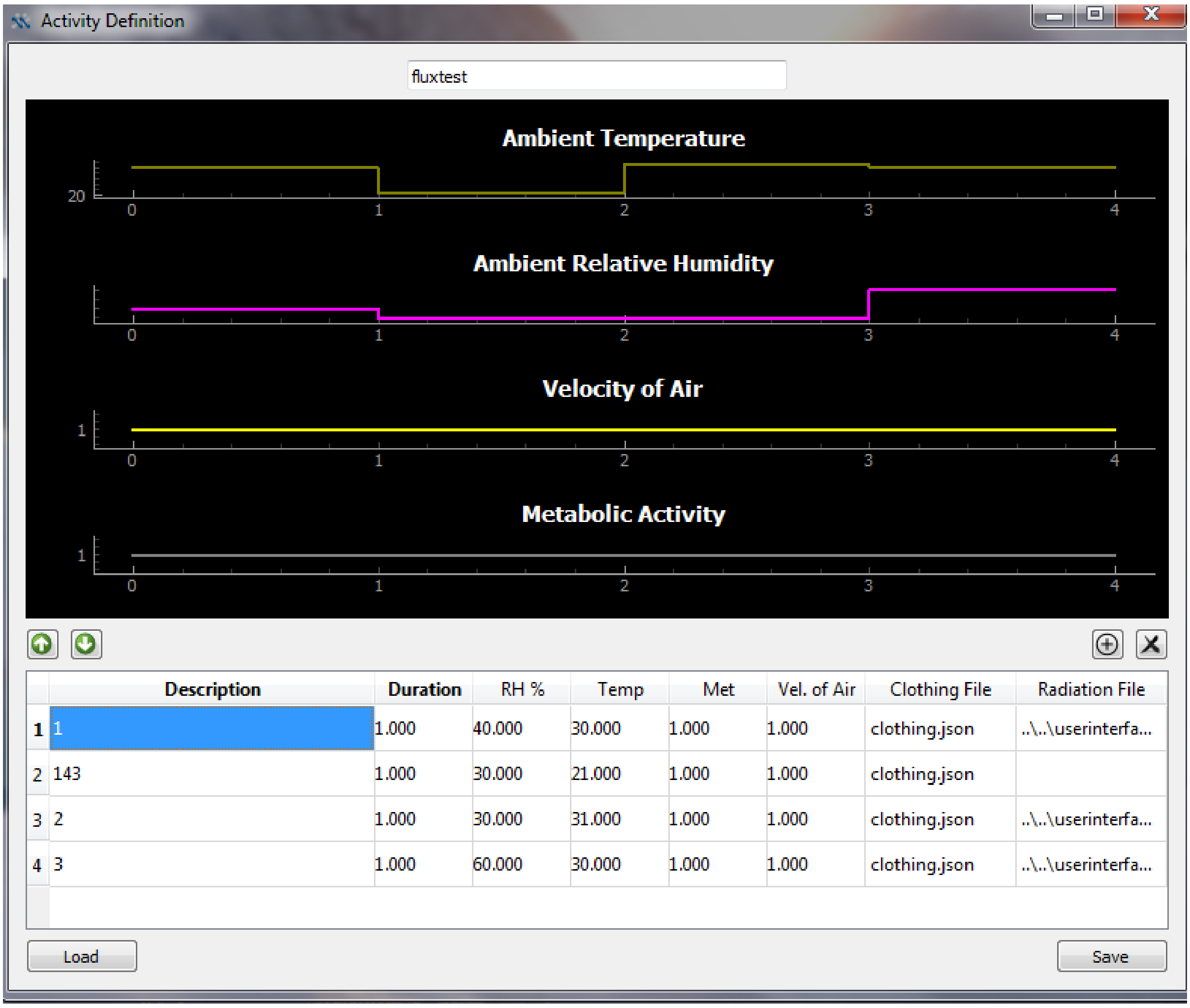
A simulation experiment, at minimum requires an activity profile and a realistic human geometry.

Activity profile specification

Activity profile consists one or more records, where each record provides

1. Ambient temperature (in Celsius),
2. Ambient Relative Humidity (%),
3. Metabolic activity level (mets),
4. Magnitude of velocity of air (m/s),
5. Description of clothing (or lack of it), (filename)
6. Description of radiative heat flux (or lack of it), (filename)
7. Duration (in seconds) for which these conditions are active,

The activity designer interface is designed to create an activity profile. The activity designer can be accessed through Experiment Setup -> Create New Activity Profile. If an activity profile has been loaded, the activity profile can be edited through Experiment Setup -> Edit Activity Profile.
The interface allows for loading existing activities and saving activity profiles. A screenshot of the activity designer with four activity records is shown below



Realistic human geometry

A realistic human geometry along with body constitution data which includes Height (in m), Weight (in kg), Age (years), Gender, Cardiac Index, Cardiac Aging Ratio, Sex based Metabolic Ratio is also required.

Generating realistic human geometry

Realistic human geometries can be created using the makehuman software tool. A nude human model is necessary, additionally a teeth base is required. The teeth base is necessary to determine parts of the head that belong to the face. The typical makehuman workflow (in version 1.1) involves

1. Create the geometry for the target individual using the “Modelling” tab,
2. Select the Geometries Tab and select the ‘Teeth base’,
3. Select the Pose/Animate Tab and select the ‘Cmu mb’ rig preset,
4. Select Files Tab and then the Export subtab. Select Collada options under the ‘Mesh Format’ options tab and export the file,
5. Import the mesh file in Blender (delete all other items in the scene prior to importing),
6. Export the mesh as a Wavefront obj file, ensure that you select the ‘Polygroups’ option in ‘Export Obj’ toolbar.

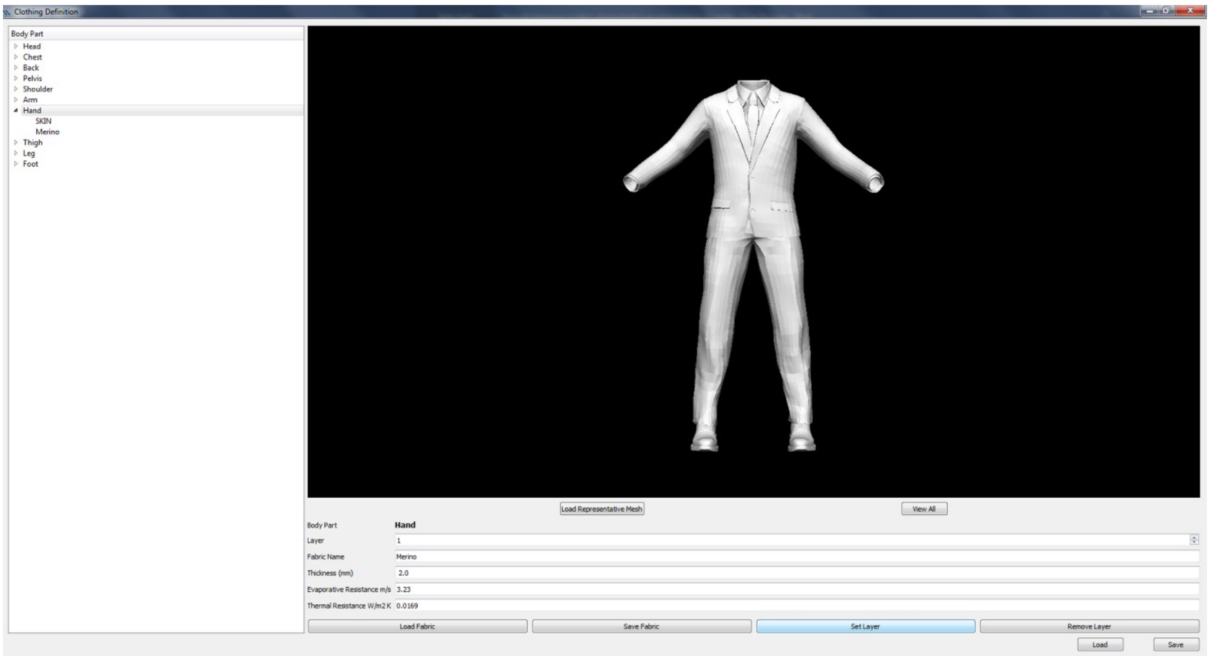
Poses can be created, especially for specifying radiative heat fluxes. Poses (like sitting in a car) can be created using Blender (with the help of the rig) and then the mesh can be exported as in step 6.

Clothing resistance specification

Clothing provides thermal and evaporative resistance, which influences thermoregulation and comfort. Clothing often involves multiple layers of different fabrics. The clothing designer interface enables the user to define these layers and related fabric's thermal and evaporative resistance. Currently the user can specify different layers of clothing for major segments of the body. The interface assumes symmetry, i.e. right and left (hands, arms things…) use the same fabric.
Layers are numbered 0,..n with layer 0 being closest to the body and is expected to be skin's resistance values. Additional layers can be created by 1) specifying the layer number, followed by 2) specifying the resistance values, and finally, 3) selecting the 'Set Layer' option. A layer can be removed by selecting the layer in the tree and then selecting the 'Remove Later' option.
Note: The 'Set Layer' option should be clicked to save any changes.

By default, a new instance of a clothing resistance project will have a **SKIN** layer as the first layer. The values for thermal and evaporative resistance of the skin with respect to the speed of the surrounding air is populated. Only for the skin/0th layer, the resistance values are **automatically** calculated based on the speed of surrounding air. Thus changing the speed will change these values. **'Set Layer' should be clicked to save any changes.**

When a fabric's resistance values are provided, the fabric's name can be associated with these values for reuse to avoid re-entry, using 'Save Fabric' option. Existing associations can be found using the 'Load Fabric' option, which will list the fabric names and their associated resistance values. When a fabric is selected from this list, the resistance values are populated for the layer.
The clothing description should be saved using the 'Save' option. Existing clothing descriptions can be loaded using the 'Load' option for modification. A screenshot of the clothing designer with a representative clothing mesh and specification of two layers for the hand is shown (Here it is assumed that the target individual is wearing a merino base layer glove).



Radiative heat flux specification

Radiative heat can significantly affect comfort, unlike ambient heat it is directional and affects different parts of the body based on their orientation to the source. Typical sources include the sun, radiative heaters, reflective materials etc. Radiative heat flux incident on the target individual can be specified using the radiative heat flux designer interface. The interface requires a realistic human

geometry that has the same mesh-face topology as the mesh used for simulation. Ideally, this would be the same mesh but with a different pose (animated using blender and exported to Wavefront obj format).
Once the mesh is loaded, directional sources can be specified. The centroid of the mesh is considered the origin of a spheroidal coordinate system. Directional sources can then be specified based on their distance from the mesh, the latitude and longitude. The intensity of the source is also required. The source values are in kW/m^2. The calculated values are shown in W/m^2.

Sources are graphically rendered as spheres and colours can be assigned to identify them. To handle sources that are very far, the interface clips the longest *rendered distance* to be 10 times the bounding box of the target mesh. The actual distance value is used for computing the incident flux using the inverse square law $I = {}^{intensity}/_{d^2}$ and the orientation of the mesh face with the source. Addition/modification/removal of sources results in the recomputing of the incident flux values and the updated flux values are used to texture the target mesh.
Users can zoom, rotate, translate the mesh using a combination of mouse and keyboard inputs.

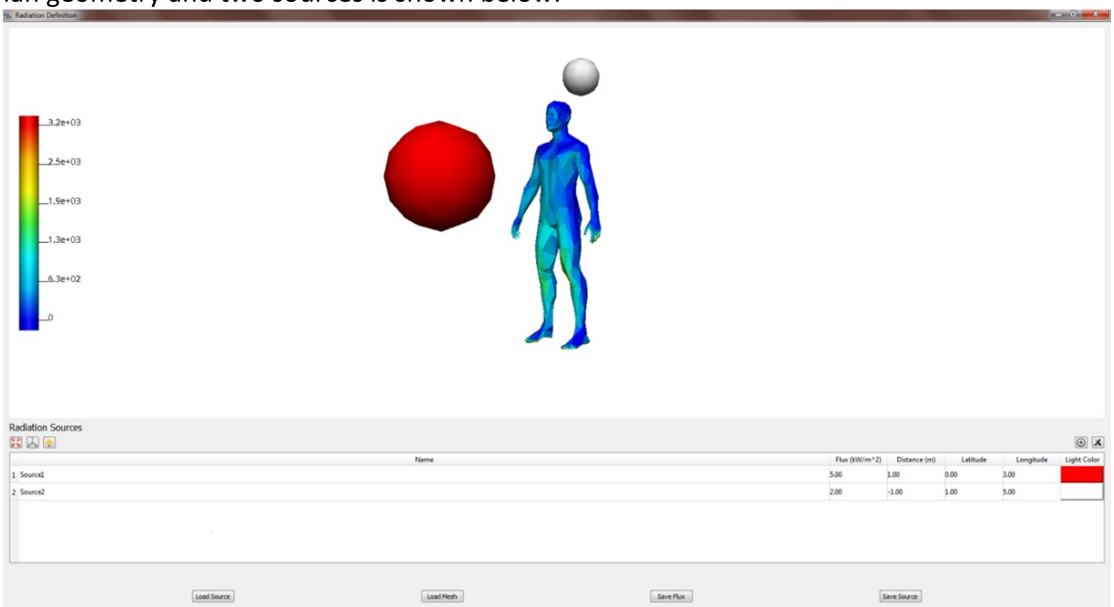
- Left mouse button press and move for rotation,
- Right mouse button press and pan will zoom in or zoom out,
- Shift + Left mouse button press and move for translation.

The meshview can be reset to show all the graphical elements by clicking the viewAll tool button 
The origin can be shown or hidden using the axis tool button  .

The light sources can be show or hidden using the light state tool button  .

Sources can be added or removed using the add and remove tool buttons  .
To remove a source, any element in the row corresponding to the source should be clicked prior to clicking the remove tool button.

User's can save the scene description in terms of the sources, their intensity and position using the 'Save source' option. The flux values can be saved using 'Save Flux' option. This is the file that should be used in activity definition to define the radiative heat flux profile.
New meshes can be loaded using the 'Load Mesh' option and an existing scene description can also be loaded using the 'Load Source' option. A screenshot the radiative heat flux designer with a target human geometry and two sources is shown below.



Simulation

Prior to starting a simulation, the target individual's geometry (Loaded using File -> Open Mesh) and the activity profile (Loaded using File -> Open Activity) are required.
A particular configuration of activity profile and target geometry can be saved as an unsolved project file. The project could be loaded later on to be submitted for simulation or to be modified.

Depending on the preference settings (Help -> Preferences), options to Start, Pause, and Stop a simulation or to submit the job to a server, and query the status of submitted jobs will be provided.
By default, the simulation using a server option is disabled.
Further, the option to use the reduced 65MN model or the realistic geometry to simulate is also provided (Simulation -> Project To Standard Model).

In the non-server based simulation mode, the results of the simulation are loaded once it completes. The experiment configuration and results can be saved as a project file and reloaded later. The results of the simulation can also be saved separately (Simulation -> Save simulation). Past solutions can also be loaded (Simulation -> Load simulation). However, the user must ensure that the number of degrees of freedom in the current mesh and those of the results being loaded match.

In the server based simulation mode, the user must manually Query the server to determine the status of the simulation job. The query results show the current progress level and if complete the progress is 100%. When a simulation is completed, the simulation can be downloaded as a **project** and loaded to visualize the results.
Currently, the server does not remove completed jobs from its database, it is a good practice for the user to remove the job once the results have been downloaded.

Job identification information is stored in the workspace, if the workspace is different, jobs submitted through a different workspace to the same server will not be accessible.

Visualization

Simulation results can be visualized using the main window. The skin-, core-temperature, predicted amount of skin wettedness, thermal and evaporative resistance values can be rendered on the mesh by selecting the appropriate radio buttons.

The weighted-mean skin and core temperatures for each of the 16 body segments can also be plotted, the plot colour can be chosen using the 'Temperature by Anatomy' Controls. To show a plot, the  button should be clicked. If the plot is already shown, the  tool button should be clicked to hide it. All the anatomy related plots are collated in a single plot. The plot widget allows the user to export the data for analysis outside the tool.
Further the mean-skin, core- and rectal-temperatures for the target geometry can also be plotted. The predicted mean vote and predicted percentage dissatisfied comfort scores can be plotted or hidden by checking the appropriate check boxes. Screenshot of rendering an experiment and its simulation results is shown below.

The plots allow of scrolling and panning. To reset plot view to view all contents, click on **A** graphic element that appears at the bottom left corner of the plot. Similarly, to reset the human geometry view to be centred on the window, click the 'Reset Mesh View' button.

Simulation server

The server component for remote simulation of jobs takes an optional port number as an argument. The default port is 5570. The tcp ip address of the computer on which the server is started is the ip address on which the service is made available, the administrator is required to ensure that network access and firewall restrictions are appropriately handled.

Clients require the tcp ip address along with the port number to communicte with the server.
The server creates two files: thermoregulationResults.sqlite and thermoregulationProgress.sqlite in the directory where it was launched. These files are used to store results and progress information. The server does not have options to clear or track the age of these records and expects the clients to remove simulations that have completed or failed. Deleting these files, would destroy all related information.

Installation

The code is compatible with python 3.6. The tool relies on dependencies which are expected to be available in the host python environment (both the client and the server).

Installation Instructions

Download opencmiss zinc library from the development releases for the target operating system
The binaries can be found at
http://opencmiss.org/downloads.html#/package/opencmisslibs/devreleases

Install/Extract the archive and determine the python binding version that has been provided.
Look into the OpenCMISS-Libraries<VERSION>/lib directory
If the directory python3.6 exists then zinc bindings for python 3.6 exists
(note that python 3.6 bindings will not work in python 3.7)

Install Python

(you can use an existing python distribution, ensure the packages are installed through appropriate installers) miniconda 3.6

Install dependencies

conda install pyqt=5
conda install scipy json
conda install -c conda-forge diskcache pyqtgraph
pip install sqllitedict

Install/Link with opencmiss-zinc

Zinc can be installed by executing
python setup.py install
from the OpenCMISS-Libraries<VERSION>/lib/python3/Release/opencmiss.zinc/

Alternatively, this library can be linked through PYTHONPATH

in bash

export PYTHONPATH=OpenCMISS-Libraries<VERSION>/lib/python3/Release/opencmiss.zinc/:$PYTHONPATH

in windows

set PYTHONPATH=OpenCMISS-Libraries<VERSION>\lib\python3\Release\opencmiss.zinc\;%PYTHONPATH%

Sample meshes and projects

Sample realistic human geometry meshes have been provided in the Configurations\meshes folder femalesuit.obj, femaleSuitWithHat.obj,malesuit.obj and infantClothes.obj are meshes that are intended to be used in the clothing designer. The remaining meshes can be used for simulation.

Sample activity definitions have been provided in the Configurations\activities folder

activities.json provides a sample activities definition profile.
Clothing.json provides a sample clothing definition file (it is used by the above activities definition)
noclothing.json provides a sample nude human definition file (values could be modified for disease conditions)

Solved project files are also available at https://models.physiomeproject.org/workspace/583 (they have been hosted separately due to their size).
emptyMale.p2.pkl, solvedSimplifiedMale.p3.pkl and solvedFullFemaleModel.p3.pkl are project files that can be loaded into the tool. Note that these projects have been solved using python 3.6 and will not load if your instance is running on python 2.7.