MODELING OF A THERMAL MANNEQUIN IN FLOVENT

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ABSTRACT

This paper presents results of a study conducted in the methods available to model a thermal mannequin in a commercially available software program. The results from the study give insight into the specific apllication of each modeling technique to simulation.

INTRODUCTION

Almost all processes that take place within the human body and that are essential to keep the body in "living" condition result in the generation of heat. Some amount of the heat is required for the processes to continue but most of it has to be dissipated to the surrounding. Due to this fact, the human body is a constant source of heat. The heat produced by a resting adult is about 100W (341.21 Btu/h) (2001, ASHRAE Handbook of Fundamentals). Depending on a variety of factors, the amount of heat generated by the human body varies.

The need to understand the interaction of the human body with its microclimatic environment is to be able to see and predict effect that are extremely small in magnitude like air flow due to thermal buoyancy and entrainment flows along the surface of the body.

Tool – Computational Fluid Dynamics Environment

The tool used for the purpose of this research is commercial computational fluid dynamics (CFD) software developed by Flomerics Inc. marketed as Flovent. The version 4.1 was used for this study. The principal applications for which this software was developed was for the analysis of flow and heat transfer within buildings and to provide a means to predict thermal comfort

Background

The most comprehensive study of thermal mannequins in digital environments using CFD was presented by S Murakami. However the tool used for that study is extremely high –end.

SIMULATION SETUP

Modeling Methodology and Assumptions

The central idea of the study was to analyze the variations in the way thermal objects especially a human body will interact with still air mass. Variation is introduced by modeling the thermal objects, in this case body parts in the different ways within the limitations of the software tool. For this purpose thermal objects are modeled as follows:

- As heat sources only
- As a cuboid or solid part with a heat source placed close to the surface
- Solid parts assigned a constant surface temperature
- Constant heat flow assigned to solid parts directly.

The thermal objects collectively form the mannequin. The manequin is assumed to be placed in 25 C (77 F) isothermal environments. There are no other gains and neither any air movement. The metric for comparison are three monitor points directly above the mannequin at increasing heights. Temperature and vertical velocity at these points determine the behavior of the models. These models consider only convective exchange of heat. All models are conceptual and use the Capped LVEL turbulence model.

CASE 1: AS HEAT SOURCES

This method employs using the "uncollpased" source primitives . The body is divided into six source and the total heat output is divided into these six. The results generated from this setup are displayed in Fig 1.

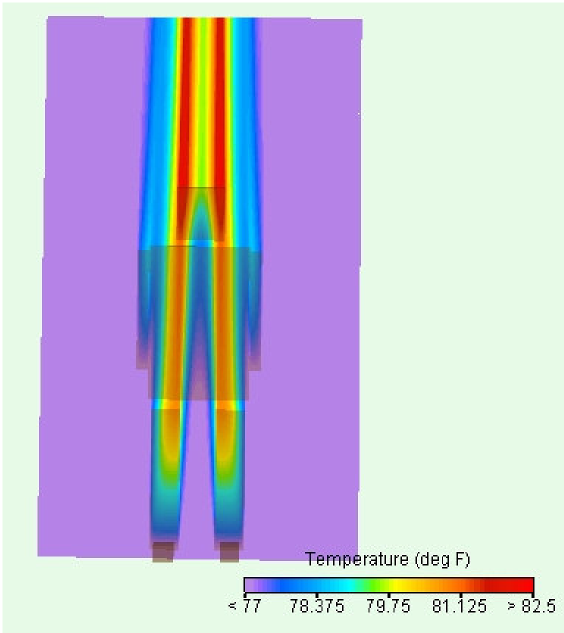

Figure 1: Distribution of Air Temperatures for Case 1.

Advantages

The following are the advantages of this method:

- Most evenly distributed heat source
- Heat generated and dissipated from the core towards outside

Disadvantages

- Source primitive is transparent to air flow
- Does not offer any resistance to the bouyant plume and therefore the behavior is not realistic

CASE 2: COMBINATION OF SOLID CUBOID AND HEAT SOURCE

In this case the body parts are modelled as solid cuboids. The cuboids have no thermal properties attached to them. The total heat output is distributed as collapsed heat sources. The heat sources have no thickness, they are planar objects. Each source is placed close to the cuboid body parts. The heat sources are distributed as follows described in Table 1.

Table 1 Heat source distribution for Case 2.

PART	NO. OF SOURCES	SOURCE (W)	TOTAL (W)
Head	5	5	25
Torso	4	5	20
Arms (2 Parts)	8	4.5	36
Legs (2Parts)	6	3.33	19.98
			100.98

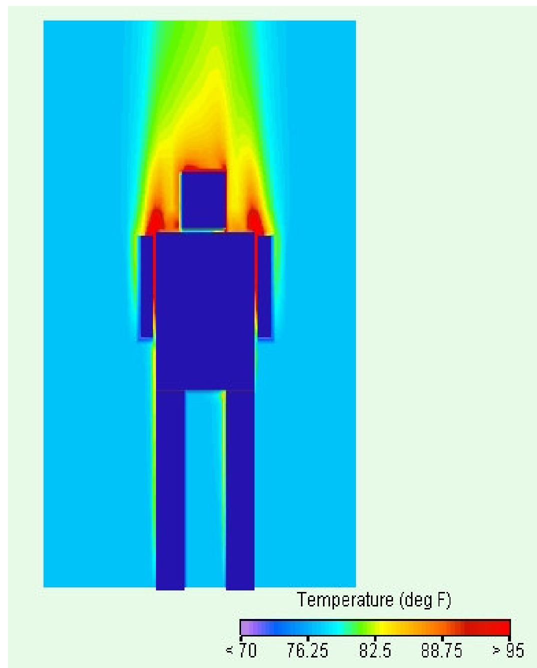

Figure 2: Distribution of temperature for Case 2.

Advantages:

- Heat sources are distributed as in case of the actual human body, head being the largest source
- Cuboids offer resistance to bouyant air plumes and generates interaction

Disadvantages

- Heat generation is neither from the core nor from the surface but very close to surface
- Number of grid points have to be increased to capture the effect of heat sources, which greatly increases runtime.

CASE 3 : CUBOIDS WITH SURFACE TEMEPARTURES.

The third case was an attempt to mitigate the problems encountered in Case 2. The same cuboid configuration was taken as in Case 2 and surface temperatures were assigned to each to reflect typical surface temperatures in conventionally air conditioned space with clothes. These temperatures are reported in Table 2. The results from this model are displayed in Figure 3.

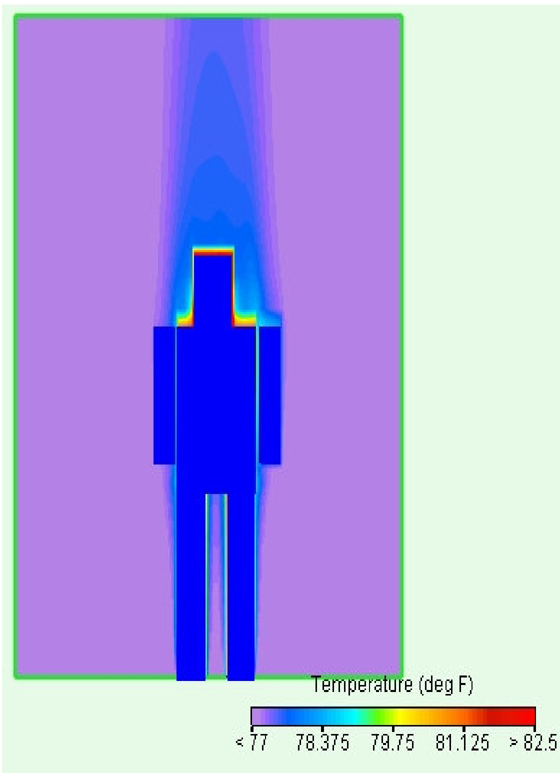

Figure 3 Temprature distribution in case 3

Advantages

- Reduces number of objects in the solution domain and hence complexity of the problem
- Reduced run time

Disadvantages

- Surface temperatures are assigned equally to all faces
- This results in cross interaction and combining of sources and reduces the impact of the individual source.

CASE 4: CUBOIDS WITH CONSTANT HEAT FLOW

This is a standard in the software libraries. No changes were made to the model and this case was run as a comparison. Solid cuboids are given constant heat flow values for this model.

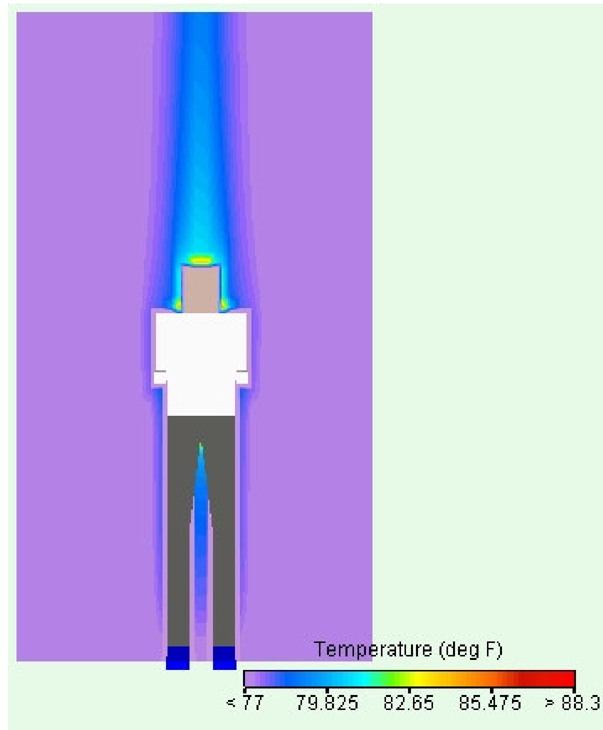

Figure 4 Temperature distribution in case 4

Advantages

- Reduces number of objects in the solution domain and hence complexity of the problem
- Reduced run time
- Visually looks close to a real human body

Disadvantages

- Heat flow is equally distributed along all faces of the object
- Some part of the heat flow is overlapping with other heat flow on unexposed surfaces and hence does not represent actual flows

RESULTS AND DISCUSSION

The results from this study are reported in tables 3 and 4 and figures 5 and 6. Table 3 reports the variation of temperature across monitor points per case. Figure 6 graphs the data. The analysis of the data shows that case 2 gives higher temperatures at all the monitor points. The individual sources results in a penalty in temperature variation as the source is directional. The 5W source representing the top of the head is directed upward normal to the head object. However when we look at the variation in vertical velocity for the same three locations across the four cases modeled, the difference in velocities at the upper monitor points is considerably smaller. Case 1 gives the highest velocities and is also expected to due to the fact that the entire object is a source. This means that the thermal plume is generated right at the center of the largest object. The height of the plume is therefore greater and has greater velocities. Also being modeled as source objects, it does not offer any resistance to the plume.

CONCLUSIONS

This study looked at the different methods of modeling thermal mannequins in commercially available software and discussed the basic advantages and disadvantages. This particular software has a limited meshing capability and cannot create complex smooth forms. This limitation not withstanding, different models of a thermal mannequin as modeled can be used. Case 1 method is useful when interaction with air mass is not of interest and only load or heat gain is important due to its shear simplicity. The case 4 method is useful if conduction is of interest with the surface in question. Since the constant heat flow is a function of the cuboid itself, it is possible to attach a conduction regime to the cuboid to take this effect into account. The case 3 model is better applied to applications in which neither interaction with air mass i.e. convection nor conduction is of interest. For mean radiant temperature type calculations where only the absolute temperature of the surface is important and not its heat generation capacity case 3 model is extremely well suited. When convective plumes due to thermal buoyancy are of interest, case 2 model works best due to the distribution of heat sources and their subsequent interaction with a still air mass. Though air temperatures very near the object are over predicted by this model, the resistance of the body to air flow plays an important role. Depending on the specific application any one of these models or their combinations can be successfully applied. The author is currently using a simplified version of the case 2 model to study buoyancy effects in large occupancy spaces.

ACKNOWLEDGEMENTS

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Table 2 Measured surface temperatures on clothed human body

Temperature Measurement Across Human Body - Measured Data						
		A	**B**	**C**	**D**	
	Sex	**Male**	**Male**	**Female**	**Male**	**Average**
Section Name	**Section#**	F	F	F	F	F
Forehead	1	92	92	91	89	91.0
Right Upper Arm	2	82	82	83	84	82.8
Right Palm	3	84	89	81	83	84.3
Left Upper Arm	4	80	84	82	85	82.8
Left Palm	5	84	89	82	82	84.3
Chest	6	81	81	86	85	83.3
Right Thigh	7	84	83	86	84	84.3
Left Thigh	8	81	82	82	83	82.0

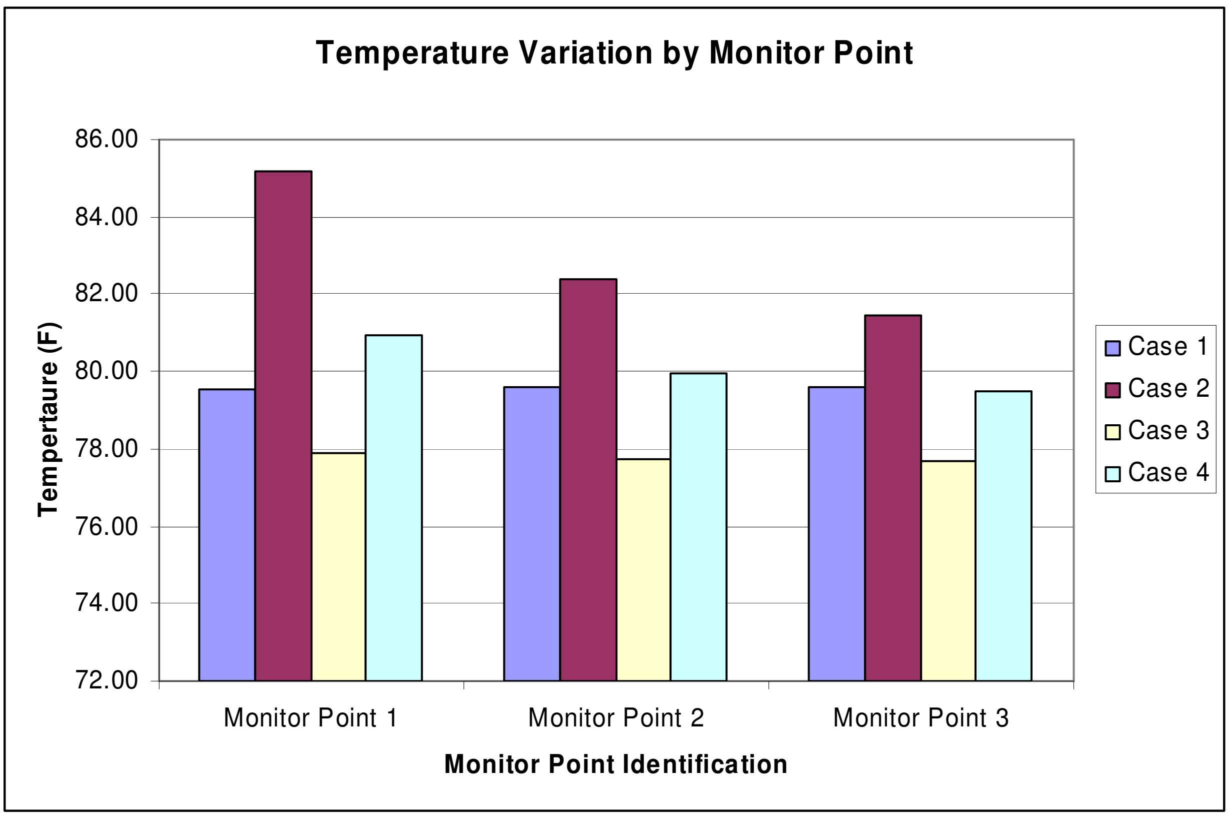

Figure 5 Temperature variation by monitor points per case

Table 3 Temperature variation by monitor point per case

Case Number	Monitor Point 1	Monitor Point 2	Monitor Point 3
Case 1	79.55	79.60	79.62
Case 2	85.19	82.39	81.45
Case 3	77.90	77.75	77.69
Case 4	80.96	79.94	79.48

Table 4 Vertical velocity variation by monitor point per case

Case Number	Monitor Point 1	Monitor Point 2	Monitor Point 3
Case 1	0.672	0.705	0.746
Case 2	-0.048	0.479	0.664
Case 3	0.200	0.553	0.652
Case 4	0.224	0.585	0.730

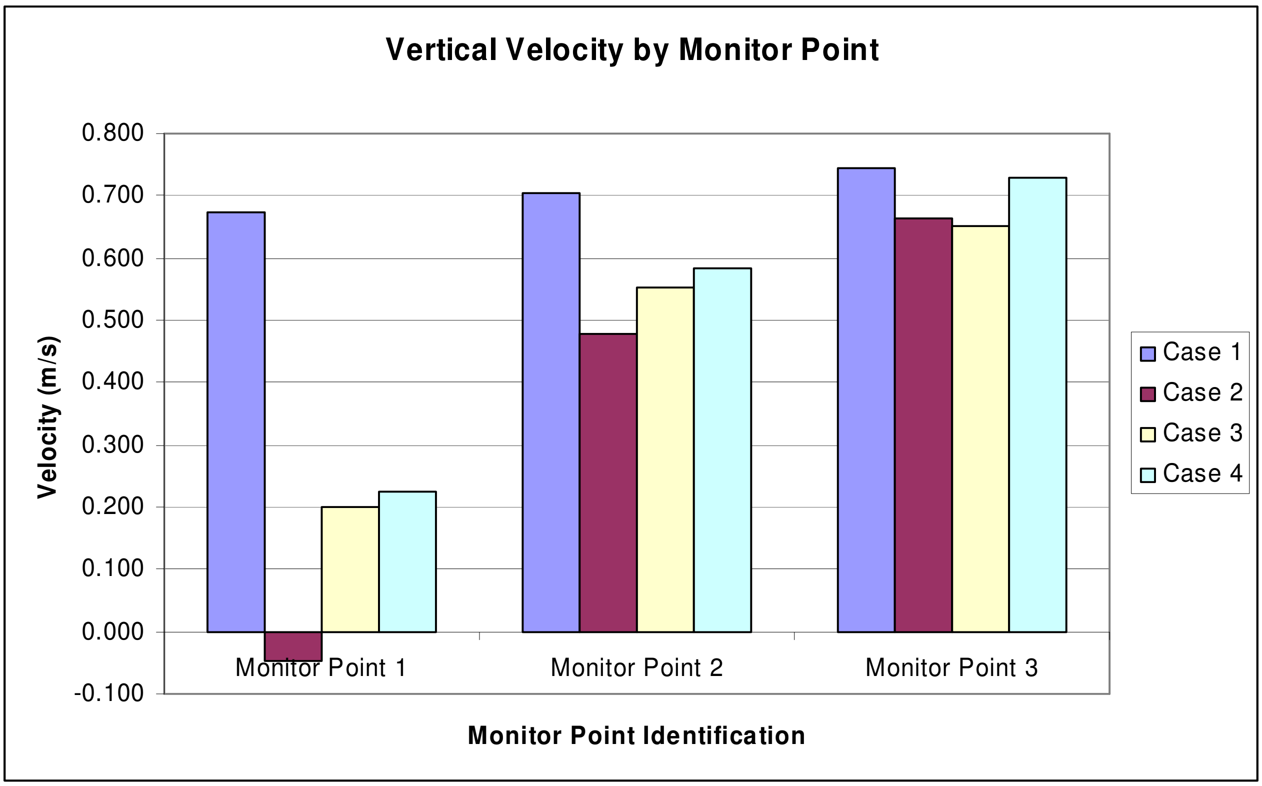

Figure 6 Vertical velocity variation by monitor point per case