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Human Physiology & Clothing

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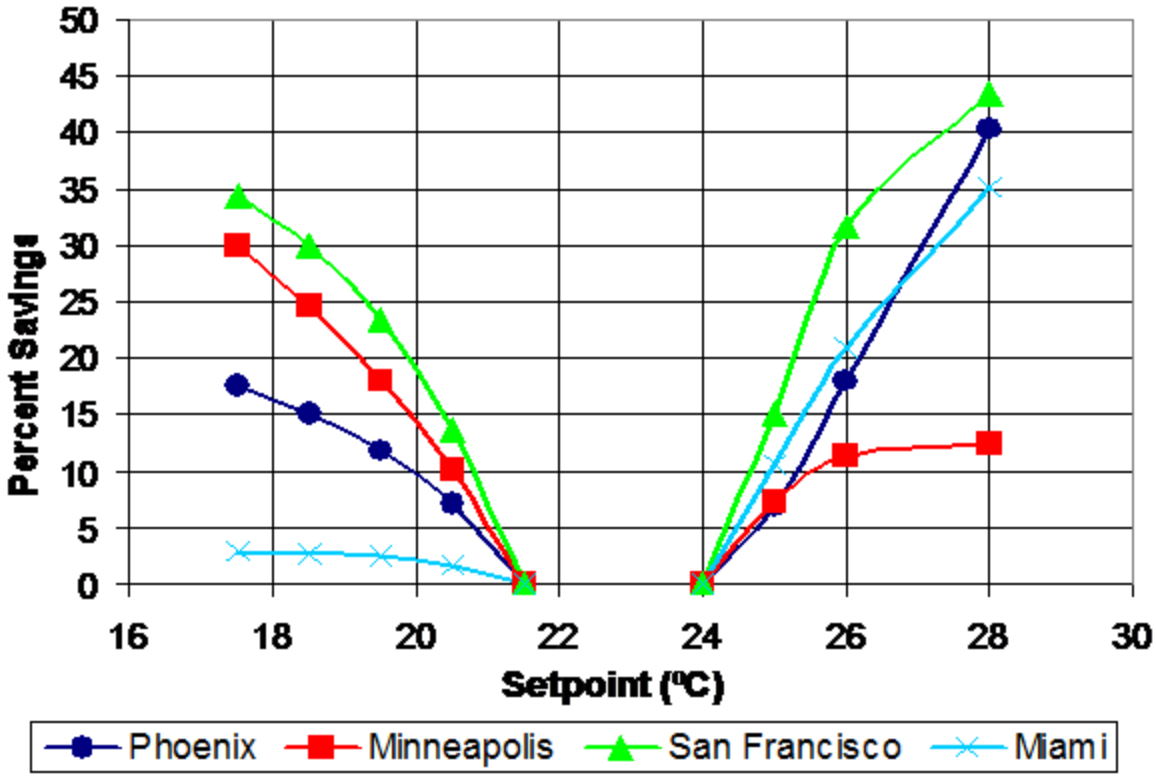
Professor & Department Chair
Department of Fiber Science & Apparel Design
College of Human Ecology



Hoyt, T, HL Kwang, H Zhang, E Arens, T Webster (2009), Energy savings from extended air temperature setpoints and reductions in room air mixing. *International Conference on Environmental Ergonomics* 2009, August.

HEAT BALANCE

Core temperature: $T_c \approx 37^o C$

Skin temperature: $a \le T_{sk} \le b$

Perspiration: $c \le E_{sw} \le d$ Insensible perspiration: ~10g/m^{2}hr

Heat Balance Equation of Human Body

$$M - W = (C + R + E_{sk}) + (C_{res} + E_{res}) + S$$

ISO 7730: MODERATE THERMAL ENVIRONMENTS-

DETERMINATION OF THE PMV AND PPD INDICES AND SPECIFICATION OF THE CONDITIONS FOR THERMAL COMFORT

$$PMV = (0.303e^{-0.036M} + 0.028) \times S$$

$$PPD = 100 - 95 \times e^{-(0.03353 \times PMV^4 + 0.2179 \times PMV^2)}$$

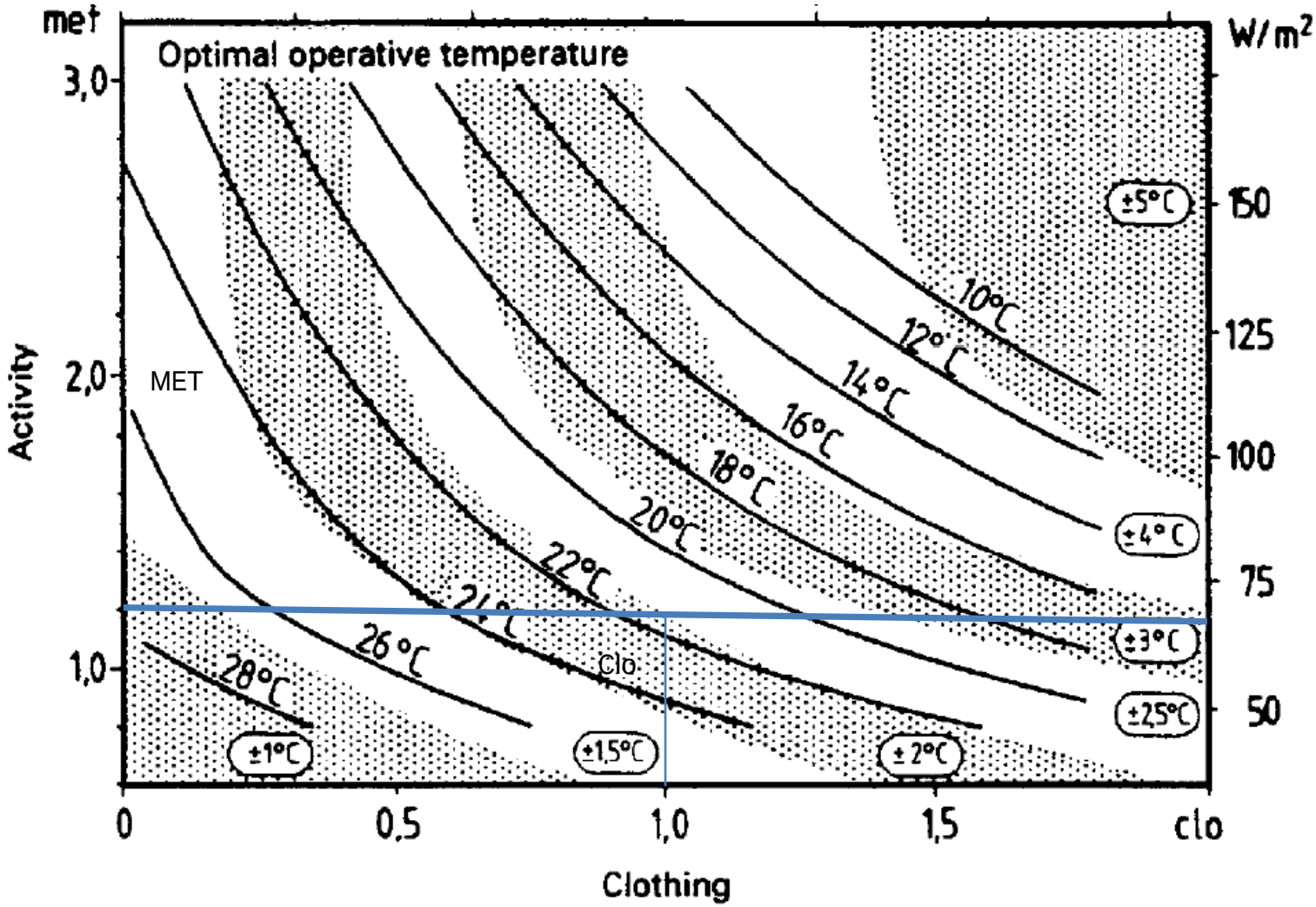
$$S = M - W - \{(C + R + E_{sk}) + (C_{res} + E_{res})\}$$

$$C = f_{cl} h_c (t_{cl} - t_a)$$

$$R = 3.96 \times 10^{-8} f_{cl} \times [(t_{cl} + 273)^4 - (t_r + 273)^4]$$

$$t_{cl} = \frac{35.7 - 0.028(M - W) - I_{cl}\{3.96 \times 10^{-8} f_{cl} \times [(t_{cl} + 273)^4 - (t_r + 273)^4] - f_{cl} h_c t_a\}}{1 + I_{cl} f_{cl} h_c}$$

OPTIMAL OPERATIVE TEMPERATURE AT PMV=0



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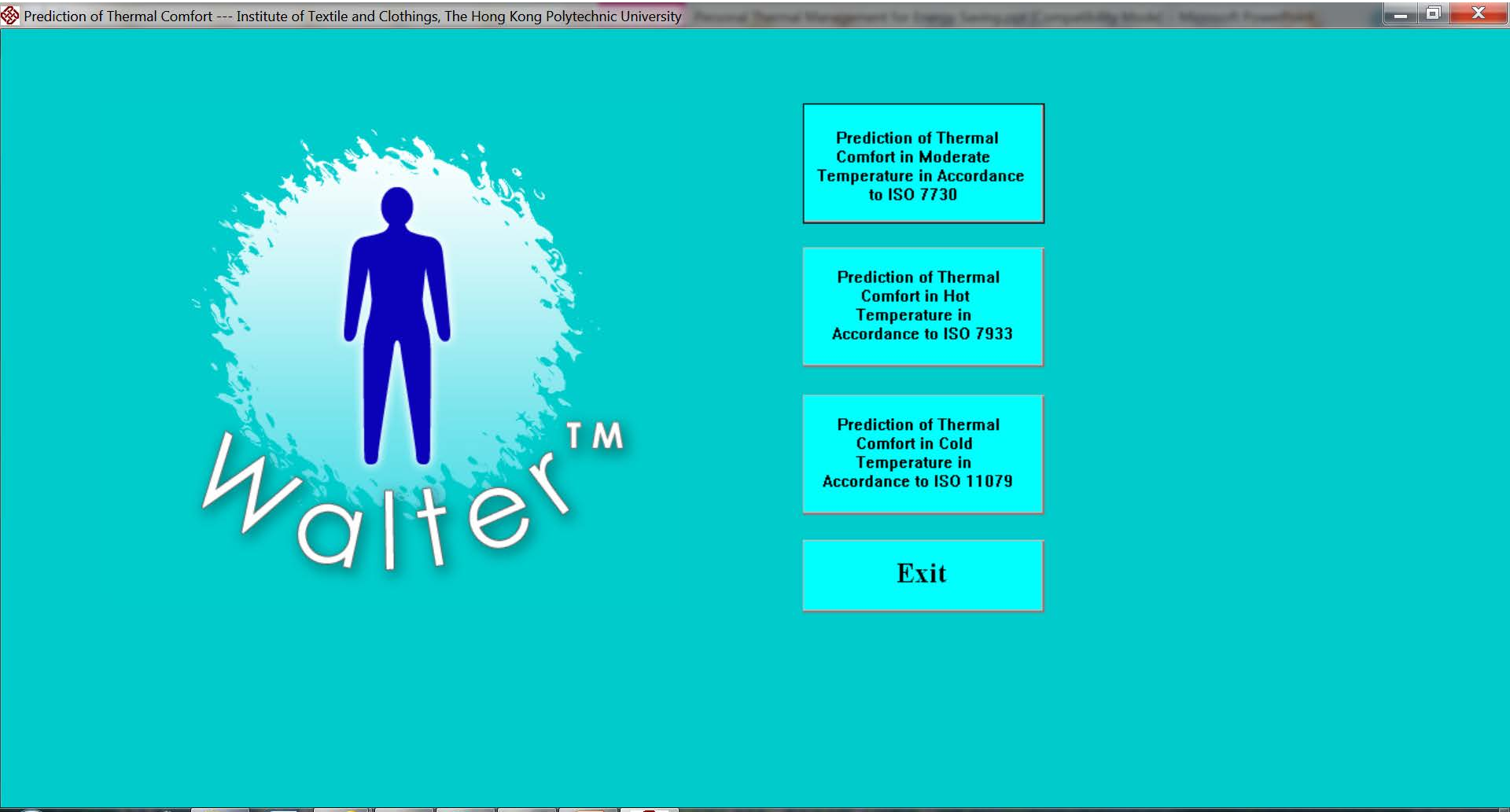
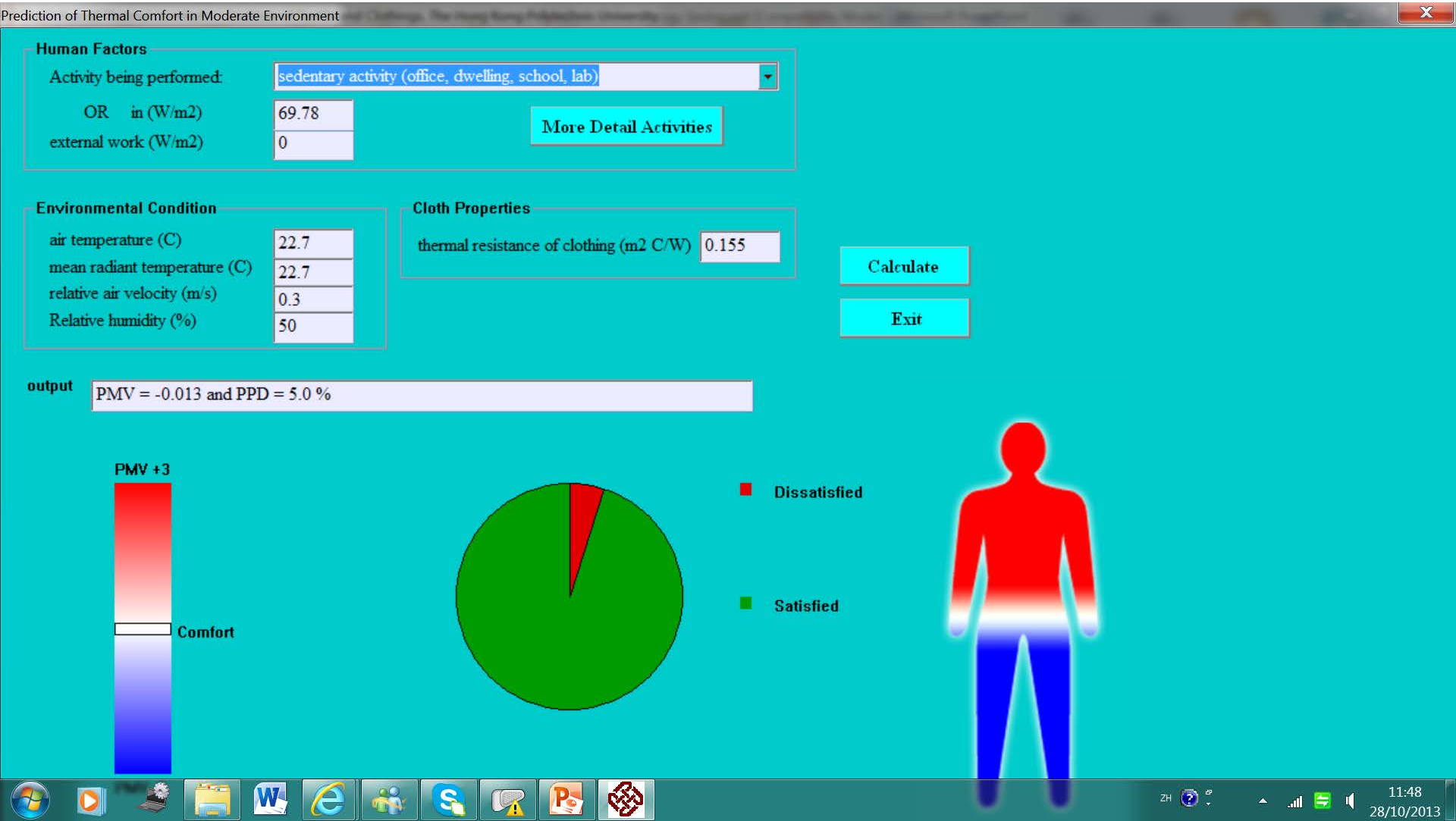
WALTER™ INFORMATION SUPPORT SYSTEM



Optimum set-point for an average person wearing 1 clo thermal insulation



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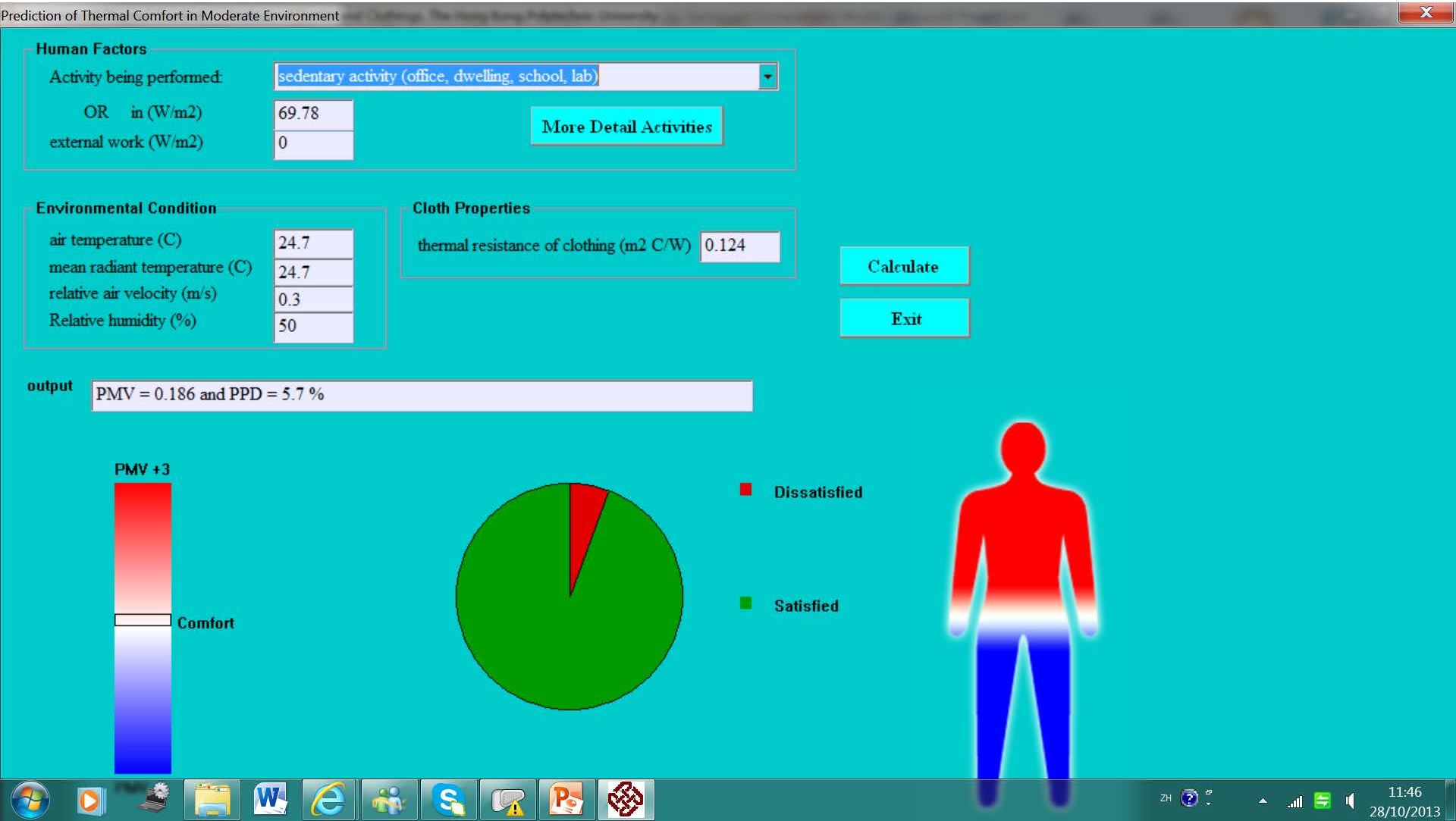
20% decrease in thermal insulation corresponds to 2 ^{o}C increase in optimum set point



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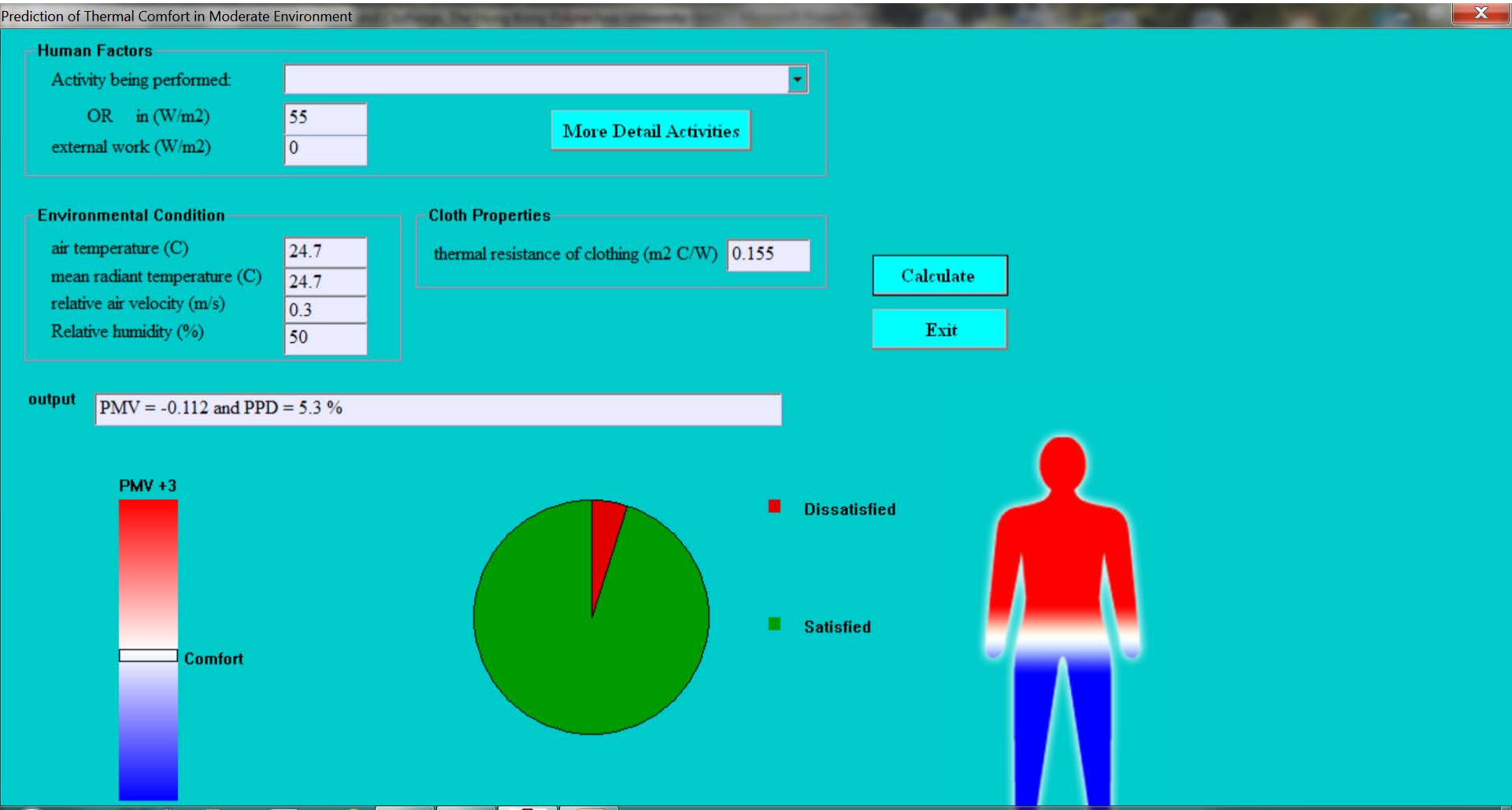
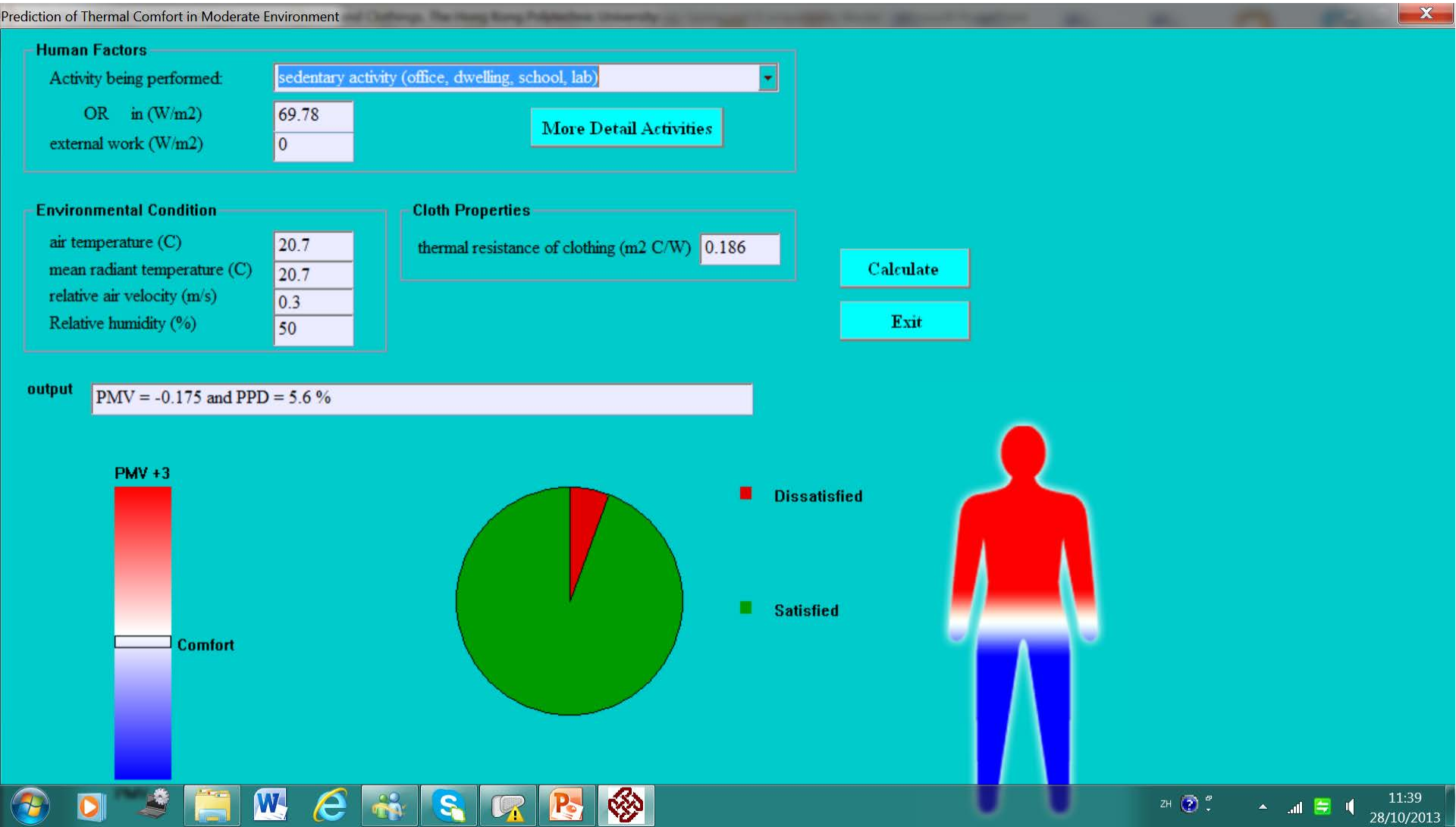
15 W/m^2 (24 Watts) cooling corresponds to 2 ^{o}C increase in optimum set point



20% Increase in thermal insulation corresponds to 2 °C reduction in optimum set point



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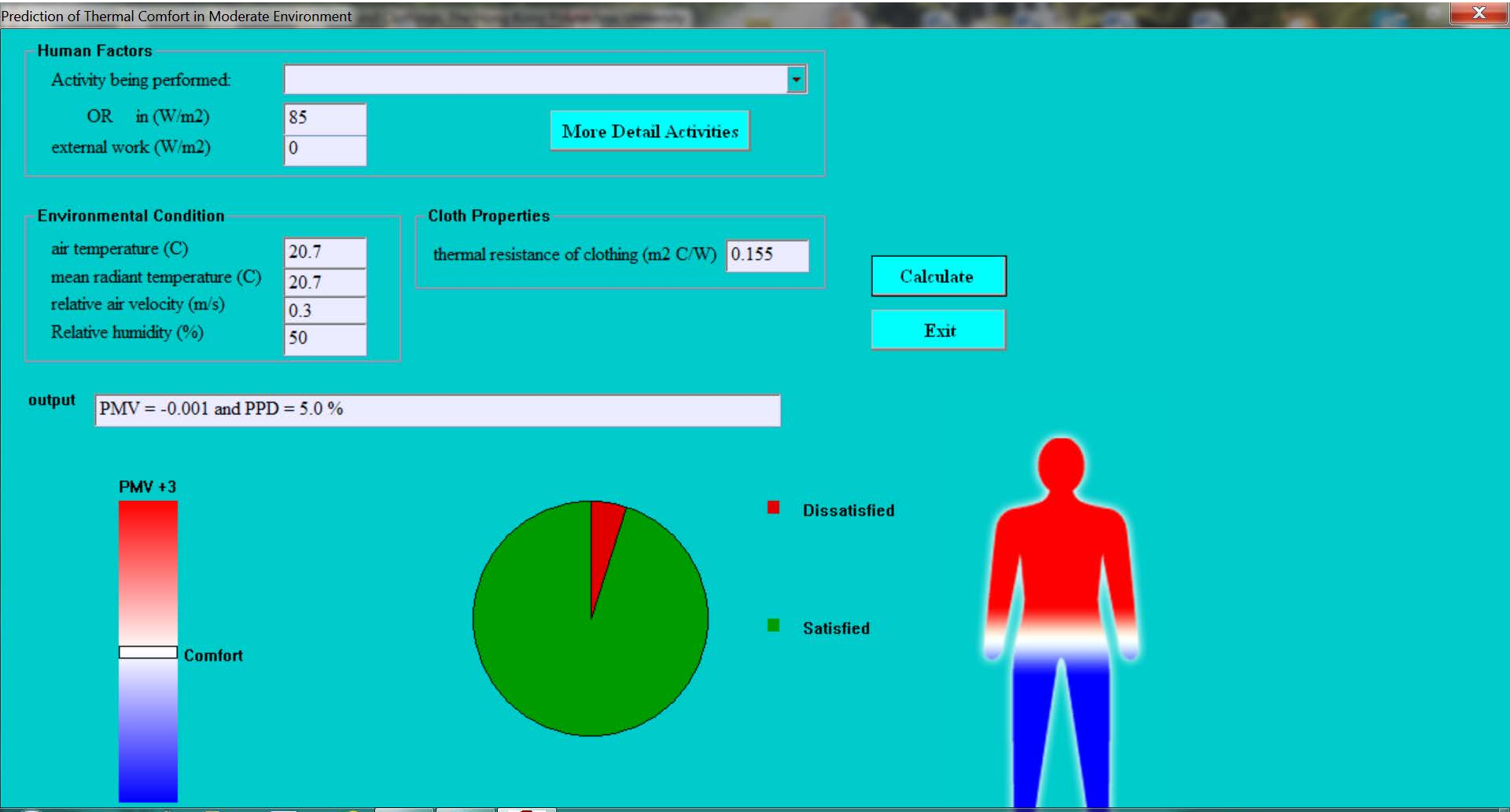
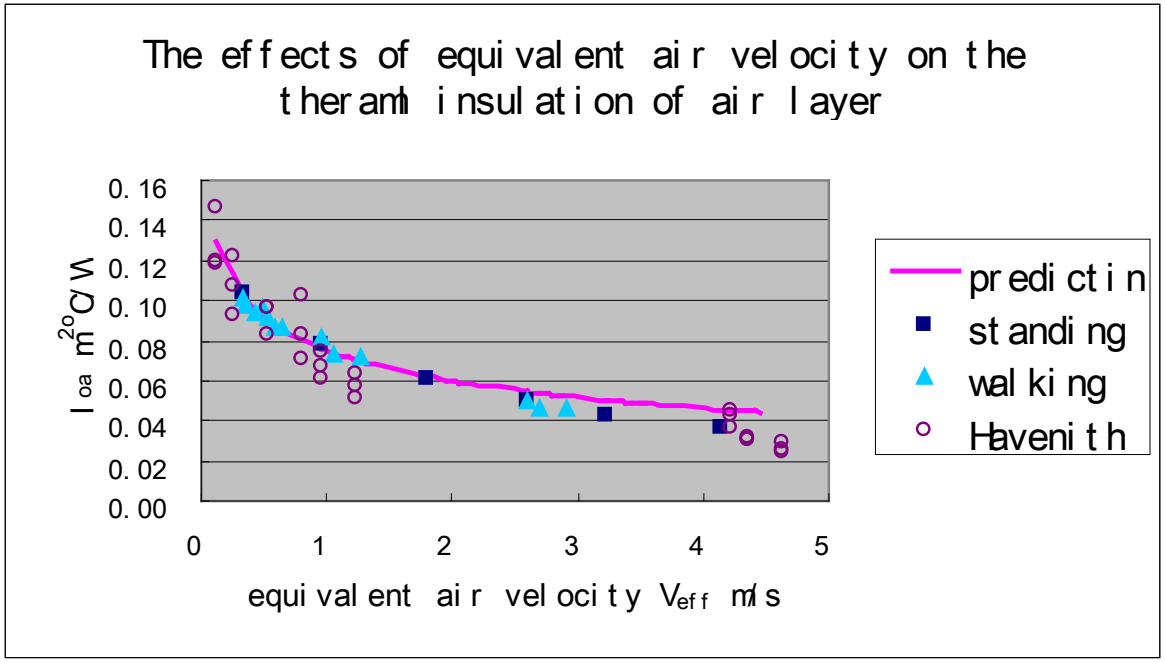
15 W/m^2 (24 Watts) heating corresponds to 2 ^{o}C increase in optimum set point



SWEATING FABRIC MANIKIN-WALTER

SURFACE INSULATION

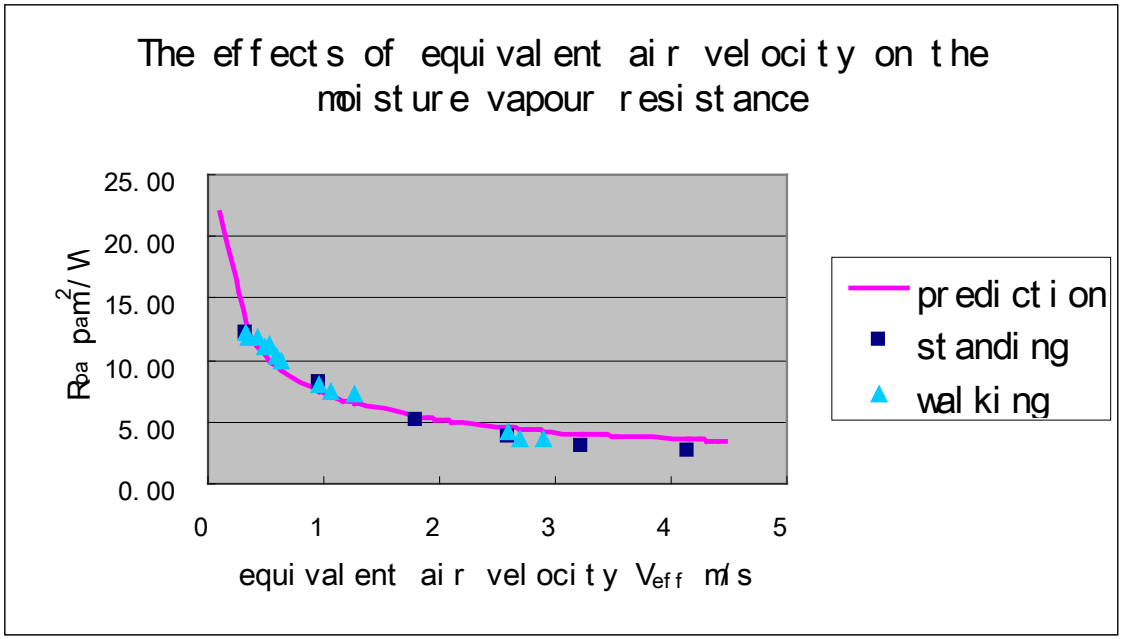
$$I_a = \frac{1}{5 + 8.3\sqrt{0.11 + V_{wind} + 0.45 \times V_{walk}}} \qquad {}^{o}Cm^2/W$$



X. Qian and J. Fan, Interactions of the Surface Heat and Moisture Transfer from the Human Body under Varying Climatic Conditions and Walking Speeds, *Applied Ergonomics*, 37(6), 685-693.

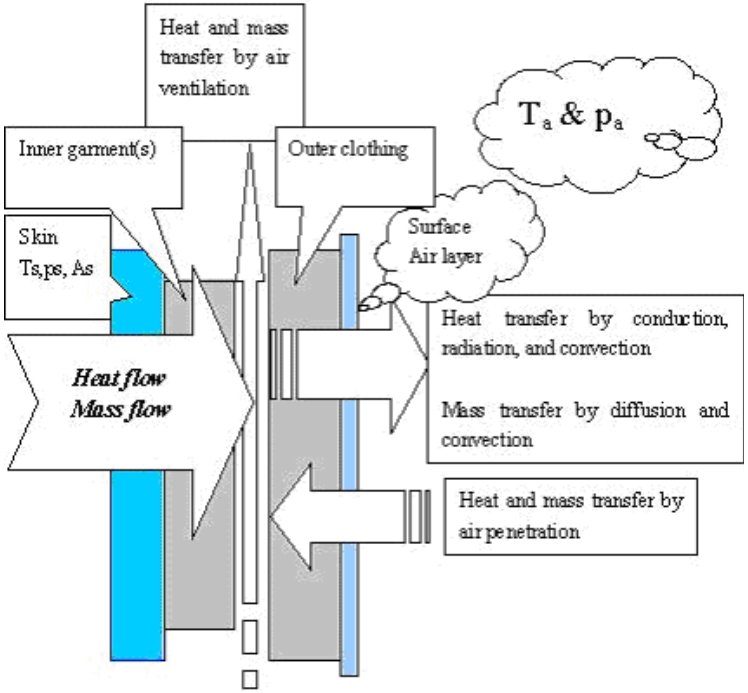
SURFACE EVAPORATIVE RESISTANCE

$$R_a = \frac{1}{0.0165 * 8.3\sqrt{0.11 + V_{wind} + 0.45 \times V_{walk}}} \qquad p_a m^2 / W$$



X. Qian and J. Fan, Interactions of the Surface Heat and Moisture Transfer from the Human Body under Varying Climatic Conditions and Walking Speeds, *Applied Ergonomics*, 37(6), 685-693.

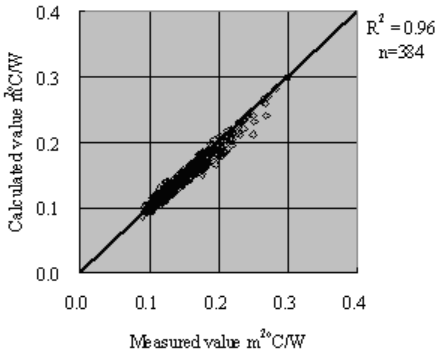
DYNAMIC CLOTHING INSULATION:
EFFECT OF WIND AND BODY MOTION



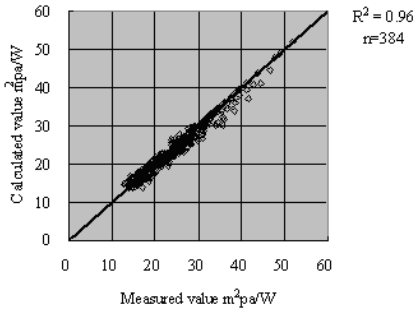
X. M. Qian and **J. T. Fan**, A Quasi-physical Model for Prediction of clothing thermal insulation and moisture vapour resistance, *Applied Ergonomics*, 40 (2009), pp. 577-590.

EFFECT OF WIND AND BODY MOTION ON CLOTHING THERMAL INSULATION AND EVAPORATIVE RESISTANCE

$$I_{tdyn} = mI_c + \frac{1}{KVI(V_{wind} + \beta_V V_{walk} - v_0) + \frac{1}{(1-m)I_c + \frac{1}{f_{co}} I_{oa}}}$$



$$R_{tdyn} = nR_c + \frac{1}{KVR(V_{wind} + \beta_V V_{walk} - v_0) + \frac{1}{(1-n)R_c + \frac{1}{f_{co}} R_{oa}}}$$



X. Qian and J. Fan, Interactions of the Surface Heat and Moisture Transfer from the Human Body under Varying Climatic Conditions and Walking Speeds, *Applied Ergonomics*, 37(6), 685-693.

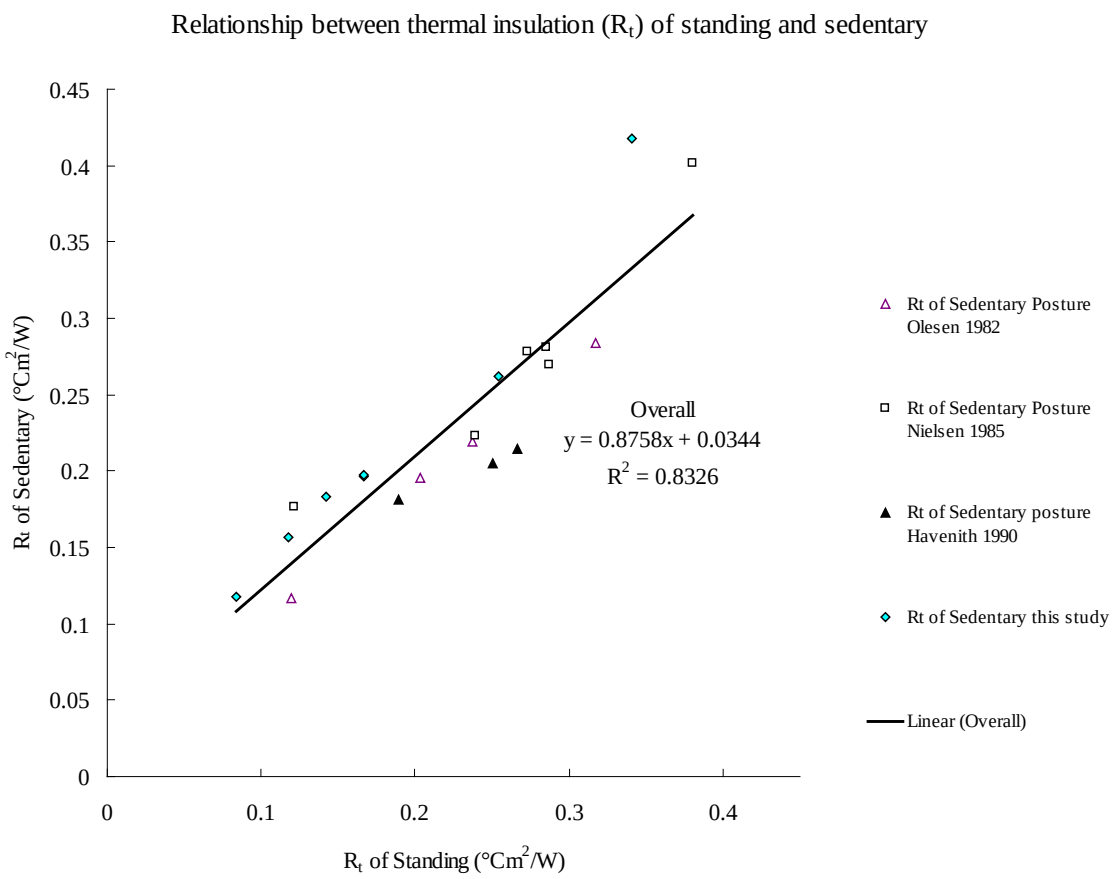
CLOTHING AREA FACTOR

Based on the work of McCullough et al 1985 and ISO 7933, we have:

$$f_{ci} = 1 + 1.97 I_{ci}$$

$$f_{co} = 1 + 1.97 I_{c}$$

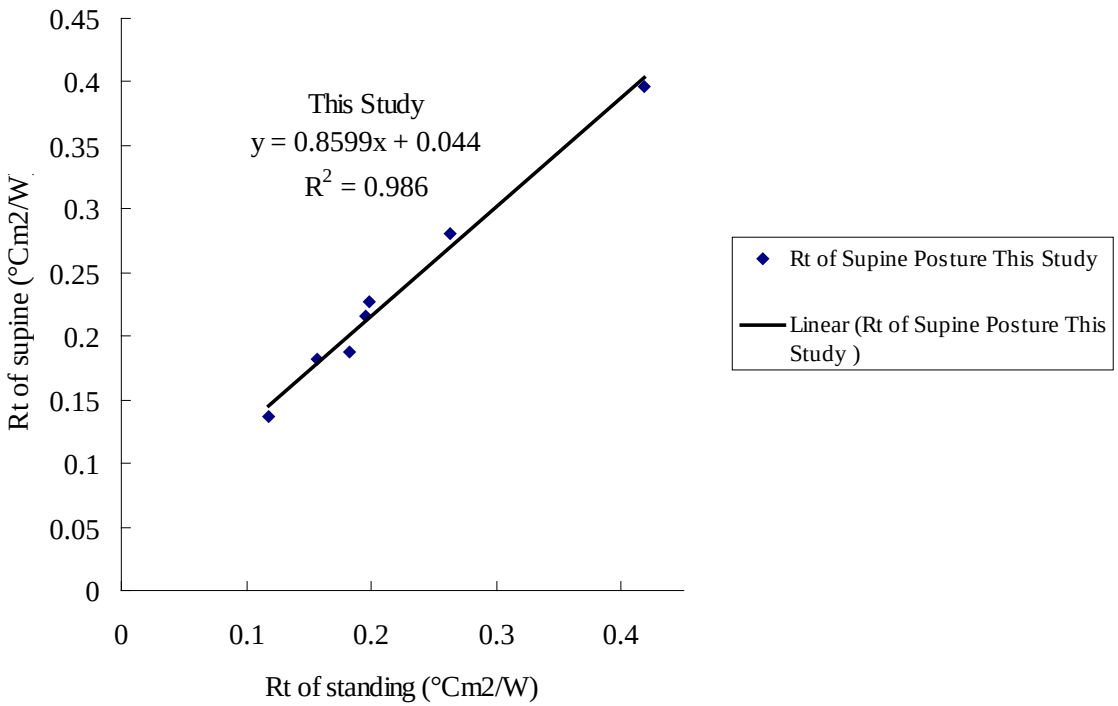
EFFECT OF POSTURE



Wu, Y. S., Fan, J. T. and Yu, Y. M., (2009) Effect of posture positions on the evaporative resistance and thermal insulation of clothing, under review by *Ergonomics.*

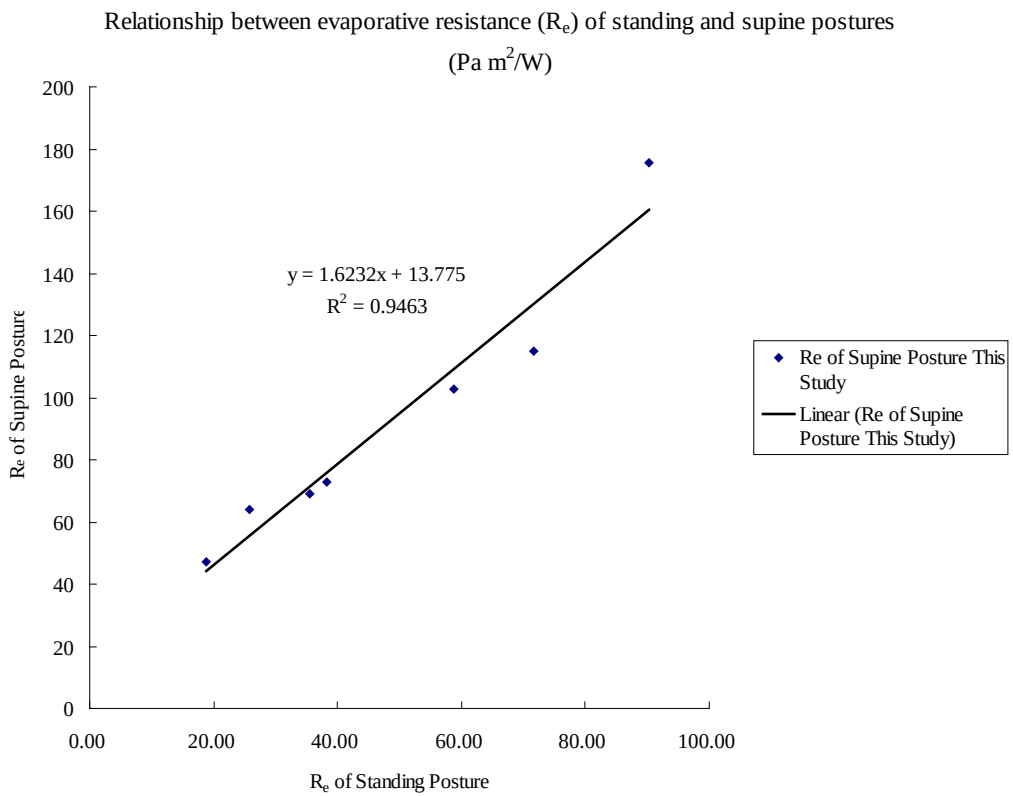
EFFECT OF POSTURE

Relationship between thermal insulation (R_t) of standing and supine postures



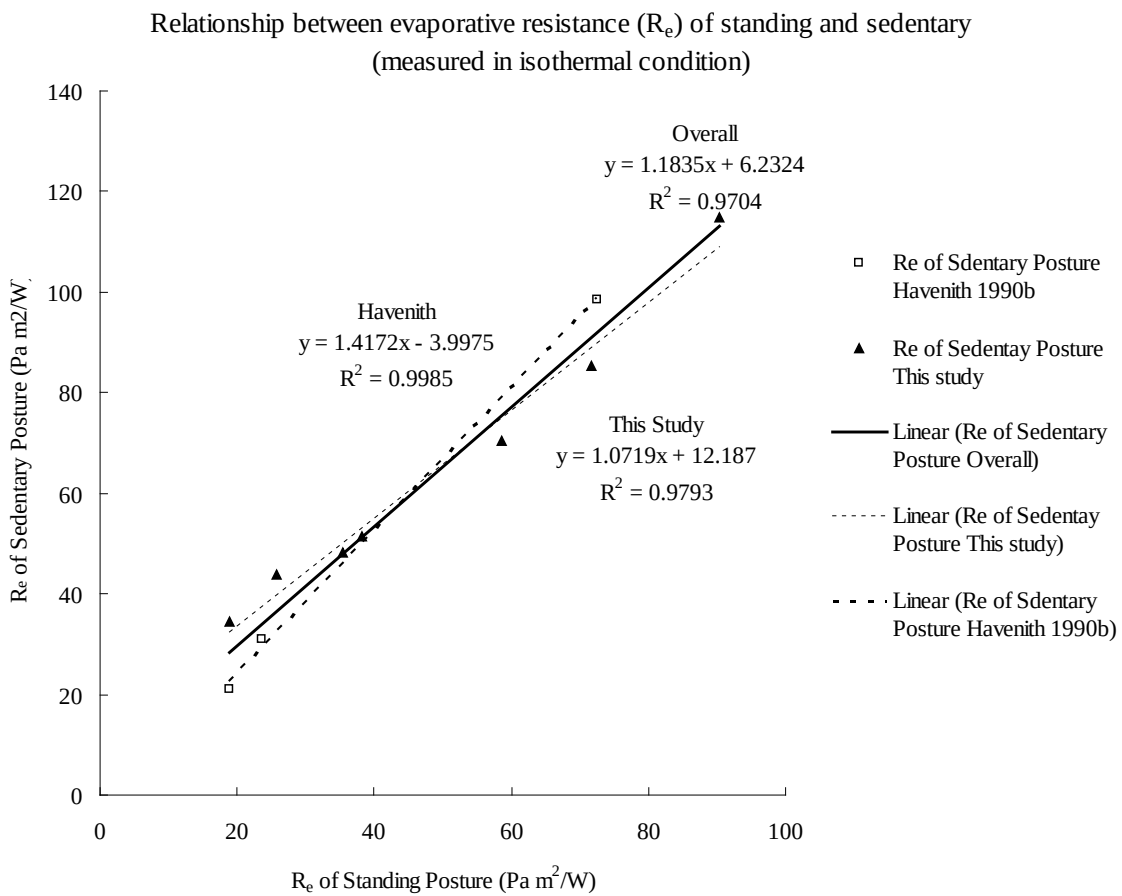
Wu, Y. S., Fan, J. T. and Yu, Y. M., (2009) Effect of posture positions on the evaporative resistance and thermal insulation of clothing, *Ergonomics.*

EFFECT OF POSTURE



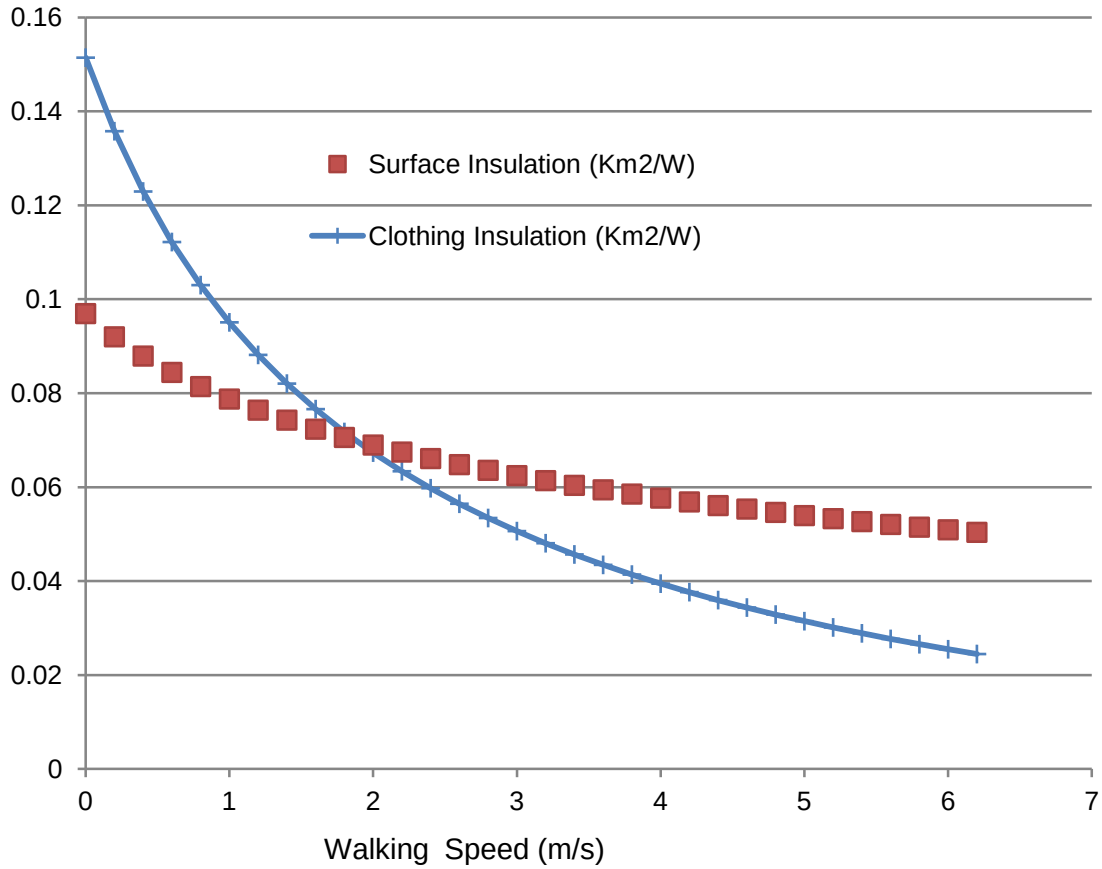
Wu, Y. S., Fan, J. T. and Yu, Y. M., (2009) Effect of posture positions on the evapourative resistance and thermal insulation of clothing, under review by *Ergonomics.*

EFFECT OF POSTURE

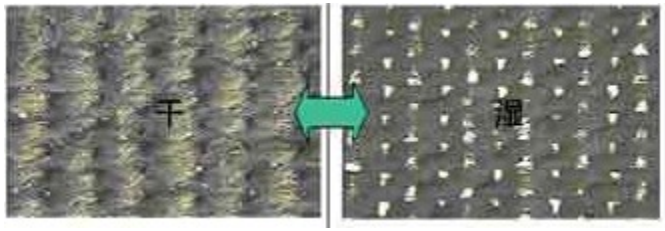


Wu, Y. S., Fan, J. T. and Yu, Y. M., (2009) Effect of posture positions on the evapourative resistance and thermal insulation of clothing, under review by *Ergonomics.*

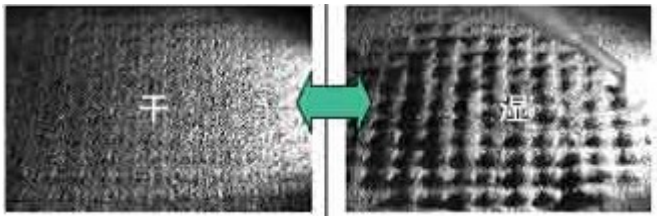
REDUCTION OF THERMAL INSULATION BY BODY MOTION



ENABLING TEXTILE/CLOTHING TECHNOLOGIES



Nike Sphere React Cool



Nike Sphere React Dry

Nike Sphere Macro React

Moisture responsive fabric

MK Sarkar, FA He and JT Fan, Moisture-responsive fabrics based on the hygro deformation of yarns, *Textile Research Journal, 80 (12), 1172-1179, 2010.*

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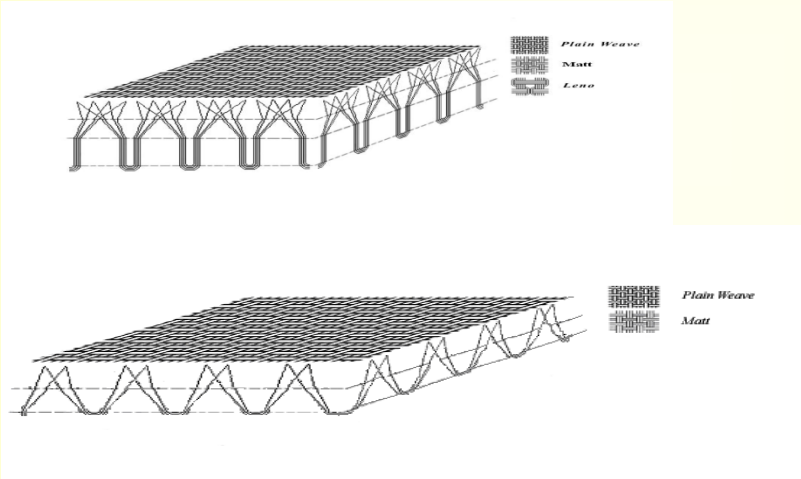
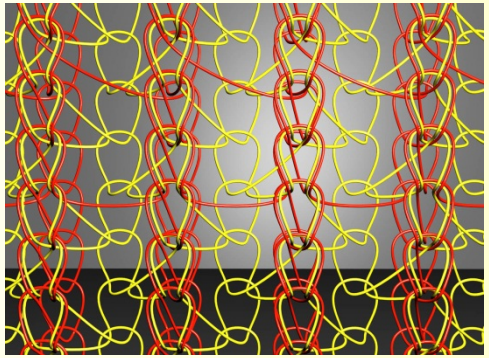
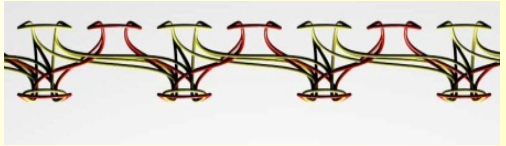
BIOMIMETICS OF PLANT STRUCTURE FOR MOISTURE MANAGEMENT FABRICS

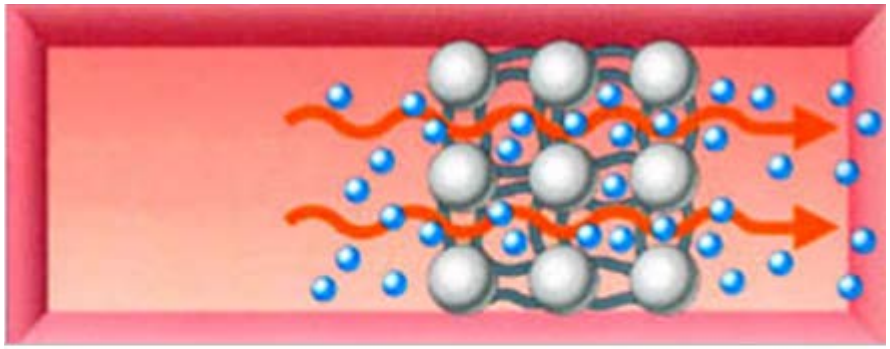




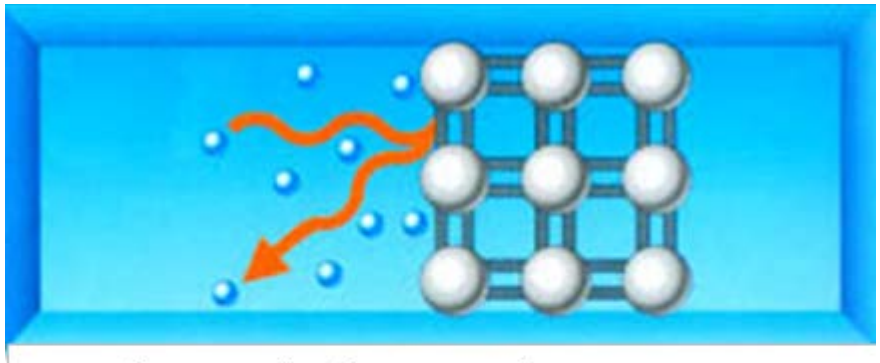


M Sarkar, J Fan, YC Szeto and XM Tao, Biomimetics of Plant Structure in Textile Fabrics for the Improvement of Water Transport Properties, Textile Research Journal, 79(7), 657-668, 2009.

Shape memory fabric - Diaplex®



Above deformation temp.
Open structure



Below deformation temp.
Closed structure

When ambient temperature increases:

- Allow heat release and sweat/moisture evaporation

When ambient temperature decreases:

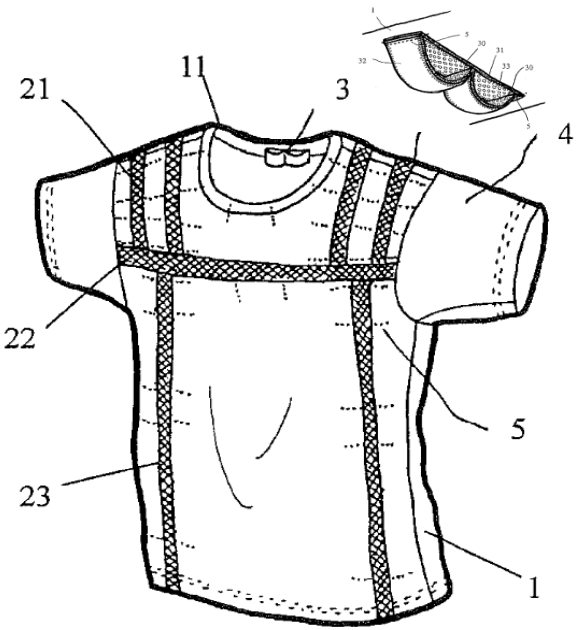
-No heat and moisture transfer to keep body warm

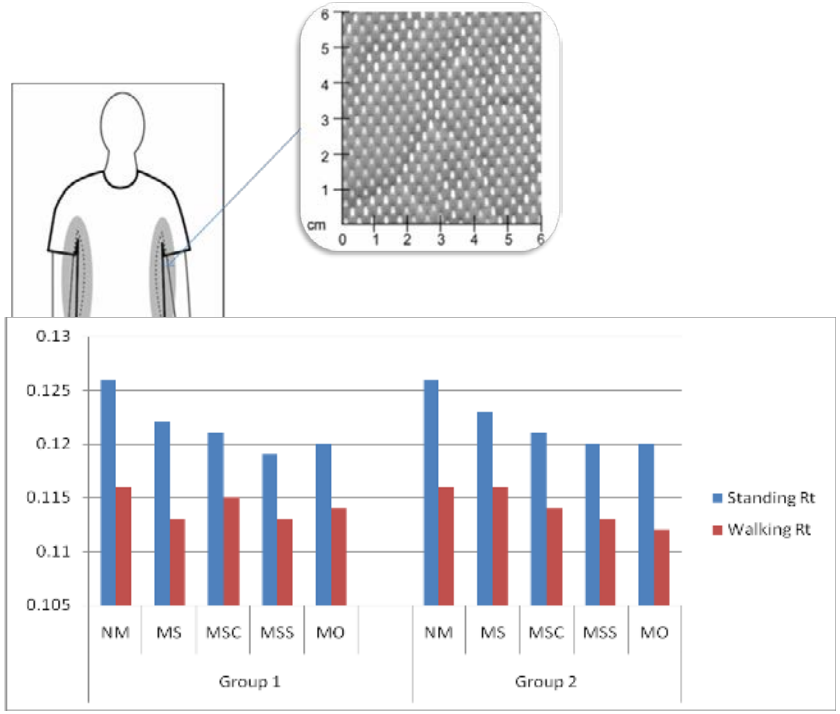
Deformation temperature can be easily set in the manufacturing process

Applications:
sportswear such as skiwear and golf-wear

Callaway Golf rain jacket:

ENABLING TEXTILE/CLOTHING TECHNOLOGIES

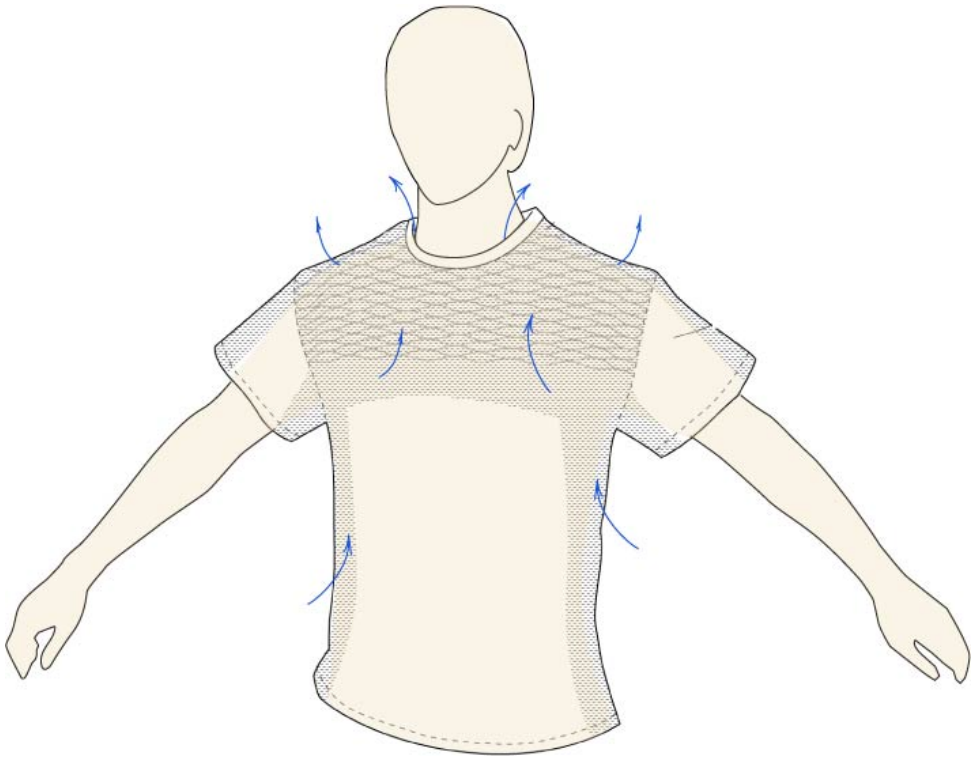


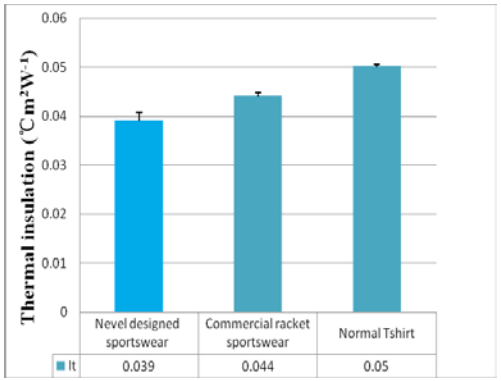


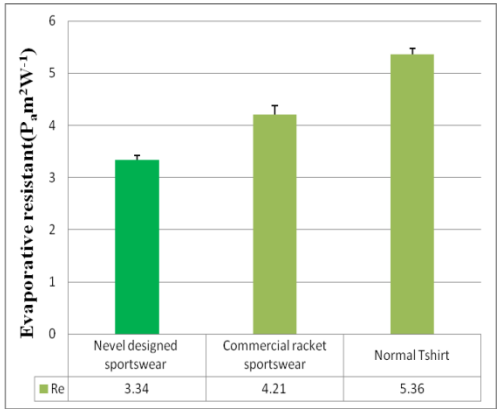
Ventilation Garment Design

NM: no mesh; MS: mesh at shoulders; MSC: mesh at shoulder and chest; MSS: mesh at shoulders and side panels; MO: mesh all open

ENABLING TEXTILE/CLOTHING TECHNOLOGIES







PCM - OUTLAST

Textiles that regulate temperature, heat, and moisture

Phase Change Materials absorb, store, and release heat

Outlast = PCM microencapsulated and protected in polymer shell

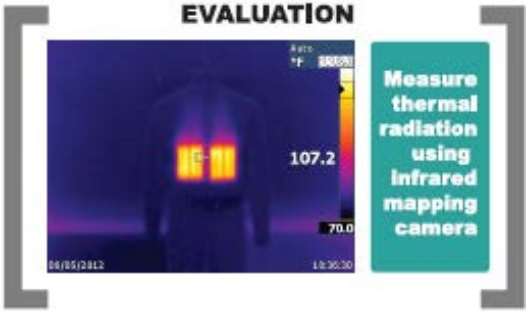
Originally for NASA

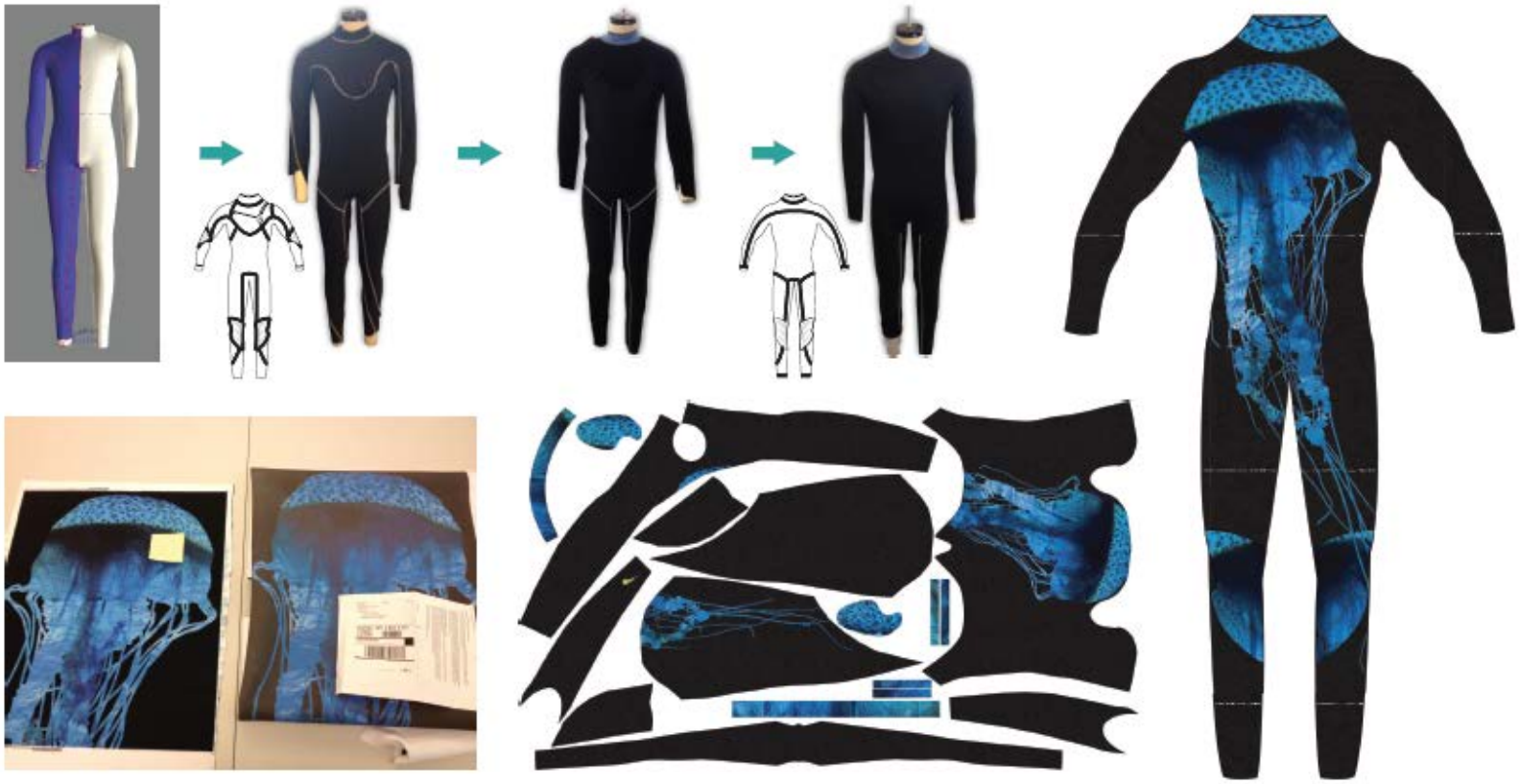
http://www.outlast.com/

‘Air-conditioned clothes’ by Kuchofuku Co. Ltd

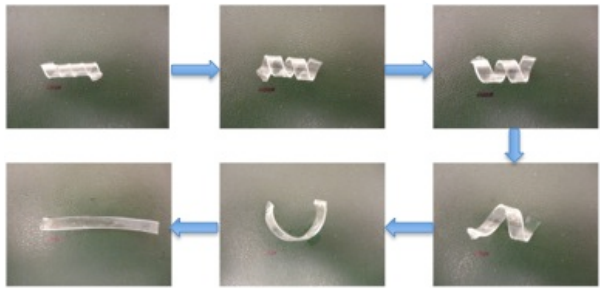
HEATED WETSUIT PROJECT

Two heating panels. Each panel has 9.5W output (5V DC x 2A x about 95% heating efficiency). So total of 19Watt. The surface temperature of the panel can reach 115ºF (46 oC).





ENABLING TEXTILE/CLOTHING TECHNOLOGIES



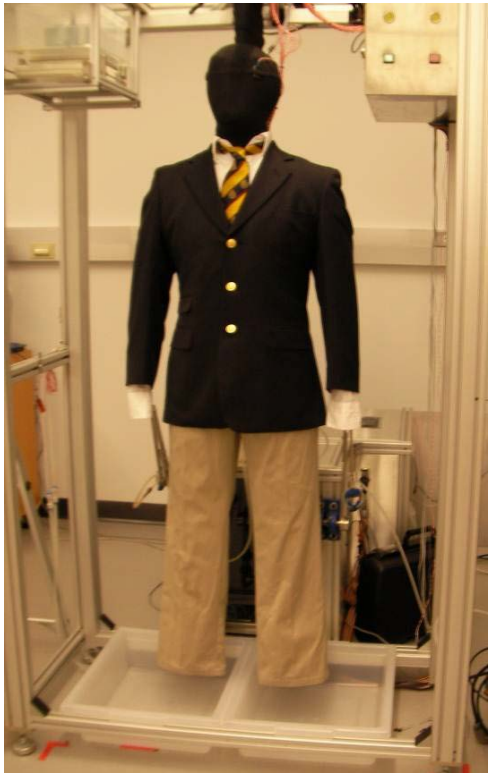
Shape Memory Polymer

Shape Memory Alloy Shirt and Jacket (2010)

Museum of Science and Industry

–Chicago Collection

Testing with 1st Prototype Cooling Undershirt



Results of 1st Prototype Cooling Undershirt

Cooling heat loss: 12.3 Watts (Additional dry heat loss: 9.4 Watts)
Reduction of Clothing Thermal Insulation: 10.0%

Cooling Effect		Ambient Temp (oC)	Mean ambient RH%	Heater Power (Watts)	Water loss (gm)	Evaporative heat loss (Watts)	Total Thermal Insulation ($m^{2o}C/W$)	Clothing Insulation ($m^{2o}C/W$)	Total Evaporative Resistance (m^2P_a/W)
Before Activation	Mean	21.5	71.2	220.2	200.9	135.0	0.241	0.159	41.9
	Std	0.0	0.1	0.9	5.2	3.5	0.008	0.008	1.3
After Activation	Mean	21.2	72.2	232.6	205.3	138.0	0.225	0.143	40.8
	Std	0.1	0.4	0.7	7.9	4.6	0.013	0.013	1.6

$$I_c = I_t - \frac{I_{oa}}{f_{cl}} = I_t - 0.105/1.28$$

Reduction of clothing thermal insulation: $\frac{0.159 - 0.143}{0.159} \times 100\% = 10.0\%$

Testing with 2nd Prototype Cooling Undershirt

Results of 2nd Prototype Cooling Undershirt

Cooling heat loss: 13.8 Watts (Additional dry heat loss: 11.5 Watts)
Reduction of Clothing Thermal Insulation: 13.4%

Cooling Effect		Ambient Temp (oC)	Mean ambient RH%	Heater Power (Watts)	Water loss (gm)	Evaporative heat loss (Watts)	Total Thermal Insulation ($m^{2o}C/W$)	Clothing Insulation ($m^{2o}C/W$)	Total Evaporative Resistance (m^2P_a/W)
Before Activation	Mean	21.4	70.2	221.1	205.4	138.0	0.254	0.172	41.0
	Std	0.0	0.4	1.0	4.2	2.8	0.008	0.008	1.1
After Activation	Mean	21.2	71.2	234.9	208.9	140.3	0.232	0.149	40.4
	Std	0.1	0.5	0.7	5.8	3.9	0.006	0.006	1.4

$$I_c = I_t - \frac{I_{oa}}{f_{cl}} = I_t - 0.105/1.28$$

THANK YOU
FOR YOUR ATTENTION!