Ken Ledward Equipment Testing Service

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Natural Vs Synthetic Base layers

Introduction

Ken Ledward Equipment Testing Service, or KLETS as it is usually known, is an independent field-testing company. The field-testing team test prototype materials, garments, footwear & equipment for all outdoor end uses. Much of the testing work undertaken is two years ahead of possible brand production.

For a number of years, KLETS has had an interest in comparing traditional natural clothing to synthetic clothing that is widely used on the hill today. The discovery of Mallory's clothing on Everest re-ignited the interest in this project. KLETS decided therefore, to undertake a project to study the performance of natural clothing systems and synthetic clothing systems using field tests. The KLETS team divided the project into three stages. The initial stage of the project was to explore the clothing systems used on the hill today. Following on from this study, two types of field tests were undertaken. The first field test involved the comparison of a 100% natural clothing system to a 100% synthetic clothing system. These field tests were conducted during two separate intensive weeks in Scottish winter conditions. During these field tests the clothing systems were monitored using miniature temperature and relative humidity data logging sensors. The second field tests were conducted over 12 months and focused on comparing natural and synthetic base layers. These field tests involved a variety of different activities and the base layers were used in combination with a range of different clothing layers.
The Clothing Research Group at the University of Leeds worked along side KLETS undertaking a similar project from a laboratory test perspective. The work undertaken by Leeds has been reported separately and is not included in this report.

Outdoor Clothing Survey

To understand the clothing layers that are worn on the hill at the current time, a survey was undertaken of 254 people. Included in this survey were mountain rescue personnel, outdoor centre staff, full time mountain guides and hill shepherds.

A mass of garment types were reported although the most popular system was a 3-layer system comprising a next to the skin vest, a mid insulation layer and an outer waterproof shell layer. Due to the vast number of items in use, it was decided that initially, for this project, focus would be given to the next to the skin layer.

Vests in use were manufactured from three types of fibre, polyester, polypropylene and polyamide (table 1). None in the original survey wore a natural yarn item. Polyester was the most dominant fibre used by 76% of those surveyed. The polyester vests were from 12 different brands. Polypropylene was the next most popular fibre being used by 23% of respondents. Two different brands were in use. The final 1% was polyamide from 2 brands.

When exploring the polyester vests in more detail, it was identified that 22% of this group used a single garment and had no separate vest. These garments were comprised of a 100% polyester lining with a 100% microfibre polyamide or 100% polyester outer from 5 brand names.
Of this single garment group, 19% commented that waterproof shells were only used in the most severe conditions. 3% could not recall the last time they needed to use a waterproof jacket.

Table 1. Survey results for the next-to-the-skin layer

Brand	Yarn Type (as reported on survey)	No.	%
Helly Hansen	100% polypropylene	56	21.87
Lowe DriFlo	100% polyester	54	21.09
Patagonia “Capilene”	100% polyester	41	16.00
Paramo warpknit	100% polyester inner /100% polyester outer	26	10.15
Buffalo pile	100% polyester inner/100% nylon outer	23	8.98
Odlo “light”	100% polyester	13	5.07
Lowe Driflo “light”	100% polyester	13	5.07
Berghaus Powerdry	100% polyester	8	3.12
Patagonia “Light”	100% polyester	5	1.95
Marmot stretch	100% polyester inner/100% nylon outer	3	1.17
Arc’teryx	100% polyester inner/100% nylon outer	2	0.78
Berghaus	100% polyester inner/100% nylon outer	2	0.78
Craghoppers	100% polyester	2	0.78
Karrimor DryX	50% polyester/43% nylon/7% elastane	2	0.78
TNF	100% polyester inner/100% nylon outer	2	0.78
Falke	100% nylon	1	0.39
Snugpak	100% polypropylene	1	0.39

The findings of this survey were used to guide the selection of the clothing layers for the synthetic system in both types of field test.

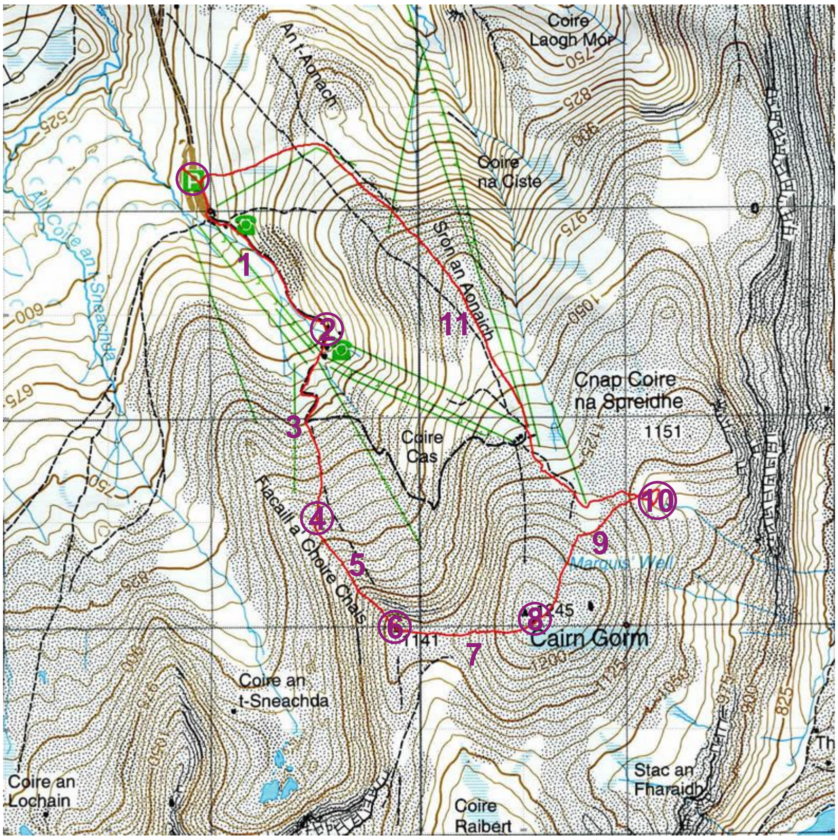
Since none in the survey wore a natural yarn item, the natural clothing layers were determined based on items for sale at retail in the UK. At the start of the programme, five brands with vests containing wool were known to KLETS to be available at UK retail. Two brands only proved to be 100% wool and 4 of these vests were chosen for the project. The average weight for these vests was 285g/m². Silk and cotton vests were also considered but were rejected based on cost and chilling respectively.

Sensor Controlled Field Tests

For the sensor controlled field tests, the popular 3-layer system was adopted. The synthetic clothing system comprised a 100% polyester vest, a polyester fleece and 3 layer laminate shell garment comprising a nylon face / PTFE membrane / warp knit. The natural clothing system comprised a 100% wool vest, a Shetland wool sweater and a double layer cotton Ventile jacket.

A set route was used for the sensor controlled field tests as shown in figure 1. The route was broken into 11 sections as described below.

1. Ascent
2. Stop
3. Steep ascent
4. Stop in survival shelter1
5. Steep Ascent
6. Stop
7. Undulating and steep ascent
8. Stop
9. Undulating and descent
10. Snow hole
11. Short ascent and long descent



Map copyright Harvey 2006
Route verified by GPS - John Gay

During these field tests, temperature and RH sensors were placed between the outer and the fleece, the fleece and the vest and the vest and the skin. In these severe weather conditions, the RH sensors failed to monitor the ambient conditions and intermittent readings were taken using a mechanical gauge. The wind speed was also measured intermittently using a digital gauge as shown in figure 2. It was found however, that the digital windspeed gauge also succumbed to the freezing temperatures and hence the wind speed was measured using a mechanical anemometer that was worn around the neck.

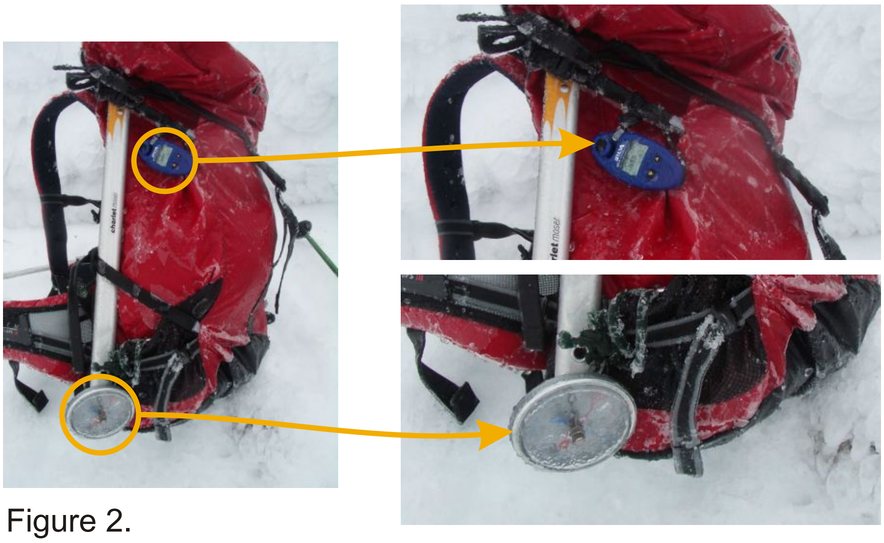


Figure 2.

The field tests were undertaken during two separate weeks in Scottish winter conditions. The temperatures were typically between -5°C and zero with wind speeds in the region of 25 mph (40kph), although on one day the wind speed reached 50 mph (80kph). The following series of pictures in figures 3 - 7, aim to indicate the terrain and weather conditions experience during field tests.

Figure 3.

Figure 4.

Figure 5.

Figure 6.

Figure 7.

The sensor controlled field tests were repeated several times over the two weekly sessions with two wearers alternating between the natural and synthetic clothing systems. Following each session, graphs displaying the temperature and RH sensor readings were generated as shown in figures 8 & 9.

Figure 8 Temperature Graph

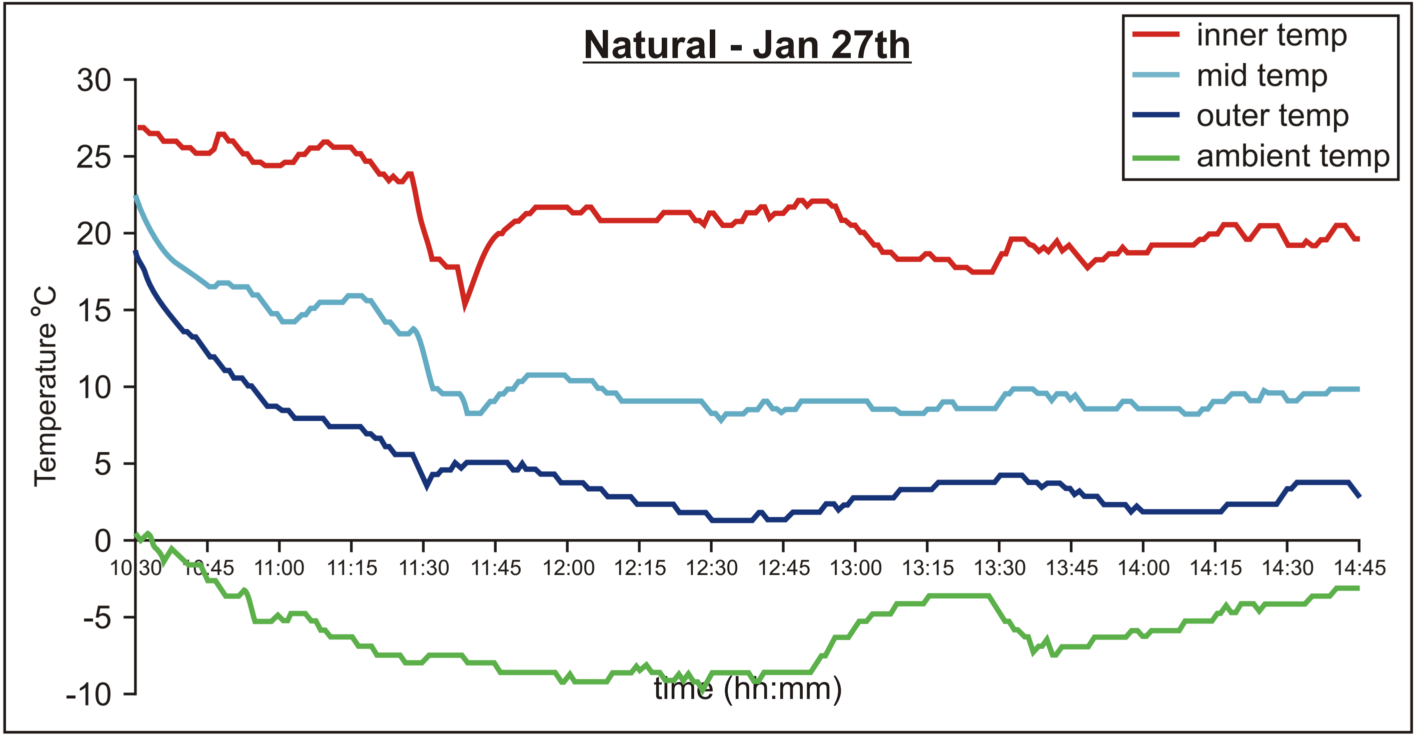
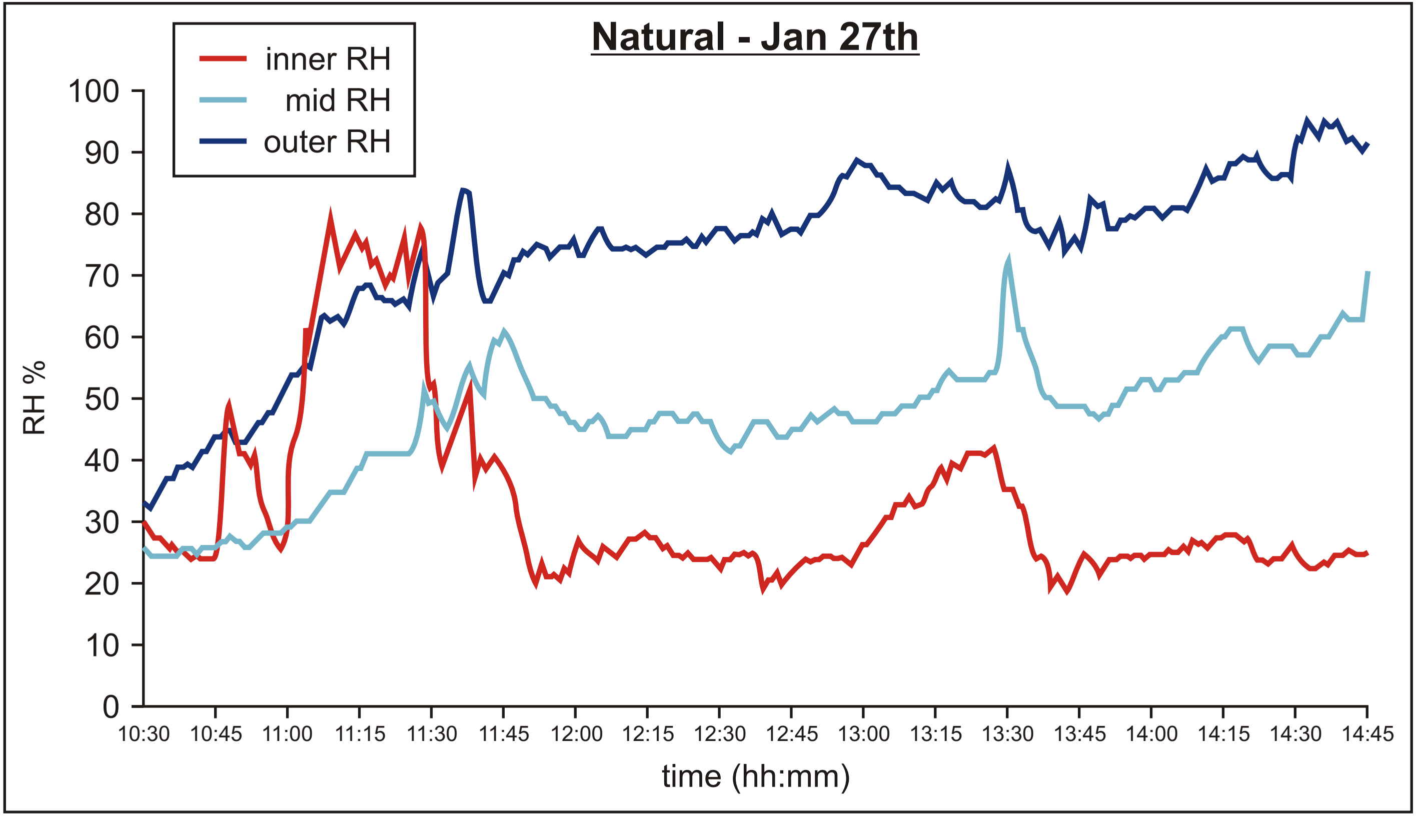


Figure 9 RH Graph



At the end of the two weekly sessions the output graphs from the temperature and relative humidity sensors were analysed in conjunction with the recordings of the ambient temperature, humidity and windspeed. Changes in the ambient conditions did give rise to some daily differences in the sensor readings, however, due to the closely controlled nature of these field tests it was possible to draw general conclusions regarding the comparative performance of the natural and synthetic clothing systems.

The first significant difference was observed during the initial steep ascent as shown in figures 10 & 11. The relative humidity between the skin and vest in the synthetic clothing system did not rise significantly during this first ascent suggesting a good comfort level was maintained. The relative humidity in the natural clothing system however, increased significantly during this first ascent indicating retention of moisture produced by the body in the fabric.

Figure 10 RH during the first 3 stages of field test

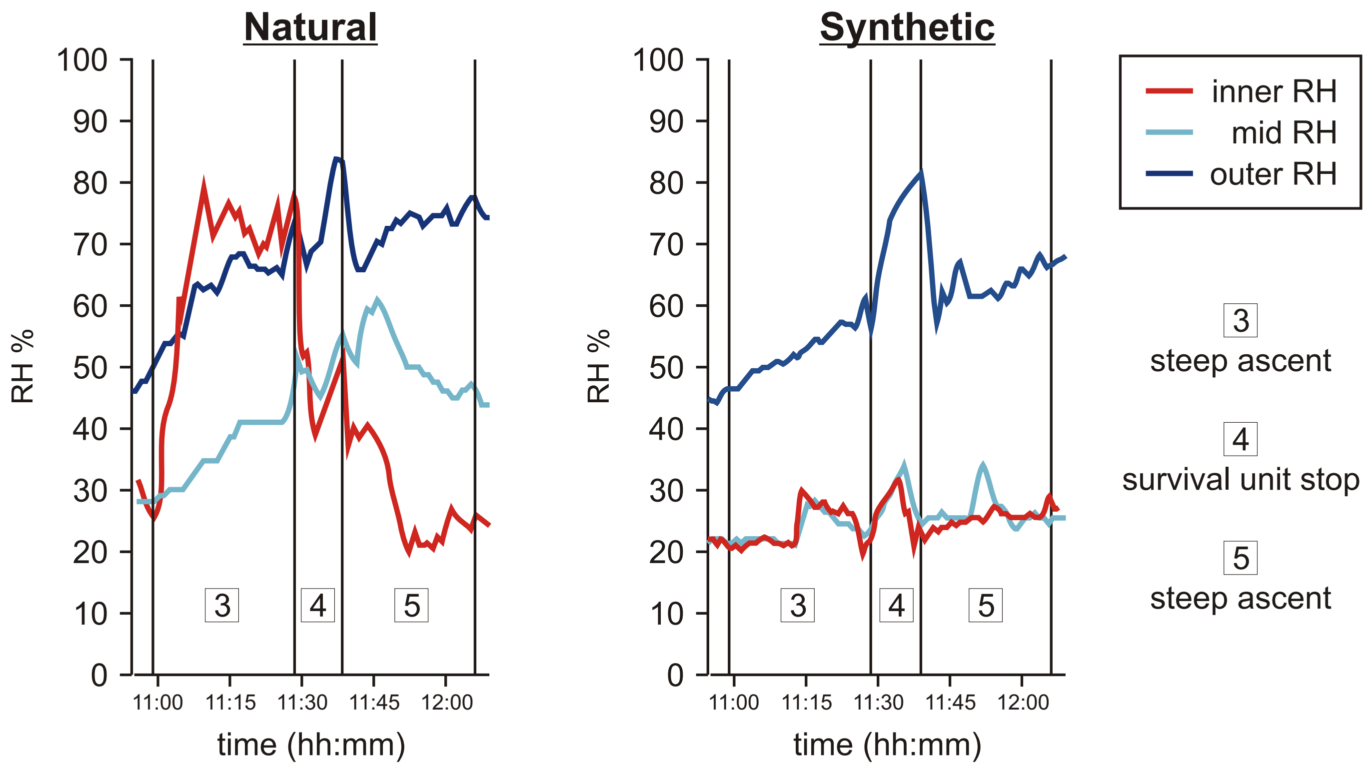
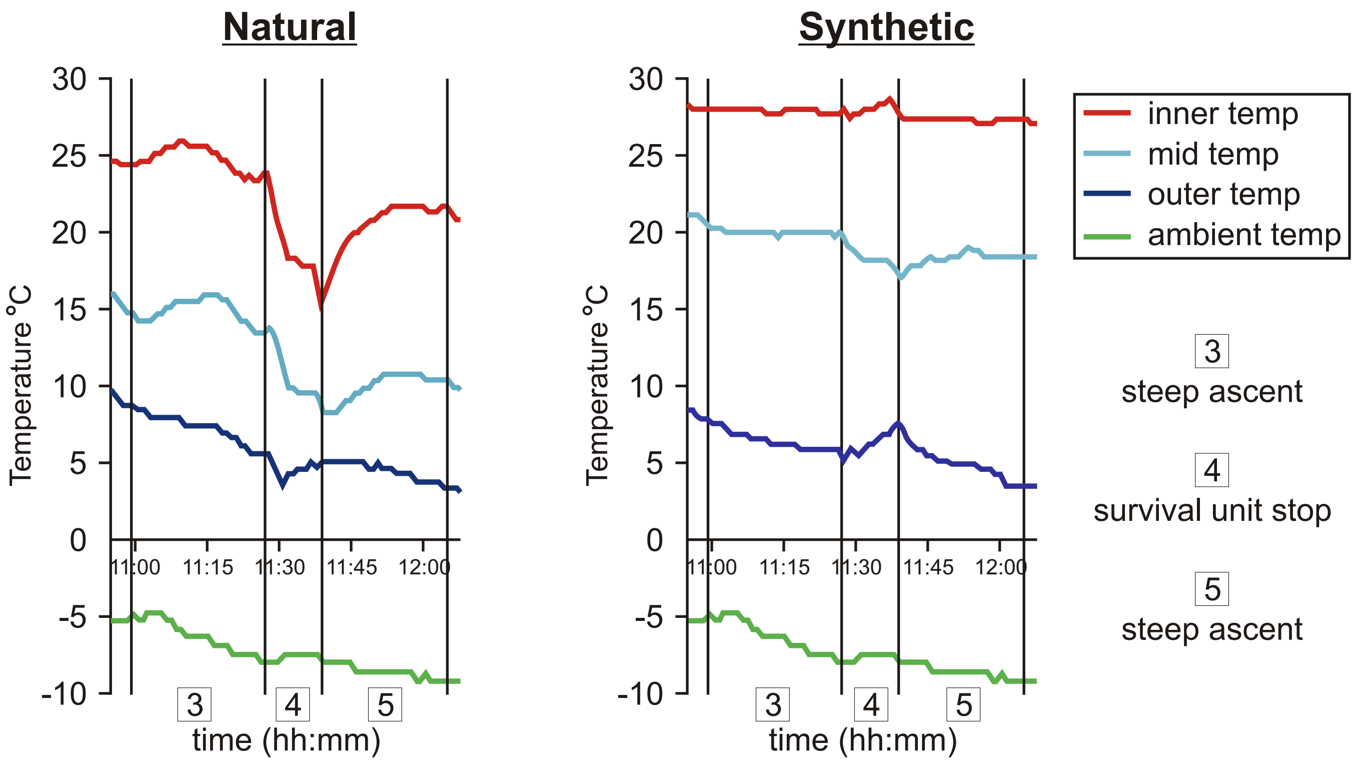


Figure 11 Temperature during the first 3 stages of field test



At the point of the first stop, the natural clothing system exhibited a significant cooling particularly at the skin / vest interface resulting in chilling of the wearer which continued for the rest of the session. This cooling in the natural clothing system is likely to be a result of the retained moisture in the clothing layers increasing the thermal conductivity of the layers.
At the point of the first stop, the synthetic clothing system slightly rose in temperature and no chilling was experienced. This reflected the lower retention of moisture in the clothing layers.

Although the chilling experienced during this field tests was not life threatening, it does demonstrate the potential threat of retained moisture in clothing layers. In strenuous sessions, when the base layers are not performing well, usually the whole clothing system cannot cope with the moisture vapour generated. Many people undertaking outdoor activities will have experienced that, in continuous rainfall, the waterproof breathable shell garment is unable to cope with the massive amount of water vapour trying to escape. In such situations, water droplets from the inside of the shell can soak back into the mid and even base layer. This compounds the moisture that has already accumulated in the base layer. If the wearer becomes immobilised due to accident or injury the retained moisture and resultant chilling can become life threatening.
The Scottish field tests also demonstrated that strong winds can further aggravate heat loss. During the field test sessions typically the wind speeds were in the region of 25 mph, on one particular day however the wind speed rose to 50 mph (80kph). This increase in windspeed had a dramatic effect on the temperature and humidity recordings within the clothing system as show in figures 12 & 13.

Figure 12. Effect of increasing wind speed on the temperature within the synthetic clothing system

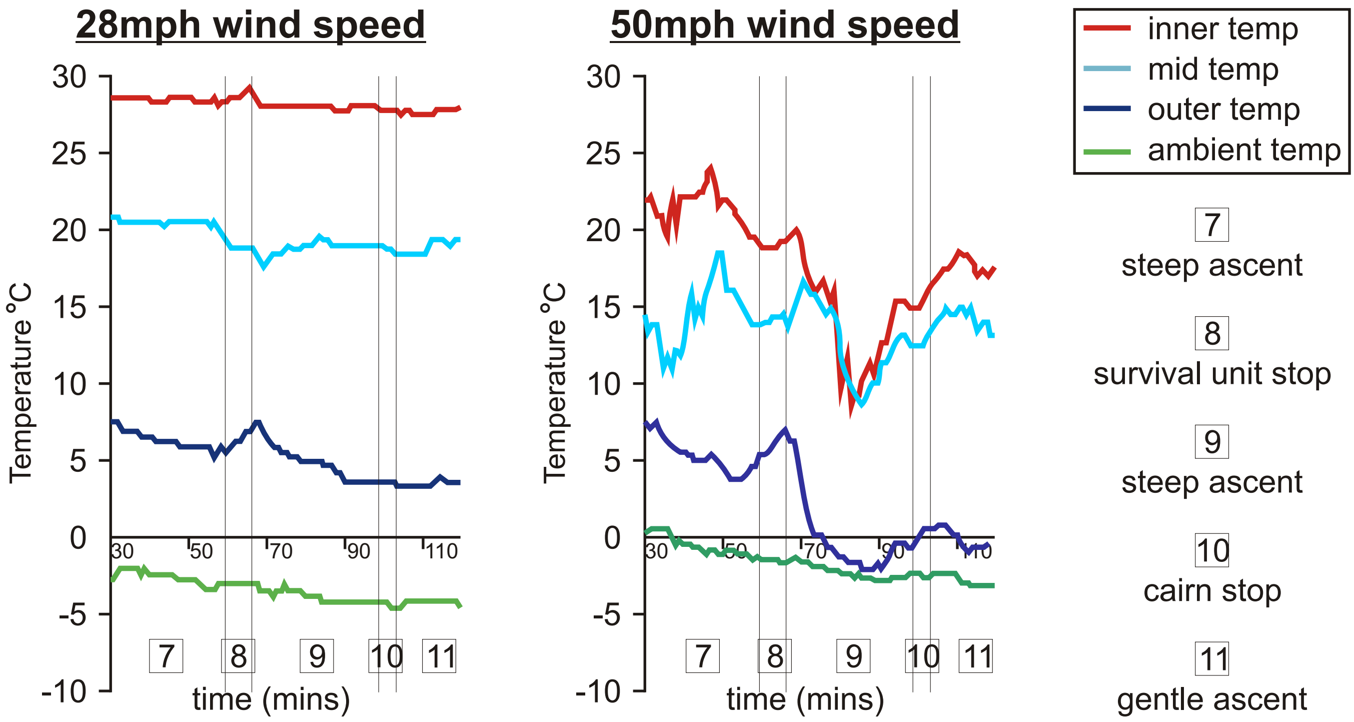
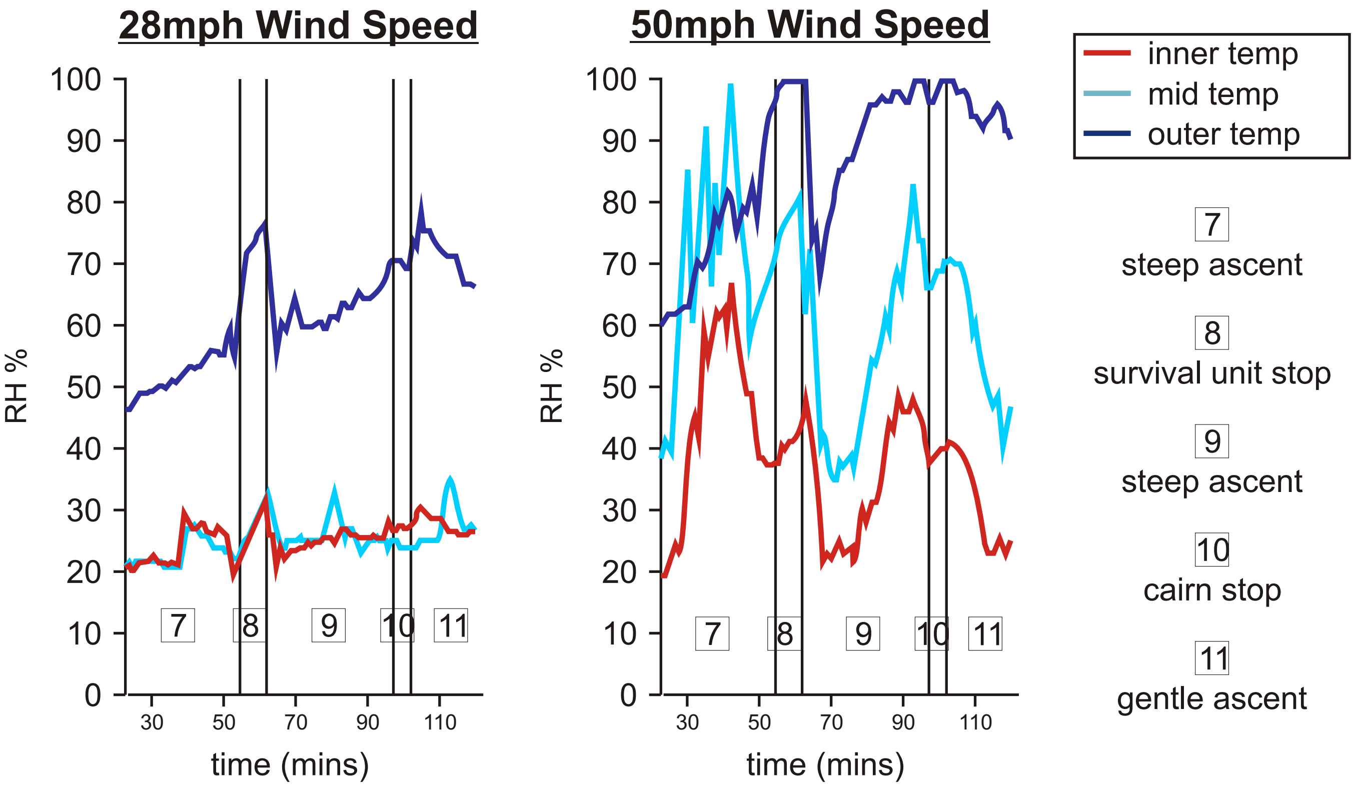


Figure 13. Effect of increasing wind speed on the RH within the synthetic clothing system



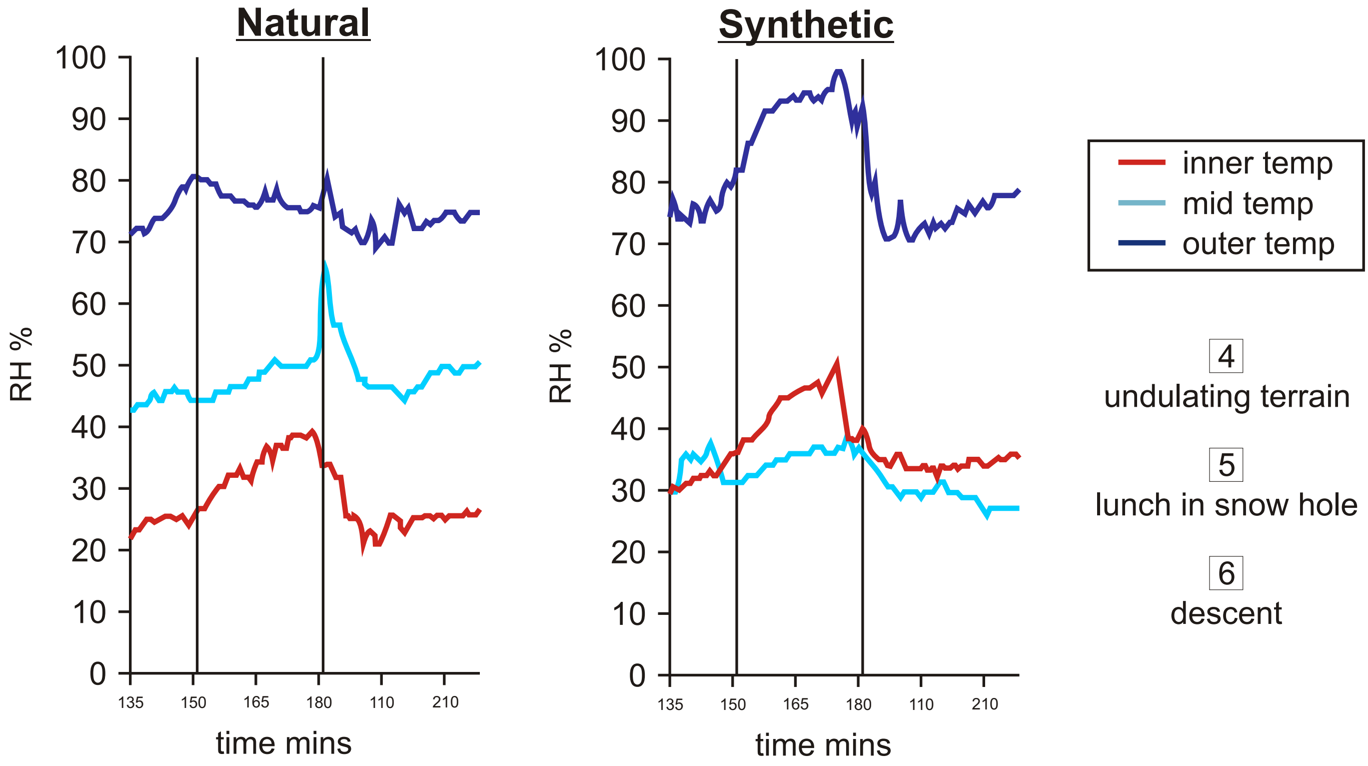
As the wind speed increases immediate chill is usual against the exposed skin areas. In very strong wind conditions however, the clothing layers become profiled against the body and the thermal insulation of the clothing system dramatically reduces. Figure 12 indicates that when the wind speed increased to 50 mph, the profiling of the clothing layers against the body caused the temperature between the fleece and outer to match that of the ambient at -3°C. The temperature between the fleece and base layer and between the base layer and skin reduced to just 6-7°C. In these conditions virtually all the warm air pockets disappear by compression between both the yarn structure and between the clothing layers. In such situations, heat can be lost from the clothing system by conductive heat loss.

As the temperature reduces, the saturation vapour pressure falls and condensation will form with a smaller amount of water vapour. During the periods of ascent, the moisture vapour generated by the body quickly condensed when it reached the cold outer layers. In these situations any air pockets remaining in the profiled clothing layers are replaced by condensed water vapour and this further accelerates the conductive heat loss. The most likely outcome of continued exposure to these effects is accidental hypothermia, a contributing factor in the tragic Edinburgh School Party incident on Cairngorm in 1971.

Another key difference observed between the natural and synthetic clothing systems related to the build up of humidity during rest periods as indicated in figure 14. The shell garment in the synthetic clothing system was impermeable to air. During periods of activity the movement of the body created a bellows effect, which aided moisture-ridden air to leave the clothing system via the garment openings. During rest periods however, this bellows ventilation ceased and there was an associated sharp increase in the humidity beneath the shell layer.

With the natural clothing system, the shell layer offered a degree of air permeability. With this clothing system the bellows effect was less pronounced since air also flowed through the fabric not just through the garment openings in the clothing system. During the rest periods therefore, there was not such a significant increase in humidity beneath the shell layer since air continued to pass through the fabric.

Figure 14. The effect of fabric air permeability and bellows ventilation



These field tests have reinforced the importance of understanding and optimising fabric air permeability and bellows ventilation in outdoor clothing garments.

Soft shells are becoming increasingly popular garments to provide comfort and weather protection in all but the most severe conditions. Soft shells fabrics are available with a variety of air permeability levels. Those soft shell fabrics that contain membranes have no air permeability but tend to offer greater level of water resistance when compared to non-membrane systems, which allow a degree of convective heat transfer through the fabric. The activity level and the weather conditions dictate which system offers the ideal balance of comfort and protection. It is important that the users are educated by the brands and retailers to understand these trade-offs and to select the most appropriate system for their outdoor activities.

For a number of years brands have sought to optimise ventilation in shell garments through garment design. Pit zips have been used as a method of ventilation. The problem caused by this method however, is that ambient air is introduced into the main torso and chills the moisture-ridden microclimate. This cold air lowers the saturation vapour pressure, which results in condensation forming earlier within the clothing system. The KLETS team continue to experiment with ideas to more effectively optimise venting without accelerating the formation of condensation.

12-month field test

The aim of the 12-month field tests was to compare the natural and synthetic base layers with a range of different clothing layers under a variety of different activities. The vests were used in partnership with other synthetic layers including soft shell, waterproof breathables and on their own in contact with a rucsac. The plan was to expose the vests to 1248 hours over 12 months to mimic a very regular hill walker's diary in all seasons. It seems to be that people buy a base layer vest and expect it to work in all seasons. The purpose of this extended field test was to test out this theory. During this time the vests were used exclusively as the base layer vest as part of a clothing system for two thirds of the time and for one third of the time were used as the single torso cover in contact with a rucsac. Care was taken to ensure that the same rucsac fabric type was in contact with all vests.

For the synthetic base layers, the top 7 vests (74%) from the survey were adopted. The average weight for these vests was 202g/m². All the vests were commercially available at retail at the time of commencing these field tests. Single garments (polyester lining / nylon outer) were not included in this project since most users did not think they classed as a next to the skin `base-layer` vest. For the natural base layers the same 100% wool vests that were used for the sensor controlled field tests were adopted for the 12-month field tests.

At the conclusion of the second week spent undertaking the sensor controlled field tests in Scottish winter conditions, the KLETS team felt frustrated that none of the three layer systems was giving a high enough performance level. Some items certainly did not warrant their high cost when giving the same or less performance of items at half the price. In view of the frustrations experienced in trying to get a system that would work better in winter, a much wider variety of garments in all three clothing layer categories were purchased. The KLETS team dedicated a significant amount of time to a really rigorous period of cross-linking every permutation possible.

Some experimental vests were also obtained. Figure 15 indicates that an ever-watchful eye will be required to ensure that any new chemically impregnated fabric or any wash-in or spray application has been thoroughly tested before entering the retail chain. Fortunately the base layer that caused this reaction has not progressed to the production line.

Figure 15. The reaction caused by a chemically treated base layer

During winter weather use in a three-layer clothing system, all vests performed reasonably well at passing moisture vapour at low energy output activity.

The most common comment was that the natural yarn vest did not pass moisture vapour at a fast enough rate; they became very sodden and did not dry off noticeably after hard exertion had finished and lower rate exertion was continued. The synthetic vests also could become sodden but did dry off after hard exertion when exertion continued at a lower rate. This factor led to the natural vests being withdrawn from testing during the summer months. Many of the field testers complained of excessive dampness, skin irritation and chaffing.

With the Shetland wool sweater and previous experience in other woollen sweaters, there is a noticeable but transient feeling of warmth when the sweater first becomes damp, however this soon goes as the sweater takes up more moisture and a perception of chilling then takes over. It has not been possible to identify any similar effect in the natural yarn vests; as soon as the vest becomes damp there is usually an immediate chill effect against the skin if not working hard.

A second area noted, was the low abrasion resistance of some vests to the regular movement of rucsac back, shoulder harness and waist belt. Those vests that suffered most from these contacts were noted for an increase in water uptake and longer drying time. This affected all natural and all but 4 synthetic vests.

Summary

So, is it reasonable to expect one base layer item to perform satisfactorily in all four seasons? Not all suppliers specify seasonal uses; even in these instances we do not believe that they have their calculations correct.

In summer the important things are moisture management, good air permeability and a good resistance to abrasion contacts. Whereas in winter, moisture management is again vital, however increased bulk to provide some thermal insulation could be beneficial, whilst resistance to abrasion is not a significant factor. This leads us to pose the question, should the trade optimise the performance of base layers by engineering fibre, yarn and knitted fabric technologies to specifically work in a chosen season.

For example, the level and type of texture in a yarn would ideally be different for a summer and winter vest, as would the knitted fabric structure.

A common feature raised by all field testers is that British winter conditions pose huge problems for any clothing system. None of the soft shells proved sufficiently good at preventing water ingress during a full day of heavy rainfall. This led to a wet and cold microclimate drawing heat and energy away from the core and ultimately leading to fast fatigue. Even the most committed soft shell users among the testers, added a totally waterproof shell in prolonged heavy rainfall. From KLETS field test experience of mountaineering in Britain, we reckon only to have to wear a totally waterproof shell for a maximum of 40% of the time and mainly in winter months.

In an ideal world, it would be nice if we could encourage people to think more about their personal abilities in terms of fitness, metabolism, physiology and even psychology. It is not written in stone that we should use three layers and we should encourage people to understand what works for them in different weather conditions.

We have all had too many wonderful winter days on the high hills of Scotland for anyone to berate all our equipment. When however, we meet a prolonged storm of mini epic proportions which you have, or will do sooner or later, there is the discovery that we still have work to do in improving all our fabric layers, the way they interact together and the actual design of the clothing system.

We had tried every permutation in the clothing layers to achieve high comfort and been unsuccessful, the problem must lie elsewhere:

Was the yarn type best suited to the area we were using it?
Was the weight of the fabric and garment correct?
Was the fabric structure type correct?
Was the clothing design correct?
And did the layers interact well together?

From the field test experiences, we have discovered some alternate layering combinations, developed many theories and an understanding of the best microclimate temperature ranges that can be worked upon to optimise the performance of clothing systems. One that will more correctly link the natural yarn with the synthetic yarn to the benefit of all users.

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