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Conception of a simplified seated thermal manikin for CFD validation purposes*

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Rezumat. *Aceasta lucrare prezinta unul dintre cele cinci prototipuri de manechine termice concepute la Facultatea de Inginerie a Instalatiilor de la Universitatea Tehnica de Constructii. Acest prototip a fost conceput pentru a avea o forma simplificata cu unghiuri drepte pentru validarea modelelor numerice în cadrul unor studii de tip CFD. Toate testele sunt coerente si indica posibilitatea utilizarii acestui prototip în cadrul unor studii viitoare. Modelul este funcțional si temperatura fiecarei zone a corpului poate fi usor modificata în conformitate conditiile la limita dorite de utilizator. Forma geometrica a manechinului are un rol important în generarea curgerilor convective din jurul lui, de aceea acest prototip nu este potrivit pentru studii experimentale de rezolutie fina a micro-climatului corpului uman. El poate fi utilizat în cadrul unor studii globale de confort atât pentru cladiri cât si pentru vehicule.*

Cuvinte cheie: manechin termic, confort termic, validare CFD

Abstract. *This paper is presenting one among the five prototypes of thermal manikins conceived at the Building Services Faculty (Thermal-Hydraulic Systems Laboratory) at the Technical University of Civil Engineering. This particular prototype was chosen to have a simplified square angled shape in order to be used for validation in CFD studies We designed a seated thermal manikin that can simulate the human presence in a room. All the tests are coherent and this manikin can be further used to validate our CFD models. The model is fully functional and the temperatures of each body zone can be easily modified in accordance to our needs. The shape have an important role in the air movement o around the human body and this manikin is not suitable for local and high resolution measurements around the human body but can be used for global measurement in a room or inside a vehicle.*

Key words: thermal manikin, thermal comfort, CFD validation

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1. Introduction

Thermal manikins were used for more then 70 years. At the beginning they were used for testing clothing for soldiers by the US Army [1]. The shape and heating system were very simple at that stage. Since then the shape and complexity of the thermal manikin raised and start to approach the complexity of the human body. The number of independently controlled zones increased from a single zone corresponding to the entire surface up to 120 individually controlled zones [2]. The material used for developing the thermal manikin have diversified, from copper to plastic and carbon fibber to skin like silicon. If at the beginning the purpose of the thermal manikin was limited to clothing testing, in time, the range of applications become wider. The use of thermal manikin in the field of thermal comfort research become more and more active. The technology used to create thermal manikin had different approach. Most of them try to simulate the human body and the heat emission in the environment, while others are more or less complex measurement devices for assessing thermal environment quality by simulating the human body thermal regulation mechanisms and measuring its heat loss towards its environment [1]. The most advanced of them can also simulate body sweating and heat exchange through evaporation [1-4].

This paper is presenting one among the five prototypes of thermal manikins conceived at the Building Services Faculty (Thermal-Hydraulic Systems Laboratory) at the Technical University of Civil Engineering. This particular prototype was chosen to have a simplified square angled shape in order to be used for validation in CFD studies. Further evaluations of the importance of the shape in modelling hypothesis were also taken into account when the manikin was designed.

2. Building the manikin

The thermal manikin was designed in a seated position and is divided in 9 body parts (head, neck and shoulders, two hands, upper leg, lower leg, torso, back, seat) as displayed in Fig. 1 The size of the manikin is a standard human size with a total surface of 1.8mp (Fig.2). The base structure of the manikin was manufactured from extruded polystyrene. The body parts were welded with polyurethane foam and screws.

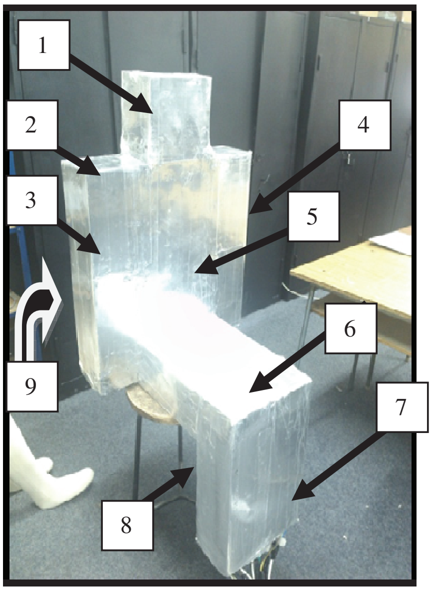

Fig.1 – Independent controlled body parts. 1 – Head; 2 – shoulders; 3,4 – Right/Left hand; 5 – torso; 6- upper legs; 7 – lower legs; 8 – seated part; 9 – back);

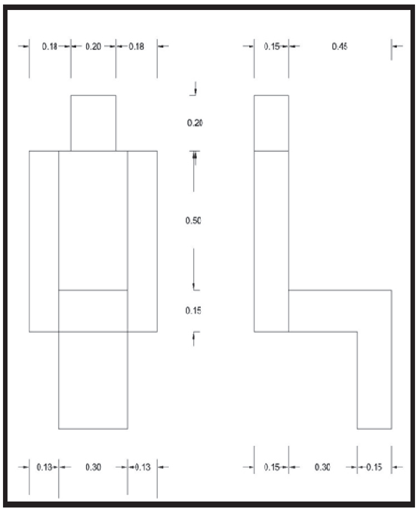

Fig.2 – Dimensions of the manikin

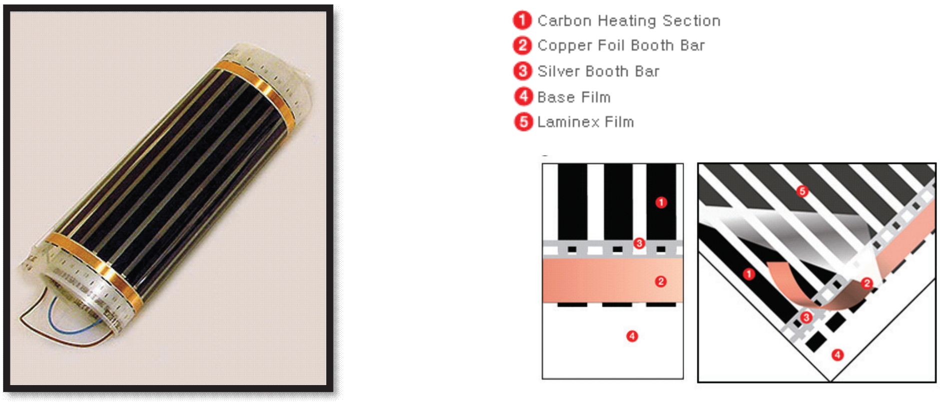

Fig. 3 a) Photograph of the heating film used for the thermal manikin, b) Sketch of the composition of the heated film.

Several types of films from different producers were tested. During these tests heating film from one of the manufacturers was found to produce non uniform surface temperature distribution, with a gradient of 7°C on across its width of 30cm (Fig. 4).

The heating film patches were placed on the polystyrene base using with double side adhesive tape. After covering a body zone the electrical connections and circuits were created. Every electrical connection was tested for leakage for safety reasons. The electrical wire was embedded in the polystyrene basis. In order to ensure that the thermal load of the film mounted over the wires is not influencing the cable stability we selected special wire that works at temperatures above 70grd.

During a preliminary test, without any control of the circuits, the temperature of each zone stabilized at 45°C when the room temperature was stable at °C, a rather encouraging result offering a wide range to control the temperature of each zone and the possibility to simulate different cases of body heat release.

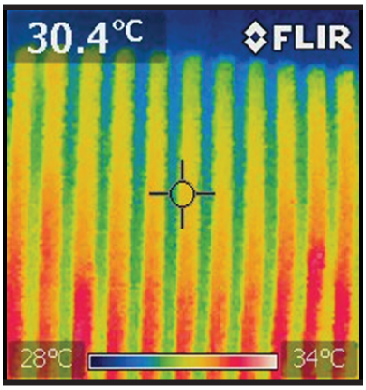

Fig. 4 Problematic surface temperature on one of the tested heating films

Using this kind of heating element has also some disadvantages. Because of the space between the electrical elements (i.e. carbon film stripes – see Fig. 3) it appear a zebra phenomenon, an alternation of hot– cold stripes and therefore an non-uniform temperature of the surface, phenomenon that need to be avoided [5]. As a solution we decide to cover the entire manikin surface with adhesive aluminium foil to ensure enhanced conduction heat transfer and thus better surface temperature uniformity. Finally, in order to facilitate further investigations with a thermal (IR) camera the entire manikin surface was covered with light black textile.

3. Electrical power consumption

In order to validate the manikin prototype we performed several tests.

a) Infrared surface temperature

For this test we used an infrared camera FLIR E60. The air temperature was stable at 26°C. Each zone was electrically powered. The surface temperature control of each zone was performed using a dedicated electrical dimmer (Fig.5). The temperature for each body zone was set using the measurements with IR camera and contact sensors and compared with human body temperature and with literature. Given that the air temperature of the room was constant and considering the simulated activity of the human body reaching the desired zone temperature was easy to reach and was similar to human body in the same conditions (fig.6).

Fig 5. Electrical dimmer installed on every circuit.

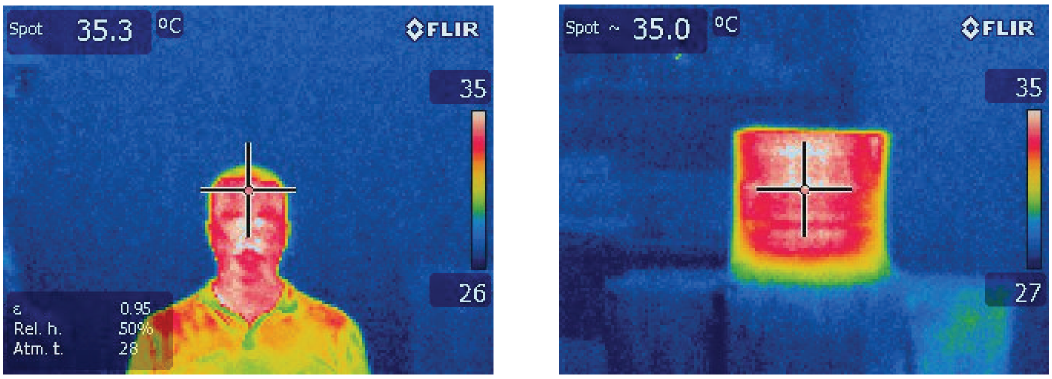

Fig. 6a. Comparing the surface temperature of the human body and of the thermal manikin using the IR camera

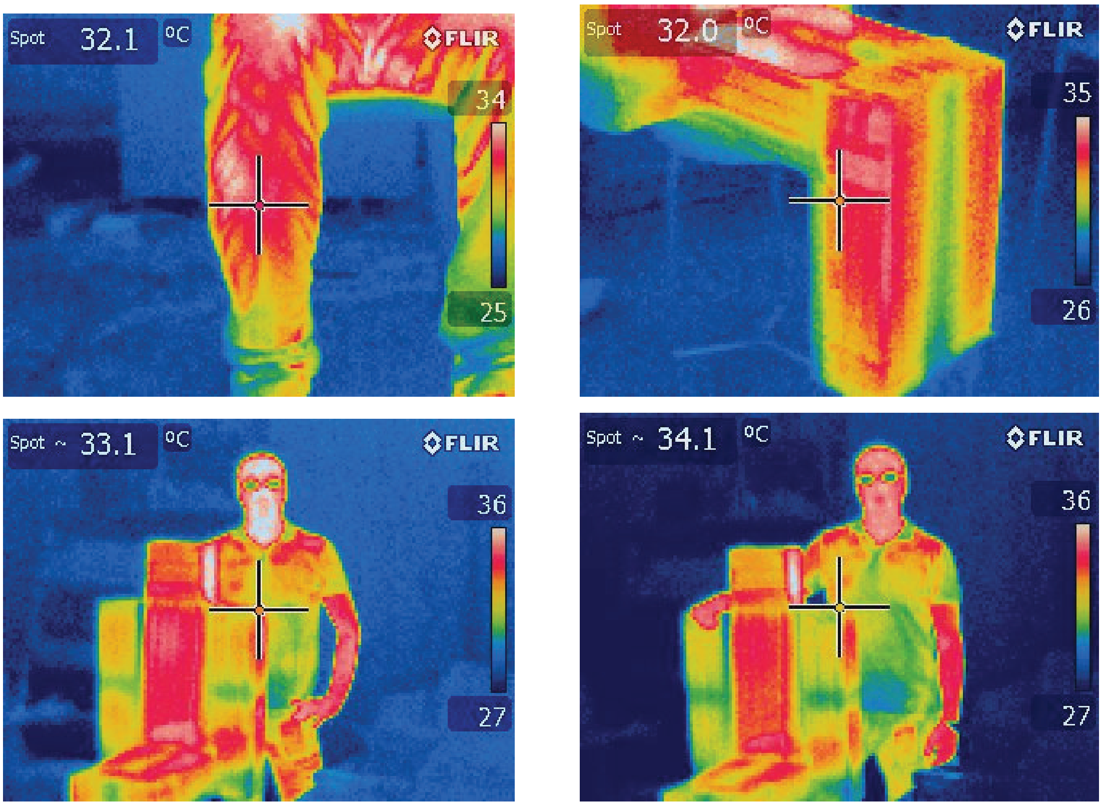

Fig. 6b. Comparing the surface temperature of the human body and of the thermal manikin using the IR camera

b) Contact temperature sensors

In order to eliminate eventual errors introduced by the IR camera calibration we used contact thermal sensors [6]. For each zone we used two sensors to measure the temperature uniformity of the surface. In Table 1 we centralized the temperature measured with the contact sensors on every thermal zone. The thermometer used was a Lutron device model TM939 type with 2 thermocouples of type J (fig.7).

Fig 7. Thermometer TM 946 with contact sensor

c) Electrical power consumption

The electrical power is the only power source that is converted in heat 100%. We aimed to measure the electrical consumption of the thermal manikin [1]. In order to do this we used an EU socket wattmeter (fig.8). We measured the power consumed by the wattmeter without any consumer and found that it consume 2W running without connecting any power consuming source. In table 2 we centralized the power consumed by every circuit of heating film. As a design condition the manikin surface is 1.8m² which is the equivalent surface of standardized human body [6]. After the electrical power measurements we find the power generated by the thermal manikin to have a coherent value equal with the dry heat generated by a human body in the sitting position, performing office activity.

Fig.8 – Employed wattmeter

Table 1 – Measured surface temperature with the contact sensors

Zone/temp	**Right down**		**Left down**		**Left up**		**Right up**	
Shoulders	34.5	32.6	33.5	33.5	35	35.1	34.2	34.4
Head	**Face**		**Top of the head**				**Neck**	
	34.1	33.9	34.3	33.7	33.8	33.8	34.2	34.5
Torso front	**Right down**		**Left down**		**Left up**		**Right up**	
	32.7		33.1		33.4		32.2	
Torso back	**Right down**		**Left down**		**Left up**		**Right up**	
	33.1		33.4		32.6		32.2	
Upper legs	**Right down**		**Left down**		**Left up**		**Right up**	
	32		31.6		32		32.2	
Lower legs	**Right down**		**Left down**		**Left up**		**Right up**	
	32		32.1		32		30.6	
Left hand	**Front**		**Lateral**		**back**			
	33.1	32.8	32	32.4	32	32.2		
Left hand	**Front**		**Lateral**		**back**			
Right hand	32	32.5	32.9	32.7	33.2	32.1		

Table 2 – electrical power consumed on each circuit

Zone	Head	Torso front	Torso back	Left Hand	Right Hand	Upper legs	Lower legs	Shoulders	Total [W]
Power[W]	6	8	9	10	12	9	18	9	81

4. Convective flow around manikin around the manikin

We wanted to check also the convective flow around the body of the manikin using IR measurement following a method described in [7]. The measurements show that the natural thermal flow around our manikin body (fig.10) is not completely similar to the one generated by a humanoid shaped thermal manikin. However this was not the primary goal in manufacturing this prototype. The thermal plume was expected to be not similar with the one produced by with a thermal manikin with anatomic shape given our previous CFD studies [7] (Fig 10).

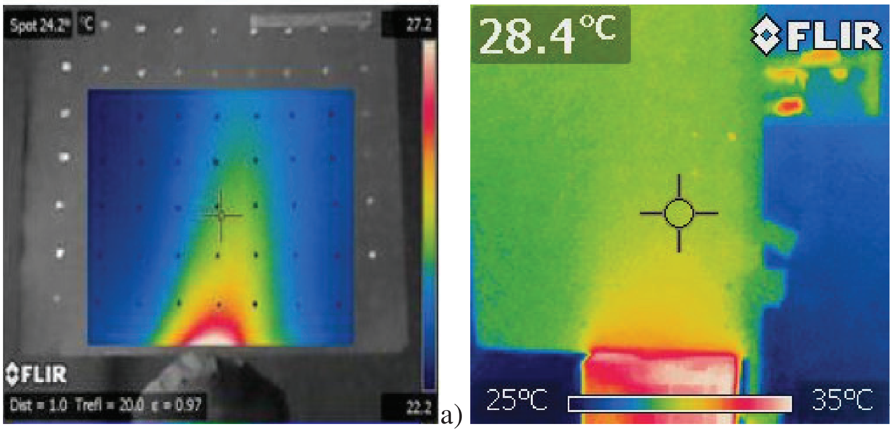

Fig. 9 – a) Convective plume of a humanoid shape thermal manikin [7], b) Fig 9 – b) Convective plume of our manikin

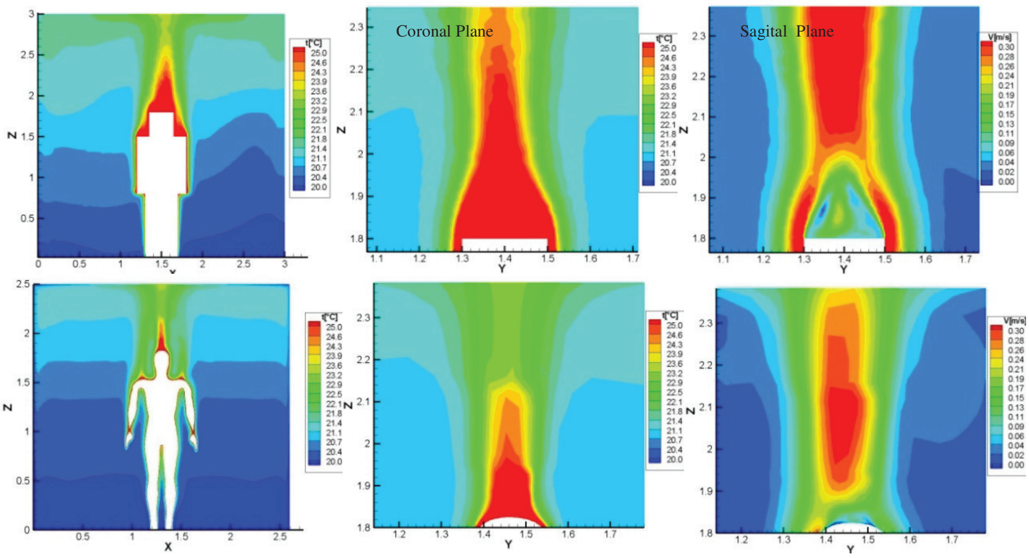

Fig. 10 – Comparison between the temperature distributions in the convective plume of a simplified and of an anatomic model of human body. CFD results from our previous study [7]

5. Conclusions

Our goal was met and we manage to create a sitting thermal manikin that can simulate the human presence in a room. All the tests are coherent and this manikin can be further used to validate our CFD models. The model is fully functional and the temperatures of each body zone can be easily modified in accordance to our needs.
The shape have an important role in the air movement of the air around the human body and this manikin is not suitable for local and high resolution measurements around the human body but can be used for global measurement in a room or inside a vehicle.

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