Executive summary:

The regulation of the body temperature is controlled by the release of heat by blood vessel dilatation or constriction, muscle (shivering) and sweat gland activity. The most comfortable skin temperature is within the range of 28-33°C. In this comfort zone the human body is unaware of warmth or coolness. Outside this range the body feels discomfort. This means that the balance between the rates of heat loss and heat generated must be maintained. This is usually done by putting on or taking off clothes. However, in many situations it would be a significant advantage if the cloths could play an active role in maintaining the body within the thermal comfort zone without taking them off or on that frequently. Especially during short term changing conditions this would be of particular relevance. For instance, moving between air conditioned locations in warm climates or going in and out from stores in cold climates. Also during short term intermittent physical activity it would be advantageous if the cloths could buffer some of the energy released by the body. For instance, after a short run to the bus stop or departure gate, a cooling effect preventing start of sweating would be of interest.

Clothes with built-in thermoregulatory properties may help the body to stay within the comfortable temperature range at different activity levels and ambient conditions. Integration of phase change materials (PCMs, e.g. hydrocarbon waxes) in clothes is one way of achieving thermoregulatory properties. When the body temperature increases, the PCM melts and absorbs the heat from the body in the form of latent heat (cooling effect). When the temperature drops, the PCM crystallizes and the stored heat is released again (warming effect).

PCMs can be integrated into textile fabrics both by means of melt spun bi-component fibers with a sheath/core structure and by using solution spun cellulosic fibers with a dispersed PCM phase. In this way PCM is permanently trapped inside the fibers. Both types of fibers have been successfully developed within recently finalized EU funded Seventh Framework Programme (FP7) project NOTEREFIGA (NMP2-SE-2008-203831). Melt spun bi-component fibers (PET, PA) with a latent heat greater than 60 J/g in the temperature range 27-36 °C and with sufficient strength (tenacity greater than20cN/tex) has been demonstrated in industrial scale production. An industrially feasible and efficient processing concept to produce PCM/polymer alloy with 70% PCM and more in the form of free flowing particles was also demonstrated. Suitable bio-based PCMs were identified and used. By the application of certain compatibilizers and additives very fine Lyocell textile fibers in a range 1.7-2.5 dtex with more than 50% PCM and with properties suitable for further textile processing can be produced. With the developed technology it is possible to get fibers with a latent heat capacity of more than 120 J/g in both pilot and production scale. By the use of cellulose and bio-based PCMs, fibers closely approaching 100% in terms of renewable resources are produced.

Assessments of thermo physiological properties of the developed fabrics, garments and clothing ensembles has been done using bench scale devices, thermal manikin in climatic chamber and with human subjects in a controlled environment. Clear effects of using PCM fibers in garments can be detected in bench scale and with the thermal manikin; the effect is however rather short lasting and depends mainly on the applied PCM surface weight. Several test protocols involving human subjects were

developed. In the majority of studies using human subjects a statistically proven positive effect could not be confirmed.

Dyeing and finishing operations have been successfully applied showing that the PCM fibers developed can be used in standard processes used by the textile industry. LCA show similar environmental load as compared to standard textile fibers.

Project Context and Objectives:

The human body is an automatic self thermo-regulated organism. The human body constantly generates CO_2 and H_2O by the metabolism of food and muscle activity. The regulation of the body temperature is controlled by the release of heat by blood vessel dilatation or constriction, muscle (shivering) and sweat gland activity. The most comfortable skin temperature is within the range of 28-33°C. In this comfort zone the human body is unaware of warmth or coolness. Outside this range the human body feels discomfort. This means that the balance between the rates of heat loss and heat generated must be maintained. This is usually done by putting on or taking off clothes. However, in many situations it would be a significant advantage if the cloths could play an active role in maintaining the body within the thermal comfort zone without taking them off or on that frequently.

The objective of the NOTEREFIGA project has been to develop novel temperature regulating fibers and innovative textile products for thermal management. The temperature regulating effect is achieved by novel methods of incorporating large amounts of phase changing materials (PCM) in textile fibers. When the body temperature increases, the PCM melts and absorbs the heat from the body in the form of latent heat (cooling effect). Then, when the temperature drops, the PCM crystallizes and the stored heat is released again (warming effect). It is assumed that clothes with built-in thermo-regulating properties will provide maintained thermal comfort in difficult thermal environments and physical activity situations. The PCMs to be chosen should have a large latent heat (heat of fusion) and melting/solidification temperatures in the range 28-33°C. During melting the temperature of the PCM stays constant while the heat consumed for melting is stored as latent heat. A well known example of this principle is the use of ice for cooling. A mixture of ice and water will stay at 0°C as long as there is un-molten ice left.

The NOTEREFIGA concept is based on two main ideas. One is based on bi-component melt spinning of fibers with a core/sheath structure confining the PCM to the core. The second is based on a new concept for incorporating PCMs in wet spun cellulose fibers based on direct addition of free PCM to a cellulose solution. An important part of the project was devoted to product related research, lead by the small and medium-sized entreprises (SME) in the project. In particular, specific, value-added products were targeted within underwear, sports, leisure, work wear, medical and home textiles as well as in specific technical textiles applications. Bio-based raw materials (polymers, PCMs) were addressed wherever possible and economical. The project is expected to contribute to the transformation of certain sectors of the European textile and clothing industry from commodities into specific, value-added products securing sustainable growth and employment within the European textile sector.

The main Science and Technology (S&T) objectives of the project were:

1. To develop novel temperature regulating textile yarns, including bio-based, with significantly improved thermal capability (greater than 60J/g) compared to state-of-the-art (less than 10J/g). This involves material and process development.

2. To check on common finishing operations (mainly dying) for fabrics from the new yarns and propose best practices.

3. To develop protocols for evaluation of the thermal effect and to develop an optimized strategy for the incorporation of the novel temperature regulating fibers in garments.

4. To check on the processability (knitting, weaving) of new yarns and develop new garments with improved thermal comfort to the level of working prototypes.

5. To evaluate possible health and safety issues as well as environmental impact (LCA) of new PCM-containing garments.

6. To contribute to the standardization of characterization methods for PCM-fabrics.

Project Results:

All main project objectives were reached during the stipulated project time. After completed project, industrial scale production of the new fibers is thus expected to commence. For the Lyocell type PCM fibers there is already a demand of some 300 TPY identified and the problem is rather a limited available production capacity and a competition with other value added fibers on the same production facility.

NOTEREFIGA aims for a much higher market penetration with the PCMs than is currently the case. The research activities in the project were aimed for solving longstanding problems with PCMs. Based on current project results the amount of PCMs in the textile can be increased by a factor 5-10 compared to existing commercial PCM-fibers and the development of PCMs in finer yarns improve the flexibility of the products. The introduction of PCMs in all types of fiber materials (Cellulose, Polyesters, Nylons, Polylactide) will increase the potential for use of PCMs into any type of textiles. The combination of higher effectiveness and of a broader range of raw materials is a technological breakthrough that will largely broaden the potential market for PCMs. Together with the research on new and improved textile products, the project also allowed the small and medium-sized entreprises (SME) participants to develop cutting-edge science and technology in the field of compounding, extrusion, clothing design and physiological testing and evaluation.

TECHNICAL ACHIEVEMENTS REGARDING MELT SPUN FIBERS

Optimized PCM/polymer alloys based on paraffin wax and polyolefin viscosity modifiers with regard to thermal efficiency, melt viscosity and cost in order to be able to produce melt spun bi-component fibers with a latent heat greater than 60 J/g in the temperature range 27-36 °C and with sufficient strength for use in garments and other products (tenacity greater than about 20 cN/tex) has been demonstrated in industrial scale production.

An industrially feasible and efficient processing concept to produce PCM/polymer alloy with 70% PCM and more in the form of free flowing particles was also demonstrated. The PCM/polymer alloys are possible to use with standard melt spinning grades of PLA, PET and PA and produce fibers fulfilling the requirements set by the final applications (texturing, dying, finishing, wash ability, health and safety aspects, cost etc.). PP was found not suitable for fiber production due to migration of PCM. The use of nanoclay in PP to reduce migration did not work out despite a proven exfoliation (TEM analysis). On the contrary, migration of PCM was increased by addition of PCM. This was tentatively explained by the formation of micro/nano cracks around clay platelets formed during the solid state drawing process of the fibers.

In order to produce fibers with PCM/polymer alloy on standard industrial extrusion equipment it was found necessary to apply certain proprietary precautions. It was also found that the addition of certain proprietary functional additives to the PCM/polymer alloy significantly improved the extrusion performance.

Suitable bio-based PCMs (functionality and cost) were identified and used in the project. However, a bio-based viscosity modifier for the PCM was not found. This means that about 10-15 % of the fibers will be from non-renewable sources (crude oil) in case of a PLA sheath polymer (bio-based sheath polymer).

TECHNICAL ACHIEVEMENTS REGARDING WET SPUN CELLULOSE FIBERS

The essential condition to obtain wet spun free PCM containing cellulosic fibers lies in the use of the current Lyocell treatment using tertiary amine oxide N-methyl-morpholin-N-oxid to dissolve the cellulose. Ensuing from the known technology incorporating microencapsulated PCM, the goal was to integrate free PCMs in the cellulosic fiber matrix to achieve higher capacities of heat and finer titers.

Substances from the classes of hydrogen waxes such as linear alkyl ethers can be used acting as PCM in the fibers. The main problem to solve thereby is the thermodynamic incompatibility between the hydrophobic PCM and hydrophilic cellulose. So it was essential to find a system of substances consisting of compatibilizers and coupling agents to surmount the incompatibilities between the separate phases. These substances where found in silicic acids to disperse the PCM homogenously and isotropic on the one hand and layered silicates e. g. nanoclays to enclose the PCM and fix them permanently in the cellulosic fiber matrix. The function of layered silicates is to mediate between the hydrophilic cellulose and the hydrophobic PCM because they are hydrophilic at the one side and hydrophobic on the other side. Additionally a copolymer is used to interact between the complexes of silicic acids and PCM enclosed between the layers of the nanoclays and fiber matrix. Whereas the amount of PCM in the fibers regulates the capacity of heat, the number of carbon atoms in the chain of the hydrocarbons regulates the transition temperature of the PCM. So the producer has the ability to adapt the fibers thermo physiological properties to the requirements of use in a wide range.

By the application of these principles we could produce very fine textile fibers in a range between 1.7 to 2.5 dtex with high contents of more than 50% of PCM and with properties suitable for further textile processing. With the developed technology it is even possible to get fibers with a latent heat capacity of more than 120 J/g in both pilot and production scale. In production scale it was only possible to produce trouble free a fiber fineness of 2.0 dtex, however, these fibers are suitable for further textile processing. By the use of cellulose and bio-based PCMs, fibers closely approaching 100% in terms of renewable resources are produced.

Sufficient amounts of fibers could be provided for the further textile processing and tests within the project. At the beginning of the processing of staple fibers to yarns problems arose. These were solved by a changed finishing of the fiber.

In spite of the high loading of the cellulose fiber with more than 50 % PCM it could be guaranteed that the phase change material was strongly anchored in the cellulose structure. We haven't found any significant losses of latent heat capacity (heat of fusion) after washing of the textiles made from the highly loaded fibers.

YARN SPINNING FROM NEW LYOCELL TYPE CELLULOSE STAPLE FIBERS CONTAINING HIGH AMOUNTS OF PCM

During the development of the yarns different constructions of yarns have been produced in order to reach the highest possible value of heat of fusion. In most cases the PCM modified Lyocell fibers from Smartfiber with heat of fusion from 45 to 90 J/g have been used (Clima fibers). Melt spun monofilaments from Luxilon were also considered for yarn manufacture (core spun yarn).

The yarns, which are suitable for sports underwear products, have been selected and used to make samples of knitted fabrics for further testing. Depending on the results of thermo regulative capacity (heat of fusion) they were selected to be offered to our costumer. So far the results have showed that the new Clima fibers are most suitable for the sportswear for which the extreme thermo regulative or thermo isolative properties of the products are not required, particularly at high temperature differences. On the other hand the positive effect of Clima fibers to the comfort of the wearer has been proven. It has greater contribution to the improved thermal properties in blends with cellulosic fibers than in blends with woolen or synthetic fibers.

New fibers based on cellulosic fibers with the incorporated PCMs are only efficient when used in products which are in direct contact with the skin while wearing. Their effect becomes recognizable already when small shares have been added to the product. They can be blended with all kinds of natural and synthetics fibers.

With latest industrial trials we have managed to prove the efficiency of these fibers even in the blends for the core yarns, which are most demanding for spinning - yarns for elastic underwear. The thermo regulative effect would be far less detectable in usual elastic knitting (where the elasticity would be reached by adding nude Elastan during the knitting process). In the production the standard spinning equipment and procedure were used at optimized conditions.

So far all the trials have showed the correlation between spinning properties of Clima fibers and the content of absolute humidity in the air. This reflects in the static friction fiber – metal and dynamic friction fiber - fiber. With regard to the high share of PCM in the fiber and their distribution within the fiber, different resistance to rubbing and other mechanical as well as temperature influences during the spinning process, ring spinning has been proven as suitable. Individual parameters can be changed and different constructions - different kind of yarns can be used and upgraded by using different blends of fibers in the yarn.

The essence of development of the new constructions of the final products derives from the required heat of fusion in the final product and of selected peak melting point with regard to the end-use of the final products. These requirements then further determine the construction of the yarns, of the blends and the type of the used PCMs in the fiber.

Further development depends on availability of new modified thermo regulative fibers and of requests from market. Independently to the requirements of the project partners, marketing activities for the new thermo regulative fibers in special yarns are carried on. These offers are being adjusted to the particular requests of each potential client and the precisely determined target properties of each product. The limit value of the minimal heat of fusion cannot be set generally, but it has to be adjusted to each product individually.

FINISHING AND DYING OF NEW FIBERS

Melt spun bi-component fibers

Laboratory dyeing and finishing experiments on knit fabrics made of bi-component filament yarns with high PCM content (PES or PA6 in sheath) were performed. Investigation of the dyeing process performance and study of the effects on the latent heat and the dimensional stability of the finished samples in washing were also made.

Following the finishing procedures there is no evidence of significant latent heat loss in comparison with the untreated reference. A lower dyeability has been observed in the case of both PET and PA6 yarns with PCM as compared to the corresponding yarns without PCM. The knitted fabric with PCM content displays lighter colors (1½ or max. 2½ tones difference) compared to a reference without PCM content. This is expected since the hydrophobic fiber cores will not pick up any dyestuff. The dye will be confined to the PET or PA6 sheath. This effect thus needs to be considered in deciding on the dyeing prescription. The lower pigment pick up of melt spun bi-component fibers with PCM core was also verified in full scale production at FOV Fabrics.

The presence of PCM in the composition of PET bi-co fiber has no negative influence on the dyeing fastness; good color fastness to washing, acid or alkaline perspiration and very good fastness to dry and wet rubbing was found. High shrinkage of the knitted fabrics during finishing, reduced stretchability and hard handle after finishing remain the main concerns. The hot air setting is not recommended as a method to pre or post-set the bi-co filament yarn PA6 knitted fabrics with PCM content; the alternatives to be taken into consideration are the steam pre-setting or the hot water setting. It is recommended to design the structure of the knits so that the negative effects related to the increase of density, decrease of elasticity and increase of rigidity acquired during wet finishing process is reduced as much as possible. It should be pointed out that these problems probably, to a large extent, can be remediated by a higher temperature in-line annealing during fiber production. They are thus not connected to the presence of PCM, rather to a so far un-optimized melt spinning process in certain aspects.

For PET fabrics an approx. 3% loss in latent heat is recorded after scouring; for the rest of finishing operations there is no evidence of latent heat loss. A somewhat lower color fastness was found in the case of PET samples with PCM as compared to a reference without PCM content.

Wet spun cellulose fibers

Laboratory and pilot scale dyeing and finishing experiments on knits made of man-made cellulosic fibers with PCM content, enabling the overall finishing processes influence on physical-mechanical characteristics, thermal properties, dyeability and color fastness properties were performed.

Pre-treatments in a single phase or mild alkaline or enzymatic treatments in successive phases are preferred for good results in terms of hydrophilicity, whiteness degree, dyeability and physical-mechanical characteristics of final product.
Dyeing process can be done in a conventional way with good qualitative results in terms of tinctorial yield, evenness and color fastness.
Causticizing and bio-polish operations should be avoided in the case of

blends with cotton due to the high loss of maximum force. In the case of blends with PES, causticizing followed by bio-polish has no negative influence on the maximum force and abrasion resistance. Special care should be given to temperature and duration of drying and heat-setting operation, to avoid the loss of latent heat (loss of PCM).

PHYSIOLOGICAL EVALUATION AND THERMAL CHARACTERIZATION OF GARMENTS WITH PCM

Sweating thermal cylinder tests

The thermoregulation properties of fabrics developed and produced were evaluated at an early stage in the project by means of the new generation sweating thermal cylinder at Tampere University of Technology. Altogether 7 different samples - out of which four samples included PCM and three samples were references - were considered. The basic properties of the samples were also determined: square mass, thickness, air permeability, thermal insulation and water vapor permeability.

Samples containing PCM have clearly cooler feeling when touched by hand than the reference samples without PCM. However, measuring the magnitude and duration of the effect is quite challenging and requires modifications for existing standard test methods used for steady state thermoregulation measurements. Also it requires excluding the effect of fabric construction, square mass and thickness which means using samples that have only difference in whether they have PCM or not in their construction. When precooling the samples for the quick dynamic tests it is important that the tested samples have the same temperature before dressing on the cylinder. Thicker and denser samples may require longer exposure time in the selected cool temperature than thinner and more air permeable samples.

Thin knitted PCM 6, 7 and noPCM8 samples (bi-co filament yarns) have construction, square mass, thickness, air permeability and thermal insulation very much close to each other so the comparison of PCM effect is reliable from that point of view. These samples have the lowest thermal insulation and very high water vapor permeability and very low moisture content in layers after the test. Washing did not noticeably affect thermal comfort properties.

Nonwoven samples PCMnw1895 and noPCMnw1894 (Lyocell with and without PCM) are the thickest samples and they have the highest thermal insulation values meaning that they have a lot of still air bound into their construction. Their air permeability is lower than of the thin knitted samples. The reference sample had a little lower square mass, higher thermal insulation and lower air permeability than the PCM sample.

Thick knitted samples PCM0127A and noPCM0131A (bi-co filament yarns with and without PCM) are the heaviest samples, the reference sample being the heaviest and having the lowest air permeability. There is not much difference in thermal insulation between the reference and PCM samples.

Determination of heat supply shows the differences between PCM and noPCM samples, the PCM samples always having higher heat supply than the reference samples without PCM. When compared to their references the nonwoven samples seem to have the highest, the two-layer thin knitted samples the second highest and the one-layer thin knitted samples the third highest difference in energy per unit area (kJ/m2). The duration of the effect varies from 5 to 7 minutes.

Determination of outer surface temperature shows also that the PCM samples always have lower outer surface temperature than their references without PCM meaning that they are cooler than their references. The effect varies in magnitude and in duration between different sample constructions and different loads of PCM in the construction. Thin knitted samples seem to have the highest outer surface temperatures and the shortest duration for PCM effect. The PCM nonwoven 1895 and the thick knitted PCM 0127 sample have lower outer surface temperature than the thin knits and the effect duration time is higher for PCM knit 0127A. However, higher effects are reached with nonwoven samples in pockets and the highest effects with hydrated inorganic salt packs. The amount of PCM (g/m2) is thus the main factor.

The optimization of PCM has been experimented via using double layers of PCM samples or placing folded test pieces in the pockets of the cylinder garment. As a preliminary result an increase of the effect has been able to be detected in the quick dynamic tests of heat supply and surface temperature. The gain e.g. on using the nonwoven folded samples instead of 30 hydrated inorganic salt packs could be the wearing comfort (flexibility, softness, less weight, possibility for better water vapor permeability or moisture absorption, less super cooling etc.) and perhaps the PCM effect could still be improved and tailored for a particular end use purpose. This optimization need to be studied further.

The effect of sweating on PCM efficiency is a very interesting area to study and it needs further development of the test method. The first determinations clearly showed the existence of PCM effect but also they show that the effect is still rather short tempered.

Thermal manikin test

As part of the NOTEREFIGA project thermal manikin tests with 18 different clothing assemblies that incorporated PCM and corresponding placebos were performed. The objectives were to:

1. Quantify cooling effects of different garments with different amounts of PCM.

2. Compare the effects of PCM on a range of garments.

3. Compare garments that incorporate PCM to conventional garments without PCM (references).

A thermal manikin with 16 measurement zones and a constant surface temperature of 34 ± 0.2 °C was used. The manikin was kept in a stationary upright position. The climatic chamber air temperature (Ta) was kept at 34 °C for all tests. Air temperature was measured by three thermistors located 0.5 ± 0.1 m from the manikin's feet, waist and head. The undressed manikin was stabilized in the climatic chamber for 60 minutes in order to ensure stable conditions between the manikin and the environment. Heat supply (W/m2) and surface temperature were recorded every 10 seconds for each of the 16 body zones. The climatic chamber air temperature was kept at the same level as the manikin surface temperature (34°C) in order to obtain isothermal conditions, which should have prevented any heat loss from the manikin to the environment. The clothing samples were kept at 15 °C during the night before the tests in the climatic chamber. After stable conditions were obtained in the climatic chamber, the samples were fitted to the manikin. The cooling effect of the PCM fabrics and their references was determined by measuring the effect on the heat supplied (W/m2) by the thermal manikin. The heat supply when the manikin was dressed represents the cooling effect of the clothing since the surface temperature of the manikin is unchanged. The clothing included knitted fabrics, pullovers and long johns with different surface weights and PCM loadings and jackets as well as garments with pockets filled with Glauber salt (conventional cooling vest). Clothing included samples that incorporated PCM and clothing without PCM, representing the reference clothing.

The results show that the duration of the heat supply on the thermal manikin is dependent on the PCM mass and the latent heat of fusion as well as the area covered. The small increase in heating power observed at some of the body segments when the manikin is dressed in the placebo garments is probably due to the fact that all the garments were kept at an ambient temperature of 15 °C before they were placed on the manikin. The increased heat supply observed is therefore the manikin warming the garment to 34 °C. Some representative findings are summarized below.

Knitted sweaters (200 g/m2 fabric with a heat of fusion of 50J/g) from melt spun bi-co yarn (Tm=28 and 32°C) and commercially available PCM packs (Tm=24, 28 and 32°C) integrated in a sweater were compared. The initial cooling effect (first five minutes) of the PCM textile sample with a melting point of 32 °C was larger than that of the PCM packs. However, the effect of the PCM lasts for a much shorter period of time than the PCM packs. The difference is expected based on the much higher weight of the Glauber salt packs. No measurable effect of the PCM sample with melting point at 28 °C was found, nor on the placebo sample. Of the PCM packs, the highest heat supply effect was observed in the packs with a melting point of 24 °C, followed by the packs with melting points of 28 °C and 32 °C. This is expected since the heat flow is proportional to the thermal gradient.

A Lyocell based sweater with and without PCM (Tm=28°C) were compared. The maximum values of heat supply on the back and chest segments of the manikin dressed in PCM Lyocell were 39 and 30 W/m2, respectively. The heating power lasted for 3-4 minutes. The heating power of the back segment using the reference garment was 6 W/m2, lasting for 10 seconds. No measurable heating power was registered at the chest segment.

PCM Lyocell (Tm=32°C) and reference garment 170 g/m2 : The heat supply of all segments of the manikin in contact with the garment rose when it was dressed in PCM Lyocell 170 g. The largest increases were observed on the back, chest, lower leg and thigh segments of the manikin. The peak heat supply of the back and chest segments of the manikin was 42 and 38 W/m2 respectively and the effect lasted for 6-7 minutes. No effect of the reference garment could be observed. The peak heat supply values of the lower leg and thigh segments were 32 and 45 W/m2 respectively and the effect lasted for 8-9 minutes. Only a small increase in heating power was observed after being dressed in the reference garment. The greater heat supply seen in this garment can be explained by the higher PCM content (45 wt.-%) of the Lyocell PCM-fiber which increases the cooling effect on the manikin, resulting in increased heat supply.

PCM Lyocell (Tm=32°C) and reference garment 470 g/m2: The heat supply of all segments of the manikin in contact with the garment rose when it was dressed in PCM Lyocell 470 g. The peak heat supply values of the upper arm and forearm segments of the manikin were 76 and 56 W•m-2 respectively and the effect lasted for 22-23 minutes. No measurable effect of the reference garment could be observed. The peak heat supply values of the lower leg and thigh segment were 87 and 79 W/m2 respectively and the effect lasted for about 5 minutes. No measurable effect of the reference garment was registered. The even greater heat supply and time effect seen in this garment can be explained by the higher PCM content (45 wt.-%) combined with the greater thickness of the garment. This increased the cooling effect on the manikin, resulting in increased heat supply.

Sports jacket with a PCM fiber filled liner (350 g/m2, Tm=28°C) and reference jacket without PCM: Both the PCM Sports jacket and the reference jacket displayed a cooling effect on all of the dressed segments of the manikin. The peak heat supply values of the pelvis and back segment when dressed in the PCM Sport Jacket were 37 and 56 W/m2 respectively and the effect lasted for 8-14 minutes. The peak heat supply of the pelvis segment when dressed in the reference jacket was 30-40 W/m2 and the effect lasted for about 4-6 minutes. In all the garments except the sports jacket the PCM material lay close to the manikin's surface. An increased distance between the body surface and the clothing will reduce the effect of the PCM. The sport jacket is a much looser fit, and the effect of the PCM might therefore be lost to the environment. This might explain why we see only a moderate effect of the PCM in the sport jacket compared to the samples with the same PCM fabric without the inner and outer layers. These may have reduced the effect of the PCM on the surface of the manikin.

Knitted sweater from PET based bi-co yarn (200 g/m2, 60J/g, Tm=28°C) and reference garment: The greatest increase in heat supply was observed on the pelvis segment of the manikin (136 W/m2), while only a negligible effect in heat supply was measured when it was dressed in the reference garment. The PET based bi-co yarn sweater had the highest heat supply value observed. The yarn in this garment contained 26.7 wt.-% PCM showing that the amount of PCM incorporated in the clothing has a significant effect on the measured heat supply. However, the effect lasted for only 5 minutes.

The results demonstrate that it is possible to measure potential beneficial thermoregulatory effects of PCM when using a thermal manikin. The results show that the duration of the heat supply on the thermal manikin is limited and depends on the PCM mass and the latent heat of fusion as well as the area covered and distance between the body surface and the clothing.

Physiological experiments results

To fully utilize the potential of PCMs in garments it should be identified and evaluated as a part of the total heat exchange mechanism through the clothing system, together with the capacity of the body to maintain thermal neutrality and comfort. Knowledge of mechanisms of heat and moisture exchange between body surface and clothing in different layers and wear situations, skin regions with different thermo-sensitivity and importance is crucial to be able to optimize cooling/warming performance of PCM. Real assessment of the potential thermo physiological effect of PCM can only be done by means of wear trials on human subjects. This can be done by means of careful experimentation by researchers with expertise within the fields of clothing physiology, product design and medicine. Hardware like a work physiology laboratory with climatic chambers and equipment for evaluation of clothing in realistic use is a prerequisite.

The thermo physiological effect of the developed PCM clothing garments in the project have been tested on human subjects performing defined activity/passive cycles in different temperature and humidity conditions. Both physiological data and subjective perception during the tests have been recorded. Our studies on 14 subjects wearing the melt spun ID60 sweater PCM garment developed in the project (PET based bi-component fiber with PCM in the core, PCM melting point = 28.4°C, heat of fusion = 60J/g based on fiber weight, about 10 kJ/m2 of fabric), demonstrated a significant cooling effect and improved thermal comfort when used in a warm environment (30.0°C). However, the cooling effect was relatively short lasting. The ID60 PCM sweater has substantially improved the latent heat of fusion (60J/g) in comparison to existing similar products on the market. The sweater is covering a large area of the skin, is lightweight and enhances evaporative cooling, all factors that are advantageous to improve thermal comfort and wear comfort. A large latent heat flux over a long time is desirable and this can be achieved by a large amount of PCM. Our studies of the PCM Glauber salt packs demonstrated that the effects on the skin temperature is more long lasting than melt spun PCM fibers, however the Glauber salt packs have the disadvantage of high weight and bulkiness. Our study of the non-woven cellulosic based Lyocell PCM Smartfiber (170 and 470g) demonstrated that the mean skin temperature of the subject wearing the PCM garment was slightly lower in the warm ambient condition (22°C) and higher in the cold ambient condition (-10°C). This indicates that the PCM is absorbing heat from the body in the warm environment and when moving to the cold environment it releases the latent heat when PCM change phases. This explains the stabilizing effect observed on the skin temperature. However, the clothing received was so fragile that it was not possible to run the test on more than one subject. Therefore we have insufficient data to draw any significant conclusion on this cellulosic based PCM fiber. The FOV sport jacket with Lyocell PCM (melting point 28°C) was tested by six subjects and did not show any significant improvement of thermal sensation and comfort when tested during high and low work intensity in 10°C. For the future it is interesting to investigate the melt spun PCM technology used in other applications. A countless number of different user scenarios and test protocols are possible to explore. Today, there is a lack of scientific documentation of the thermoregulatory effect of PCM clothing in human subject's wearer trials. This documentation should be considered before launching PCM products on the market.

PARTICIPATION IN STANDARDIZATION WORK

Partners of the NOTEREFIGA project takes active part in the ongoing standardization work of CEN/TC 248/WG 31 Smart textiles. Regarding the standardization work of CEN/TC248 WG 28 Thermoregulation and WG 31 Smart textiles two work items were suggested by the WG 31 in co-operation with WG28, i.e. one concerning conductive textile tracks and one concerning determining the heat storage and release capacity of PCMs. They were accepted in CEN/TC 248 plenary meeting in November 2011. The first meeting was arranged in Ghent, 17-19 Jan 2012 to discuss further on the very first standard proposal. As a contribution on behalf of NOTEREFIGA and WG28 a brief description of the test methods applied today for detecting PCM effect on fiber, fabric and garment levels was provided. Also more options for test methods already on fiber and fabric level were proposed.

NOTEREFIGA project participated actively on WG31 Smart textiles meeting in Brussels, 10-11 May, 2012. Prof. Bengt Hagström was speaking for DSC method, Mr Detlef Gersching presented their WOTKA and Solution calorimetric methods and Mrs Minna Varheenmaa presented their Sweating thermal cylinder method for PCM determinations on material level. In addition Dr Hilde Færevik gave feedback by proposing manikin measurements on garment level, the effect of evaporation on comfort can be determined by weighing and using moisture sensors in layers as it is shown in NOTEREFIGA documentation.

The latest meeting of WG31 Smart textiles was held again in Brussels, 15-16 October 2012 and Mrs Minna Varheenmaa participated. The standardization work continued with further development of DSC method parameters, and for fabric testing three options were proposed: ASTM D7024, Alambeta and modified Kawabata.

As a conclusion the standardization work for developing a standard with three parts for detecting PCM capacity goes on. So far DSC method has been chosen for one method and the discussions are going on which method would be the most suitable for fabrics impregnated with PCM. The challenge is to find a method where no reference would be needed and that would give an accurate and representative quantitative indication. The sample size (less than10mg) in DSC might in this regards be too small to be representative.

LCA

The objective was to study environmental impacts of new fibers and products during the whole life cycle by means of defined indicators. Background information about LCA-methods and standards was collected and studied. LCA work was carried out applying the principles of EN-ISO 14040 and EN-ISO 14044 standards and in line of the recommendations of European Commission LCA guide. Scope definitions and limitations were made together with project partners. The main focus was on comparative LCA study of fibers and one reference product, T-shirt. Existing fibers, materials and chemicals related to the new thermo regulating fibers were included in the study.

Data collection about raw materials, fibers, chemicals and involved manufacturing processes was made by inquiries from project partners and in generic databases. Questionnaires were sent to the relevant project partner's concerned regarding fiber and yarn manufacturing. In these questionnaires detailed knowledge about the process inputs and outputs related to fiber manufacturing was requested. Raw materials, chemicals, energy and water consumption, waste and manufacturing methods were the main issues. Based on the questionnaire feedback and collected data from generic databases eco profiles were drafted for the produced fibers and example products (T-shirts).

In the frame of LCA work first five T-shirt examples based on different fiber material content with PCM have been reviewed in terms of the environmental impacts. This focusing have been made because of numerous variations of different material combinations with variable percentage values are possible when manufacturing these new bi-component fibers and yarn mixtures. Afterwards on request of the industrial project partner one T-shirt case more have been included into the research work. These six T-shirt examples with different material combinations have mainly been selected according to the samples already made in the project. Fiber materials and PCM´s under the study are both renewable and non-renewable. Fiber and polymer materials like polyester, polyamide, polypropylene, PLA, Lyocell, Wool, HDPE and phase change materials like octadecane, natural alcohols and natural esters were included in research work.

Raw materials and process chemicals have been evaluated by means of the environmental indicators as hazardous material use, energy and water consumption and emissions to air (CO2). Safety data sheets, information from project partners and chemical data basis have been used in this study. Safety data sheets mainly have poor information about notable ecological impacts like toxicity, persistence, degradability or bioaccumulation potential. No significant environmental hazards have been found with regard to the raw materials or chemicals used in the production processes of fibers.

Assessment have been made in all phases of T-shirt´s life cycle focusing to the fiber production and wet processing but also included in use phase, recycling and disposal of these example products. Energy and water consumption in fiber production have been assessed in general level including the resin production, because the novel fiber manufacturing during the project mainly was made in laboratory scale.

Wet processing consists of different pretreatments, dyeing and finishing procedures and the combination of these treatments is varied extensively. How many treatments and what type of dyes and chemicals are needed depends on the sheath material in the fibers and doesn´t essentially differ from the similar ones of conventional fiber materials. These different fiber materials and related process combinations have been under the review and conclusions and definitions are based on project laboratory trials and generic databases. In the frame of LCA inputs of dyeing and finishing process like water consumption, energy consumption, chemicals and auxiliaries and outputs like emissions to water and air and solid waste have been studied.

Environmental impacts in textile wet processing are strongly associated with waste water and the level of this treatment. The main indicators are effluents to water e.g. heavy metals and persistent compounds, biochemical and chemical oxygen demand (BOD, COD) and solid matter load. Modern equipment and automatic systems in wet processing contribute environmental benefits. Innovative dyeing methods with less water input or completely without water have been developed and e.g. dyeing in pressurized carbon dioxide is workable for main synthetic fibers and under the study for cellulosic fibers. Dyeing without water naturally means the elimination of environmental load with waste water outputs.

Use phase, recycling possibilities and the final disposal essentially belong to the range of life cycle assessment and these last phases in T-shirts´ life cycle have also been reviewed. Energy and water consumption related to washing cycles are noteworthy in LCA of the textile products like T-shirt. The durability of the of PCM- materials i.e. both functional and mechanical properties are key factors when time period of the use phase and eco efficiency of these products are evaluated. The main outputs during the washings are effluents to water and air. Domestic washing in case of T-shirts seems to be one the most considerable environmental load in life cycle and differences between raw materials are quite small. In addition product construction and quality questions are significant for the environmental performance in use phase.

Studies or knowledge about recycling for especially PCM fibers and products are not very much found. Different mechanical and chemical recycling technologies for polyester, polyamide, polypropylene, PLA, wool and Lyocell already exist, but problematic is to find out information if these recycling methods are the same available when PCM component is included in the fiber material. Probably some sorting and/or cleaning operations are necessary before the recycling. Various solution methods already are applicable for cellulosic fibers e.g. Lyocell with PCM component. For synthetic fibers included in PCM component incineration are recommended by some commercial producers. It's remarkable that in spite of various technologies available for recycling heavy expenses generally restrict the implementation of these actions.

If any recycling route is not usable, disposal of PCM products is the last step in their life cycle. When these products after use are thrown out, dumping to the landfill or burning in the incineration plants are possible within the law and regulations. PCM´s used in bi-component fibers and mixtures, like alkyl hydrocarbons, fatty acids or natural ethers and alcohols are non-toxic and they are not found to have hazardous environmental impacts. Some of the fiber materials used in T-shirt examples like Lyocell, wool and PLA are biodegradable and similarly the PCM chemicals like natural alcohols and esters and fatty acids.

When these six virtual T-shirt cases were under the study exact numerical data and knowledge about all the details and environmental indicators were not available. Based on database information, scientific studies and inquiries from project partners, the conclusion can be drawn that PCM components in fibers and products don´t substantially add the environmental load in life cycle of these example T-shirts and environmental impacts are in line when manufacturing conventional fibers and T-shirts.

HEALTH A SAFETY ASPECTS

The objective was to assess any health and safety risks connected to incorporation of PCM in textile fibers. For this purpose, the substances considered harmful according to the eco-label standards that might be released by the polymer-PCM systems have been subjected to physical-chemical analysis and the compounds identified have been quantified in conformity with specific EN ISO standards.

The following physical-chemical analyses were performed on the synthetic filament yarns and cellulosic fibres with PCM content synthesized by the project partners:

- The formaldehyde content determined in aqueous solution (in conformity with standard EN ISO 14184-1:1998) and in artificial perspiration solution;

- The content of heavy metals (copper, cadmium, cobalt, chrome, nickel, lead) was determined by extraction in acid perspiration solutions (SR EN ISO 105 E 04: 1998) and extracts analysis by means of the atomic absorption spectrophotometer – SpectrAA 880 – on flame;

- PCMs composition identification, to study the migration of PCMs from fibres into solution of artificial perspiration and hexane, using gas chromatography and mass spectrometry;

- Paraffin's qualitative identification to study the migration of PCMs from fibres, using FT-IR spectrometry;

- The burning behaviour of knitted fabrics made of filament yarns and manmade cellulosic fibres containing PCM, in conformity with standard SR EN ISO 6941:2004.

The results were as follows:

- The quantities of formaldehyde released in aqueous solutions by the synthetic filament yarns are below the value of 30 ppm, thus complying the provisions of the European Directive EC 371/2002 and of the ECO-TEX Standard 100, regarding to textile products found in direct contact with skin;

- None of the analyzed yarns and fabrics contains free formaldehyde;

- Formaldehyde presence was not highlighted in any of the extracts obtained in acid or alkaline perspiration solutions;

- None of the analyzed synthetic filament yarns and manmade cellulosic fibres with PCM's, contain heavy metals;

- None or extremely small amounts of PCM migrate in alkaline and acid perspiration solutions;

- All fabrics studied are classified as flammable according to standard SR EN ISO 6941:2004. This is the normal classification of synthetic and manmade cellulose fabrics without flame retardant treatment. However, all the PCM containing fabrics burn faster, with bigger flames, compared to non PCM fabrics.

Potential Impact:
CELLULOSE FIBERS (SMARTFIBER/TITK)
Based on the gained knowledge on direct incorporation of free components in a cellulosic shaped body a new technological approach integrating thermodynamic incompatible phases into a cellulosic matrix was taken on to the industrial plant of SmartFiber AG. The main condition was to avoid any substantial changes in the technological regime of the Lyocell process. Recipes from the laboratory scale trials were carried over from the most useful trials. Parameters for scaling-up the process conditions e. g. volumes, areas of heat transfer, heating powers, treatment times and stirring speed were defined. Also the levels of the technological parameters of the spinning process were concluded regarding the industrial scale of the treatment. Because of the larger scale of the production charges it was necessary to adapt the technological treatment of mixing and dosing all the components in the spinning solution. So it was found to be suitable to proceed from discontinuous mixing and dosing to continuous mixing and dosing. So continuous working mixing aggregates and blenders were used for preparing the spinning solution on-line based on the principles of dynamic mixing. Surprisingly it was found that the treatment time could be kept on the same level as under laboratory conditions. So no more degradation of the spinning solution was obtained compared with laboratory scale conditions.

The following most important technological results were obtained:

- Silicic acids disperse the PCM most homogenous and isotropic in the cellulosic matrix. Layered silicates e. g. nanoclays enclose the PCM and fix them permanently in the cellulosic fiber matrix. Layered silicates mediate between the hydrophilic cellulose and the hydrophobic PCM because they are hydrophilic at the one side and hydrophobic on the other side. Copolymer interacts between complexes of silicic acids and PCM enclosed between the layers of the nanoclays and the cellulosic fiber matrix

- Extending the assortment of modified cellulosic fibers

- Defined principles and parameters for scaling-up the process conditions from lower to larger scale

- Technology developed for continuously mixing and dissolving components of the spinning solution

- Established the treatment of dynamic mixing into the technological regime

- Improved after spinning treatment resp. fiber finishing regarding the properties of the PCM-modified cellulosic fibers

- Getting experiences in usage of compatibilizers for direct integrating additives in cellulosic fibers

- New technological approach incorporating thermodynamic incompatible phases into a cellulosic matrix

- Substances from the classes of paraffin waxes as well as linear alkyl ethers are found to be suitable acting as PCM in cellulosic fibers

- Thixotropic effects were found to be essential for a most effectively and economical spinning process because they allow a higher mass throughput

Assuming a staple fiber price of about 10 EUROS per kg the following table gives the expected impacts for Smartfiber in terms of estimated sales volumes year 2013-2017.

	2012	2014	2015	2016	2017
Turnover, k€	1500	2500	4500	7000	10000
Earning, k€	300	450	660	750	1800
Amount, TPY	150	250	450	700	1000

Depending on a successful development of produced amounts several new jobs can be generated. There could be a new assortment of modified cellulosic fibers with new and exclusive properties placed on the market.

SmartFiber has disseminated results from the NOTEREFIGA project by exhibiting fibers and products made thereof international textile fairs such as Avantex, Heimtextil, Texprocess and Techtextil. Furthermore there were articles published in leading journals for fashion textiles and technical textiles like Melliand International and Textilwirtschaft.

For TITK as a scientific institution especially all benefits regarding to new knowledge in cellulose shaping are essential and most necessary. So the project got a good opportunity to extend the basis of technical and scientific know-how on interaction of several substances with cellulose and other polysaccharides in a solution with tertiary amine oxides and water.

Furthermore special aspects of incorporating free and unbound components into a cellulosic matrix under stable conditions are a new field of work for future to obtain new kinds of modified cellulosic fibers. The obvious advantage of the Lyocell process, the possibility of direct incorporation of several additives in cellulosic shaped bodies, gave the condition to develop new kinds of modified cellulosic fibers within the framework of the project.

The following main scientific results can be mentioned:

- New kinds of substances acting as PCM in modified cellulose fibers were found

- A new principle for enclosing and coupling of additional components in a cellulose matrix was found

- The difficulties related to phase separation in the spinning solution were surmounted

- Knowledge on Intercalation and exfoliation of layered silicates as basis for compatibilization between hydrophobic PCM and hydrophilic cellulose was gained

- Ensuing from the classical method of DSC to calculate the heat capacity new methods for measuring the impact of incorporated PCM where established

- Important aspects on the influence of integrated nanoparticles on the rheological properties of the spinning solution were discovered

- Formulating a set of parameters for scaling-up the process conditions to industrial scale

Economical impact for TITK results from given licenses for the production of PCM-modified fibers to SmartFiber. An extension of capacities for research and development on cellulosic fibers leads to Socio-economic impact.

Results of the scientific work are published on the ALCERU®-Symposium in Rudolstadt all two years. Additionally a dissemination of the results ensued on the International Textil Conference at Aachen and Dresden, also on the Man-made Fibres Congress in Dornbirn and coming soon on the user forum in Leipzig in 2013.

TEXTILE YARN PRODUCTION FROM CELLULOSE FIBERS (LITIJA)

Adding the results of the project to the production range is in accordance with the strategic orientation of Predilnica Litija, which is to transfer the innovations from the fiber into final textile products and thus produce products with higher added value. It has been the objective of Litija to increase the production of the single and twisted yarns for the use in technical segment of the market. At the same time Litija aim to add new properties to the yarn, which are derived from the properties of the in-built fibers and production capabilities as well as new options during finishing and confectioning of the final textile products.

A successful transfer of the project results to the production process enables the offering of fresh products to the market; it enforces competitiveness and strengthens market position.

The introduction of new fibers with inbuilt PCM to Litijas production process does not require any special production equipment or additional investments. The existing production resources can be fully used.

Predilnica Litija has been present in the demanding technical textiles' field of the European market for many years. We participate at trade fair presentations such as FILO, EXPOFIL, MOOD, A + A, HEIMTEXTIL and TECHTEXTIL, where we meet the customers, many of which already know Predilnica Litija for this type of products. The samples that have been produced during the project so far in the wide range of different blends already enabled us to prepare a small collection of these products, based on which we can start immediately with the marketing of these new thermo regulative yarns.

MELT SPUN FIBERS (LUXILON/POLISILK/SWEREA IVF/CENTEXBEL)

Luxilon has proposed the potential of these new yarns to several interested customers. A presentation was given at the NOTEREFIGA dissemination event in Gent. NOTEREFIGA was also mentioned in several presentations given by Luxilon on multiple seminars and conferences e.g. Sport Congress Centexbel in Gent and Nanoitaltex in Milan. By further positive test results, the product will be introduced to sport customers and medical customers (bandages, burn treatment).

Commercial activity planned to start during 2013. Price indication level: 30 – 50 €/kg, initial estimated volumes: 5000 – 10000kg. Markets: sportswear , medical (bandages, ortheses), sheets, blankets (furniture, bedding).

Benefits for Polisilk have been:
Gained competence in the extrusion of PCMs.
Networking with other partners like: collaboration with Addcomp in the development of different additives for our Polypropylene yarns , introduction to new markets and new business opportunities thanks to contacts supplied by Luxilon and FOV.

Polisilk has ongoing trials with 2 Spanish potential customers on PCM yarns for office upholstery fabrics and thermal blankets.

The financial objectives are:

1st YEAR after the project: 0,2 M EUROS turnover on thermo regulating yarns

2nd YEAR after the project: 0,7 M EUROS turnover on thermo regulating yarns

5th YEAR after the project: 5 M EUROS turnover on thermo regulating yarns (investment in new production capacity needed)

The main impacts for Swerea IVF are:
IVF has gained increased competence in polymer compounding and processing as well as in the area of polymer nano-composites (nanoclay).
IVF has become known in a European and global context as a competent Research and Development (R&D) partner within the field of functional textile fibers.
Network building and new contacts resulting in new project applications.
IVF will continue its efforts to sell licenses on the manufacture of melt spun PCM fibers (with due regard to the interests of Luxilon and Polisilk).

During the project Centexbel gained more knowledge about the compounding and extrusion of polymers containing PCM materials. Especially they got more experienced in the melt spinning of bi-component yarns with (bio-based) PCM materials and biopolymers.

After the NOTEREFIGA project, this knowledge will be further used in private and collective research with textile companies that want to make use of the developed technology experience. Also the analysis routes of PCM materials and their impact on the comfort aspects will be further exploited for commercial testing of these types of comfort textiles. Future development projects to other types of PCMs active at different temperatures are not excluded.

PCM/POLYMER ALLOYS (ADDCOMP)

Addcomp Holland BV is a producer of additive masterbatches and one-packs and is specialized in the development and production of additive stabilization systems and masterbatches for the polymer industry.

Addcomp will increase their volume of business because a new market will be created. A new technology of compounding PCM/alloys has been developed leading to free dosable compounds. These alloys have better performance compared to the standard micro encapsulated PCM/alloys and lower production costs. These pellets can be used with only minor modifications in the subsequent spinning process to produce textiles.

The development of these new PCM/alloys represents an innovation from which Addcomp can benefit by increasing their market in new applications like artificial grass or building industry. It will increase their expertise and the ability to offer higher added value products.

Exploitation strategy of Addcomp is:
New products with low melting additives: ADD-PCMs for bi-component fibers for textile (Luxilon and Polisilk), ADD-PCM (m.p. 40°C) for cool artificial grass bicofibres.

Increase sales in existing products by improved processability: Antifogging masterbatch based on glycerol esters, Anti scratch masterbatch based on mixture of silicon oil.

New business opportunities: Floors for building industry, WPC (decking, panels, garden).

THERMO PHYSIOLOGICAL CHARACTERIZATION OF PCM FIBERS, FABRICS AND GARMENTS (SINTEF, TUT)

The work performed has increased the expertise in thermo regulating textile materials and the assessment of their properties, which is directly in line with the research in smart and functional textile and clothing solutions. New ways to apply the sweating thermal cylinder for determining PCM effect objectively for different types of materials integrated with PCM were found to have objectively measured data for new innovative materials. Knowledge on Environmental, Health and Safety aspects of PCM materials in textile applications and processes increased along the work done in life cycle assessment.

The experience can be utilized in future RTD projects, both on national and international level, and it will also be valuable as background for future European standardization work. The methodology with the sweating thermal cylinder and later for the sweating thermal manikin will be developed further. In standardization work CEN/TC248/WG31 Smart Textiles, work item for developing the standards for determining the efficiency of PCM integrated textiles is important to be able to measure the real effect. Later the products on market may apply different labels so it is important to take this into account also in standardization work CEN/TC248/WG32 Use of the Terms Ecological, Green and Organic in the Labeling of Textiles and Textile Products.

Dissemination activities include the paper and the oral presentation given for ECPC conference in Valencia 29-31 June, 2012: Methodology for determining the thermoregulatory effect of PCM containing materials and garments. Minna Varheenmaa, Hilde Færevik. The results of applying the new sweating thermal cylinder for detecting PCM effect will be presented in future conferences and in different types of scientific publications.

Impacts and exploitation possibilities for Sintef are:
Network: Increased network to potential future partners in EU projects both industry and research
New projects: No new projects at the moment, but the petroleum's industry in the High North and potential subcontractors of protective clothing and garments have shown interest in the PCM technology
New methods: SINTEF have developed a new methodology for evaluation and validation of the effect of PCM garments by using manikin. SINTEF have also developed new methodology for evaluation and validation of the

thermoregulatory effect of PCM on humans at different work intensities and ambient temperatures.
Sellable services: The methodology can be reused in future test protocols for suppliers for PCM garments
Research and Development (R&D) commissions: Potential new customers from HSE services in industry where employees are subject to cold/warm environment problems, also manufacturers of sports clothing may have interest in documentation of potential benefits of using PCM in clothing
Scientific papers: SINTEF plan to publish the results from physiological and manikin testing in peer review papers and international conferences e.g. European Journal of Applied Physiology, ICEE (International Conference of Environmental Ergonomics) and ECPC (European Conference of Protective Clothing).

FINISHING AND DYING (INCDTP)

INCDTP will exploit project results by submission of a national patent application, issuing a guide for dyeing and finishing of PCM textile materials to be offered to the market, working out training materials and offer courses on a commission basis and offering services to dyeing mills on a commission basis.

END USERS (WOOLPOWER, FOV)

Benefits for Woolpower have been better understanding of yarn production, how the body works, i.e. skin temperatures, improved knowledge on test methods and the network established with the project partners.

However, Woolpower is not going to use PCM yarns in their production of undergarments as it looks now due to too little PCM-effect, especially blended with wool.

Benefits for FOV have been an extended European network, something new to offer old customers, some new customers; especially from the PPE conference, helped to strengthen FOVs position as 'innovator of high tech fabrics'.

FOV will continue discussions with possible yarn manufacturers and pursue the following concepts; Golf trousers, Work Wear, Hunting, Insulation, Inner lining and will continue to search for further application areas.

MAIN DISSEMINATION ACTIVITIES

- NOTEREFIGA was presented to a wider European audience during the 4th annual meeting of the European Technology Platform (ETP) for the Future of Textiles and Clothing. The event took place 1-2 April 2009 at Husa President Park Hotel in Brussels.

- An Exploitation Strategy Seminar (ESS) was held on June 23. The seminar was animated by Mr Maoro Caocci of Cimatec, Italy. The outcome of the seminar was important to the consortium in its proper preparation of a Plan for Using and Disseminating the Foreground (PUDF) generated by the project.

- Oral conference contribution during PPS-2009 at Larnaca, Cyprus (October 18-21, 2009) with the title 'TEMPERATURE REGULATING MELT SPUN BI-COMPONENT TEXTILE FIBERS CONTAINING A PHASE CHANGE MATERIAL IN THE CORE'.

- Poster presentation with the title 'Health and Safety Aspects on Textile Materials with PCM's included' at the 22nd International IFATCC Congress, held in Stresa, Italy, May 7-9, 2010.

- Poster presentation at the international congress on 'Innovations in Sports Textiles', 24-25 June in Ghent, Belgium.

- A brief overview of the NOTEREFIGA project was presented at the third Nordic Smart Textiles Meeting in Oslo 24th June 2010 in connection with the pHealth conference. Title of presentation: 'Smart textile research projects' by Hilde Færevik, Preventive Health Research, SINTEF Technology and Society. Link; http://www.sintef.no/Projectweb/pHealth2009/Programme/Smart-textiles-network-meeting

- An update of the NOTEREFIGA project was submitted (October 2010) to the EC funded project SYSTEX, a coordination initiative, geared to foster cooperation between the different knowledge carriers industry, academic and government institutions, research and users.

- A paper with the title 'Temperature regulating textile fibers containing large amount of phase change material' was submitted and presented at the 49th Dornbirn man-made fibers congress (September 15th-17th, 2010). More than 400 delegates from industry and academia attended the congress.

- As a follow up to the Dornbirn congress a shortened version of the paper (with the same title) was published in Chemicals Fibers International (nr 4, 2010, p. 221-223).

- The above mentioned paper was also selected to appear in the Man-Made Fiber Year Book 2011 (p. 41-43) published by Chemicals Fibers International.

- Participation at the exhibition 'SMART TEXTILES, A Textile m 2.0, Forum Textis do Futuro, Porto, Portugal, February 23-24, 2011. A poster and fabric samples were exhibited by the help of Citeve to give a "hands on experience of the PCM effect'.

- Paper presented at the 4th TEXTEH INTERNATIONAL CONFERENCE in Bucharest, Romania, June 23-24, 2011. Title 'Study procedures for finishing of PCM's textile materials'.

- A poster and fabric samples were presented during Techtextil 2011 (May 24-26, 2011) in Frankfurt in the both of FOV, Fabrics were demonstrated containing two different PCMs. One with a melting point of about 28°C and one with melting point of about 32°C.

- A poster and fabric samples were presented during ITMA 2011 (September 22-29, 2011) in Barcelona in the both of Swedish School of Textiles (hosted by AUTEX). Fabrics were demonstrated containing two different PCMs. One with a melting point of about 28°C and one with melting point of about 32°C.

- Contribution to the first meeting of CEN TC 248 WG31 Smart Textiles wi 00248532 Phase change materials (Varheenmaa, M.) held 17-19 January, 2012 in Ghent. PowerPoint –slides an overview of the currently applied methods for determining PCM effect.

- Presentation of project results at the 7th annual public conference of the ETP for the Future of Textiles and Clothing in Brussels, March 28th, 2012.

- Presentation at the ECPC2012 conference held in Valencia on May 29th 2012 with the title 'Methodology for determining the thermoregulatory effect of PCM containing materials and garments'.

- Presentation of the NOTEREFIGA project at the 51st Dornbirn man-made fibers congress (September 19th -21st , 2012). More than 500 delegates from industry and academia attended the congress.

- In CEN/TC 248/WG 31 Smart textiles nwi proposal for determining the heat storage and release capacity of PCMs NOTEREFIGA project was mentioned in A3 Resources and timeframe of Form N of the nwi as an external (e.g. EC) financing expected due to that the standardization is part of the DoW of NOTEREFIGA.

- International conference arranged specifically to disseminate the results of the NOTEREFIGA project. The title was 'New ways towards improved clothing comfort – Can PCM fibers make a difference'. The conference was arranged at Place Monasterium PoortAckre in Gent on December 13th, 2012.

- A manuscript is prepared for publication in Chemicals Fibers International where the results of NOTEREFIGA are summarized. Will be published mid 2013. Authors from SINTEF, SWEREA IVF and TITK.

List of Websites:

http://extra.ivf.se/noterefiga