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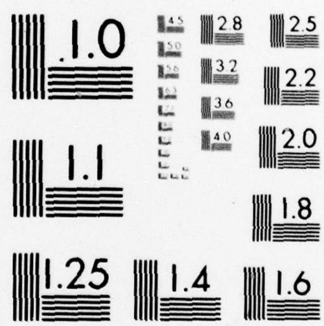


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Comfort is a "state of contented well being" which depends on the interaction between three factors: a) the environment, b) the clothing worn and c) the body's response to them. Physical, physiological and psychological factors must all be involved in clothing designed for comfort in any environment; failure to include all three elements in studies of such clothing has frequently led to an unacceptable product. Much time and unnecessary expense can be saved by an ordered, analytic program of clothing development; a program involving five

levels of analysis has evolved:

1) A physical analysis of the fabrics being considered is carried out.
2) A biophysical analysis of the insulation and permeability of sample garments fabricated from the most promising fabrics is carried out.
3) Small scale (6 to 8 Ss), climatic chamber, "validating" physiological studies are carried out to confirm that the projected differences do indeed occur.
4) Modest scale (~20 to 50 Ss) field trials are conducted; the clothing ensembles are worn by the intended users in the actual environment of proposed use.
5) Full, free use wear trials (test "marketing" in the civilian community, use on "user wear or maneuver trials" in the military) are the final steps.

This progression of test levels decreases in scientific information yield and reproducibility and increases in cost and possible confounding from level one to level five. Many new materials and/or ideas can be eliminated even at level one, with enormous savings of subsequent research effort; still more may be eliminated at level two, but the real savings here comes in the selection of "adequate forcing functions" (i.e., optimal test conditions) for demonstrating supposed differences in user response to the clothing ensemble. If the essential "background" studies of level one and two are conscientiously carried out, there should be few surprises during level three testing; any real world factors in level four which might otherwise confound the field trial results can usually be dissected out; finally, user acceptance and market penetration or resistance can be rationally assessed between the real merit of the product, its advertising, its marketing and its sales.

The views of the author do not purport to reflect the positions of the Department of the Army or the Department of Defense.

Optimal Methods for Physiologic Research on Clothing

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Comfort is a "state of contented well being" which depends on the interaction between three factors: a) the environment, b) the clothing worn and c) the body's response to them. Physical, physiological and psychological factors must all be involved in clothing designed for comfort in any environment; failure to include all three elements in studies of such clothing has frequently led to an unacceptable product. Much time and unnecessary expense can be saved by an ordered, analytic program of clothing development; a program involving five levels of analysis has evolved:

1) A physical analysis of the fabrics being considered is carried out; thermal insulation (clo values) and moisture permeability transfer ($i_m$ values) are measured on heated, dry and/or wet flat plate apparatus to determine agreement with the usual physically dependent standards of bulk (~1.57 clo/cm of thickness) and sweat evaporative potential (~0.45 $i_m$ at 0.3 m/sec of air motion). Materials which fail to meet these criteria will seldom make up into acceptable garments; the few that exceed them may not carry over their unusual potential when fabricated into practical garments, but represent the most promising candidate materials. Mechanical properties of the fibre and fabrics which affect tactile sensation are also beginning to be evaluated at this level. The effects of various fibre or fabric treatments and finishes can also be evaluated most easily at this stage as can the optimal number and arrangement of layers for a given use.

2) A biophysical analysis of the insulation and permeability of sample garments fabricated from the most promising fabrics is carried out using a heated, dry and/or "sweating" copper manikin in a controlled climate chamber; items providing more than ~.35 clo/kg of weight or $i_m$/clo ratios of 0.33 are unusually promising. The practically realizable effect on insulation and/or permeability by use of approaches suggested as promising at the flat plate analysis (e.g. reflective layers, various fibre or fabric finishes and layer assemblies) can usually be evaluated more easily at this level of analysis as can the effects of wind, precipitation and even such details as effects of rapid changes in humidity and/or temperature (e.g. sorption heat; mass damping). Also at this stage the potential heat exchange allowed by the clothing between the wearer and his thermal environment can be estimated; i.e. 5.55 kcal/hr$\cdot$m$^2$ with one clo of clothing insulation (5.55/2 with two clo, etc.) exchanged by radiation and convection ($H_{R+C}$) for each °C difference between his skin and the ambient adjusted air temperature ($T_{ADB}=T_o$) plus a maximum of 12.2 kcal/hr$\cdot$m$^2$ times the $i_m$/clo value of the clothing ensemble transferred by evaporation ($E_{max}$) for each mm Hg difference between the vapor pressure of his 100% sweat wetted skin ($P_s$) and the ambient air vapor pressure ($P_A$). It is essential to carry out this biophysical analysis in order to: a) assess any imbalance between the proposed wearers' heat production ($M \simeq 50$ kcal/m$^2\cdot$hr) up to 333 kcal/m$^2\cdot$hr at work and his non-evaporative heat losses (i.e. clo value dependent); b) compare the sweat evaporation required by the wearer $E_{req} = M \pm (H_{R+C})$ with the $E_{max}$ allowed by the clothing

(with $E_{req}/E_{max} \geq .2$ being uncomfortable, 0.6 unacceptable and 0.8 to 1.0 intolerable); c) define the psychrometric range of each clothing ensemble and compare them in order to select appropriate combinations of M, $T_{ADB}$ and $P_A$ so that the smallest physiologically measurable and/or psychologically sensed differences between two systems can express themselves during subsequent levels of analysis; d) predict the physiological and psychological responses (rectal and skin temperatures, heart rate, sweat production, percent sweat wetted skin area, discomfort, unacceptability and/or intolerance as functions of time at the selected combination of M, $T_{ADB}$ and $P_A$) to establish whether the differences in clothing ensembles measured on the copper manikin should, in fact, produce measurable differences in the physiological/psychological responses of the wearers under the proposed test conditions; if not, parameterize M, $T_{ADB}$ and/or $P_A$ to see if there are any test conditions (whether they occur in the real environments of expected use or not) which will produce measurable differences in wearer response.

3) As with most physical systems, the response to the possible spectrum of M, $T_{ADB}$, and $P_A$ combinations is sigmoid, with some conditions showing no effect, others maximal responses; "adequate forcing functions" (i.e. combinations of M, $T_{ADB}$, and $P_A$ between these extremes) should best discriminate between clothing ensembles. Using an "adequate forcing function" selected at level 2, carry out small scale ( 6 to 8 Ss), climatic chamber, "validating" physiological studies to confirm that the projected differences do indeed occur under these

"adequate" test conditions. Failure to find anticipated measurable differences might still imply that the test conditions selected were "inadequate" (i.e. insufficient to discriminate between the ensembles being tested since any responses to the ensembles were minimal) or "excessive" (i.e. physiological strains were so severe that differences in ensembles could not be manifest since even the best elicited a maximal response); however, such failure is more likely to indicate that the practical differences between the ensembles are too small to be meaningful and they are masked by the wearer induced alterations (wearer motion generated "pumping coefficients") of the clothing insulation and permeability. Such studies, obviously, must be of a statistically randomized, balanced design, with each subject serving as his own control and wearing each garment on a different day; a three to four hour exposure each day, involving both rest and work periods, is recommended.

4) Modest scale (~20 to 50 Ss) field trials, where the clothing ensembles are worn by the intended users in the actual environment of proposed use (preferably at the time of the extreme of the actual environment); the level of work (M) is closely monitored, if not indeed fixed, by the investigators. Although measurements may be as simple as heart rate, time to report of shivering, weight loss over the test period (again 3-4 hours is recommended) and subjective comfort ballots or questionnaires, a balanced order of wear, with each subject wearing each garment on a different day, statistical experimental design is used.

5) Full, free use wear trials (test marketing" in the civilian

community, use on "user wear or maneuver trials" in the military) are the final step; few actual measurements are possible, but sales, use preference surveys, and any complaints are elicited.

This progression of test levels decreases in scientific information yield and reproducibility and increases in cost and possible confounding from level one to level five. Many new materials and/or ideas can be eliminated even at level one, with enormous savings of subsequent research effort; still more may be eliminated at level two, but the real savings here comes in the selection of "adequate forcing functions" (i.e. optimal test conditions) for demonstrating supposed differences in user response to the clothing ensemble. Note that inclusion in level 2 and 3 testing of a "control" item, a currently available, comparable clothing ensemble used by the proposed wearers of the ensemble being developed, is an essential part of the experimental design. If the essential "background" studies of level one and two are conscientiously carried out, there should be few surprises during level three testing; any real world factors in level four which might otherwise confound the field trial results can usually be dissected out; finally, user acceptance and market penetration or resistance can be rationally assessed between the real merit of the product, its advertising, its marketing and its sales.