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A Study on the Comfort and Thermo-Physiological Properties of Car Seats

Dissertation

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Dedicated to my Husband

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Publications in International Journals

1. ***Buyuk Mazari Funda***, Mazari A, Havelka A, Wiener J. Effect of a Superabsorbent for the Improvement of Car Seat Thermal Comfort. Fibres & Textiles in Eastern Europe 2017; 25, 2(122): 81-85. DOI: 10.5604/12303666.1228187 (Impact Factor:0.7)
2. ***Buyuk Mazari Funda***, Michal Chotebor , Adnan Mazari , Jawad Naeem, Antonin Havelka, Effect of Perforated Polyurethane Foam on Moisture Permeability for Car Seat Comfort, Fibre and textile in Eastern Europe, Vol (26), 6(120),14-18 2016(Impact Factor:0.7)
3. ***Buyuk Mazari Funda**, Havelka, A. Pressure distribution of car seat at different angle of backrest. Vlakna a Textil 2015 (3-4), pp. 33-39 (SCOPUS)*
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ABSTRACT

In this research the comfort and the thermo-physiological properties of the car seat's cover is examined. Car seats are a made up of multiple layers of textile material with Poly-Urethane foam as cushion material. The research is organized to make the car seat more breathable and keeps the microclimate between the driver and the seat as dry as possible.

Firstly the factors affecting the breathability of car seat are examined. For this the car seat's cover material are tested for moisture and air permeability and compared with the properties of individual layer of the car seat cover material. This analysis gives us a real idea of which factors negatively affects the breathability of the car seat. The focus of this part of research was to identify the issues within the car seat material and not factors like external cooling or clothing of driver. It was observed that the PU foam and lamination significantly reduces the permeability of the car seats. Whereas the 3D spacer fabric shows the best top layer properties as compared to classical woven, knitted or leather car seat covers.

Secondly with the knowledge of the factors affecting the breathability of the car seats, different techniques are used to improve the breathability of the car seat. In this research the breathability of the car seat is improved by using PU foam with molded perforation & laser cutting, Super Absorbents to absorb excess moisture and stitching car seat layers without lamination. Results shows that all three techniques significantly improve the breathability of the car seat without sacrificing the aesthetic properties. The research work is initial work on replacing the car seat with perforated PU-foams with Super Absorbents.

Thirdly doing any improvement in design of the car seat brings doubt for the durability or life time of the car seat. The most improvement factors which influences the life time of the car seat is the compression properties of the layer and PU foam with time. In this research firstly the pressure distribution of driver on the car seat are examined. Experiment is performed with 50 randomly chosen people; who have different weight and height. Each person sits in three different angles (90^o, 100^o and 110^o) of sitting position. This results is beneficial for us to test the car seat under repeated loading. A special testing was arranged in which a repeated load was applied on the car seat's cover material to 10000 times, which provides the actual life time performance of the classical and newly designed layers for the car seat.

Fourthly the experimental techniques for the measurement for car seats needs a lot of improvement. The complete car seat testing is almost impossible to identify the performance of car seat comfort, and usually each layer is tested separately. In this research we designed thin sheet of sensor which can be placed above the car seat during driving to obtain actual humidity and temperature level. Thermal cameras are used to obtain the thermal field of the car seat after usage. A unique portable device is made to observe the heat flux of the car seat. Then the standard CUP method is modified to measure the water vapour permeability under loading. All this novel techniques gives us better information about the comfort of the car seats.

Lastly A theoretical mode is made for predicting the airflow through the Car seat material considering the air flow and moisture permeability are related to each other in the case of car seats. The model is initial approach to design layer and see the performance of the car seat including loading on the car seat. The research is beneficial for the industry as well as the scientific researchers.

ABSTRAKT

Tento výzkum se zaměřuje na hodnocení termo-fyziologických vlastností potahů autosedaček. Potahy autosedaček jsou tvořeny z několika vrstev textilních materiálů a z polyuretanové pěny jako čalounického materiálu. Koncepce výzkumu se zaměřuje na to, aby byla autosedačka prodyšnější, a udržovala mikroklima mezi řidičem a sedadlem bez přítomnosti vlhkosti.

Napřed byly zkoumány faktory ovlivňující prodyšnost autosedaček. Krycí potah autosedaček je testován na vlhkost a prodyšnost vzduchu a výsledky jsou pak porovnávány s vlastnostmi jednotlivých vrstev potahu autosedaček. Tato analýza nám dává reálnou představu o tom, které faktory negativně ovlivňuje prodyšnost autosedačky. Těžištěm této části výzkumu bylo identifikovat problémy v rámci jednotlivých vrstev potahů a nikoli vnější faktory jako jsou externí chlazení nebo oděv řidiče. Bylo pozorováno, že potah s PU pěnou a laminováním výrazně snižuje propustnosti (vlhkosti a vzduchu) sedaček automobilů, zatímco potah s 3D distanční textilií vykazuje nejlepší užitné vlastnosti v porovnání s klasickými tkanými, pletenými nebo koženými potahy.

V druhé části, se znalostí faktorů, které mají vliv na prodyšnost autosedaček, byly vyzkoušeny různé postupy ke zlepšení parametrů prodyšnosti autosedaček. V tomto výzkumu je prodyšnost autosedačky zlepšena pomocí PU pěny s použitím perforace a řezání laserem, použitím super absorbentů, které absorbují přebytečnou vlhkost, a vrstvy potahu autosedačky bez použití laminace. Výsledky ukazují, že všechny tři použité techniky výrazně zlepšují prodyšnost autosedačky, aniž by tomu byly obětovány estetické vlastnosti autosedačky. Výzkum je počáteční prací při nahrazování potahů autosedaček potahem s perforovanou PU pěnou se super absorbenty.

Následně, provádění změn v konstrukci autosedačky vyvolalo pochybnosti o trvanlivosti či životnosti autosedačky. Nejvíce zlepšujícím faktorem, který ovlivňuje životnost autosedačky, jsou kompresní vlastnosti při stlačení vrstvy PU pěny v průběhu času. Nejprve se zkoumá rozložení tlaku řidiče na sedadle automobilu. Experiment se provádí za použití 50-ti náhodně vybraných lidí různé výšky a váhy. Každý člověk sedí ve třech různých úhlech (90°, 100° a 110°). Výsledky z tohoto experimentu nám umožnují testovat autosedačku při opakovaném namáhání. Byla provedena speciální zkouška, při které byl potah autosedačky opakovaně (10000krát) zatížen pro simulaci odolnosti potahu proti namáhání, což umožnovalo simulovaně

porovnat trvanlivost klasického potahu a nově navrženého potahu autosedačky při jejich reálném použití.

Dále bylo nezbytné experimentální techniky pro měření autosedaček ještě upravit a vylepšit. Kompletní testování autosedaček je náročné a je téměř nemožné určit výkonnost a komfort autosedačky, obvykle se tak testuje každá vrstva samostatně. V tomto výzkumu bylo navrhnuto řešení tenkého potahu se senzory, který může být umístěn na povrchu autosedačky pro zjišťování údajů o teplotě a vlhkosti během simulace jízdy. Termo kamery pak slouží pro záznam a vizualizaci tepelného pole autosedaček po sezení. Byl vyroben unikátní přenosný přístroj pro sledování tepelného toku z autosedačky. Misková metoda byla upravena tak, aby umožňovala měření propustnosti vodní páry pod zatížením. Všechny tyto nové techniky nám poskytují lepší informace o komfortu autosedaček.

Nakonec byl vytvořen teoretický model pro predikci proudění vzduchu skrze materiál autosedačky s ohledem na proudění vzduchu a propustnost par, které spolu u autosedaček vzájemně souvisí. Tento model je počátečním přístupem k návrhu vrstev potahu a pro sledování plnění funkce a komfortu autosedaček při jejich zatížení. Tento výzkum je prospěšný jak pro průmysl, tak pro vědecké pracovníky.

Özet (Abstract in Turkish language)

Bu araştırmada otomobil koltuk kılıflarının konfor ve termo-fizyolojik özellikleri incelenmiştir. Otomobil koltukları, minder malzemesi Poliüretan sünger olan çok katlı tekstil malzemelerinin bir araya getirilmesiyle üretilmektedir. Araştırma otomobil koltuklarını daha nefes alabilir ve sürücü ile koltuk arasındaki mikro klimayı mümkün olabildiğince kuru tutmayı amaçlamaktadır.

İlk olarak otomobil koltuğunun nefes alabilirlik özelliğini etkileyen faktörler incelenmiştir. Bunun için otomobil koltuk kılıfı malzemesi nem ve hava geçirgenliği açısından test edilmiş ve otomobil koltuk kılıfı malzemesini oluşturan her bir katmanın özellikleri karşılaştırılmıştır. Bu analiz hangi faktörlerin otomobil koltuğunun nefes alabilirliğini olumsuz yönde etkilediği hakkında gerçek fikirler vermektedir. Araştırmanın bu bölümünün odak noktasını çevresel faktörler veya sürücü kıyafeti değil araç koltuk malzemesindeki sorunları tanımlamaktı. PU sunger ve laminasyon araç koltuklarının geçirgenlik özelliklerini önemli derecede azalttığı gözlemlenmiştir. Bununla birlikte 3D spacer kumaşlar, klasik dokuma, örme veya deri araç koltuk kılıfları ile karşılaştırıldığında en iyi üst katman özelliklerini göstermektedir.

İkinci olarak nefes alabilirliği etkileyen faktörlerin bilgisiyle araç koltuğunun nefes alabilirlik özelliğini geliştirmek için farklı teknikler kullanıldı. Bu araştırmada araç koltuğunun nefes alabilirliği aşınmış perfore ve lazer kesime sahip PU köpük kullanılarak, laminasyon olmadan dikerek ve aşırı nemi emmek için süper emiciler kullanılarak, iyileştirildi. Sonuçlar her üç tekniğin araç koltuğunun nefes alabilirliğini estetik beklentileri bozmadan önemli ölçüde iyileştirdiğini göstermektedir. Araştırma çalışması süper emiciler ile perfore PU köpüklü araç koltuklarının değiştirilmesine yönelik etkin çalışmadır.

Üçüncü olarak araç koltuk tasarımında herhangi bir gelişme kaydedilmesi araç koltuğunun kullanım ömrü ve dayanıklılığı hakkında şüphe uyandırmaktadır. Araç koltuğunun kullanım ömrünü uzatan en önemli etken, katmanların ve PU sünger malzemelerinin zamana bağlı olarak sıkışma özellikleri bununla birlikte kalici boyutsal deformasyona uğramalaridir. Bu araştırmada öncelikle sürücü koltuğu üzerindeki basınç dağılımı incelenmiştir. Deney, rastgele seçilen farklı boy ve kiloya sahip 50 kişiyle gerçekleştirilmiştir. Her kişi üç farklı açıyla (90^o, 100^o ve 110^o derece) oturmuştur. Bu sonuçlar, araç koltuklarının, tekrarlanan yükleme testleri için araç koltuklarına uygulanması gereken yükün bilinmesine ve sürücü ile araç koltuğu arasindaki

temas alanının bilinmesine yardımcı olmaktadır. Otomobil koltuğunun kaplama malzemesine tekrarlanan bir yükün 10000 kez uygulandığı, otomobil koltuğu için klasik ve yeni tasarlanmış katmanların gerçek yaşam süresi performansını ön görmeyi sağlayan tekrarli yükleme testleri uygulanmıştır.

Dördüncü olarak, otomobil koltuğu ölçümünde kullanılan deneysel teknikler gelişime ihtiyaç duymaktadır. Bütün olarak otomobil koltuğu testi ile otomobil koltuğu konforunun performansını tanımlamak genellikle zordur ve öncelikle her katman ayrı olarak test edilir. Bu araştırmada gerçek nem ve sıcaklık elde etmek için sürüş esnasında araç koltuğunun üzerine yerleştirilebilen ince bir tabaka sensör tasarladık ve termal kameralar, kullanımdan sonra otomobil koltuğunun termal haritasini gözlemlemek için kullanıldı. Otomobil koltuğunun ısı akışını gözlemlemek için yeni bir taşınabilir cihaz yapılmıştır. Bunun yanında koltuk katmanları oturma esnasındaki nem gecirgenliklerinin bilinmasi için farklı yuklemeler altında nem geçirgenlikleri test edilmiştir. Tüm bu yeni teknikler bize otomobil koltuklarının konforu hakkında daha iyi bilgi vermektedir.

Son olarak, otomobil koltuklarında hava akışı ve nem geçirgenliğinin birbiriyle ilişkili olduğunu göz önüne alarak otomobil koltuğu materyali içerisinden hava akışını öngörmek için teorik bir model geliştirilmiştir. Model, katman tasarlama da ve otomobil koltuğuna yükleme de dahil olmak üzere otomobil koltuğunun hava geçirgenliği performansını görme de yenilikçi bir yaklaşımdır. Araştırma sanayide kullanim ve bilimsel araştırmacılar için faydalıdır bir çalışmadır

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List of Symbols

Symbols used in the research are listed below. Some common symbols are mentioned next to respective equations.

q	rate of flow (m/s)
Q	volume of flow of fluid through the sample (m^3)
A	the cross-sectional area (m^2)
t	time (s)
K_p	flow permeability coefficient (m^2)
μ	viscosity of the flow (pa·s)
ΔP	pressure gradient (pa)
L	thickness of sample (m)
V	volume flow (m^3/s)
w	flow velocity (m/s)
S	flow cross-section (m^2)
ρ	density (kg/m^3)
PU	Poly Urethane
SAF	Super Absorbent Fibres
ε	Emissivity of material
σ	Stefan’s constant $5.67*10^{-8} w/m^2K^4$
WVT	rate of water vapour transmission, $g/h{\cdot}m^2$
E_{sk}	Heat lost by evaporation from skin (W / m^2)
E_{res}	Evaporative heat loss due to respiration (W/ m^2)
C_{res}	sensible heat loss due to respiration (W / m^2)
λ	thermal conductivity of the material (W/m.K)
α_c	convective heat transfer coefficient of the process (W/m^2K)

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1 Introduction

Comfort is the basic and universal necessity of human being. Though, it is very complicated and challenging to define. Slater [1] defined comfort as pleasant state of psychological, physiological, neurophysiological and physical harmony between environment and human being. According to him comfort can be defined in following three ways:

i. Psychological comfort is ability of mind to keep its function adequately without external aid.
ii. Physiological comfort is associated with human body's ability to maintain life.
iii. Physical comfort is related to effect of external environment on the body.

Clothing serves several functions in human life such as decoration, social status, protection and modesty.

As a psychological comfort, aesthetic clothing according to latest fashion gives the wearer mental comfort and a feeling of looking good, while well-fitting and luxurious dresses enhance the status of the wearer. Clothing can provide a feeling of modesty and also the mental comfort of having the body covered properly as per the standard of the society. At the interface between the human body and its surrounding environment, clothing plays a very important role in determining the subjective perception of comfort status of a wearer. Sometimes it is called a 'second skin' [2].

For comfort and efficiency, the human body requires a fairly narrow range of environmental conditions compared with the full scope of those found in nature. The factors that affect humans pleasantly or adversely include:

- Temperature of the surrounding air
- Radiant temperatures of the surrounding surfaces
- Humidity of the air
- Air motion
- Odours
- Dust
- Aesthetics

- Acoustics
- Lighting

Of these, the first four relate to thermal interactions between people and their immediate environment. Researchers have identified the major determinants of thermal comfort response:

- Air temperature
- Humidity
- Mean radiant temperature
- Air movement
- Clothing
- Activity level
- Demographic character of the subject (age, sex, health, etc.).
- Rate of change of any of the above[6]

As a physiological clothing comfort, there are three aspects of comfort. These are:

i. Thermal comfort – attainment of a comfortable thermal and wetness state; it involves transport of heat and moisture through fabric

ii. Sensorial comfort – the elicitation of various sensations when a textile comes into contact with skin.

ii. Body movement comfort – ability of a textile to allow freedom of movement, reduced burden, and allow body shaping, as required.[2]

The activity and the health of human is directly affected by comfort. Human microclimate is an important factor in maintaining of optimal capacity for work and feeling of comfort. High heat conditions may cause health problems, as well as psychiatric problems, which can lead not only to the reduction in quality of work, but also to the human vital organ dysfunction [7]. Benefits associated with improvements in thermal environment quality include:

- Increased attentiveness and fewer errors
- Increased productivity and improved quality of products and services
- Lower rates of absenteeism and employee turnover
- Fewer accidents
- Reduced health hazards such as respiratory illnesses[6]

1.1 Human physiological aspect of comfort

Normal internal body temperature of human beings is 37 ^{o}C (98.6 ^{o}F) with tolerance of $\pm$ 0.5 ^{o}C under different climatic conditions. Any variation from of body temperature from 37 ^{o}C may create changes in rate of heat production or rate of heat losses to bring the body temperature back to 37 ^{o}C. Metabolic activity or oxidation of foods causes production of heat and can be partially adjusted by controlling metabolic rate [2].

The skin is the major organ that controls heat and moisture flow to and from the surrounding environment. The skin also contains thermal sensors that participate in the thermoregulatory control, and that affect the person's thermal sensation and comfort. The skin has many (ten times) more cold sensors than warm, and the cold sensors are closer to the surface than the warm sensors. Skin contains four types of thermally-sensitive nerve endings (to cold, warmth, and hot and cold pain) that sense the skin's temperature and transmit the information to the brain. Humans have no known sensors that directly detect humidity, but they are sensitive to skin moisture caused by perspiration, and skin moisture is known to correlate with warm discomfort and unpleasantness [8]

1.1.1 Heat vs. Temperature

The sense of touch tells whether objects are hot or cold, but it can be misleading in telling just how hot or cold they are. The sense of touch is influenced more by the rapidity with which objects conduct heat to or from the body than by the actual temperature of the objects. Thus, steel feels colder than wood at the same temperature because heat is conducted away from the fingers more quickly by steel than by wood.

As another example, consider the act of removing a pan of biscuits from an oven. Our early childhood training would tell us to avoid touching the hot pan, but at the same time, we would have no trouble picking up the biscuits themselves. The pan and biscuits are at the same temperature, but the metal is a better conductor of heat and may burn us. As this example illustrates, the sensors on our skin are poor gauges of temperature, but rather are designed to sense the degree of heat flow.

By definition, heat is a form of energy that flows from a point at one temperature to another point at a lower temperature. Temperature is a measure of the degree of heat intensity. The temperature of a body is an expression of its molecular excitation. The temperature difference between two points indicates a potential for heat to move from the warmer to the colder point. There are two forms of heat of concern in planning for comfort: (1) sensible heat and (2) latent heat. The first is the one we usually have in mind when we speak of heat.

1.1.2 Sensible heat

Sensible heat is an expression of the degree of molecular excitation of a given mass. Such excitation can be caused by a variety of sources, such as exposure to radiation, friction between two objects, chemical reaction, or contact with a hotter object.

When the temperature of a substance changes, it is the heat content of the object that is changing. Every material has a property called its *specific heat*, which identifies how much its temperature changes due to a given input of sensible heat.

1.1.3 Latent heat

Heat that changes the state of matter from solid to liquid or liquid to gas is called latent heat. The latent heat of fusion is that which is needed to melt a solid object into a liquid. It is a property of the material [6]

The body's heat exchange mechanisms include sensible heat transfer at the skin surface (via conduction, convection, and radiation), latent heat transfer (via sweat evaporation on the surface), and sensible plus latent exchange via respiration from the lungs. [8]

With every energy conversion (from one form to another) process, there is certain conversion efficiency. For the human body, only about 20% of all the potential energy stored in food is available for useful body functions. The remaining 80% takes the form of heat as a by-product of the conversion. This results in the continuous generation of heat within the body, which must be rejected by means of sensible heat flow (radiation, convection, or conduction) to the surrounding

Environment or by evaporating body fluids like sweat. If more food energy is ingested than is needed, it is stored as fat tissue for later use [2]. Body heat cycle is shown in figure 1.

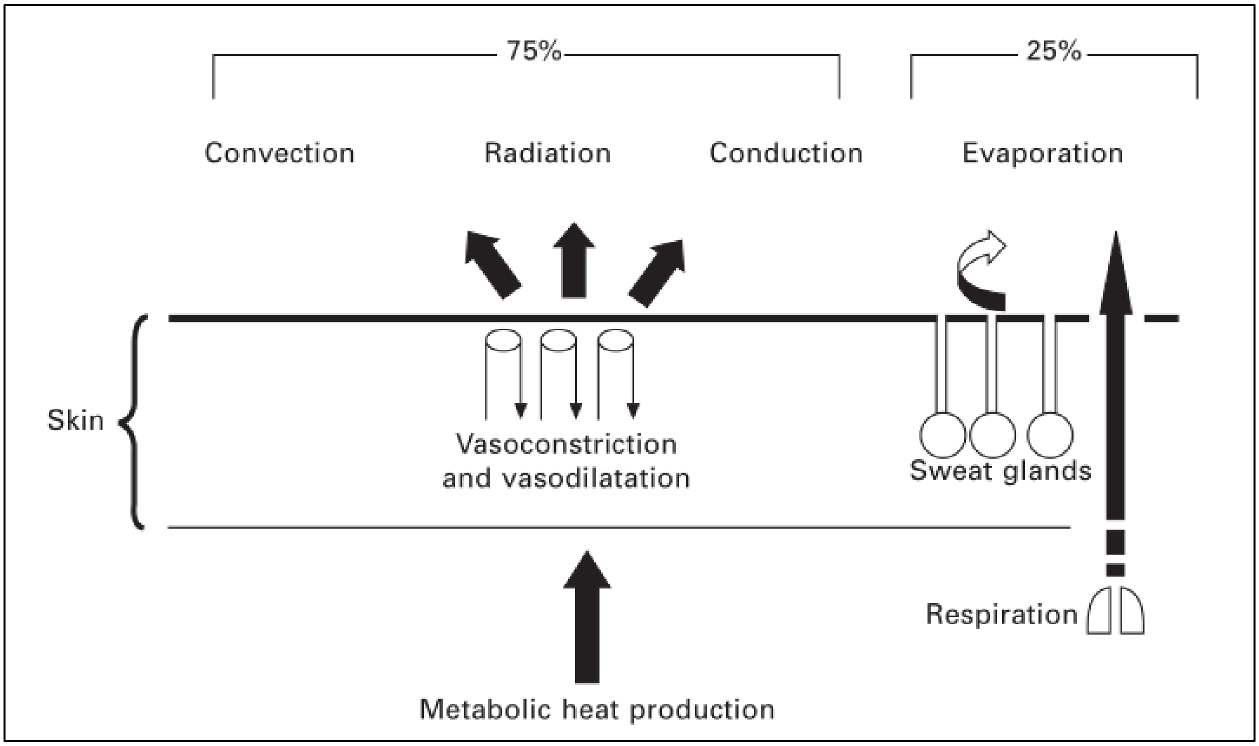


Figure 1 Body heat cycle

Most of the body's heat production is in the liver, brain, and heart, and in the skeletal muscles during exercise. This heat is transferred, through the network of blood vessels and tissue, to the skin. The amount of metabolic heat generation depends on the level of muscular exercise, and to a lesser degree on factors such as illness and time in the menstrual cycle [8]. Metabolic rates of human is shown in table 1.

Table 1 Metabolic rates for selected human activities.[2]

Activity	Metabolic rate		Activity	Metabolic rate	
	Met	Wm^{-2}		Met	Wm^{-2}
Sleeping	0.7	40.7	Walking (2 mph)	2.0	116.4
Seated and reading	0.9	52.4	Walking (3 mph)	2.6	151.3
Seated and writing	1.0	58.2	Walking (4 mph)	3.8	221.2
Seated and typing/talking	1.2	69.8	Car driving	1.5	87.3
Cooking	1.6	93.1	Motor cycle riding	2.0	116.4
House cleaning/ ironing	2.0–3.4	116.4–197.9	Heavy vehicle driving	3.2	186.2
Shopping	1.4	81.5	Fishing	1.2–2.0	69.8–116.4
			Golf	1.4–2.6	81.5–151.3
			Dancing	2.4–4.4	139.7–256.1
			Wrestling	5.0–7.6	291–442.3

Thermoregulation of human body generally refers to four mechanisms:

1. sweating
2. shivering
3. vasodilatation
4. vasoconstriction

Sweating increases body heat loss by increasing sweat evaporation. **Shivering** produces heat by involuntary movement of muscle. **Vasodilatation** and **vasoconstriction** refer to changes in blood vessel diameter, which affect skin temperature by changing the rate of blood exchange with the interior. In the heat, increased conductance below the skin surface (due to increased blood flow) facilitates heat transfer from body interior to the skin. Then convection and evaporation of sweat carries the heat away from the surface of the body to the environment. In the cold, muscle tensing and shivering increase heat production and body temperature. Decreased conductance (due to decreased blood flow) keeps the heat from escaping to the cold environment. This combination of heat loss and heat gain control mechanisms is able to maintain human body core temperature. All these thermoregulation of body controlled by hypothalamus. Evaporation of body moisture is a highly efficient heat removal process, and therefore complex physiological mechanisms have evolved to encourage evaporation under conditions of heat stress.

There is always a constant amount of trans-epidermal loss of water vapour directly diffused through the skin, by the breathing through skin, resulting in heat loss by ‘insensible evaporation’. In addition, the breathing cycle involves humidifying exhaled air, producing another evaporative heat loss. The transdermal moisture diffusion is about 100 to 150 ml/day/m^2 of skin surface, representing a heat loss 6% as great as the evaporation from a fully wetted surface.

There is also another driving force for sweating mechanism is that psychological stress. The palms of hands and soles of feet have a large number of eccrine sweat glands, but these do not respond during thermal stimulation or play a substantial role in thermoregulation. They do, however, sweat profusely as a result of emotional excitement and strong mental activity [8].

The human being is habitual to live in a certain atmosphere and can withstand the temperature range prevailing in surrounding area throughout year. Physical Reponses to body temperature is shown in table 2.

Table 2 Physiological responses at different body temperature [2]

Body temperature	**Physiological response**
43.3 ^oC (110 ^oF)	Brain damage, fainting and nausea
37.8 ^oC (100 ^oF)	Sweating
37 ^oC (98.6 ^oF)	Normal
<37 ^oC (98.6 ^oF)	Shivering and goose bumps
<32.2 ^oC (90 ^oF)	Speechless
26.5 ^oC (80 ^oF)	Stiff and deformed body
<26.5 ^oC (80 ^oF)	Irreversible body calling

The basal metabolic rate (BMR) is the metabolic rate of human being calculated under basal conditions i.e. when a human being is awake and in absolute mental and physical rest after 12 hours of absolute fasting and when environmental temperature is 20-25 ^oC [2].

Ogulata [3] figure out mathematically that relationship between heat loss and heat production can be determined by the heat balance equation:

Heat production = Heat loss

Or

$$M - W = C_v + C_k + R + E_{sk} + E_{res} + C_{res} \quad \text{Eq.1}$$

Where

M = metabolic rate (internal heat production, W/ m^2)

W = External work (W/ m^2)

C_v = Heat lost by convection

C_k = Heat lost by thermal conduction (W / m^2)

R = Heat lost by thermal radiation (W /m^2)

E_{sk} = Heat lost by evaporation from skin (W / m^2)

E_{res} = Evaporative heat loss due to respiration (W/ m^2)

C_{res} = sensible heat loss due to respiration (W / m^2)

1.2 Thermal clothing comfort

One of the prime requirements of clothing is of course to provide protection from extremes of climatic conditions and it acts as a barrier between human body and the external environment [9].The most important feature of thermal clothing is to create a stable microclimate next to the skin in order to support body's thermoregulatory system, even if the external environment and physical activity change completely [19]. The thermal comfort of clothing system is related with thermal balance of body and thermoregulatory reactions to dynamic interactions with clothing and environment. Clothing acts as a regulator of heat and moisture transport between human body and the surrounding environment. [12] Transmission of heat and moisture play very significant role in preserving thermo-physiological comfort. The fabric should permit moisture (in the form of sensible and insensible perspiration) to be transferred from the body to the environment for cooling the body and decline the possibility of thermal decrease in thermal insulation of fabric due to build-up of moisture within the microclimate environment [4]. If clothing in contact with human beings is not dry, there will be escalation of heat flow from body, consequently resulted in undesirable heat loss from the body. This ultimately creates cool feel. In reality transmission of heat and moisture through clothing system is carried out in steady as well as dynamic/transient conditions [5].

1.2.1.1 Heat Transfer Mechanisms

Heat transfer from body occurs as follows

- Conduction
- Convection
- Radiation
- Heat transfer by Evaporation

1.2.1.1.1 Heat Transfer by Conduction

Conduction is the transfer of heat between substances that are in direct contact with each other. Conduction occurs when a substance is heated; particles will gain more energy, and vibrate more. These molecules then bump into nearby particles and transfer some of their energy to them.

Fourier's Law [85]**,**

Heat of conduction is expressed as

$Q = - \lambda A \, dT / dX$ Eq.2

The heat transfer rate per unit area can be written as,

$$\dot{q} = -\lambda \frac{dT}{dx}$$ Eq.3

Where,

A = heat transfer area (m^2)

λ = thermal conductivity of the material (W/m.K)

dT /dX= temperature difference across the material, temperature gradient (K/m)

in this equation $\dot{q}$ is called heat flux and its units are W/m^2

1.2.1.1.2 Heat Transfer by Convection

Heat energy transferred between a surface and a moving fluid at different temperatures is known as convection.

The heat transfer per unit surface through convection was first described by Newton and the relation is known as the **Newton's Law of Cooling**

The equation for convection can be expressed as[78]:

$q = \alpha_c A \, dT$ Eq.4

Where,

q = heat transferred per unit time (W)

A = surface area of heat transfer (m^2)

α_c= convective heat transfer coefficient of the process (W/m^2K)

dT = temperature difference between the surface and the bulk fluid (K)

Convective heat transfer may take the form of either:

- Forced or Assisted convection
- Natural or Free convection

Forced convection occurs when a fluid flow is induced by an external force, such as a pump, fan or a mixer.

Natural convection is caused by buoyancy forces due to density differences caused by temperature variations in the fluid. At heating the density change in the boundary layer will cause the fluid to rise and be replaced by cooler fluid that also will heat and rise. This continues phenomena are called free or natural convection. Boiling or condensing processes are also referred as a convective heat transfer processes [86].

1.2.1.1.3 Heat Transfer by Radiation

Radiation heat transfer is concerned with the exchange of thermal radiation energy between two or more bodies. Thermal radiation is defined as electromagnetic radiation in the wavelength range of 0.1 to 100 microns (which encompasses the visible light regime), and arises as a result of a temperature difference between 2 bodies [87].

The Radiation may be incident on a surface from its surroundings. The radiation may originate from a special source, such as the sun, or from other surfaces to which the surface of interest is exposed.[88]

Heat transferred by the radiation can be expressed with the Stefan-Boltzmann Law[87]:

$$q = \varepsilon \sigma T^4 A \qquad \text{Eq.5}$$

where

q = heat transfer per unit time (W)

ε = emissivity of the object (one for a black body)

$\sigma = 5.6703 \times 10^{-8}$ (W/m^2K^4) - The Stefan-Boltzmann Constant

T = absolute temperature Kelvin (K)

A = area of the emitting body (m^2)

1.2.1.1.4 Thermal properties of textile structures

Textile structures can be characterized by three properties: thermal conductivity, thermal resistance and thermal absorptivity [9,13,14,15,].

Thermal conductivity - is an intrinsic property of material that indicates its ability to conduct the heat. It is the flux (energy per unit area per unit time) divided by temperature gradient. Thermal conductivity is calculated by the following expression:

$$\lambda = Q\ h / A.\Delta T \qquad \text{Eq.6}$$

Where, λ is the thermal conductivity ($Wm^{-1}K^{-1}$), Q, the amount of conducted heat (J), A, the area through which heat is conducted (m^2), ΔT, the drop of temperature(K) and h, the fabric thickness (mm).

Thermal resistance- depends on the ratio of thickness and thermal conductivity of the fabric and calculated by expression:

$$R = h/\lambda \qquad \text{Eq.7}$$

Where, R is the Thermal Resistance (Km^2W^{-1}), h, the fabric thickness (mm) and λ, the Thermal Conductivity ($Wm^{-1}K^{-1}$).

Thermal absorptivity - is the objective measurement of warm-cool feeling of fabrics. Heat exchange occurs between hand and fabric when human touches a garment at a different temperature than the skin. Thermal absorptivity can be calculated by expression:

$$b =.\sqrt{\lambda \rho c} \qquad \text{Eq.8}$$

λ is thermal conductivity watt/mK

C is thermal capacity j/k

ρ density Kg/m^3

The thermal resistance, thermal conductivity and thermal absorptivity of fabrics can be evaluated by an instrument Alambeta. The hot plate comes in contact with the fabric sample at a pressure of 200pa. The amount of heat flow from the hot surface to cold surface through fabric is detected by heat flux sensors. Another sensor measures the fabric thickness. The values are then used to calculate thermal resistance of fabrics [9.13,14,15,104].

The C-Therm TCi Thermal Conductivity Analyzer is another devise which can be used to determine the thermal properties of materials. TCi employs the Modified Transient Plane Source (MTPS) technique in characterizing the thermal conductivity and effusivity of materials. It employs a one-sided, interfacial heat reflectance sensor that applies a momentary constant heat source to the sample. Typically, the measurement pulse is between 1 to 3 seconds. Thermal conductivity and effusivity are measured directly, providing a detailed overview of the heat transfer properties of the sample material [50].

Alambeta and C-Therm TCi are the most commonly used testing device for materials.

1.2.1.2 Liquid and moisture transfer

Liquid and moisture transfer mechanisms in the fibrous textiles include [89]:

- Vapour diffusion in the void space
- Absorption, transmission and desorption of the water vapour by the fibres.
- Adsorption and migration of the water vapour along the fibre surface
- Transmission of water vapour by forced convection.

Water vapour moves through textiles as a result of water vapor concentration differences. Fibres absorb water vapor due to their internal chemical compositions and structures. The flow of liquid moisture through the textiles is caused by fibre-liquid molecular attraction at the surface of fibre materials, which is determined mainly by surface tension and effective capillary pore distribution and pathways. Evaporation and/or condensation take place, depending on the temperature and moisture distributions [90].

Moisture vapour transmission parameters are calculated by following different standard methods [91]:

i. Evaporative dish method or control dish method (BS 7209)
ii. Upright cup method or Gore cup method (ASTM E 96-66)
iii. Inverted cup method and desiccant inverted cup method (ASTM F 2298)
iv. The dynamic moisture permeable cell (ASTM F 2298) and
v. The sweating guarded hot plate, skin model (ISO 11092)

1.2.1.3 Air permeability of textiles

Generally, the air permeability of a fabric can influence its comfort behaviors in several ways. In the first case, a material that is permeable to air is, in general, likely to be permeable to water in either the vapour or the liquid phase. Thus, the moisture-vapour permeability and the liquid moisture transmission are normally related to air permeability. In the second case, the thermal resistance of a fabric is strongly dependent on the enclosed still air, and this factor is in turn influenced by the fabric structure.

Air permeability is an important factor in determining the comfort level of a fabric as it plays a significant role in transporting moisture vapours from the skin to the outside atmosphere. The air in the microclimate between individual items of clothing also has a physiological function.

When the body is at rest, this air in the microclimate contributes up to approximately 50 percent of the effective thermal insulation properties of the clothing. When the body is in motion, approximately 30 percent of the heat and moisture can be removed by air convection in the microclimate and air exchange via the clothing. The assumption is that vapours travel mainly through fabric spaces by diffusion in air from one side of the fabric to the other
[51, 98, 99].

1.2.1.4 Factors of textiles effecting thermal comfort properties

All the factors we mentioned about heat and mass transfer that affects the comfort are affected by some fabric and clothing parameters. At the time of designing the textile for thermal comfort or for improvement of thermal comfort it's important to know about these parameters and their possible effects

Textile structure and chemical nature of fibres effects the thermal comfort properties of textiles such as: Fibre type, fibre-diameter, fibre shape, texture method of fibre yarn types and production, porosity, pore size distribution, complexity of pores(open cell or closed cells), fabric structure and thickness , clothing design, fitting and thickness of clothing, position of layers (hydrophilic/hydrophobic), sorption of fibres and fabric and finishing applied to the fabric, etc [2,7,16-18,20-24].

1.2.1.5 Effect of Fibre Type and Yarn Structure

For thousands of years, the presence of textile products in the life of men was limited by the inherent qualities available naturally: cotton, wool, silk, linen, hemp, ramie, jute and many other natural resources. Since 1910, with the production of rayon as 'artificial silk', man-made fibres started to be developed and to be used. Nowadays man-made fibres are found in different features of life with countless applications, from apparel, sporting clothes and furnishings to industrial, medical, aeronautics and energy.

The behaviour of fabric is affected by chemical and physical properties of its constituent fibres. And different fibres has different properties of their own, these physical and mechanical characteristics of its constituent yarns [2].

As we know from the previous chapter one of the important parameter of the thermal comfort of textiles, is the thermal conductivity. The thermal conductivity is the specific property of the material so that we expect different thermal conductivity from different fibres. Table 3 shows the thermal conductivity of some textile fibres [25].

Table 3 Thermal conductivity of textile fibre

Fibre	Thermal conductivity (W/m.K)
Cotton	0.71
Wool	0.54
Silk	0.50
PVC	0.160
Nylon	0.250
PES	0.140
PE	0.340
PP	0.120
Air (still)	0.025
Water (still)	0.6

As we can see from table 3 the thermal conductivity of the air is much lower than other fibres used in textiles and the thermal conductivity of the water is much higher than textile fibres. Because of this differences we can say that the amount of air in textiles which is related the porosity will decrees the thermal conductivity of the textiles. On the other hand moisture and the liquid water will increase the thermal conductivity of the textiles.

Another specific parameter for fibres that effects the thermal properties of textiles is the specific heat. Specific heat is important for thermal absorptivity which defines the warm or cold touch of the textiles. Some of the specific heat values of the fibres shown in table 4[25]

Table 4 Thermal capacity of dry fibre

Fibre	Thermal Capacity(JK^{-1})
Cotton	1.21
Rayon	1.26
Wool	1.36
Silk	1.38
Nylon 6	1.43
Polyester, Terylen	1.34
Asbestos	1.05
Glass	0.80

Nowadays hollow fibres are being produced with various geometries such as rounded, trilobal, triangular and squared. Hollow fibres trap air, providing loft insulation characteristics better than solid fibres Hollow polypropylene microfibres are used because of their high breathability, light weight and softness [2]

The images of different hollow fibres are shown in figure 2.

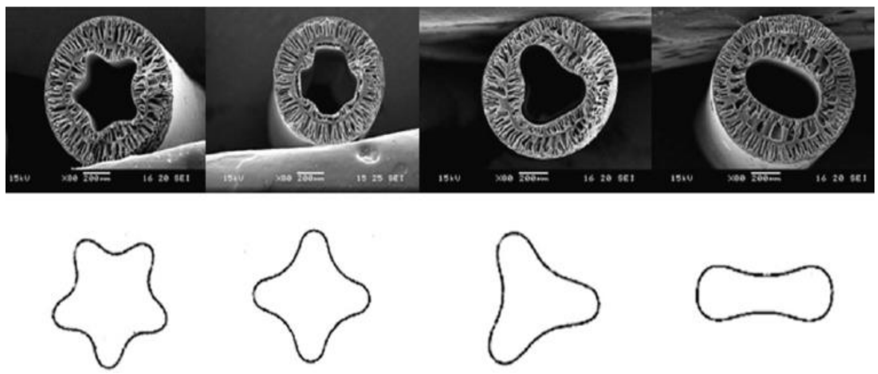


Figure 2 Images for Hollow fibres [27]

Table 5 shows the effect of the hollow fibres on thermal conductivity

Table 5 Thermal conductivity of pes woven fabric from different fibre cross-section[28]

Fibre Cross-section shape	**Fabric Pattern**	**Warp density 1/cm**	**Weft Density 1/cm**	**Fabric Weight g/m^2**	**Fabric thickness, µm**	**Thermal conductivity Wm^{-1}K^{-1}**
Round	Twill	52	34	156	292	0.0318 ± 0.0008
Hollow Round	Twill	52	35	162	330	0.0361 ± 0.0003
Trilobal	Twill	52	33	154	273	0.0292 ± 0.0016
Hollow Trilobal	Twill	52	35	159	310	0.0337 ± 0.0005

1.2.1.6 Porosity of fibrous assembly

The amount of air inside textiles is related to the porosity as shown in figure 3. All the pores in textiles will be filled with air and will influence the thermal properties.

We can see the porosity of the fibre assemblies and related factors from the model of the Neckar. The porosity of textiles assemblies can be explained with packing density (µ). Packing density (μ) of fibrous assembly is the ratio of the volume of the fibres (V_C) to volume of the total fibrous assembly (*V*)

$$\mu = {}^{V_c}/_{V} \qquad \text{Eq.8}$$

And the porosity of the fibrous assembly (Ψ) is:

$$\Psi = 1 - \mu \qquad \text{Eq.9}$$

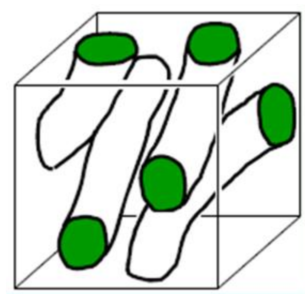


Figure 3 porosity of fibrous assembly

Other parameters that effects the porosity are shown below:
t… fibre fineness (tex)
s… fibre cross-sectional area m^2
ρ… material fibre density kg/m^3
p…fibre perimeter m
q…. fibre shape factor
ɑ…specific fibre surface area
d… equivalent fibre diameter
A… total surface area of fibres
Illustration of packing density of fibrous structure is shown in figure 4.

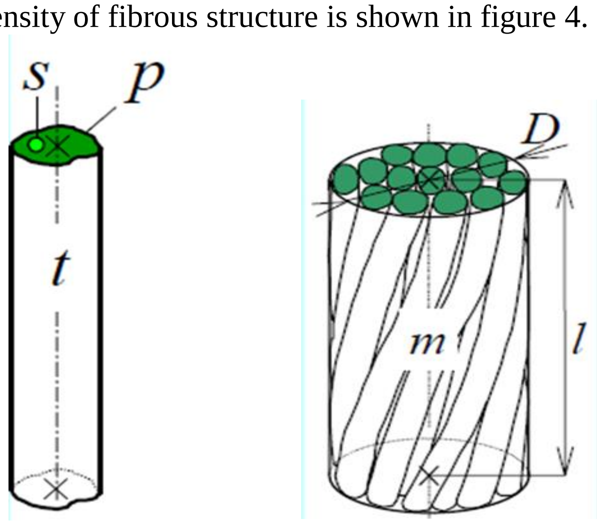


Figure 4 Packing density of fibrous assembly

Equivalent fibre diameter (d) is the diameter of the circle having the same cross-sectional area of fibre as shown in figure 5.

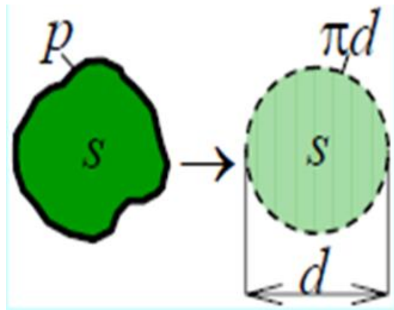


Figure 5 Equivalent fibre diameter

Shape factor (q) is the ratio of the perimeters of fibre real perimeter and the perimeter of the circle having the same cross-sectional area. The perimeter of the non-cylindrical fibre is always higher than the perimeter of the ring having the same cross-sectional area

$$q = \frac{p}{\pi d} - 1 \geq 0 \qquad \text{Eq.10}$$

$$d = \sqrt{4s/\pi} = \sqrt{4t/(\pi\rho)} \qquad \text{Eq.11}$$

Porosity characterizes volume of free space among fibres, but not the size of gaps among fibres. The porosity and the size of air gaps in a fibrous assembly are very important factors to decide the fluid flow and filtration behaviours of the fibrous assembly. The pore size distribution and the fibre diameter present in a fibrous material often have significant impact

On the moisture transport processes. Pore size distribution can influence the rate and magnitude of spontaneous uptake of liquids in porous textiles and control the flow pattern of a fluid moving through a porous material

According to the Neckar's model of porosity we can create the imaginary borders in between the pores and we can consider the pores as an air fibre so all the parameters and the equations of the fibres will be valid for the pores as well. Parameters of the pores will be subscript by "p"

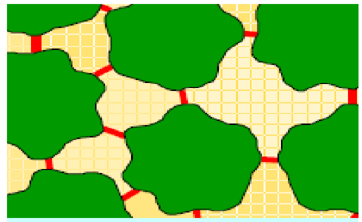


Figure 6 Imaginary border of pores

If we rewrite the equations of cross-sectional area, equivalent diameter and shape factor equations according to pores, the equations are

$$s_p = \pi d_p^2/4 \qquad \text{Eq.12}$$

$$d_p = \sqrt{4s_p/\pi} \qquad \text{Eq.13}$$

$$q_p = p_p/(\pi d_p) - 1 \qquad \text{Eq.14}$$

As a result from these equations the equivalent pore diameter (d_p) is function of shape factor of fibre shape factor q, pore shape factor q_p, fibre diameter d and packing density μ. Final version of the equation is[29]:

$$d_p = \frac{1+q_p}{1+q}\frac{1-\mu}{\mu} d \qquad \text{Eq.15}$$

From all these equations we can understand the fibre cross section area and the fibre fineness are important parameter for total porosity of the yarn. Also non-cylindrical cross-section and finer fibre in yarn cross-section will increase the total surface area of the fibre which is important for liquid and water vapor transport. Adsorption is the physical adherence or bonding of ions and molecules onto the surface of another molecule. It is the most common form of sorption [30].

1.2.1.7 Effect of high Surface area

Higher surface area increases the liquid transport. Microfibre are defined as fibres whose denier is less than 1 and micro denier fibres shows better wicking than normal denier fibre. Comfort properties of polyester microfibre fabric are much better in terms of wicking when compared with polyester micro/cotton blendsand and pure polyester non micro fibre fabrics[31]. Wicking test results of micro and normal denier fibre knitted fabrics[31] shows that the wicking values are better for micro-denier fabrics due to better packing coefficient of microdenier spun yarns than that of corresponding normal denier yarns. It is therefore expected that avarage capillary size would be less in microdenier spun yarns. Low capillary diameter is expected to increase capillary pressure and drive water faster in to in to the capillaries of yarn. This has resulted in higher wicking height in micro-denier yarns then normal denier yarns at any given time [31].

There are more researches which shows that the significance of fibre cross-sectional shapes in modifying the thermophysiological comfort properties of fabrics. Results of wear trials showed that fibre fineness represents an essential and significant influencing factor on the wear comfort of a textile. The lower decitex of micro- fibres proved to be physiologically advantageous especially in situations where heavy sweating occurs.[34,35,36,37]

Nowadays, polyester is the most widely and popularly used fibre because of its favourable characteristics, namely high strength, dimensional stability, easy care and wrinklefree characteristics, but 100% polyester and polyester-rich fabrics are not comfortable to wear because of their hydrophobicity. Some attempts have been made worldwide to overcome this limitation of polyester by introducing a change in the external form of the fibres. In this context, fibre fineness and fibre cross-sectional shapes, as essential influencing factors in wear comfort, and have been the subject matter of research investigations of fabric designers [32]

Researchers shows that retention of warmth by polyester fibre is increased by making the fibre grooved and/or hollow, which is due to the reduction of thermal conductivity polyester fibres, [33].

The researcher [38] measured the thermophysiological comfort properties of Polyester twill fabirc considering fibres with different cross sections(Circular, Trilobal, Scalloped oval, tetrakelion) with the different space factors (1.00, 1.31,1.52,1.36) and different linear densities(1.33, 1.55, 1.66 and 2.22 dtex).

The schematic diagram of cross-section shapes are shown fig.7.

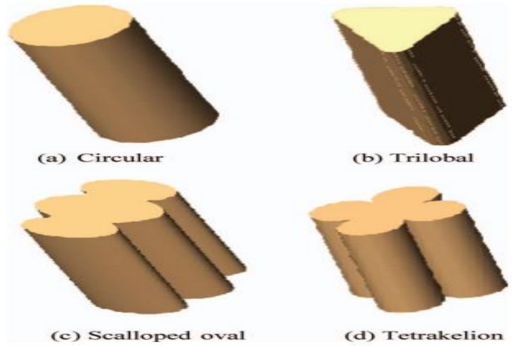


Figure 7 Shapes of fibre

The successive rise of thermal insulation values (resistance) with increase in polyester fibre linear density was observed from the results. This is attributed to rise in the volume of the air voids entrapped in the fabric sample, which leads to a reduction of heat flow through the fabric. Tetrakelion and trilobal fibres are shown to make their respective fabrics thicker and bulkier as compared to their equivalent circular fibres and hence offer more resistance to heat flow. In contrast, fabrics made of scalloped oval fibres are less thick than those made of their equivalent circular fibres, and as a result their resistance is comparatively lower.

The thermal absorptivity of fabrics reveals the influence of fibre fineness and fibre profile in polyester twill fabrics. The lesser values of the thermal absorptivity in the fabrics of tetrakelion and trilobal fibres as against circular equivalent means that these fabrics are warmer to touch. Higher value of thermal absorptivity indicates that the fabrics of scalloped oval fibres are cooler to touch. Similarly, results [38] shows that raising the fibre linear density definitely reduces thermal absorptivity.

With increase of fibre linear density, there is linear increase in the air permeability. Increase in fibre linear density decreases the surface area, thus reducing the resistance to the air flow. Porosity data show an increasing trend with an increase in linear density of polyester fibre, which results in an increase in air permeability. Similarly, the air permeability of fabrics circular fibres as compared to their circular counterparts is found to be significantly higher. In comparison with the circular profile, higher air permeability of fabrics made of tetrakelion and trilobal predominantly can be attributable to higher porosity and lower tortuosity. In the case of scalloped oval fibres, fabric porosity is the same as that of circular fibres, but comparatively less thickness, less tortuosity of the pores [38]. MVTR (Moisture vapour transmission rates) of fabrics composed of varying fibre fineness and cross-sectional shapes were also tested.

The effect of fibre fineness and fibre cross-section shape on the wicking properties of polyester fabrics are shown in figure 8 [38]. The effect of fibre shape is shown in figure 9.

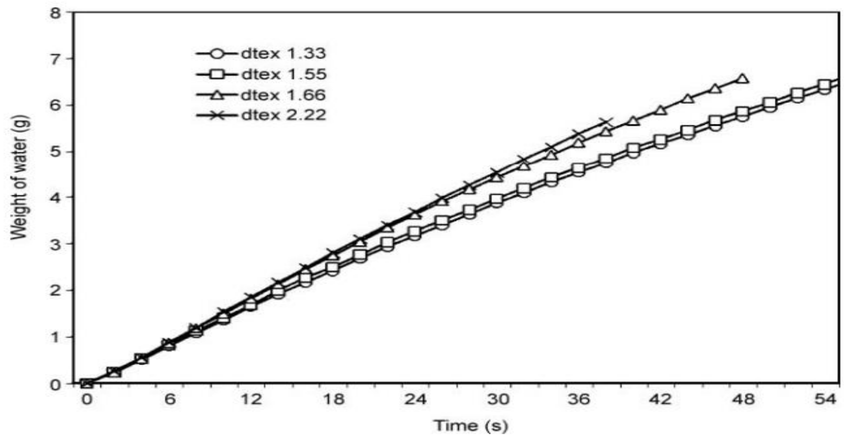


Figure 8 Effect of fibre fineness [38]

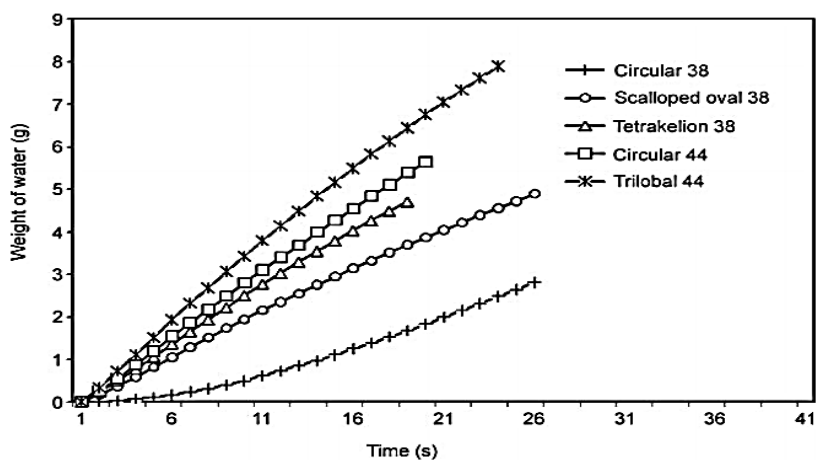


Figure 9 Effect of fibre shape [38]

The horizontal wicking time results presented in Fig.8-9 record the time taken for a water droplet to reach to a particular distance. Progressive reduction in polyester fibre linear density improves the wicking rate of the samples.[38] The fact that the liquid drop placed on the fabric spreads under capillary forces [39,40] – the magnitude of which increases as the capillary radius decreases as per the Laplace equation [41] – explains the observed trend. Indeed, finer fibres produce a tighter yarn structure, rendering the capillary radius smaller, and consequently the capillary flow becomes faster. In comparison with the circular fibres, the presence of surface channels on tetraskelion and scalloped oval fibres makes provision for water to pass more easily and quickly, as these channels work as additional capillaries for liquid water transportation [38] How well the adsorption and migration phenomenon mechanism functions depends not only on the hydrophilicity of the fibre surface but also on the extent of the fibre surface available for adsorption [34, 42, 43].

Research[38] shows that the fabrics of trilobal fibres record less time than that of corresponding circular fibres. Increase in fibre decitex raises the amount of water wicked in a specified interval of time (weight of water wicked/time) as opposed to the reduction in flow rate (spreading rate of a water droplet). This opposite behaviour can be attributed to the information that the velocity of liquid advancement is greater in a narrow pore because of the higher capillary pressure, but the liquid retention in such a pore is less. Large pores or a high total pore volume assists retention of more liquid volume [44]. At the same time, it is quite relevant to mention that smaller capillaries may create sufficient drag to slow down the liquid movement [45]. Therefore, in horizontal capillaries, the behaviour of liquid flowing under capillary pressure is governed by the Washburn–Lukas equation [46], stating that capillary flow at a specific time (i.e. rate of fluid flow) will be faster in a medium with larger pore size.

Other than all those physical properties of fibres molecular structure (chemical structure, degree of polymerisation, molecular mass) and supramolecular structure (degree of crystallinity, molecular orientation, amorphous regions and void fractions) have a strong influence on sorption properties through fibres. This is by the absorbency of the fibre. Water absorption of fibres, orientated in one particular direction, invariably causes swelling. The bigger the amount of water absorption, the bigger is the swelling. Swelling also depends on the fibre's structure, on the degree of crystallinity and on the amorphous and void regions. The degree of orientation has a significant influence on the speed of water absorption. As a result of water absorption, the fibres start to swell and their volume increases. Most importantly, the diameter of the fibres increases when using orientated fibres and the length increases when using non-orientated fibres [47]

Due to different chemical structures of different fibres, the fibres have different moisture absorbency. The comparison of the moisture regain of the different fibres is shown in table 6.

Table 6 Moisture regain of fibre [48]

Textile Fibre	Moisture Regain (%)
Cotton	8.5
Wool	13
Silk	11
Viscose	13
Acrylic	12
Polyester	0.4-0.8
Polyamide	4
Polypropylene	~0

Super absorbent fibres (SAF) or super absorbent fibrous material are popular from last decade to absorb and retain high amount of liquids (nearly 200 times its own weight). This rate can depend on salinity, it has an extremely fast absorption rate. It can easily be converted into a diverse range of nonwoven fabrics and spun yarn formats

SAF can be produced in a range of absorbency grades, staple lengths and decitex, to suit different requirements. These benefits have made it the super absorbent choice for many customers. [101].

The high hygroscopicity SAF significantly influences the perception of fabric dampness. Fabrics that contain water in excess of the equilibrium regain for the surrounding ambient conditions are perceived as damp during skin contact, which depends on the moisture sorption[102]

The SAF polymer can be produced of three different monomers – acrylic acid (AA) methylacrylate (MA) and a small quantity of special acrylate/methylacrylate monomer (SAMM) – in which the acrylic acid is partially neutralized to the sodium salt of acrylic acid (AANa). The cross-links between polymer chains are formed as ester groups by reaction between the acid groups in acrylic acid and the SAMM[103].

1.2.2 Effect of yarn structure

Other than the textile material, the production methods of the yarn and the fabric structures has influence on the thermal properties. All these processes can affect the porosity of the textiles so that their thermal properties. Cotton yarn made from different spinning technique is shown in figure 10.

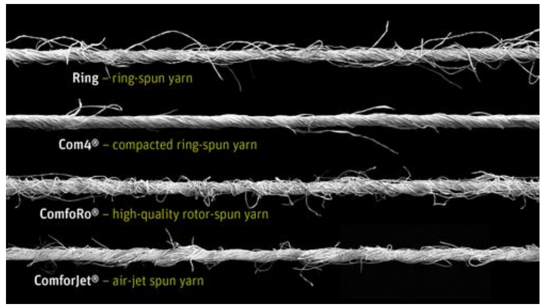


Figure 10 The image of cotton yarns spun by different spinning methods [49]

Researchers tested different textile materials to investigate the effect of all these parameter. The yarns with same count produced by different methods such as ring spinning, rotor spinning and friction spinning were tested for thermal properties [22]

Results shows that rotor yarn fabric has the maximum thickness followed by friction and ring yarn fabric. The higher thickness of rotor yarn fabric can be ascribed to a higher yam diameter. Friction fabric, although having a lower yarn diameter, has a higher thickness than ring fabric. This may be because of less compression at the cross-over points, as friction yarns are the least bulky.

Results for air permeability, as measured on the Textest air permeability tester, Fabric from rotor spun yarns is the least permeable to air, followed by ring and friction yarn fabric. It is because the rotor-spun yam, is the bulkiest yarn,

For thermal comfort both heat balance and moisture balance have to be achieved. The ratio of thermal insulation to water-vapor resistance gives a better comparison of thermal comfort provided by two fabrics. This ratio has been calculated for all these samples and the highest value was observed from friction yarn whereas the lowest value was from ring spun made fabrics.

1.2.3 Fabric Structure

Researches shows that knitted structures have a more open character when compared to other textile fabric structures, such as woven and braided. This character gives better air permeability as compared to other fabric structures [51 52]

Also for the woven fabric results shows that [22] twill fabric has higher thickness than a plain-woven fabric made from same yarns. In a twill fabric, cross-over points are lower than in a plain-woven fabric. Because of lower cross-over points, the compression of the yam at the cross-over point would be lower, and this lower compression would result in a higher thickness for the twill fabrics and small difference in the weight per unit area is due to the crimp difference. Results [22] for air permeability were higher for twill fabrics and this can be the result of difference of cover factors in two structure

Drop absorption is a simulation condition of absorption of a drop of liquid sweat by the fabric. A twill-woven fabric has a lower drop absorption time than a plain-woven fabric. Drop absorption time seems to be related to fabric cover or the number of air pores available at the fabric surface [22].

For a liquid to move in a fibrous medium, it must wet the fibre surfaces before being transported through the inter fibre pores by means of capillary action. The wetting property of textile call ass wettability. While the interactions of molecules in the bulk of a liquid are balanced by an equal attractive force in all directions, the molecules on the surface of a liquid experience an imbalance of forces. Hence, there is presence of free energy at the surface of the liquid. The excess energy is called 'surface free energy', which tends to keep the surface area of the liquid to a minimum and restricts the advancement the liquid over the solid surface. For a liquid to wet a solid completely, or for the solid to be submerged in a liquid, the solid surfaces must have sufficient surface energy to overcome the free surface energy of the liquid. To get the best information about wetting of a solid, the useful parameters are work of adhesion and solid surface energy.

The chemical nature and physical structure of the solid influence the solid surface energy.[53]

Water has a very high surface tension (72.8 mN/m), so it tends to wet only surfaces bearing highly polar groups; otherwise, it forms spherical drops with contact angles higher than 90°. Instead, liquids of lower surface tension get drops flatter than water.

The surface modification of textile fibres can be achieved by physical or chemical methods or by the combination of both. The sorption by textiles can be changed with different treatments and finishes such as mercerization, plasma treatment, chlormatin, chitosan, enzyme treatments, brushing and singing, silicone treatment, nano coatings, etc [54, 55]

1.2.4 Effect of garment fit

There is also an important air gap for thermal comfort but this time it is not inside the textile but it's in between textile and the human body. The thickness of the microclimate is also important phenomena for the thermal comfort so in this case the importance of the garment fit is the effecting parameter for thermal comfort.

Thus the thermal, evaporative and wicking properties of clothing depend not only on the properties of the fabric used for the garment but also on the magnitude and the temporal change of the contact area and air layer thickness [56]

McCullough et al.[57] investigated how garment design influences the thermal insulation value of clothing. By comparing tight-fit and relatively loose-fit long trousers, they found that loose-fit trousers provided higher insulation than tight-fit trousers. However, the researchers also stated that movement could circulate air inside the trousers and thus increase the convective heat transfer of the loose-fit trousers more than tight-fitting trousers. Havenith et al.[32] conducted research on the relationship of garment fit and clothing insulation. By testing three clothing ensembles on four male subjects (two wearing loose-fit and two tight-fit clothes) while sitting and walking, and under three wind speed conditions (air speed <0.1m/s; air speed = 0.7m/s; and air speed = 4.1m/s). The results showed that tight-fit clothing had 6–31% lower insulation than loose-fit ones. Additionally, the difference was highest during sitting and decreased in windy conditions.

The above studies were carried out under relatively low levels of body motion and wind, and at high levels of body motion and wind. Loose-fit clothing allows bigger spaces between the body and the material, thus more airflow is allowed and the replacement of warm and cool air should be more active and effective [59]

1.3 Automotive textiles

Every middle-size vehicle uses between 12 and 14 Kg of textile products, without including tire cords for pneumatic and fibres which are used in composite materials. The 65% of this quantity is used, approximately, in the interior (40 to 45 m^2 of textile material per car) with a weight between 350 and 450 g/ m^2 for the seats upholstery [60].

Textile advances in the automotive industry have been spearheaded by advances in science and technology of fibres and fabric/web forming technologies. These advances have led to the development of textiles and textile-based components for a broad variety of automotive applications which are capable of meeting the industry's tough specifications regarding high performance during use [63].

Car production development of components, parts, pieces and materials is orientated by the following criteria:

- Comfort
- Functionality
- Safety
- Economy
- Ecology

Car seat is perhaps, the most important part of the interior, it is the first element that the customer appreciates when he/she opens the door to look inside and it is the main interface between person and machine.

Therefore, the comfort is the first criterion that values the customer, specifically psychological comfort - makes reference to the aesthetic aspects - and physiological comfort captured by the view and touch. During the sitting the thermal comfort is evaluated by the "cold-hot" sensation. Functionality and material safety criteria are captured during use of the vehicle, by means of wear, seat ventilation, the internal environment, ease of care, etc [60].

1.3.1 Technical requirements of Automotive seats (Textile)

All these aspects relate to the technical characteristics of textiles. Automotive, textiles have to fulfil a certain list of technical requirements, which strongly depend on the application. It can be divided into the following groups:

• Processing properties such as:

  - sew ability
  - sewing strength
  - seam slippage resistance
  - stiffness
  - elongation
  - tensile strength.

• Service properties such as:

- mechanical behaviour (strength, elongation, bending and folding, tear propagation strength, dimension stability, pressure resistance)
- ageing behaviour (heat/cold, temperature, humidity, light)
- colour fastness (friction, light, chemicals, sweating)
- friction behaviour (brushing-up, abrasion, pilling, fibre migration)
- breathability (air permeability, heat and humidity transport in upholstery)
- emission behaviour (toxic elements, smelling, fogging, total emission)
- contamination and cleaning behaviour
- electrostatic behaviour
- Flammability
- Optical, haptic, design.

Depending on the application, some additional specific requirements may have to be considered [64].

The diversity in textiles for automotive end uses offers plenty of opportunities for growth in the automotive textiles industry because of the ever increasing demands on aesthetics, comfort and safety of passengers as well as the environmental issues such as low weight, lower energy consumption and recycling after a vehicle's life cycle [63].

New designs in automotive construction are increasingly influenced by the legal regulations on emissions and those on the waste from old vehicles, which require the use of materials that can be recycled. These influence nearly all textile developments in the automotive sector

It was required automobile manufacturers to greatly increase the recyclable products used in vehicles with a target rate of %95 recyclability by 2015[61, 62]

The textiles for interior furnishing are primarily made of woven, weft knitted, warp knitted, tufted and laminated fabrics and nonwovens. The design, aesthetics, feel and comfort are important considerations for automotive textiles [64].

Future trend for car seats is to replace the foam by a textile material able to match various constraints such as resilience and resistance to fatigue. As a result, the chemical agents used in foam production and the different solvents used during the production process are totally avoided, which may lead to environmental friendly and more easily recycled material [65].

1.4 Car Seat

Generally, car seats are composed of the following elements:

1. Metal structure.
2. Filling, cushion padding.

3. Seat cover:

- Exterior fabric,
- Foam (interlining],
- Support material (reinforcement material) [60,68].

The parts of the car seat in cross-section view is shown in figure 11.

Figure 11 the parts of the classical car seat

On the top of metal frame the most common filling material as a cushion is molded polyurethane foam. The evolution of car seat cushion material is shown in figure 12.

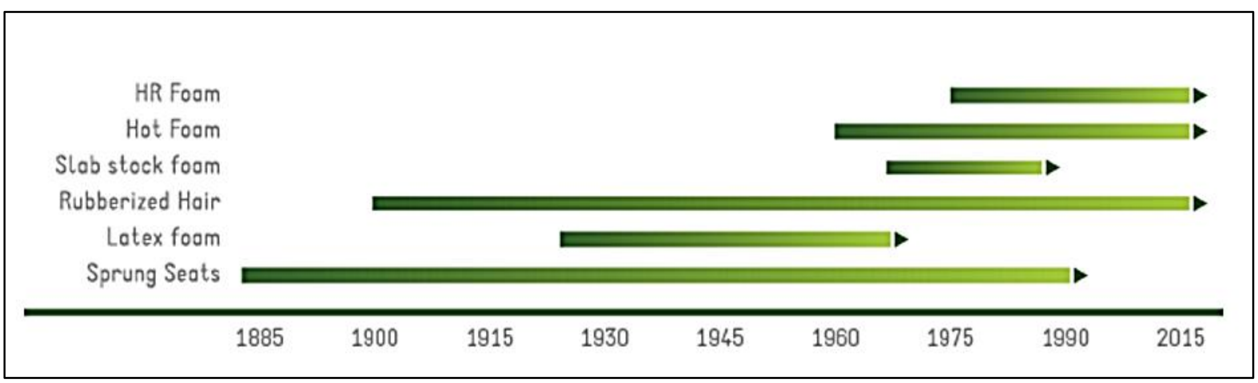


Figure 12 evolution in technology of car seat cushions [66].

In sprung seats, springs are used as shock absorbers to support the comfort of vehicle occupants, in combination with other materials such as hair, cotton or other resilient materials. This "historical" type of seats was produced in Europe until the 1960s and in Eastern Europe until the 1990s.

The seats of the Ford Model T were stuffed with hair. But, with mass production, it soon became clear that hair fibres require treatment to avoid disintegration or loosening. For that purpose, animal fibres were impregnated and bonded with natural or synthetic rubber latex. More recently coconut fibres have been used, along or in combination with animal fibres. Today, small volumes with coconut fibres agglomerated with a latex mixture are still produced in Europe.

Latex foam cushions were installed in London's buses as early as 1932. Progressively the technology was adapted to passenger cars, for which it remained the mainstream technology until the 1960s. Latex was replaced by polyurethane foam for two main reasons: the production process of polyurethane foam is easier to master and provides a more consistent product, and its cost is lower than that of the latex foam production process. This is why the technology was relatively quickly replaced by polyurethane foam when it came onto the market.

Polyurethane foam started being integrated into car seats as early as 1958, when General Motors started using PU foam topper pads (from slabstock foam) in the seats of some of its vehicles equipped with spring seats. But soon the use of slablstock foam for car seats had to give way to moulded foam.

Indeed, in 1961, the first flexible moulded polyurethane foam production started. This "hot cure foam" production was the start of a rapid growth and takeover of the seating market. Compared to slabstock foam, moulded foam can be produced directly in the shape needed and is therefore better suited for the production of car seats than slabstock foam, which required complex cutting and gluing (and hence loss of material) to achieve the desired result.

"Cold cure foam" was developed in the 1970s. Contrary to hot cure foam it can be produced at low or even ambient temperatures. This foam has a latex/rubber-like feel, higher support factor, improved inherent flammability resistance and – most importantly – better maintains its resilience over the long term. And of course, the lower production temperature means less energy consumption [66].

Polyurethanes, one of the most versatile group of plastics, are used in a wide range of applications. They are made from two basic raw materials: polyols and polyisocyanates, which are measured and mixed to form solid polyurethanes or various types of foams.
Polyurethanes combine lightweight and flexibility with strength and durability. Their versatility is instrumental in achieving the precise mechanical properties required for specific applications [67].
Polyurethane foam is commonly used as padding in car seats despite some problems concerning comfort and recycling. Their thermal properties are poor because they are not breathable. Because of this problem many research has been made and today the new developments and the testing are going on to improve the thermal comfort of the car seats

New trend 3D spacer fabrics are popular to improve the breathability of the seating and metress materials to improve the thermal comfort. Through continuous improvement of both the technology and the produced fabric quality, both warp and weft machines are now capable of producing spacer fabrics to the very highest standard of quality for a wide range of applications. Using new possibilities and improved machine technology, spacer fabrics have already become an established feature of many areas.
Unlike regular, 2D fabrics, Spacer uses two separate fabrics, joined by microfilament yarn, to create a breathable, 3D free space between layers[70] as shown in figure 13 .

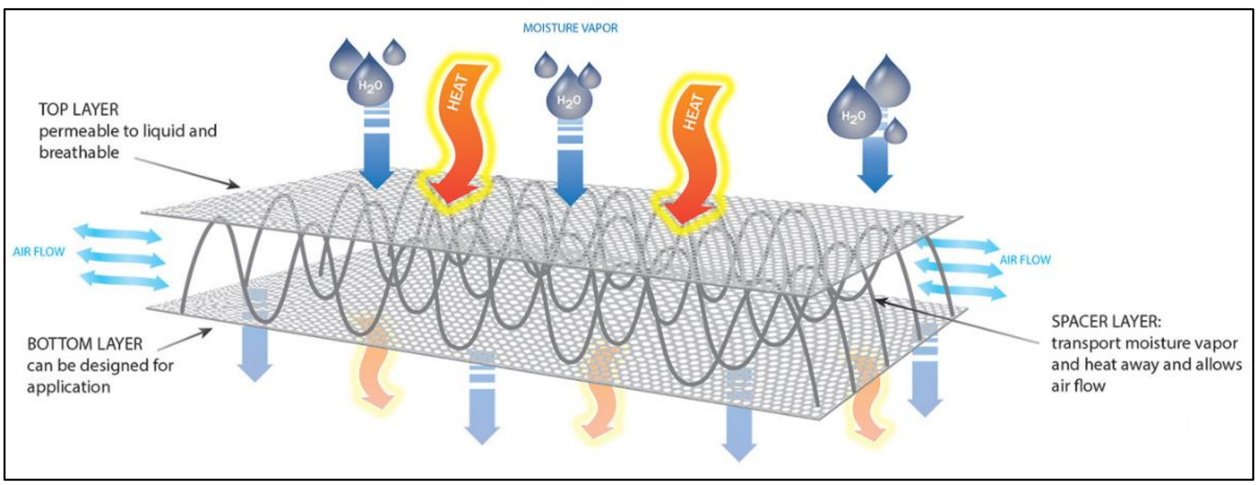


Figure 13 3D Spacer Knitted Fabric Schematic design [71]

Spacer textiles in upholstery are made from warp knitted (double-Raschel machine) or knitted (circular knitting machine) fabrics as shown in figure 14. They are made from two separate textile layers which are connected by stiff spacer yarns. Monofilaments (single) are mainly used for spacer yarns. The height of the structure is governed by the distance of the two needle bars of the Raschel machine and by the distance between the cylinder and rib discs in the circular knitting machine. The force that is necessary to keep the two textile layers apart depends on the material, thickness and structural integration of the spacer yarns (monofilaments). Spacer structures have an elastic pressure behaviour: by pressing on the surface they are compressed. When the pressure is released, they relax in an elastic way. The space between the two layers is an air-filled cavity from which the air is removed during compression, and into which air is sucked during decompression. Unlike foam constructions, these textile constructions are able to breath [64,69]

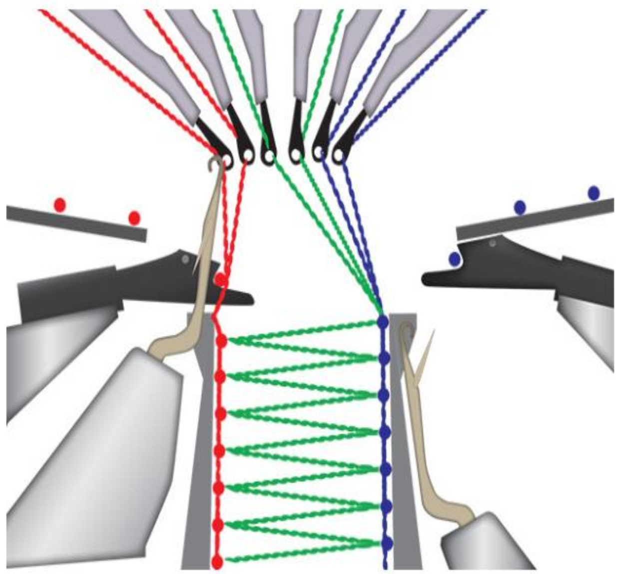


Figure 14 3D spacer Knitted fabric production [71]

Textile materials with thicknesses from 2 to 3 mm up to 7 or 8 mm are required for carseat cover interlining use. Until now, such textiles have only been produced for end-use application from stitch-bonded and thermal-bonded nonwovens and warp-knitted spacer fabrics as shown in figure 15.

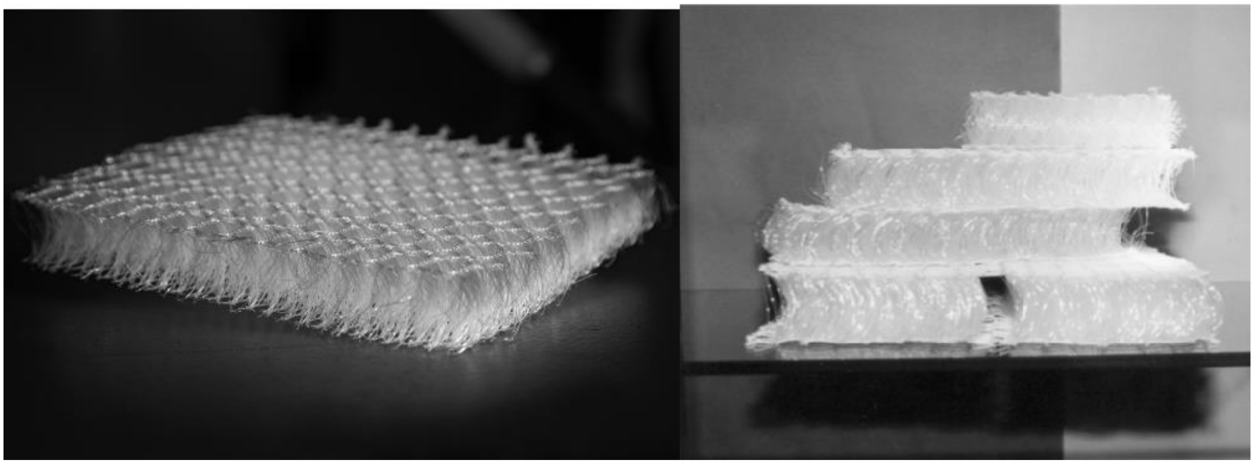


Figure 15 Wrap Knitted Spacer Fabrics [70,71]

Several nonwovens, such as stitch-bonded or needle-punched products, are already in use in car seats. Mercedes-Benz has used the Malivlies type of material as a supporting layer. However, such materials do not function as a cushioning layer in the same way as PU foam

Investigations into the use of textiles as substitutes for PU foam in car seats have been carried out by several European car manufacturers. Today, the three-dimensional, stitch-bonded nonwovens, Multiknit/Caliweb®, are used in several types of car [70]

For the car seat cover on the top of the cushion part of the car seat many manufacturers find that a three-layer composite fabric is most successful in performance, costing, and in the process of upholstering or trimming the seat. The most common three layers are composed of a top layer which is polyester; a middle layer of polyurethane foam, The foam, varies from 3 millimeters to 12 mm, and it has function of absorbing the seat surface irregularities, improves the comfort (compressibility, resilience) and indicates the stitches of the sewing lines with an adequate depth [60].; and the bottom layer, a polyamide knitted scrim[72]. Knit Scrim material has the task to give the dimensional stability to sandwich structure, facilitates the sewing and seam resistance. It can be a polyamide mesh or polyester and a non-woven as well [60].

These three layers, fabric-foam-reinforcement, are fixed by flame lamination. Machine setting controlling flame temperature, gap separation of the roller and speed can be optimized.

The available technology for the production of the external fabric is a part of the textile technology. These are:

- Woven fabric.

- Woven fabric with loom of double woven (velvets).
- Weft needle fabric done in circular knitting machine (generally with pile).
- Weft needle fabric for warp in Ketten (velvet) (Ketten knit fabric).
- Weft needle fabric for warp in Raschel of double knitting head (with pile) (Raschel knit fabric). etc.

Each technology has advantages and limitations, and car manufacturers use your criteria or priorities for different fabrics. These criteria are grouped by countries, geographical and continent areas.

Other than these textiles, leather and the artificial leather is also used in the automotive industry for car seat and the other interiors. However, coated leather as it is used in seats can impede the transport of vaporous sweat, it offers only a rather poor breathability. A fabric has better thermal comfort properties than a leather [73], Also the leather has very high production cost. Fabric, which is mostly used for the car seats, is polyester [64] with high abrasion resistance, UV light resistance and cleaning facility combined with a reasonable price, but disadvantage is that cannot absorb nor transports humidity. Cotton and the wool sometimes can be used as additional fibre in very low percentages.

The second upholstery element, the polyurethane foam, show an excellent elasticity, indicates the stitches of the sewing lines with an adequate depth and its technology is quite good develop but presents some disadvantages: low air permeability[60], environmental unfriendly as it generates harmful emissions, toxic gases and odours during process[75], non-recyclability, etc.[60]

Recycling the fabric component at the end of life is complicated in modules containing PUR foam, manufactured using several raw materials which are difficult to separate and with partially recyclable materials is the reason of this problem , Using textile structures (nonwovens, 3D spacer) made from homogeneous polymer such as polyester or polypropylene, thereby simplifying the end of life recycling[74].

The target of re-use and recovery by January 2015 was to reach 95%. It is expected future vehicles to be designed and manufactured for efficient dismantling, re-use and recycling at the end of life [61, 62, 74]

The 3D spacer fabrics and the nonwoven textiles are alternative material to be used in car seat covers, their comfort properties, sound absorption, health benefits (avoid toxicity) and recyclability can increase their use in automotive industry

Last layer of the car seat which is at the bottom is the polymer mesh fabric, highly used material is polyamide, but different polymers also can be used. It is high porous layer so that has high permeability. The biggest reason to use this layer is the PU foam, It smoothies the back side of the PU so that the sewing and the covering of the car seat process is easier and faster.

In case of the using 3D spacer fabrics and the some kind of nonwovens this last layer of polymer mesh may not be used so it reduces the number of the layer and the required lamination.

1.4.1 THERMOPHYSIOLOGICAL COMFORT OF CAR SEATS

Today, comfort has become a major quality criterion of cars. Comfort in a car is a complex phenomenon and comprises such different aspects as, for example, noise, driving behavior, or ease of handling. One of the most important factors influencing passenger convenience is thermal comfort. Therefore, car manufacturers are paying a lot of attention to this aspect, as can be seen by an increased application of air conditioning in the car [11]

A particularly important aspect of vehicle comfort is the seats. Seats do not only have to have an attractive design or meet specific design criteria for safety reasons, they must also have optimum comfort properties. But seat comfort is much more than just passenger convenience. Scientific findings show that the performance of a driver over long distances significantly decreases if the car seats do not support posture and heat balance as required. This leads to exhaustion and loss of concentration, which, in extreme cases, could result in serious accidents [10,76]

In addition to ergonomic considerations of comfort, the climatic or thermophysiological comfort of the seat is of particular importance. This indicates whether the seat is able to support the thermoregulation of the body via heat and moisture transport.

1.4.2 Parameters of seating comfort

From the physiological point of view, seat comfort comprises the following four parameters [11]:

i. The initial heat flow following the first contact with the seat. In other words; the sensation of warmth or cold in the first few minutes or even seconds after entering the car.
ii. The dry heat flow on long journeys, i.e. the amount of body heat transferred by the seat.
iii. The ability known as “breathability” to transfer any sweating away from the body. In so-called “normal sitting situations” there is no perceptible perspiration, but, nevertheless, the human body constantly releases moisture (so-called ‘insensible perspiration’), which has to be taken away from the body
iv. In the event of heavy perspiration (a car in the summer heat, stressful traffic situations) the ability to absorb perspiration without the seat feeling damp.

1.4.3 Warmth sensation

25% of human body is in contact with car seat and the car seat acts as an extra layer of the clothing thus the effecting parameter of the clothing comfort is the same for car seat thermal comfort as well.

The passenger is already sensing his first thermal impression of a car seat while entering the vehicle. This initial perception of warmth after sitting depends on the thermal absorptivity of the car seat. It is effected by is its heat capacity of the car seat material. Heat capacity is amount of heat required to raise its temperature one degree. Heat capacity varies with the mass of the cushion and the type of material. Thermal conductivity is also another parameter of the thermal absorbency and the thermal absorptivity should be as low as possible; otherwise a car seat feels cold in the winter time or hot during summer [77,11]

Although this initial feeling may last only a few minutes, it is nevertheless very important for the user’s acceptance, as it is being repeated frequently. If a car is used every day during the winter time and each morning the driver is dissatisfied when entering the car, acceptance can be significantly decreased.

During long journeys it is favorable if the seat offers a high steady state heat flow, to minimize the tendency to sweat [76,78], whereas for the initial perception a low heat flux is required . Hence a conflict arises between these two scenarios.

This conflict can be overcome, because the cover, which determines the initial perception, is only of minor influence on the steady state heat flux, which is mainly determined by the thermal insulation of the seat. Owing to its greater thickness and, hence, higher thermal insulation in comparison to the cover, the cushion becomes the dominant part.

On the other hand, the heat flux is also dependent on the ventilation in the seat. Ventilation itself is determined by the design of the seat (side supports, surface grooves), the elasticity and air permeability of the cushion and, if present, a fan to enforce ventilation. [80]

For the car seats with heating, the dominant seat components are the cover. Other than thermal properties of the car seat cover, heating power and its position are of great importance [79, 80]

As a common material used in car seats, Foams are poor conductors of heat and have a low heat capacity. A thin layer of foam (plus cover) warms up to skin temperature when driver sits on it, but does not draw much heat from the body's tissues. In warm environments, or during physical exercise, the body attempts to lose heat but is prevented from doing so in the buttocks area and back rest due to the insulating foam of the cushion. This region may therefore begin to heat, resulting in uncomfortable dampness

A car sit with impermeable foam can increase the skin temperature 10^0 C in 2 hours and increase of the temperature of the skin will cause sweating [77]

1.4.4 Moisture sensation

The moisture sensation of the passenger is very important for perceived overall seat comfort. In order to achieve a dry microclimate, the ability, known as ‘breathability’, of the seat to transport any perspiration formed away from the body is crucial. Not only under warm summer conditions is good water vapour transport necessary, but even when there is no perceptible perspiration. The human body constantly releases moisture, the so-called ‘insensible perspiration’. As the skin is not totally water vapour tight, our body loses on average 30 grams of moisture per hour. Because a car seat covers large areas of the body, the seat has to manage a large part of the perspiration formed, and, hence, a considerable amount of moisture [11].

Moisture accumulation results in discomfort and, in some cases, an increased risk of soft tissue damage. Many factors determine the causes and prevention of moisture accumulation.

Generation of excessive quantities of heat can cause the sweating. Sweat is normally generated to assist in the thermoregulation of the body by the evaporation of moisture to cool the surface of the skin. Normally, sweating is suppressed locally by pressure. However, sweating can occur in an uncontrolled manner, independent of thermoregulation as insensible perspiration.

Poor exchange of air is one of the reason of moisture accumulation if there is poor exchange of air in the supported area and the supported area is thermally insulated by the cushion, the interface temperature can exceed 38^{o}C, where upon sweating increases rapidly with increasing temperature. So that use of impermeable covers for car seat can increase the moisture accumulation. If materials in close contact with the skin do not "breathe" the sweat from body is not being evaporated so that natural environmental cooling cannot occur and resulting in more heat build-up and more sweating.

Methods for preventing moisture build-up include the use of cushion and cover materials that encourage air exchange between the cushion and skin. Any impermeable layer of car seat will be the barrier for moisture transport and will make the complete structure impermeable so that uncomfortable. Cushions with good heat dissipation characteristics help to reduce moisture build-up, if they include absorbent materials like wool or cotton, it helps to reduce moisture build-up.

Some cushions naturally pump air that is trapped in their structure when compressed. This effect can contribute to maintaining comfortable moisture levels at the cushion/skin interface, if the cushion is fitted with an air permeable cover [77].

One solution to reduce the degree of discomfort can be ventilation of the car seat. This can be the solution of both sense of high temperature and the high moisture. To be able to use the car with ventilation systems it is important that the car seat should have the sufficient air permeability and should give the good distribution of the air [81-83]. Suction or blowing of air is also another parameter that may affect the flow of air in car seats.

Insertion of a component blocking the transport of moisture (e.g. polyurethane foam of a thickness greater than 5 mm, leather and artificial leather products, flame and the other adhesive lamination of the layers) inside a carseat disqualifies the whole carseat, irrespective of the quality of the remaining components [82]. This is unwanted situation for both with or without ventilation seats. In this case the water vapour absorbency is the car seat cover layer is the only source to remove the moisture from microclimate in between human body and the car seat.

2 Present State of Problem

2.1 Material and design

There are many kinds and design available for the car seat cover, it is necessary to analyse the real performance of these material by experiment. New material like 3D spacer fabric, superabsorbent, reticulated foams and nonwoven linings needs further experimental analysis related to their performance and durability.

Therefore, it's necessary to examine the role of different material for the comfort of car seat.

2.2 Experimental techniques

The experimental verification by most of the researchers is done by measuring the top single layer of the car seat's cover using the skin model. The complete combination of car seat cover with the cushion is not studied mostly by the producers as the experimental measurement of thick car seat cover is impossible to measure using classical machines and effect of non-porous foam and the lamination is mostly neglected. It is necessary to use different experimental technique to compare the results and also find suitable technique to measure the breathability of the car seat cover with cushion and also under load to observe the real time performance of the complete car seat. The measurement by subjective and objective techniques is also necessary to obtain valuable results.

Therefore, experimental measurement on real car seat and under load needs to be investigated.

2.3 Compression properties and lifetime of car seat cover

Any modification to car seat cover especially to the PU-foam part may cause a dramatic decrease in its thickness in longer run. This low thickness changes the porosity and comfort performance of the car seat. Due to this reason the producers are hesitant to make any changes especially to the PU-foam to avoid changes in thickness over time. It is necessary to observe the change on thickness and properties of car seat foam part under repeated loading.

Therefore, classical and modified PU-foam must undergo some test of repeated loading to observe its thickness change over time.

3 Objectives

The objectives of the study are

- To identify the factors that affect the breathability of car seats
- Analyzing the pressure distribution on car seat
- To improve the overall comfort properties of car seat
- Testing the compressibility properties of newly design layers
- Testing the compressibility properties of newly design layers
- Novel techniques for experimental measurement
- Theoretical Model for air flow through car seat foam material

3.1.1 To identify the factors that affect the breathability of car seats

- Testing overall air and moisture permeability of car seat cover
- Effect of different layers and lamination on the breathability of car seats**.**
- Compare car seat cover at different conditions**.**
- Identifying the problem issue for breathability of careats

3.1.2 To improve the overall comfort properties of car seat

- Effect of perforation on the breathability of car seat cover
- Effect of super absorbents on the comfort of car seats
- Effect of different top layer of car seat on breathability of car seat

3.1.3 Testing the compressibility properties of newly design layers

- Testing the newly designed layer under repeated load for life time of car seat cover
- Comparing original and improved car seat cover under repeated load

3.1.4 Novel techniques for experimental measurement

- Designing instrument for moisture permeability under load.
- Designing portable device to test directly on the car seats

3.1.5 Theoretical Model: Analyzing theoretically the air flow through car seat foam material

- Theoretically analyzing the flow of air through the PU- foam of car seat

4 Experimental Part

4.1 Materials and equipment's

The experimental part of the research included different combination of car seats cover and the lining material including poly-urethane foam. The car seat is made of multiple layers as shown in figure 16.

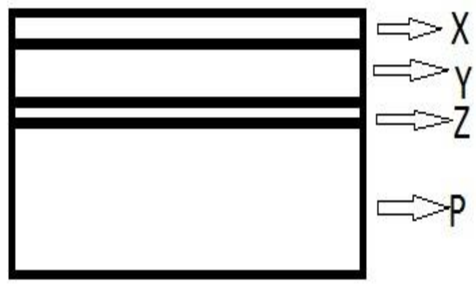


Figure 16 Layers of car seat

Where
X is top fabric layer which touches the person/driver
Y is second layer made of thin poly-urethane foam
Z is thin porous polyester mesh
P is thick 10cm PU-foam

Classical thick PU-foams are obtained for the car seat from the company GRAMMER (Germany). It is one of the biggest car seat producers in the world. The details of the foams are as shown in table 7.

Table 7 Types of cushion foams

Foam Type	Density [Kg/m^3]	Thickness [cm]
TDI	40.24	6 and 8.5
	46.16	6 and 8.5
MDI	54.65	6 and 8.5
	60.6	6 and 8.5

The top layer of the fabric are ordered from Company Johnson Control (CZE) and the details of the top layer is shown in table 8.

Table 8 Properties of car seat cover material

Number		Fleece		3D Spacer			Face Fabric			
	Mass per unit area [g/m²]	Thickness [mm]	Material Composition	Mass per unit area [g/m²]	Thickness [mm]	Material Composition	Technology	Warp direction details	Weft direction details	Material Composition
26989	100	2	100% PES	250	3	100% PES	warp knitted	14 wale/cm	29 course/cm	100% PES
25976	230	5	70% PES, 30%WO				warp knitted	13 wale/cm	24 course/cm	100% PES
25979	230	5	70% PES, 30%WO	335	5	100% PES	warp knitted	13 wale/cm	24 course/cm	100% PES
26728	230	5	70% PES, 30%WO	335	5	100% PES	woven	33 end/cm	18pick/cm	100% PES
26977	100	2	100% PES	250	3	100% PES	woven	32end/cm	18 pick/cm	100% PES
26200	230	5	70% PES, 30%WO	335	5	100% PES	warp knitted	15 wale/cm	25 course/cm	100% PES
26195	100	2	100% PES	250	3	100% PES	warp knitted	15 wale/cm	25 course/cm	100% PES
25962	100	2	100% PES	250	3	100% PES	woven	34 end/cm	18 pick/cm	100% PES
25967	230	5	70% PES, 30%WO	335	5	100% PES	woven	36 end/cm	16pick/cm	100% PES
29086	230	5	70% PES, 30%WO				warp knitted	14wale/cm	28course/cm	100% PES
29084	230	5	70% PES, 30%WO				woven	36 end/cm	16 pick/cm	100% PES

Second set of the samples were obtained from the company MARTUR (Turkey), which is famous car seat cover producer in Europe. All these layers are obtained as sandwiched as well as single layers to identify the effect of lamination. The construction of woven top layers is shown in table 9.

Table 9 Woven car seat cover materials

	WOVEN PATTERN	WARP DENSITY	WEFT DENSITY	CROSS SECTION	YARN NUMBER	FILAMENT NUMBER	TEXTURE TYPE	Number
1	1X1 PLAIN	24	17	ROUND	300	96	IMG	**P2284 (1)**
2	1X1 PLAIN	24	17	OCTOLOBAL	300	96	IMG	**P2285 (1)**
3	1X1 PLAIN	24	17	ROUND	450	96	IMG	**P2280 (1)**
4	1X1 PLAIN	24	17	ROUND	300	192	IMG	**P2281 (1)**
5	1X1 PLAIN	24	17	ROUND	300	96	ATY	**P2282 (1)**
6	1X1 PLAIN	24	17	ROUND	300	96	TWISTED	**P2283 (1)**
7	TWILL	24	17	ROUND	300	96	IMG	**P2284 (2)**
8	COYOS	24	17	ROUND	300	96	IMG	**P2284 (3)**

The properties of self-perforated foam are shown in table 10.

Table 10 Properties for perforated PU foam used for the experiment

	Foam thickness	Number of holes	Hole diameter	Total area of foam sample	Area of holes	Area of solid foam
	mm		mm	mm^2	mm^2	mm^2
A	60	0	0	16505	0	16505
A1	60	7	10	16505	550	15955
A2	60	7	15	16505	1236	15268
A3	60	7	20	16505	2198	14307
B	85	0	0	16505	0	16505
B1	85	7	10	16505	550	15955
B2	85	7	15	16505	1236	15268
B3	85	7	20	16505	2198	14307

The Figure 17 shows the real picture of the perforated foams

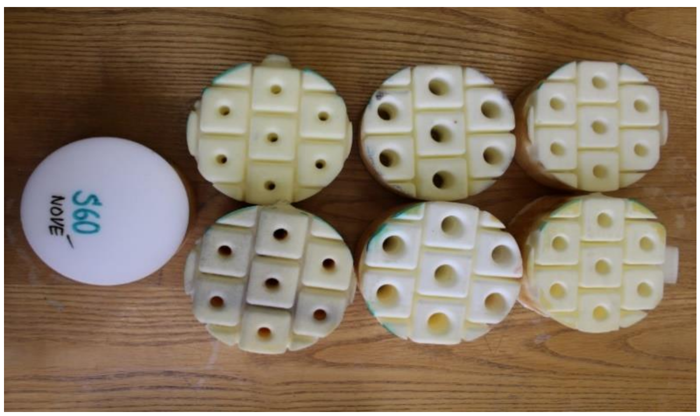


Figure 17 real picture of the perforated foams

Four real seats are also used for this research.

- Seat A is a tractor seat made from woven fabric.
- Seat B is Truck seat made form woven velvet.
- Seat C is truck seat made from Polyester knitted fabric.
- Seat D is truck seat made from leather.

Figure 18 Tractor seat A

Figure 19 Truck seat B

Figure 20 Truck seat C

Figure 21 Truck seat D

Super absorbent materials were specially obtained from the company TECHABSORBENTS. The properties of the obtained Superabsorbent are shown in table 11

Table 11 SAF Properties

	Composition	Structure	Areal weight (g/m^2)	Thickness (mm)
A	Polyester staple fibre	Needle felt, non-woven	570	5.4
B	Fluff pulp	Bi component fibre	130	1.6
C	Polyester staple fibre	Super absorbent yarn netting, laminated with PES weave	115	1

Climatic conditions in Lab

- temperature of air: 22 ºC
- relative humidity of air: 62 %

Following instruments are used to perform this research,

1- Air permeability tester (FX-3300) and SDLMO21S by using standard ISO9237 for air permeability testing
2- Alambeta and Permatester for thermal resistance and moisture resistance of material
3- Atlas sweating guarded hot plate for water vapour resistance measurement of thick samples like PU foam(ISO 11092)
4- X-ray tomography to analyse the internal structure of samples to see the pore structure and air gaps.
5- Upright Cup method to analyse the loss of water vapour loss from thick layers of car seat. (ASTM E 96-66)
6- Novel techniques to measure the moisture permeability under load.
7- Dynamic compression tester to analyse the performance of material under long term use.
8- X-sensor pressure sensing sheet to determine the average load on the car seat.
9- Thermal camera (FLIR) for direct measurement of thermal field on car seat
10- Sensor sheet to obtain direct measurement of temperature and humidity.

5 Factors affecting the breathability of car seat.

Car seats are made of multiple layers and each layer has unique importance for the comfort, durability or lifetime of car seat. The top layer is mostly made permeable to air and moisture but the bottom and middle layer made up of PU-foam are known for being impermeable to moisture or air. But PU-foam are easy to use, cheaper to produce, durable and long life so they are an essential part of the car seat. For this research all material types mentioned in the Experimental Part are tested for air and moisture permeability using device FX3300 and Atlas SGHP respectively. The results are represented as minimum and maximum of each group of material which gives us better idea where the actual problem with the breathability of the car seat is.

Different material shown in experimental part under each layer (X, Y and Z from figure 16) of car seat are tested for the air permeability and results are shown in table 12.

Table 12 Air permeability of each layer of car seat

Material	Air permeability (Min – Max) [L/m^2/s]
Different top layers-X	2000-5000
PU-thin foam or fleece-Y	700-920
Knit mesh-Z	9000-9400
PU-foam -P	15-25

This table 12 clearly shows the PU foam and the Lamination dramatically decreases the air permeability, even though the top layers are highly breathable but complete sandwich structure will not allow the flow of air.

To see the exact effect of lamination the car seat cover material from Table 9 were tested for air permeability. All the material are tested with (flame lamination) and without lamination and results are shown in figure 22 and 23.

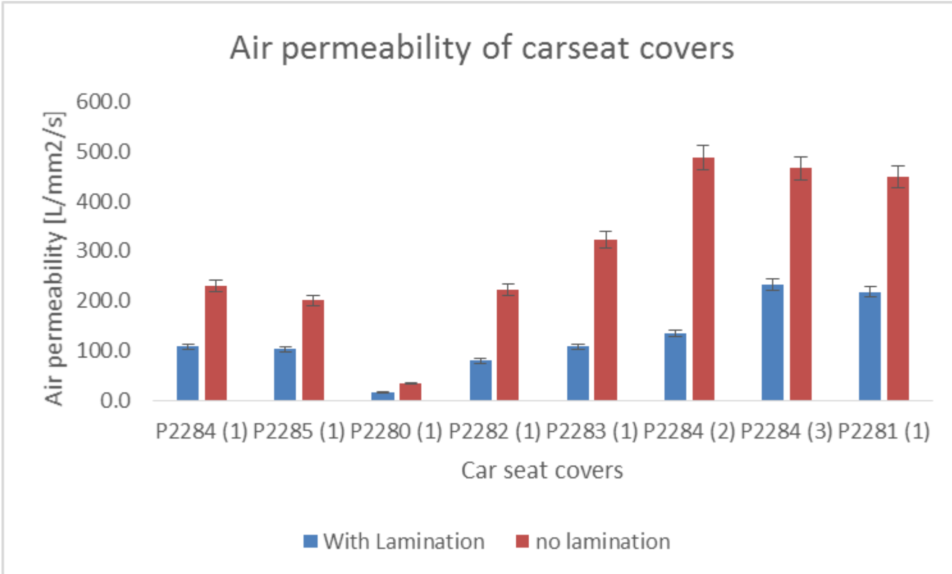


Figure 22 Effect of lamination on air permeability

The results clearly show that the lamination (to stick each layer together) significantly affect the air permeability of the car seat cover. As the lamination closes the pores of the woven or knitted textile layer and blocks the flow of air. The lamination is mostly a polymeric material which melts to stick the two layers and eventually closes the pores of the textile layer.

The set of sample were also tested for the water vapor resistance with the machine Atlas SGHP. Each experiment is repeated 5 times for mean value.

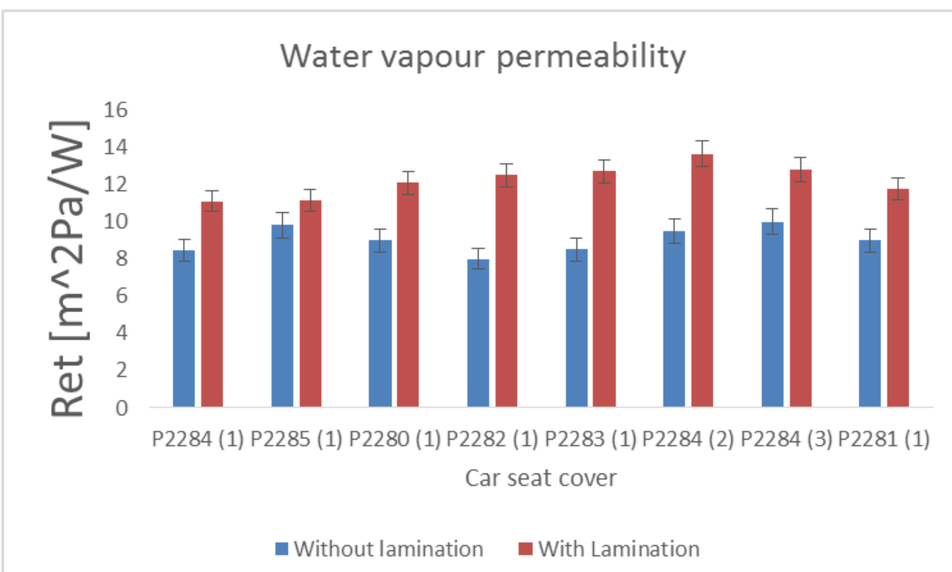


Figure 23 Effect of lamination on water vapour resistance

The similar trend can be seen that the laminated layers significantly affect the moisture permeability of the car seat’s cover material.

5.1 Effect of interlining thickness

The top layer fabric 2284-1 (details in table 9) is tested with different interlining materials to see the effect of interning thickness and material on the breathability of the carseat cover.

Table 13 shows the thermal conductivity of single top layer with multiple kinds of interlining materials. A low thermal conductivity is always preferred for carseat materials.

Table 13 Thermal conductivity of top layer with interlinings

Samples	Car seat top layer(2284-1)+ Interlining
1	3.6 mm foam
2	5.6 mm foam
3	6.7 mm foam
4	8.5 mm foam
5	3D spacer 3.6
6	3D spacer 4.8 mm
7	3D spacer 6.5 mm
8	Non-woven felt 4.5 mm
9	Non-woven felt 8.5 mm

Figure 24- 26 shows the thermal resistance, water vapor resistance and air permeability of the carseat covers respectively. It is easily seen that 3D spacer fabric shows minimum thermal resistance, water vapour resistance and the highest air permeability; both these factors plays a significant role for the comfort of the car seat

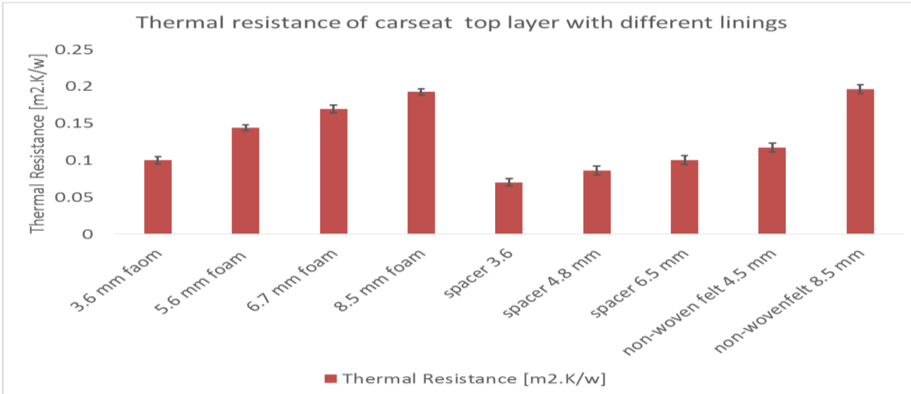


Figure 24 Thermal resistance of top layer with interlinings

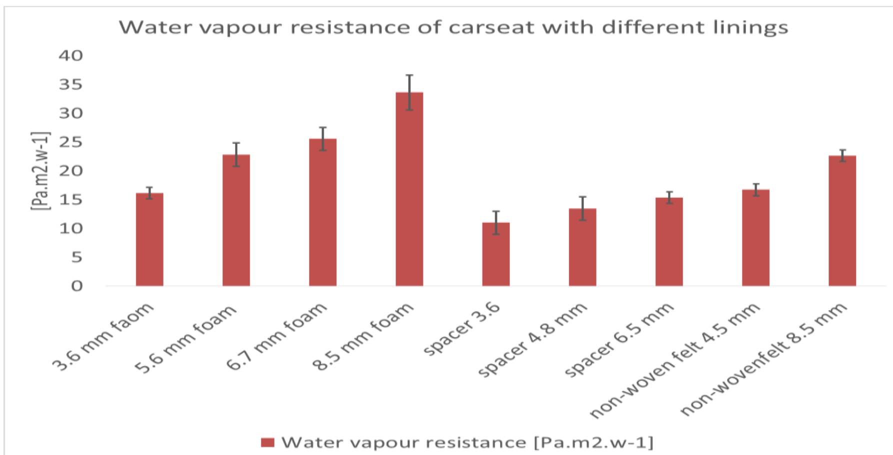


Figure 25 WVR of top layer with interlinings

The water vapour resistance according to different comfort categories can be seen in table 14

Table 14 Water vapor resistance and comfort grading [103]

Ret [m^2Pa/W]	Performance
0-6	Extremely breathable
6-13	Very Breathable, comfortable at moderate activity rate
13-20	Satisfactory but uncomfortable at high activity rate
20-30	Unsatisfactory
30+	Uncomfortable and short tolerance time

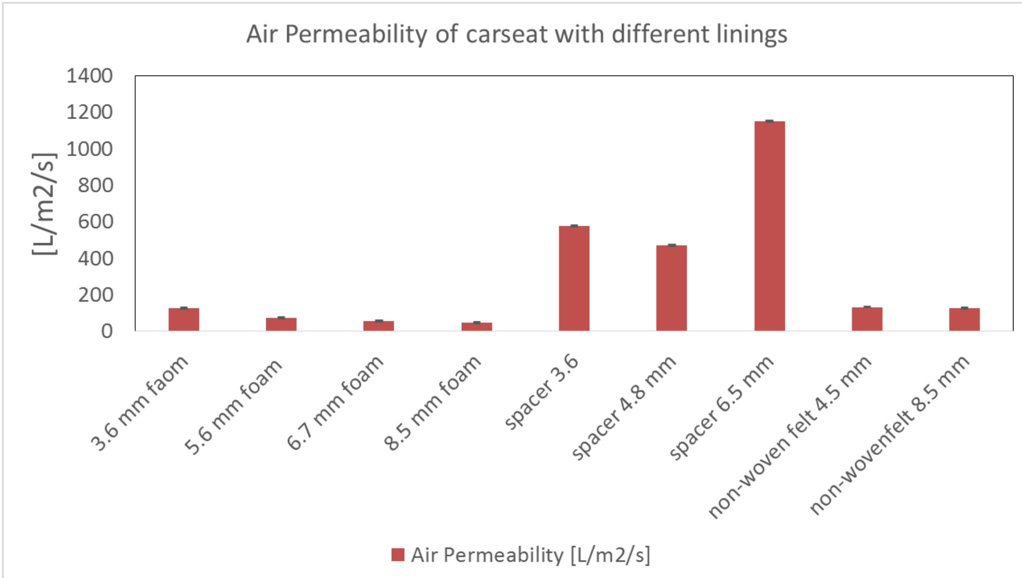


Figure 26 Air permeability of top layer with interlinings

5.2 Effect of different car seat's cover materials

A huge variety of car seat's top layers exist in the market and choice is mainly dependent on aesthetic, life time and comfort. Five common car seat covers from car seat cover producer company GRAMMER are tested to compare the breathability of the material. Table 15 shows the properties of the car seat covers

Table 15 Comparison of different top layers

Type of layer	Thickness [mm]
Woven top layer with non-woven felt	5
3D spacer	5
Classical knitted fleece with non-woven felt	5
Leather top layer with non-woven felt	5
Porous Leather with non-woven felt	5

Considering the comfort part we need the top layer to be highly breathable, the moisture and air permeability is shown in figure 27 and 28.

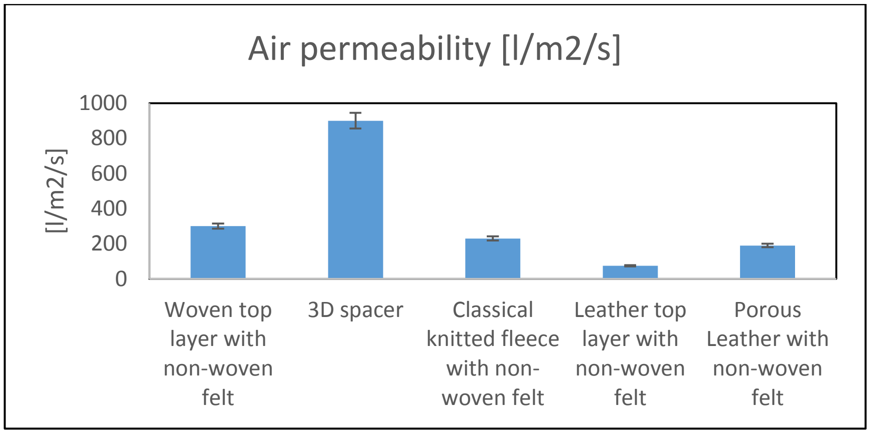


Figure 27 Air permeability of top layers

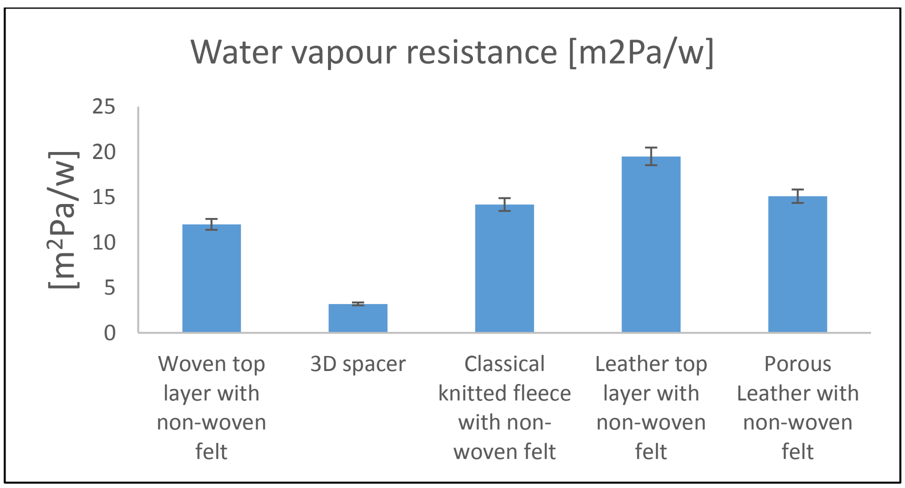


Figure 28 Water vapour resistanc eof top layer

It is visible that the air permeability is higher for the 3D spacer fabrics which is mainly due to open structure of the 3D spacer fabric and also the lowest water vapour resistance that shows that the future of car seats will be 3D spacer fabric.

It is also important to understand that these top layers are joined to thin PU-foam (usually 3-12 mm) to make the final long lasting car seat cover. These backing material is also negatively affecting the breathability of car seat as it is mostly made from PU-foam or non-woven felt. In this research a special technique is used to make identical holes in different thickness of PU-foam (this is the layer "Y" as explained in the experimental part) to improve the breathability of car seat cover.

There have been interesting developments taking place in the production of 3D fabrics using all forms of manufacturing technologies viz. weaving, knitting, braiding and nonwoven processes. The 3D textile structures have great potential as automotive components in both load-bearing and non-load bearing applications. For example, spacer fabrics can be used as substitutes for polyurethane (PU) foam in car seats and thereby solve breathability and the recycling problems with PU foam.

5.3 Impermeable PU-foam

Lastly it is clearly observed that the PU-foam are almost impermeable to air. The top layer and the PU-foam are also examined under the X-ray tomography machine to see the internal structure of the material and shows that the spacer fabric are almost open to movement of air whereas the PU-foam has a close pore structure and pores are not connected from one side to another face of the foam, which makes them impermeable to air.

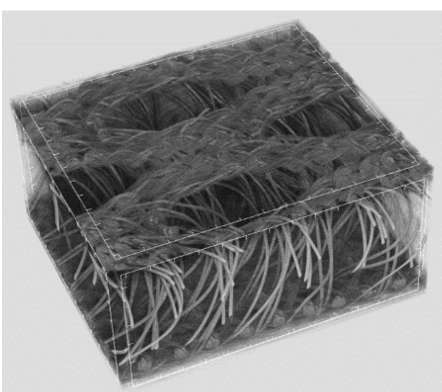


Figure 29 X-ray tomography image of 3D spacer Fabric

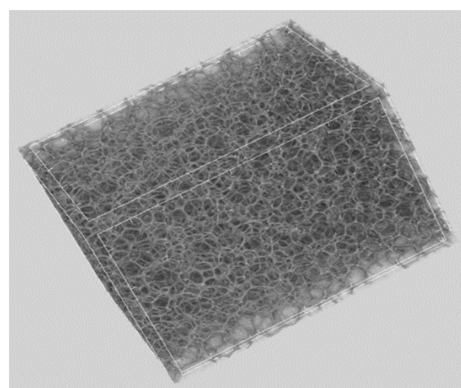


Figure 30 X-ray tomography image of PU foam

The figure 29-30 clearly shows by X-RAY tomography that the PU-foam has closed pre structure which makes the material almost impermeable to the flow of air and moisture, where as in the case of the 3D space knitted fabric there is high porosity and the air can pass from one side to another side of the material which makes it highly permeable.

5.4 Summary

From this initial research we came to a conclusion that even using the highly permeable layer cannot improve the overall breathability of the car seat because of lamination and the PU-cushion foam. This initial investigation shows us that the problem zone for the breathability will be always the PU-foam and the lamination. The focus should be to use the breathable layer with improvement to the lamination and the PU foam for better permeability. The comparison of the top layers clearly shows that the 3D spacer fabric are significantly more permeable than any other top layers of the car seat: that is mainly due to open pore structure of the 3D spacer fabric. In this research our main goal is to find causes of impermeability from the material part of the car seat, and factors like ambient cabin condition, outside environment and clothing of the driver is neglected.

6 To improve the overall comfort properties of car seat

The overall car seat can be improved by making modification to the car seat material or using the forced ventilation/suction or cooling from inside seat. Our focus of research is mainly to improve the car seat breathability with changes to the material and accessories like ventilation or cooling can be on the choice of the producers. In this research we did 3 major improvements to the car seat cover for better breathability.

- Effect of perforation on breathability of PU-Foams
- Effect of different top layer of car seat on breathability of car seat
- Effect of Super absorbent fibres (SAF)

6.1 Effect of perforation on breathability of PU-Foams

There are two common thicknesses of car seat PU foams which are used according to the seat requirement. Each foam with 3 different holes size are obtained from industry by moulding process. The foams are not drilled nor cut from top or bottom in laboratory so that the real surface property of the foams should be kept, as moulded surface are very different then the cut foams.

6.1.1 Methodology

The original foam was firstly observed under the X-ray micro tomography, the method is very beneficial to observe the internal structure of the material. The figure 31 clearly shows that the air gaps inside the PU foam are not connected from top to bottom of the foam material and the these material can never be breathable to air or moisture.

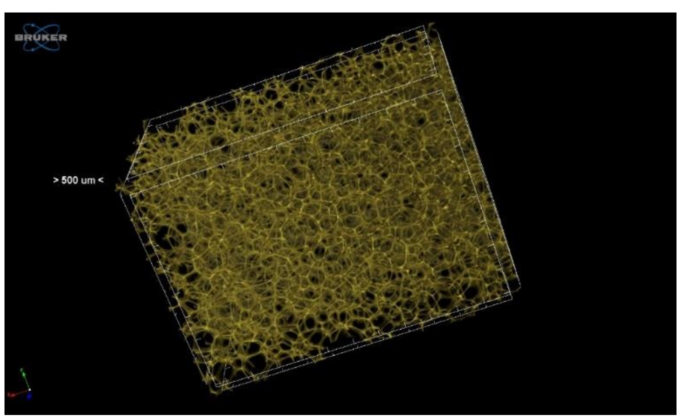


Figure 31 X-ray micro tomographic image of PU-foam

As shown in the figure 31 that the PU foam doesn't have open channel pores that means the moisture cannot be transmitted from top to the bottom surface, it was decided to replace the PU-foam with perforated foams to enhance the moisture permeability.

The original foams and perforated foam properties are shown in table 16.

Table 16 Properties for PU foam used for the experiment

	Foam thickness	Number of holes	Hole diameter	Total area of foam sample	Area of holes	Area of solid foam
	mm		**mm**	**mm^2**	**mm^2**	**mm^2**
A	60	0	0	16505	0	16505
A1	60	7	10	16505	550	15955
A2	60	7	15	16505	1236	15268
A3	60	7	20	16505	2198	14307
B	85	0	0	16505	0	16505
B1	85	7	10	16505	550	15955
B2	85	7	15	16505	1236	15268
B3	85	7	20	16505	2198	14307

The real image of perforated foams used for the experiment is shown in figure 17.

All the foams are tested with upright cup method (ASTM E 96-66) for water vapour permeability. Any other technique of moisture permeability measurement is not possible as the foams are thick and it's not possible to use such thick samples. The testing is performed in a climate chamber with controlled condition to avoid condensation of moisture in the sample. The testing is performed for 3 hours and measurements are obtained after every 1 hours. Most common top layer fabric (Table 9 from Experimental Part) from car industry and tested firstly for the water vapour resistance (Ret) on sweating guarded hot plate (SGHP) the 4 samples with minimum Ret value are selected to test for moisture permeability as combined layer with the perforated foams.

6.1.2 Results and Discussion

All the PU foams are tested for the moisture permeability tested with upright cup method (ASTM E 96-66) for water vapour permeability; the test is performed for 3 hours and measurement are obtained after every 1 hours.

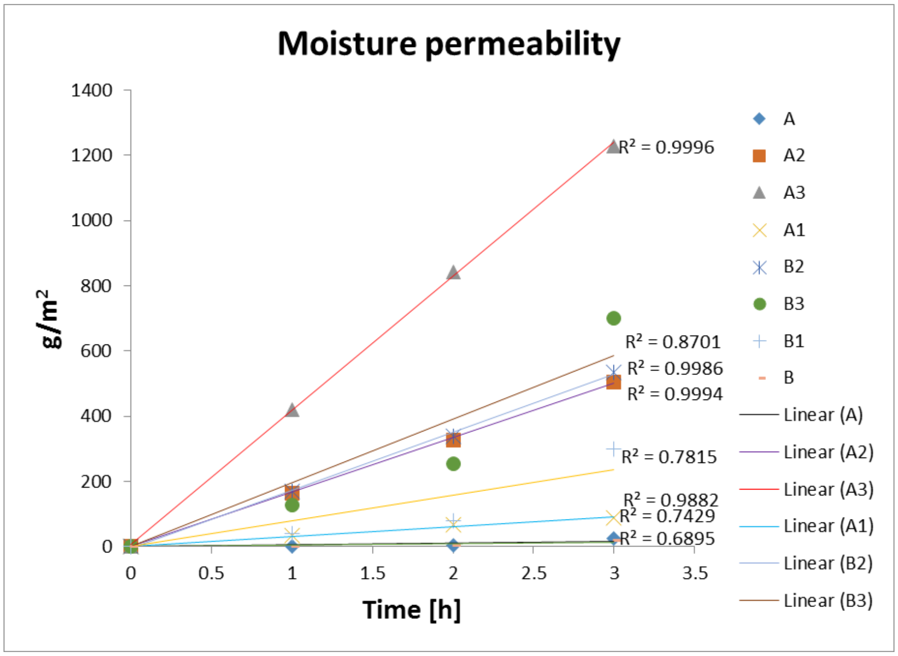


Figure 32 Moisture permeability through PU-foam

It is observed from figure 32 that the non-perforated foams A and B are almost impermeable to moisture and bigger size of the porosity is causing higher breathability of the foam, the foam A3 and B3 have the maximum air area (area of the holes) in the sample and shows a significant increase in the moisture permeability of the sample. A3 sample shows more permeability then the B3 which is due to the thickness difference of the sample and moisture permeability is dependent on the thickness of the sample.

As the results of the perforated foams came very reasonable regarding the moisture permeability so different top layers combination are used to test the overall permeability of the car seat sandwich structure. All the top layers are tested first for the air permeability by ISO standard 9237. Four of the samples are chosen according to better air permeability, and sandwiched later with the perforated foam.

Table 17 Air and moisture permeability of car seat's top layers

no.	Ret [m^2Pa/W]	Air permeability DIN EN ISO 9237 [l/min/100cm²]
26989	14.2318	500
25976	12.405	275
25979	16.1789	263
26728	16.9876	195
26977	14.7294	150
26200	17.9185	140
26195	15.3477	98
25962	15.4576	98
25967	21.9974	98
29086	31.251	93
29084	29.0179	75

As shown in table 17, the four top samples are sandwiched with the highest permeable foam A3 and again tested for the moisture permeability tested with upright cup method (ASTM E 96-66) for water vapor permeability.

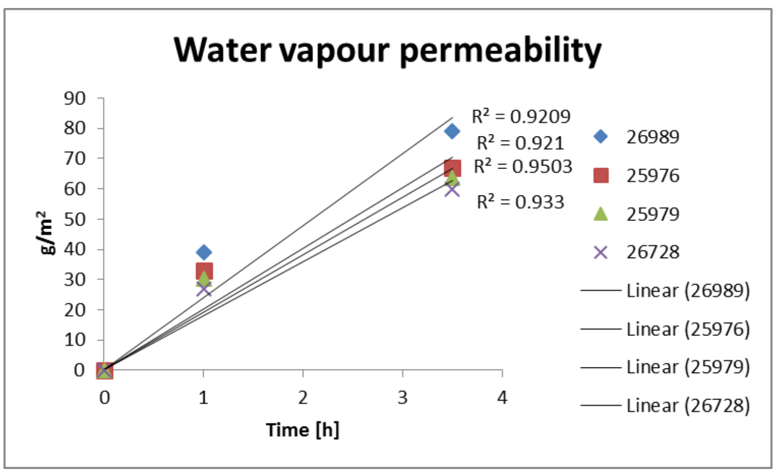


Figure 33 Water vapor permeability of sandwich car seat cushion.

Figure 33 shows the overall permeability of the car seat cover with the foam A3, it can be seen that there is nearly 20-30g of moisture transfer each hour which is almost equal to an average human perspiration during driving. The top layer with 3D spacer fabric showed better transportation of moisture. In this research the most common top layers are taken from the industry to just investigate the effect of perforated PU-foam.

6.1.3 Perforation in foam using Laser technology

Fine holes are made through the PU-foam using Flexi-CO_2 laser device and different number of holes per unit area are made with same hole size to improve the breathability of the foam. The action of a laser causes physical and chemical changes to polymer surfaces. In this research the PU-foam for car seats is obtained from company Johnson Control, Czech Republic. The PU-foam layer is used always between the face cover and the cushion of the seat. Initially the basic properties like air permeability and water vapour permeability of specimen are tested using FX3300 and SDL-sweating guarded hot plate respectively.

It was observed that the PU-foam is not breathable and restricts passage for air and moisture through the material, this finally causes the discomfort of the driver.

The holes in the foam are made using laser technology for precise holes dimensions. A Marcatex Laser is the CO_2 pulse lasers is used. Laser beams interact with fibres by local evaporation of material, thermal decomposition or changing the surface roughness. The main laser characteristics are mentioned below:

Model Marcatex 150/250 flexi Average output power 150/250 watts, Peak output power 230/400 watts, working frequency 50/60 Hz, wavelength of laser beam 10.6 micrometr.

The final product after perforation with LASER is shown in figure 34

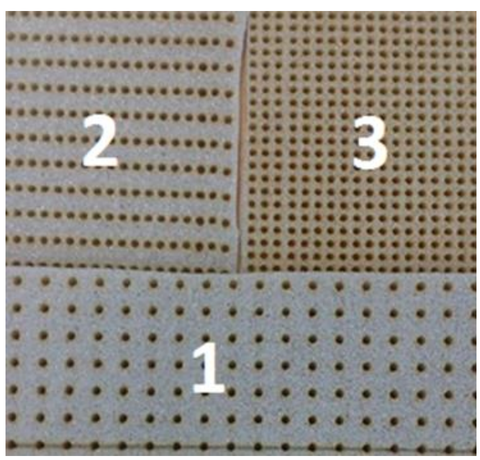


Figure 34 Thin PU foam with different density of perforation by LASER

The holes are made in the PU- foam with these parameters shown in table 18.

Table 18 Holes dimension by Laser

Foam layers name	size of holes [mm]	Number of holes[n/cm2]
0 (no holes)	0	0
1	2.5	4
2	2.5	6
3	2.5	9

The air permeability is measured using machine SDLMO21S by standard ISO9237 shown in table 19.

Table 19 Permeability of perforated foam at different pressure differences

	Foam Layers permeability [mm/sec]			
Pressure [pa]	**0**	**1**	**2**	**3**
1	17	30	55	77.5
1.5	25	45	78	100
2	35	58	98	135
3	55	83	130	188

The moisture permeability is measured by standard Cup Method and shows a direct linear relation between density of holes and the water vapour permeability as shown in figure 35.

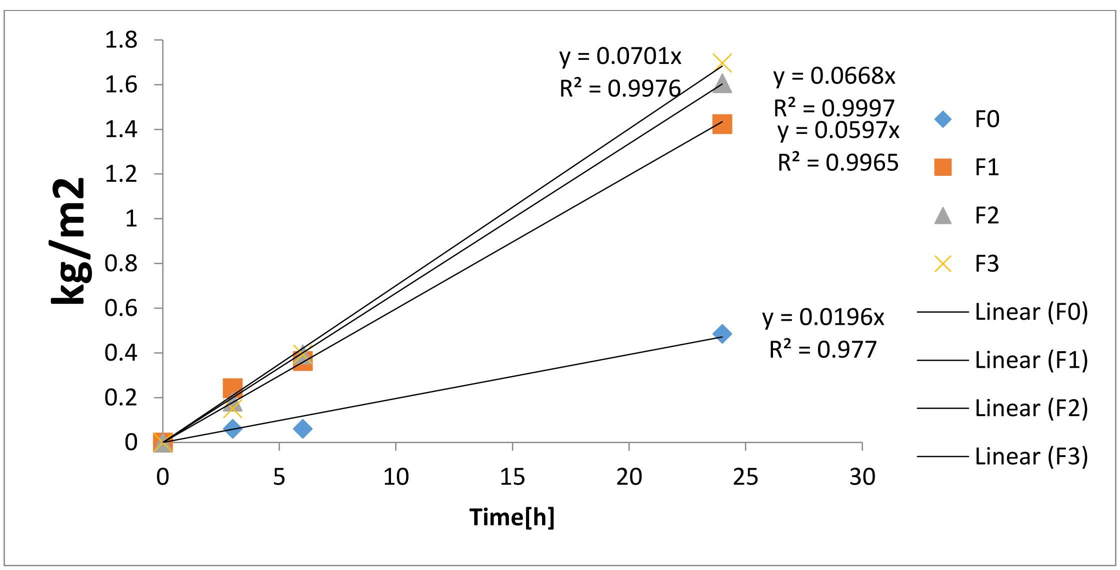


Figure 35 Effect of perforation on the water vapour permeability

This shows that each layer of the car seat is permeable and will not obstacle for the flow of air and moisture. The effect of compressibility and life time of this modification will be examined in the other chapter.

6.2 Super absorbent fibres (SAF)

Super absorbent fibres (SAF) or super absorbent fibrous material are popular from last decade to absorb and retain high amount of liquids (nearly 300 times its own weight). The SAF used in this study is prepared of a cross-linked polymer consisting of three different monomers – acrylic acid (AA) methylacrylate (MA) and a small quantity of special acrylate/methylacrylate monomer (SAMM) – in which the acrylic acid is partially neutralized to the sodium salt of acrylic acid (AANa). The cross-links between polymer chains are formed as Ester groups by reaction between the acid groups in acrylic acid and the SAMM. The chemical structure of SAF is shown in figure 36.

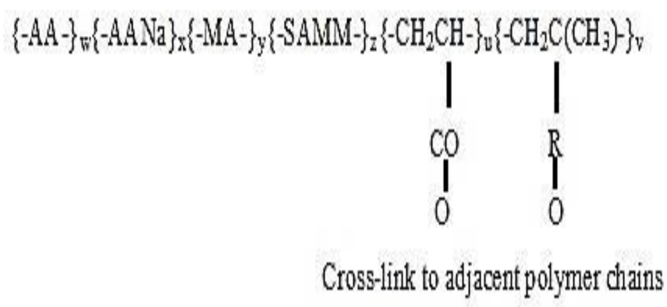


Figure 36 Chemical structure of SAF

Where:

-AA- = {CH2CH(COOH)-} from acrylic acid

-MA- = {CH2CH(COOCH3)-} from methyl acrylate

-AANa = {-CH2CH(COONa)-} from acrylic acid and caustic soda

R= -COOCH2CH(CH3)-

The values of w, x, y and z depends on the amount of heat treatment received.

6.2.1 Experimental Part

In this research, different compositions of Super Absorbent fibre (SAF) are used with the car seat covers.

The 3 SAF composition used in this research are shown in table 20

Table 20 SAF properties

	Composition	Structure	Areal weight (g/m^2)	Thickness (mm)
A	Polyester staple fibre	Needle felt, non-woven	570	5.4
B	Fluff pulp	Bi component fibre	130	1.6
C	Polyester staple fibre	Super absorbent yarn netting, laminated with PES weave	115	1

The car seat covers obtained from the Company Martur is made of different layers as already described in figure 16.

The properties of layer X is shown in table 21

Table 21 Car seat top woven layer

Woven pattern	Raw material	Warp density	Weft density	Cross section	Density [g/m^2]	Yarn number	Filament number	Texture type
1x1 plain weave	100% Polyester	24	17	round	160	300	96	Air twisted yarn

Whereas the Layer Y is thin PU-foam layer with thickness of 6mm and density of 300 g/m^2 and Layer Z is thin mesh of polyester with thickness of 1mm and density of 50 g/m$^{2:}$ this layer is used to make the sewing process easier as PU-foam is rough and compressible and causes stoppage of sewing machine.

6.2.2 Methodology

The SAF are famous of absorbing and retaining huge amount of liquid but moisture absorption and desorption is still undiscovered property of the SAF. In this research firstly the absorption and desorption properties of the SAF layers are measured. Then the most efficient SAF is used in between the car seat layers to observe the effect of superabsorbent in the car seat assembly. The measurement is performed by Cup Method (ASTM E 96-66) for moisture permeability.

6.2.3 Absorption desorption isotherm

The isotherm were obtained by the desiccator method, where the specimen are put in the sealed container having different amount of different saturated salt solutions until weight equilibrium could be assumed. Different salts are used to obtain required humidity level in sealed containers. Table 22 shows the relative humidity (RH%) obtained in different sealed container at 20^{o}C.

Table 22 Salt solution and RH% in closed containers

	Salt solution	RH%
1	Distil water	100
2	Potassium chloride	85.1
3	sodium bromide	59.1
4	potassium carbonate	43.2
5	lithium chloride	11.3

The specimens are pre dried at 7% RH prior to the absorption/desorption isotherm experiment. The specimens are weighed after every 4 days to the maximum 12 days. Each container contains 4 samples; A, B, C and P (PU-foam). Each set of container (5 containers with different percentage of humidity level) are opened after 4, 8 and 12 days respectively; a total of 15 containers are used in lab condition of temperature 20^{o}C. Weighing the samples after different days will provide us the information if the material is still absorbing the moisture, if there will be no difference of moisture gain from the last set of measurement (4 days and 8 days) then it will be considered as the maximum moisture absorbed by the sample.

6.2.4 Climate chamber measurement

The absorption and desorption of samples are also tested in the climate chamber where temperature is set as 20^{o}C and the RH is changed from 7% to 95%. The absorption and desorption of the specimen are calculated by following formula

$$\text{Moisture amount change \%} = \frac{(New\ weight\ of\ sample - original\ sample\ weight)}{original\ sample\ weight} * 100 \qquad (2)$$

Each samples weighed inside the chamber after every 1 hour. This experiment gives valuable information regarding the time and efficiency of absorption and desorption of specimens. The experiment is repeated 3 times.

Standard Upright cup method

Standard Upright cup method or Gore cup method (ASTM E 96-66) is used to analyze the overall loss of water from the reservoir. The car seat cover material with classic layer structure of X,Y, Z and P is firstly analyzed and then the SAF layer is inserted between layer X and Y to determine the effect of SAF layer on moisture resistance of the complete sandwich material. Layer P is a thick PU-foam and is well-known for being impermeable and act as moisture barrier from back side of the sandwich material. The PU-foam protect the SAF not to absorb moisture from the chamber environment so results of Cup method would be precise as flow of moisture will be only from the top Layer “X”. The visual illustration of the samples is shown in figure 37.

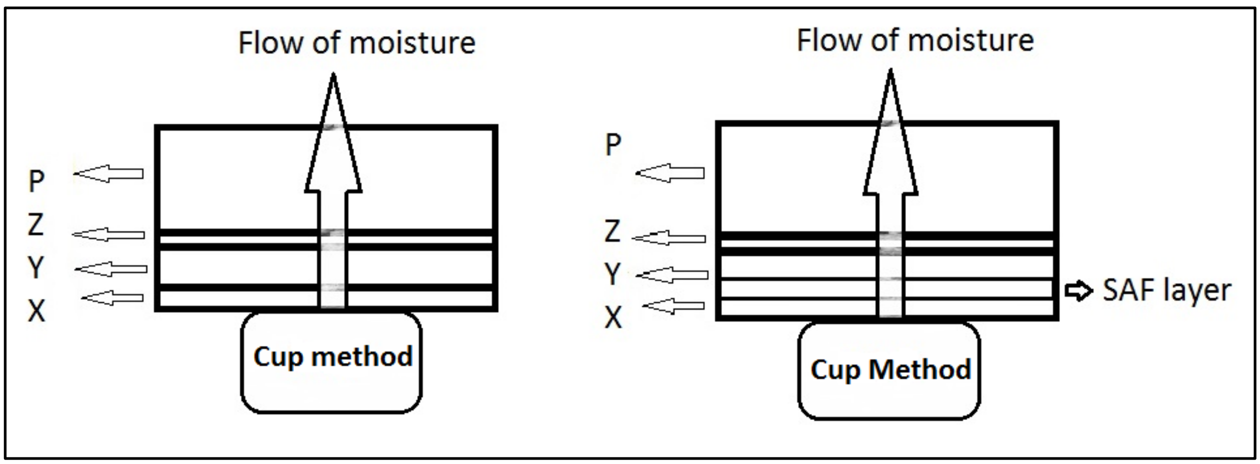


Figure 37 Visual Illustration of specimen layers during Ret testing.

6.2.5 Results and Discussion

The specimen is put in the sealed container having different amount of different saturated salt solutions until weight equilibrium could be assumed. 4 samples are placed in each container with 5 different salts solution and tested after 4, 8 and 12 days, therefore a total of 15 containers are used for this experiment. Different salts as shown in table 22 are used to obtain required humidity level in sealed containers. The Figure 38 shows the percentage gain of moisture with respect to time.

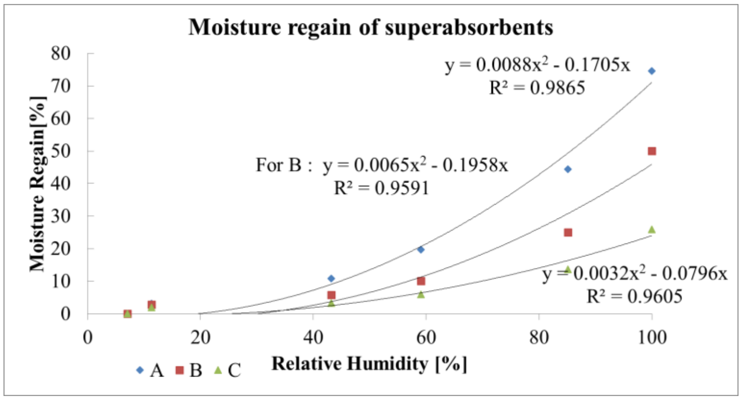


Figure 38 Moisture absorption with respect to time

It is observed that the SAF absorbed nearly 70% moisture in with respect to their weight at 100%RH. Specimen "A" showed the highest rate of moisture gain measured after 12 days. There was no difference between the measurement taken at 8 days and 12 days of testing and results observed after 12 days can be considered as the maximum moisture absorbed by the sample. The process of testing the samples at different salts providing different humidity levels is quite slow but provides accurate results.

The PU- foam sample gained less than 2% of moisture after 12 days.

The absorption and desorption of samples are also tested in the climate chamber where temperature is set as 20^{o}C and the RH is changed from 7% to 95%. The experiment is repeated 3 times. Figure 39 shows the rate of absorption and desorption of samples.

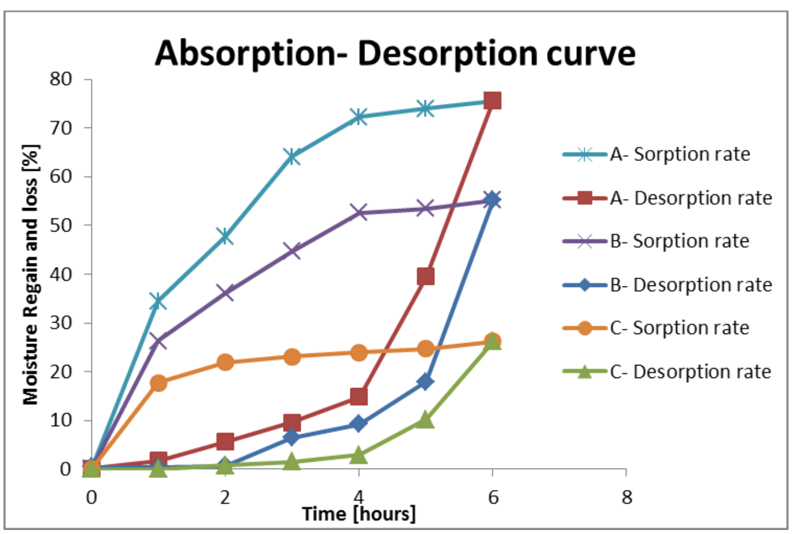


Figure 39 Rate of absorption and desorption

Specimen A is inserted in between the car seat sandwich layers as shown in Figure 16 to test the water vapor permeability cup method (ASTM E 96-66). The car seat is covered by PU-foam which is impermeable to moisture. The presence of superabsorbent will help in absorption of moisture though the top layer of the fabric and causes decrease of the water level in the cup. The superabsorbent layer is pre-dried at 35% RH that is the average ambient humidity inside the car. Later on layer is inserted in between the car seat layer as shown in figure 16 (experimental part).

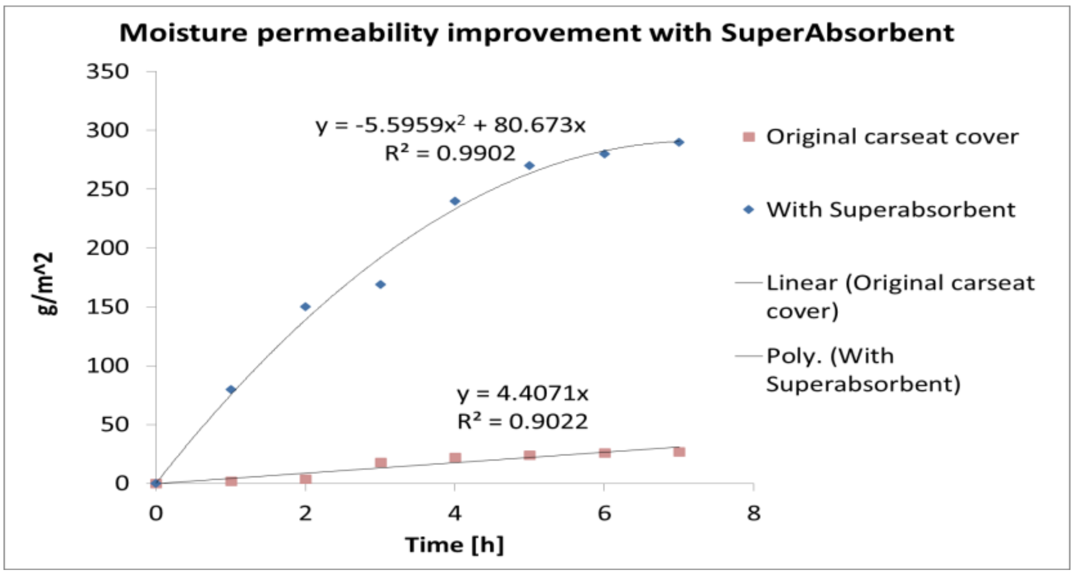


Figure 40 Effect of superabsorbent on moisture permeability

As shown in figure 40 the experiment is repeated 3 times and show a significant difference of moisture transport when superabsorbent is used.

6.3 Summary

The breathability of car seat is a serious issue and in this research a unique concept of perforated molded PU-foams is used instead of classical foams, the results shows that the perforation plays a significant role in the moisture transfer. An average human perspire 20-30g per hour during driving and classical foams are impermeable and causes a discomfort for the driver, on the other hand perforated foam and the top layer together works efficiently to transfer nearly 40g/hour of moisture. The car seat cover with 3d spacer fabric provides better transportation of moisture in compare to PU foam. The perforated foams can be future replacement for the classical foams. Different design of grooves and shapes of holes can also be introduced to increase the porosity of the foams. This is novel and initial work and further research will be done regarding the life time of the perforated foams.

The use of super absorbent polymers (SAP) for moisture absorption and comfort is still unexplored. In this research the efficiency of different SAP fibrous webs are determined under different moisture percentage to examine the sorption and desorption efficiency. The SAP fibrous web with low thickness and high moisture absorption are tested with multilayer sandwich structure of car seat cover to determine the moisture absorption through cover material. Standard Cup method is used to determine the moisture permeability of different car seat cover with superabsorbent layer closed with impermeable polyurethane foam. It is observed that the SAP fibrous layers are very effective in absorbing and desorbing water vapor under extreme high and low moisture percentages. In extreme humid condition (95%RH) the 20g of SAP layer absorbs nearly 3g of water vapor per hour and reaches the maximum absorption capacity in 6 hours.

The following is concluded from this research

- The superabsorbent material are efficient to absorb and desorb water vapor and 50% and higher rate of absorption can be easily achieved under extreme humidity level.
- The fast sorption and desorption process can be repeated multiple times and make it potential use in the comfort of car seat.

The research is initial work to see the utilization of superabsorbent in car seat. This is novel and initial work and further research will be done regarding the life time of the SAF in car seats.

7 Compressibility properties of the novel designs

Any changes to the car seat material especially to the PU-foams bring doubt for the life time performance of the car seat, as the durability is the key factor for the car seat producers. In this research the classical and improved car seat cover and PU-foam are tested under repeated loads to measure the durability and compression properties.

For compression test it is necessary to know how much is the peak pressure on the carseat and how the contact area of the driver.

7.1 Pressure distribution on car seat

The objective of this research is to obtain the average of the peak pressure on the car seat and then use these values for the compression test for repeated loading. The experiment is performed with car seat (Skoda-Fabia) along with 50 randomly chosen people and seat position is adjusted at 90^o, 100^o and 110^o named as positions 1, 2 and 3 respectively as shown in Figure 41. Pressure distribution is measured by X-sensor pressure measuring sheet for down and back rest region of car seat. Surface pressure can cause discomfort while sitting. People of different body weights and builds distribute their weight on a chair in similar patterns, but pressure intensity and areas of distribution vary from person to person. Correct pressure distribution is critical for seat comfort. A high level of surface pressure may constrict blood vessels in underlying tissues, restricting blood flow, which the sitter experiences as discomfort.

7.1.1 Experimental Part

To measure these small differences in pressure distribution and their relationship to chair comfort, researchers have experimented with a number of technologies. Most recently, thin, flexible, pressure sensitive mats connected to computers have been used to “map” the pressure-distribution properties of seating elements in office, automotive, and medical applications. These sensor-lined mats are draped over the chair’s seat pan and backrest; when a test subject sits in the chair, pressure gradients show up as different colors on the computer screen, mapping the peak pressure zones.

Pressure distribution is measured by X-sensor pressure measuring sheet for sitting and back rest region of car seat. The covered area of the car seat by the subject is calculated by the following formula

$$\text{Covered area [\%]} = \frac{\text{area covered by the subject on the carseat}}{\text{total area of the carseat}} \times 100 \qquad \text{Equation 1.}$$

The total area of the back cushion of the car seat is found to be 3290cm^2 and bottom part of the car seat as 3060cm^2. The covered area can also be obtained from the X-Sensor sheet which measures by following formula.

$$\text{Contact area by X-sensor} = \frac{\text{number of contact cells by the subject}}{\text{total number of contact cells on the carseat}} \times 100 \qquad \text{Equation 2.}$$

The sheet is divided in to multiple contact cells and each cell is 12.7mmx12.7mm in dimension.

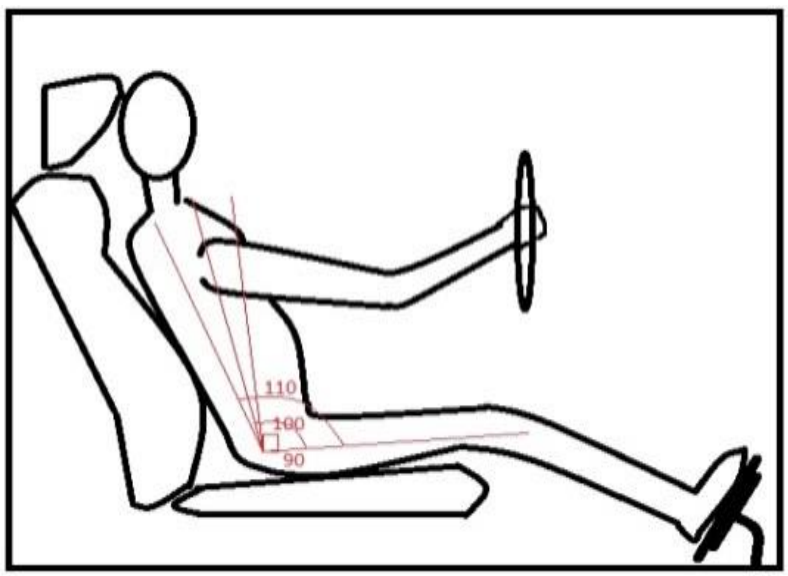


Figure 41 Sitting angle and position of car seat.

7.1.2 Results and discussion

The subjects are segmented in to 12 categories of 5 kg each ranging from 45 to 100kg, the mean of each category is presented at columns of each section, categories and absolute frequency of each category is shown in table 23. Figure 42, 43 shows that the peak pressure is noted minimum for position 2 of car seat where angle is 100^0.

Table 23 Number of subjects and weight categories

Category	Maximum weight of each category	Frequency of subjects
1	45	2
2	50	4
3	55	4
4	60	4
5	65	4
6	70	5
7	75	5
8	80	5
9	85	5
10	90	5
11	95	5
12	100	2

The subjects are segmented in to 12 categories of 5kg each ranging from 45 to 100kg, the mean of each category is presented at columns of each section, categories and absolute frequency of each category is shown in table 223.

There is a significant difference in pressure at position 1 and 2 measured at 95%confidence interval.

Our objective of this measurement was to just get the average of maximum load which is applied by the driver on the car seat. It was observed from this experiment that weight of the subject is not the factor that causes the maximum pressure on the car seats, and even a medium weight person can have the highest peak pressure on the car seat. The maximum pressure on back and cushion part of the car seat is shown in figure 42 and 43. The position 2 shows minimum pressure peak points.

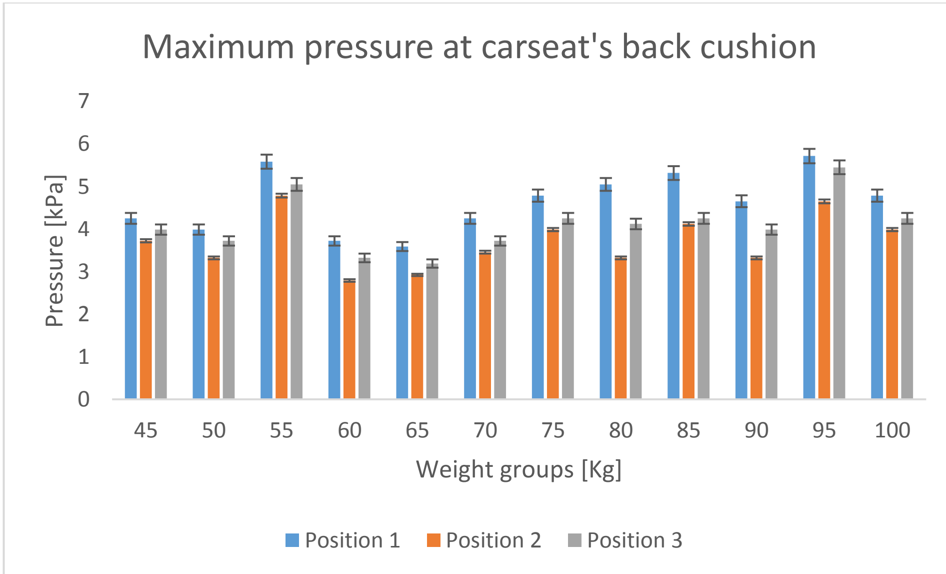


Figure 42 Maximum pressure peak at back cushion

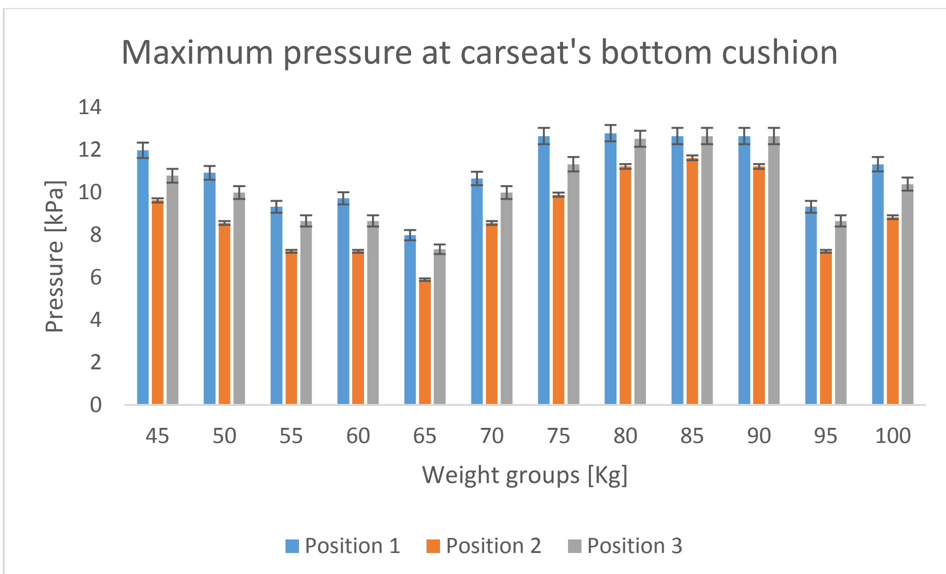


Figure 43 Maximum pressure peak at down cushion

The reason is that the covered area by person is maximum for position 2; which distributes the pressure more evenly. The covered area by the subject at different positions can be seen in Figure 44 and 45, which shows that the maximum covered area is for position 2. The small change in covered area at position 2 is also significant and causes decrease in the pressure points.

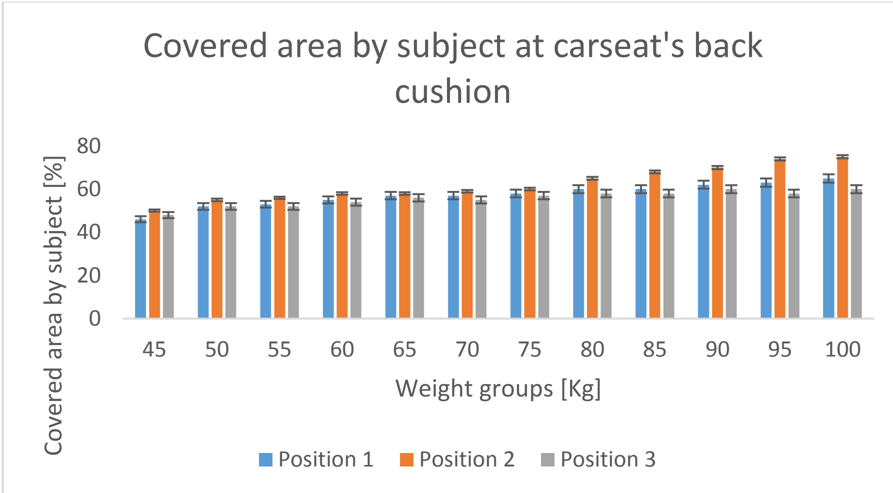


Figure 44 Covered area at back cushion

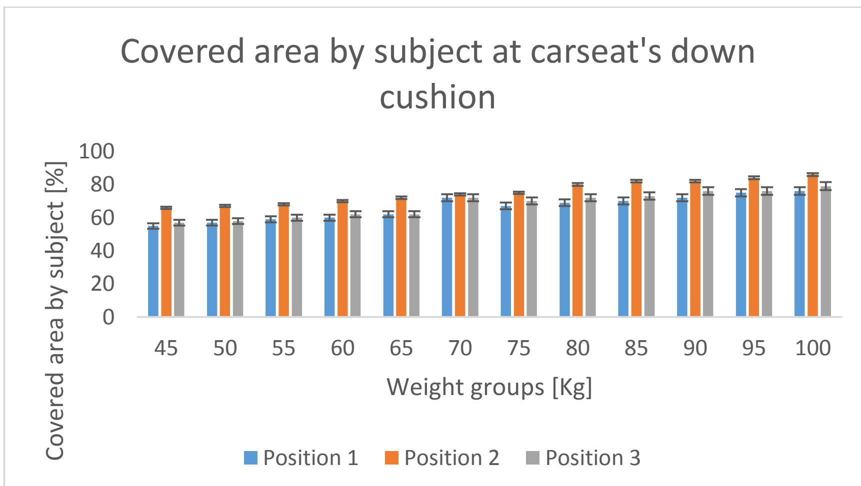


Figure 45 Covered area at down cushion

It is seen in Figure 46, 47 that even the minimum weight person can have extreme peak pressure point on the car seat, which eventually causes discomfort.

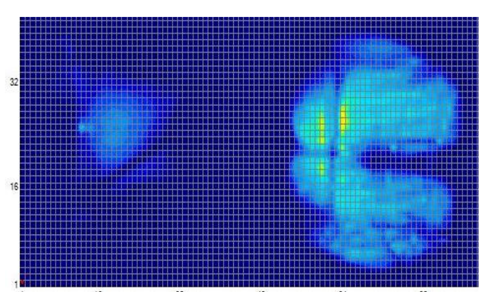


Figure 46 Pressure distribution (80kg person)

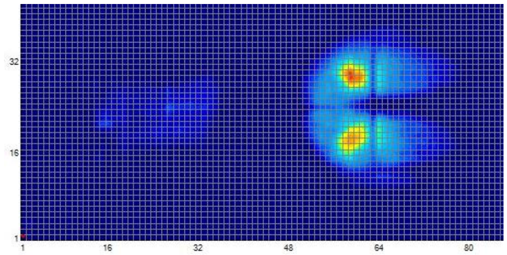


Figure 47 Pressure distribution (46kg person)

Outcome of the first part of this chapter is mention as follows

- The maximum pressure of 13kPa and covered area of 45 to 86 % was observed depending on the mass, height of the person and sitting angle.
- The position of car seat at 100^{o} of angle showed the highest cover area and minimum pressure peaks.
- There is no correlated relationship between car seat peak pressure points with respect to weight of the person.
- 90% of the subjects felt most comfortable at position 2. It was also observed that remaining 10% have their height less than 154 cm.

However our objective of this experiment is to obtain the average of maximum pressure by driver. This was obtained from our experiment as 10 kPa and this value was further used for the compressibility and life time testing of the PU-foams.

7.2 Compressibility Testing

The compression properties of the car seat cover govern the lifetime and durability of the car seat. It is necessary to know how the new and modified material will behave after repeated loading (the sitting and standing action of the driver). It was thought that the making holes to the foam might affect the overall compression properties of the layer and can decrease the life time of the seat cover. All the samples are tested under the compression tester using the Instron machine in which the program was set to run 40,000 cycles for first set of top layers and then a second set of perforated PU-foam undergoes 10,000 cycles of compression keeping the constant load on the sample of 13kPa (this value is obtained experimentally explained in the start of the chapter), as the material is compressible so it was necessary to program the machine to load the material constant pressure even when thickness is changing. For compressibility test the servo-electric loading machine Instron E3000 was used. A piece of square shape with dimensions 5 cm x 5 cm was cut from the material layer. A specimen was made up by 2 or 4 layers of the same material to get sufficient initial thickness h_0 in unloaded state. After that it was inserted between two parallel flat platens and exposed to cyclic uniaxial compression load. Time course of the loading force had a harmonic shape with mean 33 N and amplitude 22 N. These values correspond with usual pressure load in contact zone between seat and passenger. 40,000 repeated load was performed on the seat cover material and 10 000 loading cycles was performed for perforated foams respectively with frequency 0.5 Hz. During the test the minimum height h_{min} of specimen was measure for every cycle. It occurs when the value of instant force reaches its maximum value within a cycle. The time course of minimum thickness related to initial thickness called compressibility is calculated by equation (1).

$$Thickness\ (t) = \frac{h_{min}(t)}{h_0} 100\ \% \qquad \text{Eq.1}$$

7.2.1 Results and Discussion

Firstly the different interlinings of the car seats were compared. The change in thickness is analyzed after repeated loading of 40000 cycles. The top layers properties are shown in table 24.

Table 24 Testing of top layer

Top layer backing material	Thickness [mm]
3D spacer fabric	5
Non –woven felt	5
Retroculated foam	5
Classic PU-foam	5

The effect of repeated loading of 40,000 cycles is shown in the figure 48 and 3D spacer shows better properties even after 40,000 cycles of repeated loading of 13kpa.

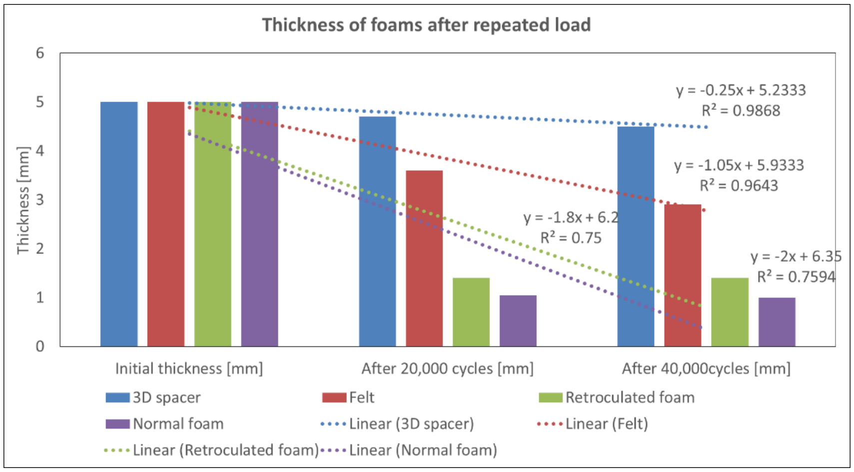


Figure 48 Compressibility properties of the car seat cover

Figure 48 shows that there is significant decrease of thickness after repeated loadings, still 3D spacer tends to show better properties as compared to other lining materials.

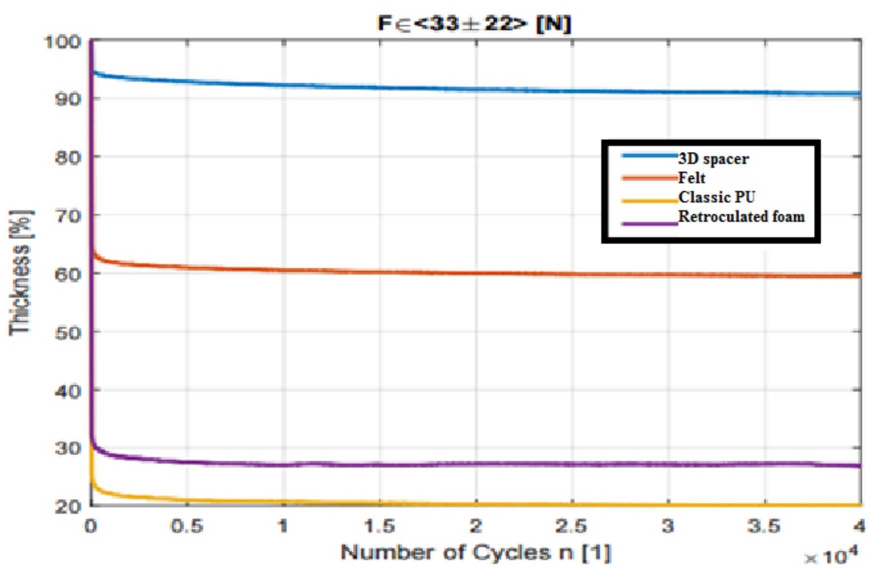


Figure 49 Layer "Y" after multiple loading cycles

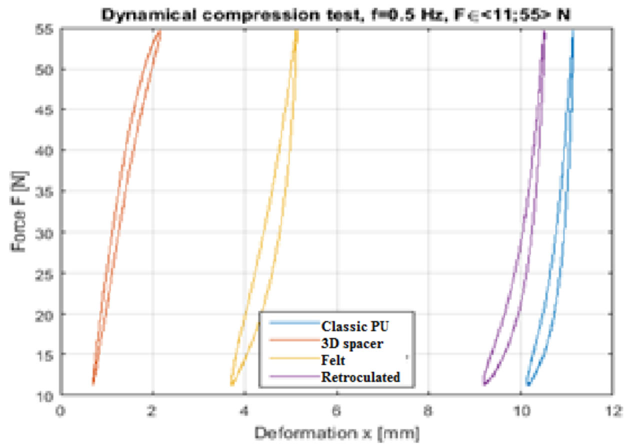


Figure 50 Dynamic compression properties of layers.

The Figure 49-50 clearly shows that the 3D spacer fabric shown better compression properties and maintained its reasonable thickness after repeated loading of 40,000 times. Followed by the nonwoven felt, retroculated foam and classic PU foam.

Whereas the classical PU-foam and retroculated foams loses its thickness in very early stages of the compression testing and then maintain a fixed compressed thickness. This shows that for the durability of carseats its better to use 3D spacer or non-woven felt and considering the breathability, 3D spacer inhibit better performance than any other carseat material.

Secondly the testing of the PU-foam with perforation was also tested, these holes are made using a laser technology and properties of the foams are shown in table 25.

Table 25 Breathability of the perforated foam by LASER

Foam layers	size of holes [mm]	Number of holes[n/cm2]	Air permeability [l/m^2/s] (std.dev)	Water vapour permeability [Pa.m^2.w^{-1}] (std.dev)
0	0	0	76 ($\pm$ 3)	27($\pm$ 1.2)
1	2.5	4	980($\pm$ 15)	12.7($\pm$ 0.8)
2	2.5	6	1267($\pm$ 22)	11.3($\pm$ 0.7)
3	2.5	9	1920($\pm$18)	8($\pm$ 0.3)

The breathability of the material were tested after perforation and shows significant improvement of air and moisture permeability due to perforation, the maximum is observed for the Sample 3, with the highest density of the holes per unit area. The Perforated PU foams showed better air and moisture permeability but the compressibility property and the life time is a very important factor to consider while making car seat covers. In this experiment the repeated load of 13kpa was applied using Intron tester and this loading and unloading is repeated for 10000 times.

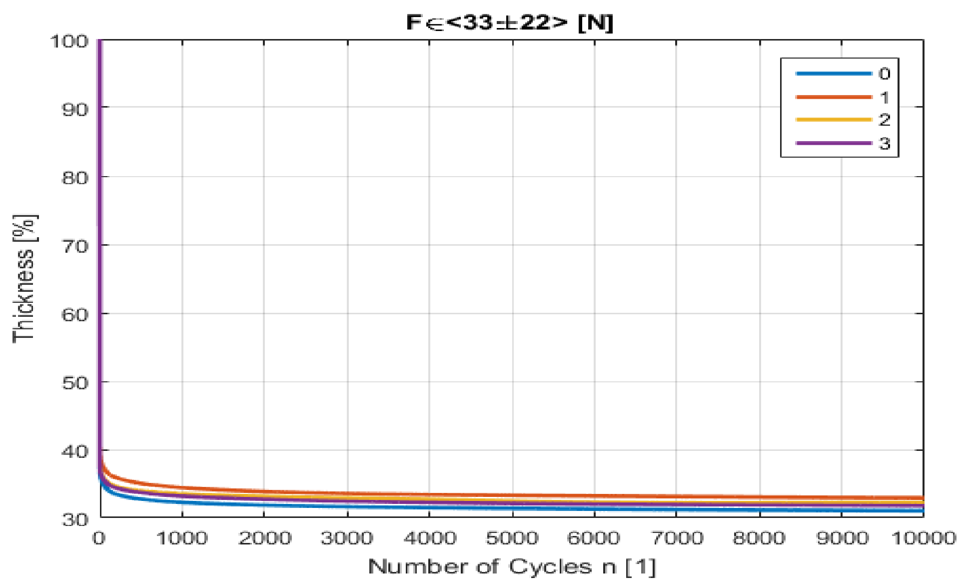


Figure 51 Effect of repeated loading on the thin PU foam (Y)

The figure 51 clearly shows that all foam loses nearly 60% of their thickness during the first 500cycles and after that the PU foam maintain its shape and even there is a negligible difference till 10000 repeated cycles. The result is very important as there is insignificant difference between each PU foam layer irrespective of the number of holes in it, this gives a great option for the future utilization of perforated PU foams.

7.3 Summary

The Objective of this part of the research was to determine the compressibility properties of the classical and modified car seat cover. To determine the compression results it was necessary to find the exact pressure inserted by the human on the car seat. This was obtained from our experiment as 13kpa and this value was further used for the compressibility and life time testing of the PU-foams. Car seat life is nearly 10-15 years so it's necessary that the properties of the material do not change dramatically with time. In this research the test is repeated for 40,000 times and shows that the 3D spacer fabric is superior in retaining its thickness even after multiple loadings.

The research work shows that there is significant improvement of the breathability of car seat's PU foam due to the perforation. The hole sizes effectively help in the transfer of air and moisture and shows a huge increase in permeability of the material. The effect of this perforation was also tested for the compressibility properties of the PU foam and it was observed that there is insignificant effect of perforation on the compressibility of foam. The repeated load of 13Kpa was inserted for compressibility measurement, this is the average of the maximum load humans insert on the car seat, measured using X-Sensor with 50 random chosen people. The research work is unique for providing an alternative for better thermal comfort of car seat with negligible effect on the application and life time of car seat.

8 Novel techniques to measure moisture permeability

8.1 Thermal camera for car seat comfort testing.

Thermal cameras can be a very handy tool to analyse the performance of car seat

8.1.1.1 Thermal Radiation Principles

The intensity of the emitted energy from an object varies with temperature and radiation wavelength. In addition to emitting radiation, an object reacts to incident radiation from its surroundings by absorbing and reflecting a portion of it, or allowing some of it to pass through (as through a lens). From this physical principle, the Total Radiation Law is derived, Total radiation (Wt) can be stated with the following formula:

$$Wt = aW + rW + tW \qquad \text{Eq.1}$$

Which can be simplified to:

$$1 = a + r + t. \qquad \text{Eq.1a}$$

The coefficients a, r, and t describe the object's incident energy absorption (a), reflection (r), and transmission (t).

8.1.1.1.1 Emissivity

The radiative properties of objects are usually described in relation to a perfect blackbody (the perfect emitter). If the emitted energy from a blackbody is denoted as W_{bb}, and that of a normal object at the same temperature as W_{obj}, then the ratio between these two values describes the emissivity (ε) of the object,

$$\varepsilon = W_{obj} / W_{bb} \qquad \text{Eq. 2}$$

Thus, emissivity is a number between 0 and 1. The better the irradiative properties of the object,the higher its emissivity.

8.1.1.2 Temperature measurement

An object that has the same emissivity ε for all wavelengths is called a grey body. Consequently, for a grey body, StefanBolzmann's law takes the form

$$\mathbf{W = \varepsilon\sigma T^4} \qquad \text{Eq.3}$$

Where

ε is Emissivity of material

σ is Stefan's constant $5.67*10^{-8} w/m^2K^4$

T is temperature of radiator

The radiation that impinges on the IR camera lens comes from three different sources. The camera receives radiation from the target object, plus radiation from its surroundings that has been reflected on to the object's surface. Both of these radiation components become attenuated when they pass through the atmosphere. Since the atmosphere absorbs part of the radiation, it will also radiate some itself (Kirchhoff's law). The total radiation power (W_{tot}) received by the camera can be written as

$$\mathbf{W_{tot} = (1 - t) \cdot W_{obj} + (1 - \varepsilon) \cdot t \cdot W_{amb} + (1 - t) \cdot W_{atm}} \qquad \text{Eq.4}$$

Where ε is the object emissivity, t is the transmission through the atmosphere, T_{amb} is the (effective) temperature of the object's surroundings, or the reflected ambient (background) temperature, and T_{atm} is the temperature of the atmosphere.

8.1.2 Results and Discussion

FLIR X6450 is used in this research to see the possibility of thermal cameras for testing the car seat comfort. The thermal field of the car seat after usage or the performance of heating or ventilation of car seat can be easily examined by this technique.

Whereas the figure 52 shows the measurement by the thermal camera.

Figure 52 Thermal camera setup

Four car seats shown in the experimental part are tested using the thermal camera and following observation is obtained as shown in figure 53.

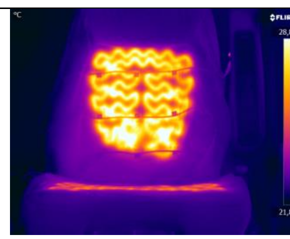
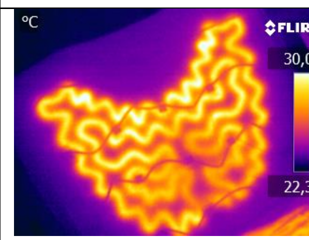
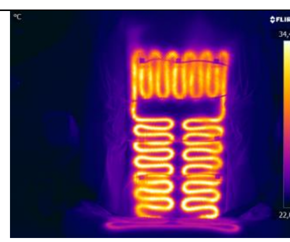
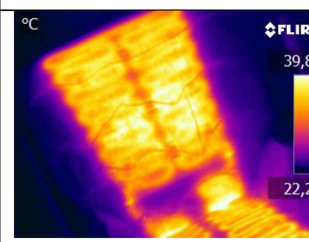
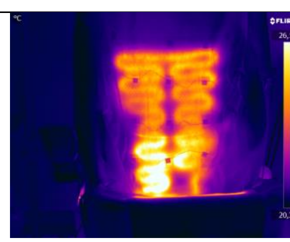
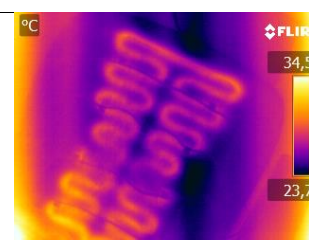
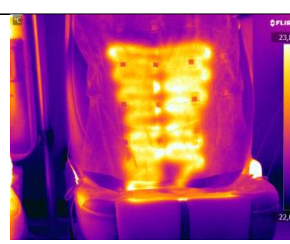
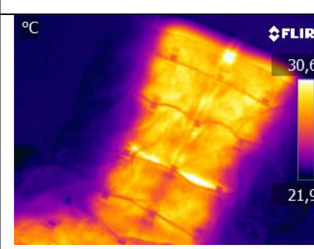
	Back part	Down part
Car Seat A		
Car Seat B		
Car Seat C		
Car Seat D		

Figure 53 Thermal camera and internal heating of car seats

8.1.3 Outcomes

This technique of using thermal camera is very effective to determine the heating and cooling performance of the car. The areas where internal heating is provided is easily seen in the figure 53 and the imperfection and improvements can be easily made knowing the exact location and temperature of the car seat cover.

8.2 Real time objective analysis of car seat comfort (Sensor sheet)

The thermal comfort performance testing of car seat majorly consist of temperature and humidity. To measure the exact distribution of temperature and humidity for the driver when sitting can give us important information on the performance of car seat. The wet and hot microclimate is always considered uncomfortable and knowing exactly the absolute values of temperature, humidity and their position can help us determine the performance and comfort properties of car seats. The measurements are taken by self-fabricated sheet which has sensors of humidity and temperature. The measurements are taken before sitting, after 2 min of sitting and after 30 min of sitting that gives us a comparison of different car seats in terms of heat and moisture permeability. Figure 54 shows the sensor sheet used for the experiment. Each sheet contains 16 sensors of type *SHT 21 Sensirion* to record full 2D areas of temperature T [ºC] and relative humidity RH [%]. Sensors were arranged to grids (sensors distance is 100 mm) and fixed to special high permeable non-woven fabric, see Figure 54. Measuring area of sheet – 40 x 40 cm, distance of first sensor line from bottom edge (from the sitting part) is 7 cm.

Technical parameters of sensors are:

- Size of sensor – 3 x 2 mm
- Measurement range of RH sensors is from 0 RH % to 100 %, accuracy ± 2 %
- Measurement range of T sensors is from - 40 to 125 ºC, accuracy ± 0,3 ºC.

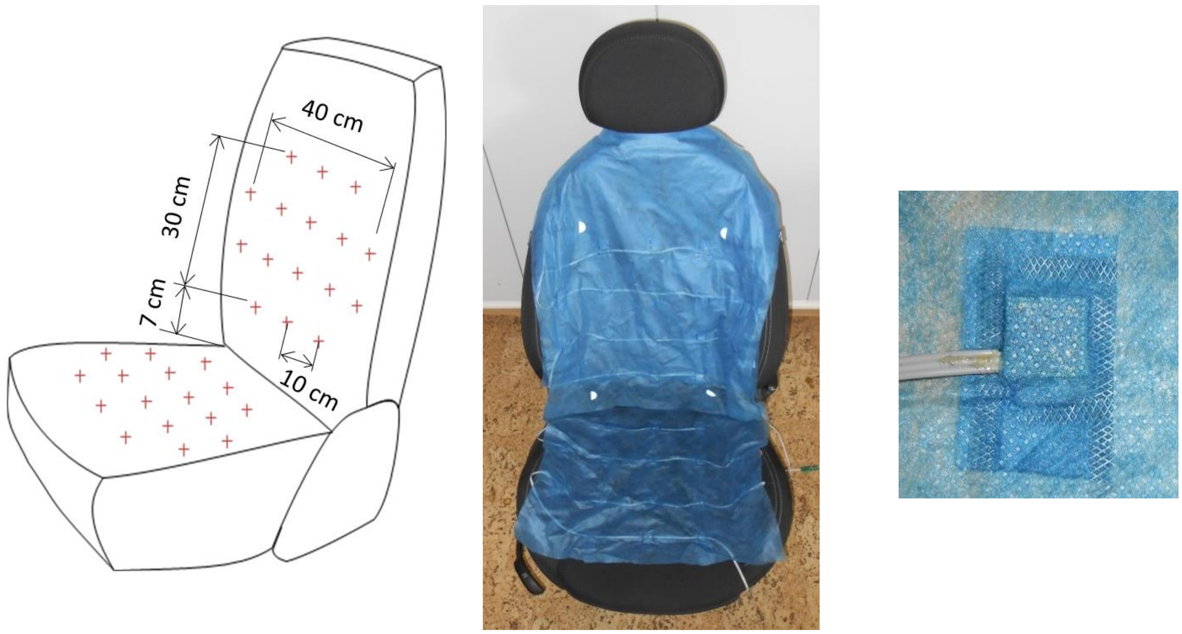


Figure 54 Sensor sheet details

The Figure 55 show example of imaging temperature and relative humidity field in the interlayer between the driver and car seat surface by means of sensor sheet and thermography. There are the thermographs and hygrographs of car seat which are correspond to state after 30 minutes sitting of driver on car seats.

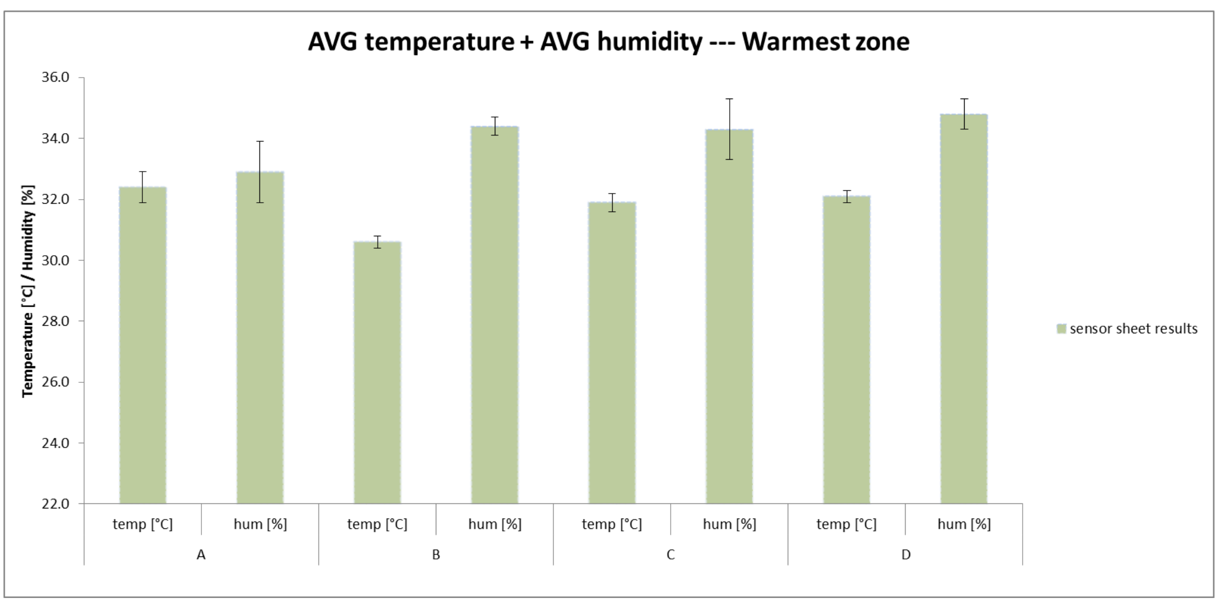


Figure 55 All Seats - Average temperature and average humidity for warmest zone

The research work described an objective evaluation of thermal comfort by measuring the heat and humidity fields in the interlayer between the surfaces of the seat and the sitting person. Temperature and humidity curves were measured at a defined period of sitting, results were used to evaluate the seating comfort. The resulting values can be used to optimize the design of car seats like blowing or exhaust air for cooling, precise composition layers of the seat and performance of heating. The technique can be also used for the longer time of sitting and also during real time driving.

8.3 Measurement of moisture permeability under load

The car seat cover material are compressible material that means that their structure, porosity and thickness changes under load. A driver sitting on a car seat can totally change the defined performance of the car seat material.

A unique modification is made to the classical CUP MEHTOD for testing the moisture permeability with and without load. A self-fabricated frame is used to hold the testing material with a constant pressure on it by using perforated metal mesh.

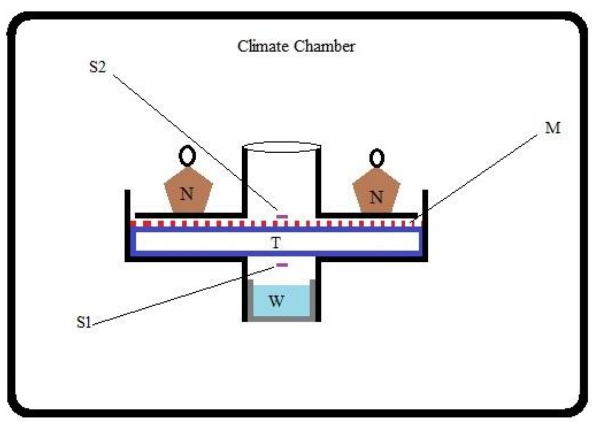


Figure 56 schematic diagram of the measuring device under load

Where W is distilled water for moisture source

T is the car seat cover material

N is the load on the sample

S1 and S2 are the humidity sensors

M is a porous sheet on the sample to apply even pressure.

Calculation of the water vapour transmission, and permeability is as follows.

WVT=G/t.A Eq.5

G = weight change, g

t = time, h

A = test area, m^2

WVT = rate of water vapour transmission, $g/h \cdot m^2$

The experiment is performed in climate chamber with a controlled environment according to standard ASTM E 96-66. The sample properties are shown in table 26.

Table 26 Sample properties

Sample	thickness [mm]
3D spacer-1	10
3D spacer-2	3
PU-foam 1	6
PU-foam 2	3
Retroculated foam	3
Non-woven felt	3

To see the effect of the pressure on the moisture permeability the carseat material are tested with and without loads. The moisture permeability of different car seat material under two different pressure (5 and 10kpa) and without pressure is shown in figure 57.

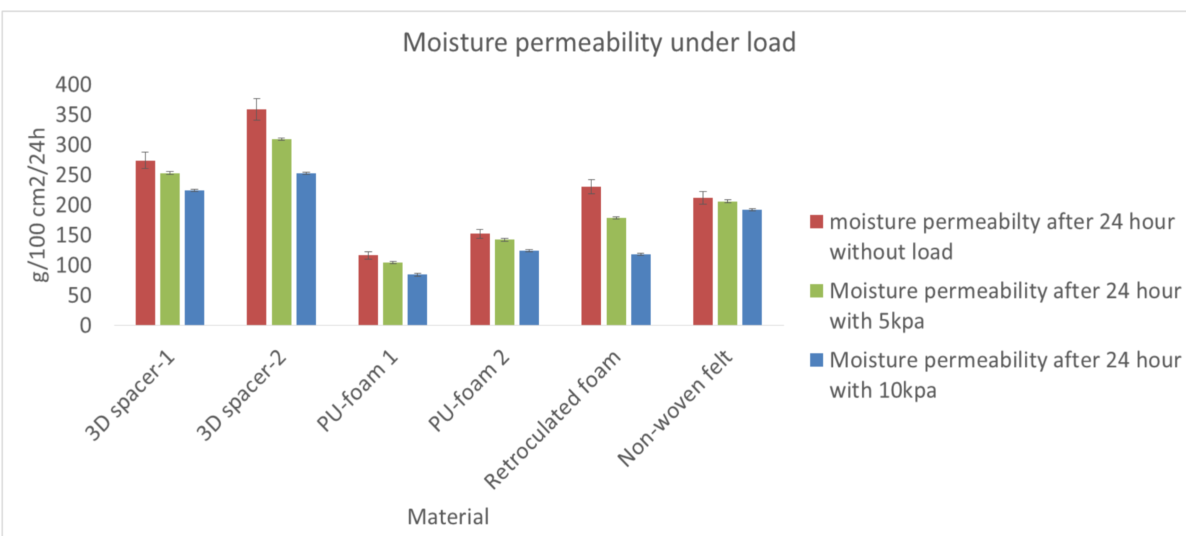


Figure 57 Moisture permeability under load

The figure 57 shows that the there is significant effect of pressure on the permeability of the car seat material. This test method is unique and can show us experimentally how material behave under load. It is visible that there is significant decrease of moisture permeability when there is pressure on the car seat cover, which can be because of the closing of pores due to the pressure. All the material are effected by the pressure but the permeability of 3D spacer is still higher as compared to any other material even after loading.

8.4 Portable device to analyze the real car seat moisture permeability

The portable device to analyze the comfort performance of car seat is always a dream for the car seat producer. The complication of design and the testing method makes it hard to have a portable device which can measure the comfort performance of the car seat even in uncontrolled condition. Some factors like the moisture permeability under different condition, heat of absorption of material negatively affect the measurement. In this research a first prototype design of device is made and later in future more advancements can be made to the technology.

For this experiment a special heat flux sensor is embedded in a measuring head which is insulated from outside. The heat transfer can be increasing or decreasing and can be in the form of convective, radiative or conductive heat transfer. Heat flux through a thermal resistance layer will create a temperature gradient. Under a temperature gradient, the two thermopile junction layers will be at different temperatures and will therefore register a voltage. The heat flux is proportional to this differential voltage.

The distill water is added from the tubes above the measuring head and heated to 35^{o}C. Special microporous membrane (Cellophane) is used on the measuring head to restrict the water drops and allow only the water vapors to pass by. The device is connected to computer by USB port and values of heat flux temperature of the water and temperature of the surface is provided by the software. Heat flux sensors measure the heat transfer through a surface, and is expressed in kw/m^2. The schematic diagram of the device is shown in figure 58-60.

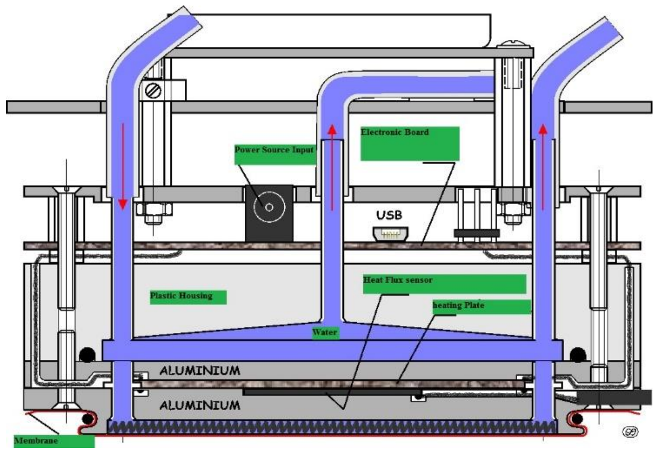


Figure 58 Schematic diagram of the new device

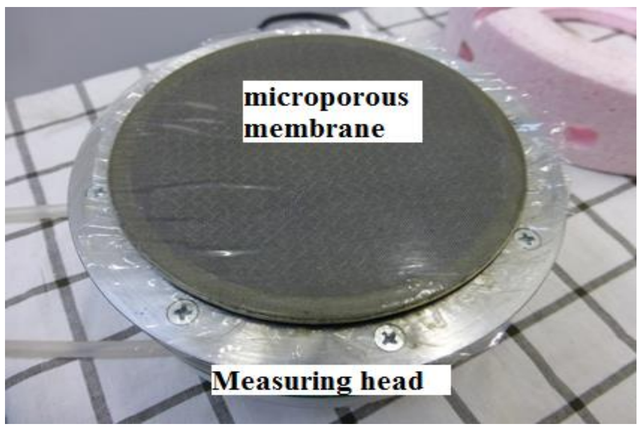


Figure 59 Measuring head of the new device

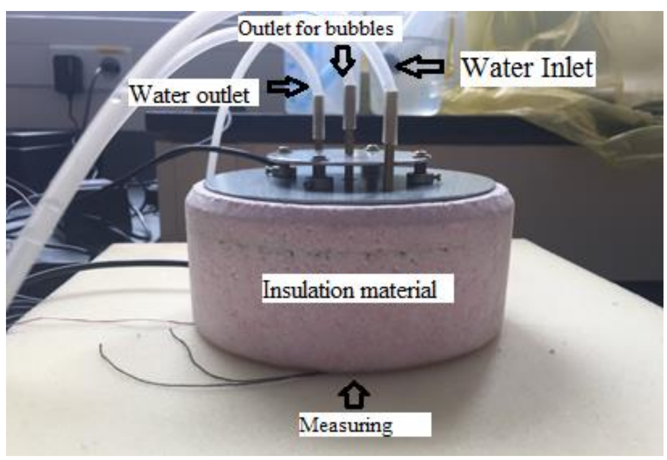


Figure 60 Part description of the new device

The experiment was performed for 30 min to avoid the initial heat flux change due to the first touch with the sample. Following results are obtained.

Table 27 Comparison of New device and classical machine

Sample	Ret[m^2.Pa/w](stnd.dev)	New device [watt/m^2] (stnd.dev)
Seat A	20 ($\pm$ 1.67)	149($\pm$ 5.46)
Seat B	39($\pm$ 2.34)	240($\pm$ 7.94)
Seat C	45($\pm$ 3.72)	263($\pm$ 8.21)
Seat D	29($\pm$ 1.55)	164($\pm$ 3.76)

The above table 27 gives us a good idea that the trend of measurement by ATLAS SGHP (Ret) value and the measurement by the new device are comparable and knowing more information about the temperature and humidity on other side of the sample the Ret value can be also calculated. The device was also tested for classical and perforated PU cushion. One top layer from table 9 is sandwiched with 3 different kinds of interlining material of 1cm thickness as shown in figure 61, Where

1= classic PU foam, 2= Retroculated foam, 3=3D spacer fabric

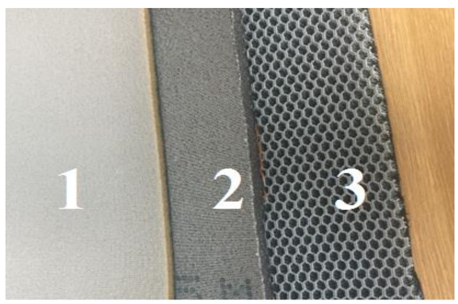


Figure 61 Top layer with different intelinings

The sandwich material is placed above classical PU cushion foam and perforated PU-foam, following results are achieved as shown in figure 62.
The results are repeatable and the 3D spacer with the perforated cushion shows highest heat flux.

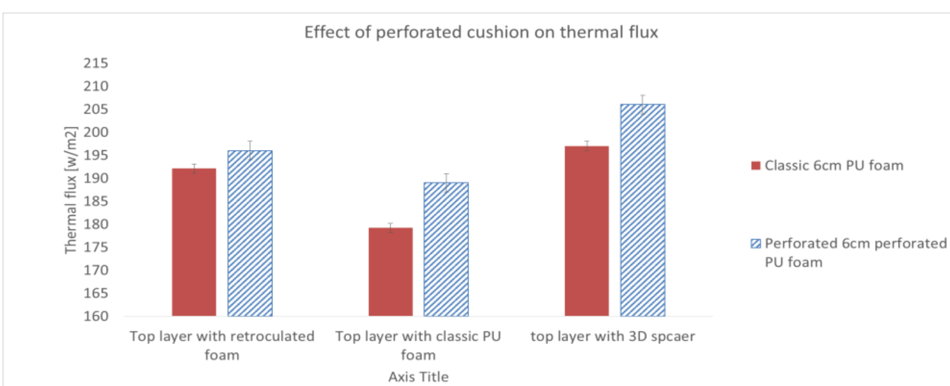


Figure 62 Effect of perforated and classical PU foam on heat flux

The device can be used over a real carseat as shown in figure 63.

Figure 63 Portable measuring device on a real car seat

The device is initial prototype and with further improvement can be a very reliable device to measure the performance of the car seat comfort from a real car seat, without any need to remove the material test separately in testing equipment. The idea is very unique and results are repeatable and the device can be further modified in future.

8.5 Summary

The porosity of the material is important parameter affecting the thermal properties, also the porosity of the compressible materials changes with loading on the top. So that material can show different breathability under loading. Therefore it was important to develop measurement technique to measure car seat material under different load. On the other hand, experimental techniques should be developed to measure the comfort of the whole car seat. Commercial measurement techniques gives us the opportunity to measure the thermal properties of the car seat layer but there are also other parameter affecting thermal comfort of the car seats other than materials, such as heating and the ventilation of the car seat. With new experimental techniques it is possible to evaluate the car seat comfort with other effecting parameter that gives us more realistic values of car seat comfort and comparison of different car seats is possible.

9 Theoretical Model: Analysing theoretically the air flow through car seat foam material

9.1 Car seat foam material

Air permeability describes the rate of flow of a fluid through a porous material, and the mathematical expression is given by

$$q = Q / At \qquad \text{Eq.1}$$

Where q is rate of flow (m/s), Q is volume of flow of fluid through the sample (m^3), t is time (s) and A is the cross-sectional area (m^2).

Textile material stand out as a unique class of porous media, which contain relatively high volume of air and very complex structure due to the random arrangement of fibres or pores. Air permeability is one of the most important properties of textile materials in many applications, Numerous researchers have worked on the air permeability of non-woven fabrics in both experiment [92,93,94] and analytical prediction [95,96,97]. Darcy derived an equation for calculating the air permeability based on hydraulic radius theory, which states that rate of flow is directly proportional to the pressure gradient causing the flow. The equation is as follows:

$$Q = A.t.(K_p.\ \Delta P)/(\ \mu.L) \qquad \text{Eq.2}$$

Where q is the rate of flow (m/s), kp is the flow permeability coefficient (m^2), Δp is the pressure gradient (pa), μ is the viscosity of the flow (pa·s), L is the thickness of sample (m), Q is the volume flowing in time (m3), A is the cross-section area (m^2) where flow goes through, t is time (s).

As explained in the Literature review part that the air flow and the water vapor permeability are the connected properties. This gives us the idea to theoretically analyses the flow of air through the textile layers and predict the performance of the car seat materials. For this research the software FLUENT is used for the theoretical analyses and the results are compared with the experimental results.

The permeability is defined as the volume flow V (m^3/s) through the cross-section of the sample S (m^2). So the permeability is identical with flow velocity through tested sample

$$w = V/S \text{ (m/s).} \qquad \text{Eq.3}$$

9.1 Application of measured data

1.1. Used samples

Thick PU cushion part of the car seat is used for this research. The classical foam and the foam with the perforation are used for this research the properties are shown in table 28 below.

Table 28 PU-foam properties for the numerical simulation

	Foam thickness	**Number of holes**	**Hole diameter**	**Total area of foam sample**	**Area of holes**	**Area of solid foam**
	mm		**mm**	**mm^2**	**mm^2**	**mm^2**
A	60	0	0	16505	0	16505
A1	60	7	10	16505	550	15955
A2	60	7	15	16505	1236	15268
A3	60	7	20	16505	2198	14307

The hole dimensions of used samples are shown in figure 64.

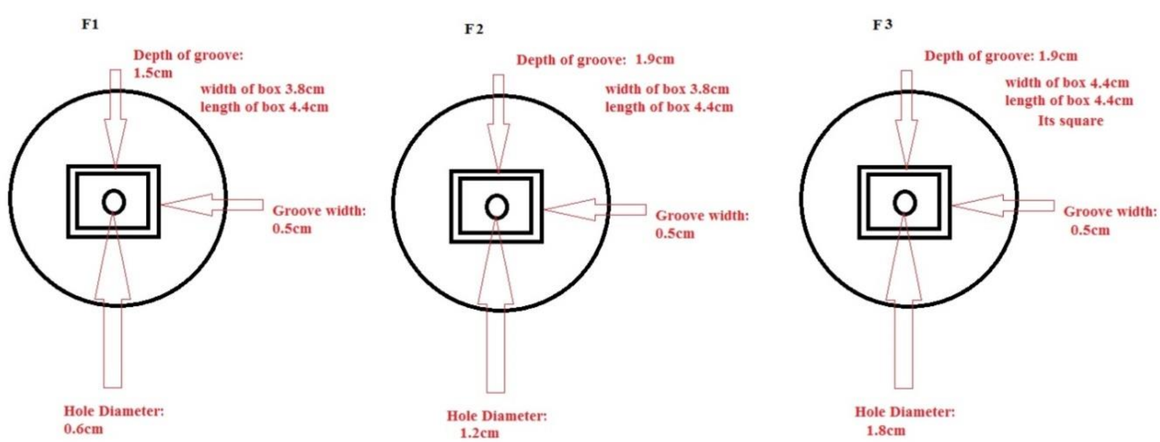


Figure 64 description of real sample of PU-foam with holes

1.2 Measured air permeability

The Air permeability of the samples are tested under different pressure difference by standard method ISO standard 9237. Results are shown below. It is quite obvious that the PU-foam without holes is almost impermeable and the flow increases with the size of hole.

	Unit [mL/sec]			
Press. [Pa]	F0	F1	F2	F3
1,1	0,2	19	43	60
1,5	0,6	45	92	140
2	1,1	70	125	200
2,2	1,25	80	145	235

Permeability of the classical foam (F0) is 64-188 times lower permeable than cases F1-F3 as shown in figure 65.

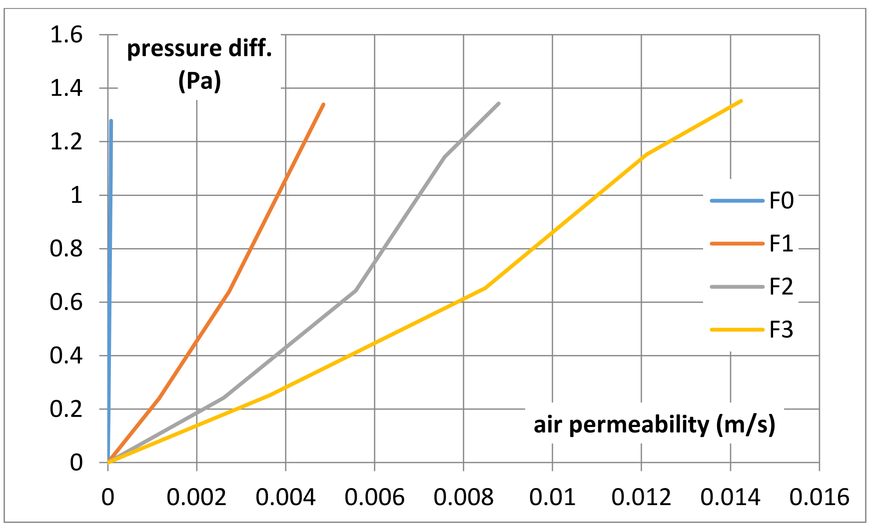


Figure 65 Air permeability at different pressure

9.2 Adaptation of measured data

Following evaluation of measured data and determination of permeability parameters is explained for the case F0 (full foam) only. Next cases (F1-F3) are created as foam bodies (F0) with additional perforations and grooves.

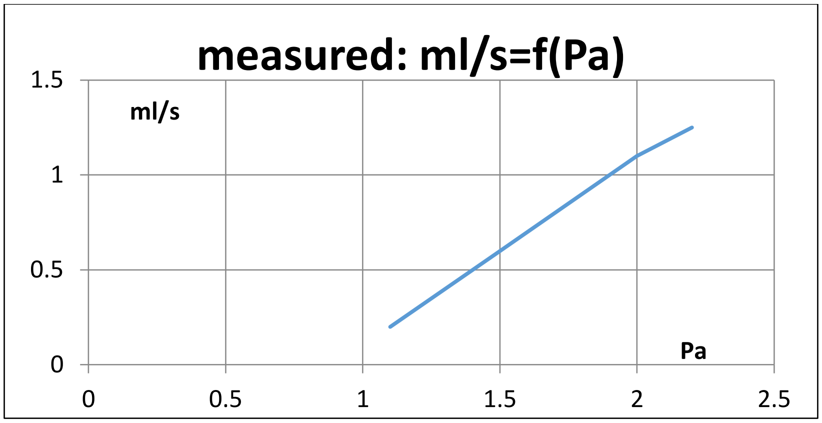


Figure 66 Measured values of volume flow

The flow starts at 1 Pa approx. – from the physical point of view it is not precise – and might be influenced by the insensitivity of measuring device under 1 pa pressure.

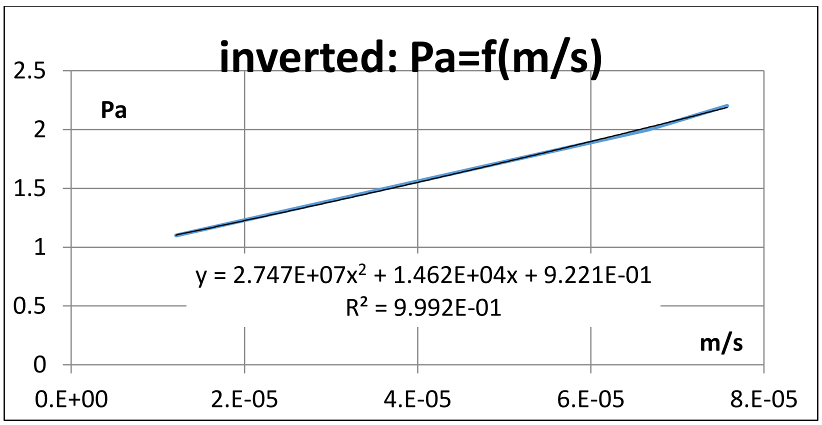


Figure 67 Recalculation in permeability

Measured volume flows (ml/s) are recalculated in permeability m/s (=$m^3/s.m^2$) and inverted.

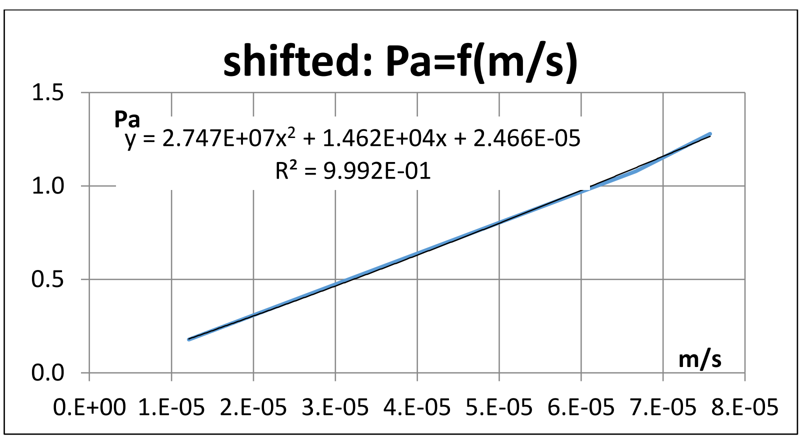


Figure 68 Shifted values

Values are shifted, to correct any measuring error (at zero mass flow the flow resistance must be zero, too).After such correction the permeability parameters can be determined.

9.3 Permeability parameters determination

The method is described in [100] for so-called „pressure jump" in one-dimensional flow and thin porous layer. Here is the method used for so-called „porous zone", generally as the flow in 3-dimensional permeable volume (thick porous layer). Theoretical formulas [100] are analogous, so it is supposed to use the same procedure in 3D for homogenous permeability. Generally, the qualitative results (images of flow fields), are all right, but the quantitative results of simulations (m/s, kg/s etc.) are different from measured values.

The permeability of the observed layer is given by its flow resistance. This resistance consists in general from the linear term, typical for instance for small velocities (so-called Darcy's law) and from the quadratic term, typical for flow around bodies or through channels (Weissbach's or Moody's law)

$$\Delta p = C_2 \,.\, \rho/2 \,.\, t \,.\, w^2 + \mu / \alpha \,.\, t \,.\, w \qquad \text{Eq.4}$$

where

$w = V / S$ (m/s)	flow velocity
V (m^3/s)	volume flow
S (m^2)	flow cross-section (here 20 cm^2)
t (m)	layer thickness
ρ (kg/m^3)	medium density (for atmospheric air 1,2 kg/m^3)
μ (m^2/s)	viscosity (for air 1,806e-5)
α (m^2), C_2 (1/m)	unknown permeability parameters [100].

Two unknown permeability parameters α, C_2 , depending on the layer structure, can be determined from the experimental data.

In previous graphs the function Pa = f(m/s) is substituted by quadratic function with very high correlation coefficient. Parameters of this substitution are used as follows:

Comparing the formula for pressure resistance as function of velocity

$$\Delta p = A \,.\, w^2 + B \,.\, w + C \qquad \text{Eq. 5}$$

From Eq. 4 we can determine two unknown permeability parameters C_2, α from

$$A = C_2 \cdot \rho/2 \cdot t \qquad \text{Eq. 6}$$

$$B = \mu / \alpha \cdot t, \qquad \text{Eq.7}$$

where A, B (and C, which should be equal zero) are parameters of the quadratic substitution. For given values of

thickness $t = 0{,}03$ m,

air density $\rho = 1{,}2$ kg/m^3,

dynamic viscosity $\mu = 1{,}806e\text{-}5$ (Pa.s)

the permeability parameters are as follows

$$C_2 = 2 \cdot A / (\rho \cdot t)$$

$$\alpha = \mu \cdot t / B$$

Determined permeability parameters for F0 are

$$C2 = 1{,}526e{+}09\ (1/m), \qquad 1/\alpha = 2{,}698e{+}10\ (1/m^2),$$

For testing purposes the foam F0 is used, only, foams F1, F2, F3 are not evaluated here, because the relevant models are created as foam body (permeability parameters of F0) with perforations and grooves.

NUMERICAL SIMULATIONS

The basic model of the numerical simulation was designed and the software was run with the input equation and the parameters form the experimental results. The basic model is shown in figure 69.

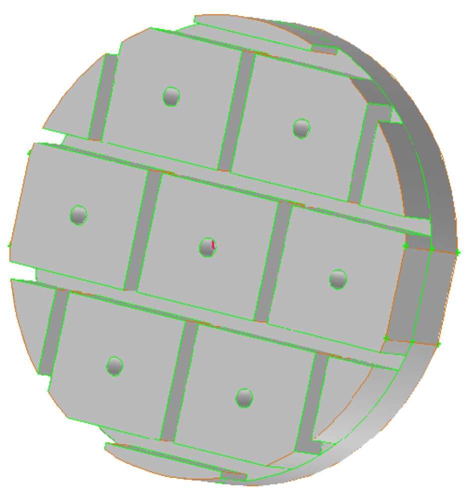


Figure 69 basic model of numerical simulation

The main results of the numerical simulation are shown in the table 29. Differences between flows of inlet and outlet are not important. Even if the holes area is 1,1% of the total area of sample, the main flow is going through holes and the flow through the foam material is less than1% approximately. It could be stated that the foam is practically impermeable and used as compressible cushion.

Table 29 Inlet and outlet prediction of low

		area		mass flow		measured
		m^2	%	kg/s	%	kg/s.
inlet	foam	0.012858	78.2	0.92794e-6	0.3	
	grooves	0.003415	20.8	2.24480e-6	0.8	
	holes	0.000178	1.1	2.80000e-4	98.8	
	sum	0.016452		2.83300e-4		0.415e-4
outlet	foam	0.016273	98.9	2.07184e-6	0.7	
	holes	0.000178	1.1	2.81000e-4	99.2	
	sum	0.016451		2.83300e-4		0.415e-4

Next serial of flow fields presents main qualitative results. To get full details of individual flow fields different scales are used. The model is shown with different graphical representation.

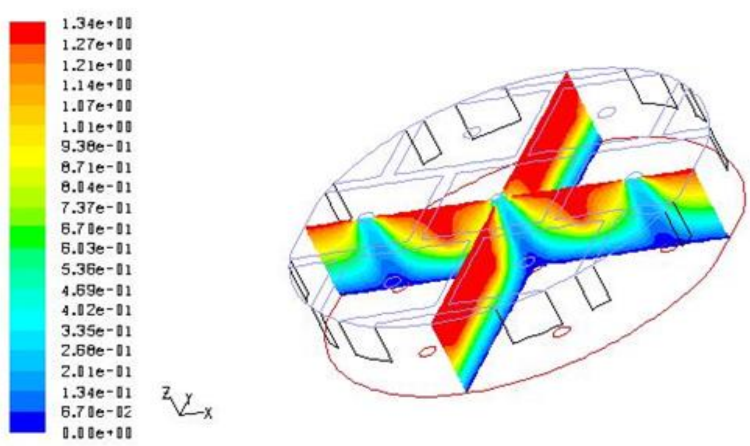


Figure 70 Pressure field – axial cross sections

Pressure is penetrating into blind/closed grooves, stopped at the groove bottom. In continuous holes the value is low due to conversion of the pressure into velocity.

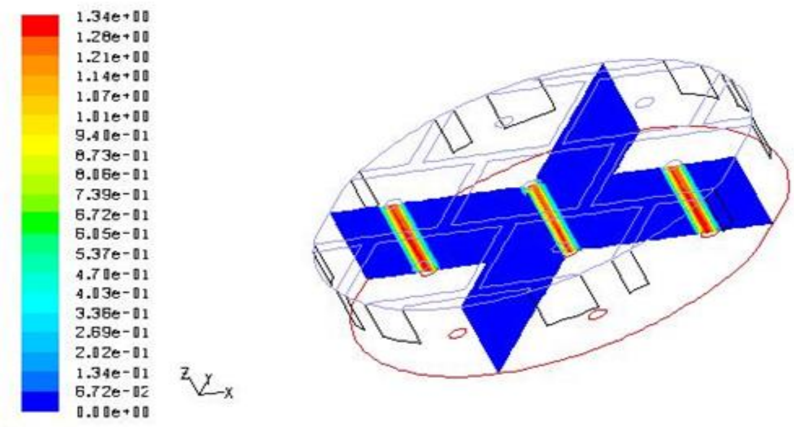


Figure 71 Velocity field – axial cross sections. full scale

The main flow is through holes, the flow through foam is extremely low.

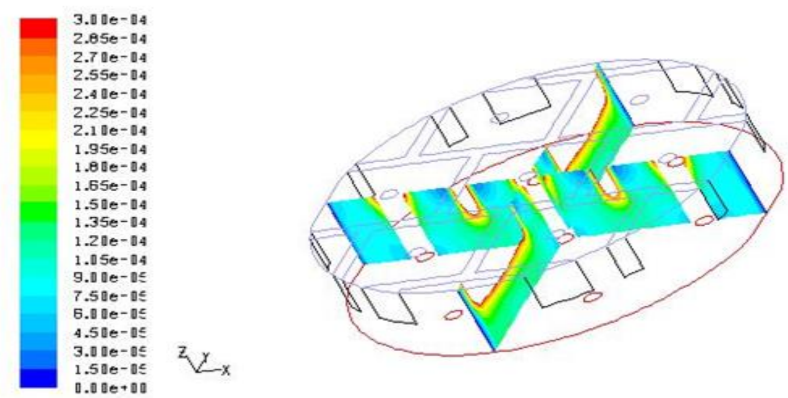


Figure 72 axial cross sections. suppressed scale

Flow in grooves is stopped at the groove bottom and slightly is penetrating into foam volume. Simulation can explain details of flow in permeable volume.

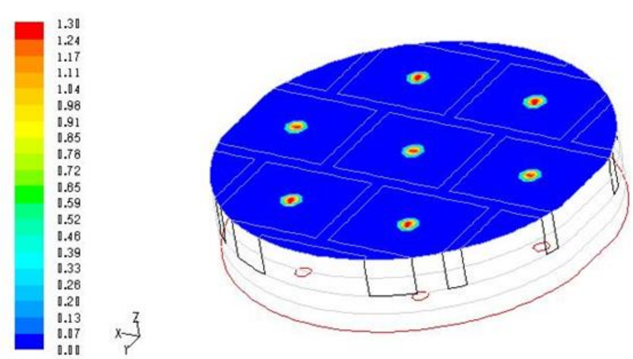


Figure 73 Velocity field at the inlet plane – full scale. Maximum in holes

The velocity field at the inlet plane is maximum in the holes

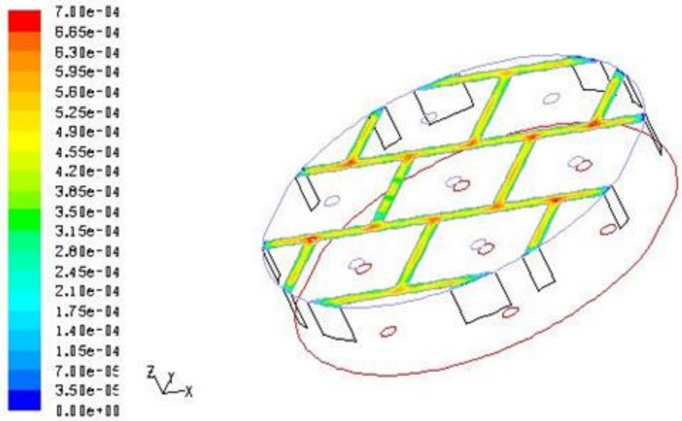


Figure 74 Velocity field in grooves at the inlet side – suppressed scale

Local maximum in larger cross sections (in T-junctions). Individual irregularities could be suppressed by finer mesh.

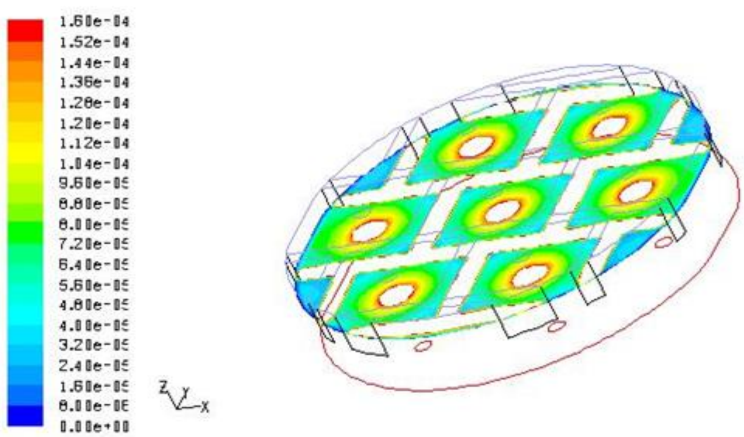


Figure 75 Velocity field 7.5 mm from the inlet side – suppressed scale

Figure 70- 75 shows flow fields from main qualitative results. To get full details of individual flow fields different scales are used. The model is shown with different graphical representation.

9.4 Foam under load (pressed)

Hypothesis for this part of the model is that if the foam is pressed then the foam volume by 50% in the flow direction. The inner permeable cells are also pressed by 50% too, so eventually the permeability is also decreasing by 50% too. And more, it is supposed that geometry deformation is along the axis of deformation and there is no abnormal shape or buckling in cross directions. For simple verification the model geometry remains the same. New parameters of permeability are determined as in the table 30 from the condition of 50% of measured flow.

Table 30 Permeability parameters for 50% flow (due to foam pressing)

	C2	α (m^2)	1/α ($1/m^2$)
F0	1.111E+10	7.052E-12	1.418E+11

Results are summarized in the tab. 31 where original mass flows mass flows through foam and grooves is decreased by 28% and 27% respectively of original values. It means from 1% of the whole flow to 0.3% approximately. It has not any influence on the flow through holes, as it represents 99% of the whole flow and some small flow changes in foam and grooves does not have any influence.

Table 31 Prediction of flow under compression

		original		pressed	press/orig.
		kg/s	%	kg/s	%
inlet	foam	0.92794e-6	0.3	2.6134e-7	28.2
	grooves	2.24480e-6	0.8	6.0319e-7	26.7
	holes	2.80000e-4	98.8	2.8160e-4	100
	sum	2.83300e-4		2.8247e-4	99.7
outlet	foam	2.07184e-6	0.7	5.5473e-7	26.8
	holes	2.81000e-4	99.2	2.8190e-4	100
	sum	2.83300e-4		2.8247e-4	99.7

9.5 Testing cases of full foams

Two cases of full foams (F0, F1) were solved; differences between simulated and measured mass flows are 1%-5%, only. The detailed geometry gives good imagination about fine details of velocity and pressure field in the foam volume, the main flow is going through perforations. On the other side, the simple model of "foam" presents the average flow, regardless of perforations and grooves. Therefore the correlation of measured and simulated mass flow is very good, but details of flow field inside the foam volume cannot be perceived.

Fig.76 shows differences between mass flows in F0 and F1

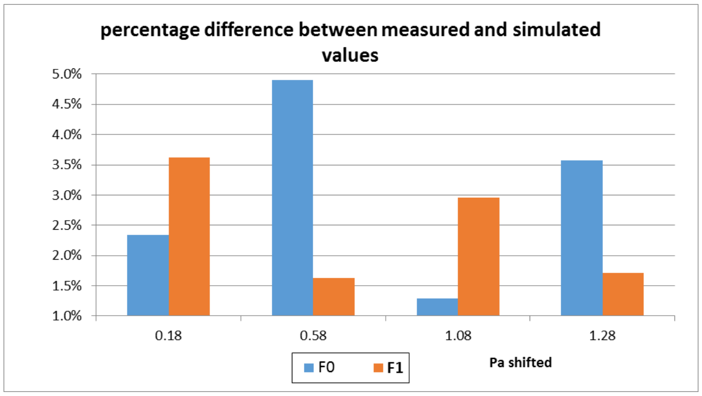


Figure 76 Difference between measured and simulated mass flows for foams F0 and F1

9.6 Summary

The results from many solved cases of numerical flow simulation in the PU-foam with the perforation can be summarized as below

1- It is possible to state that the method of numerical flow simulation used for the air permeability through porous medium gives a good imagination about the main features of the flow field in complicated structures, considering both continuous and blind air volumes and foam volumes (for instance the pressure or velocity distribution. concentration of the flow in the foam area around individual holes and grooves, flow spreading from the groove bottom in foam. flows in foam. induced by strong flow in adjoining holes etc.).

2- Using the simple geometry of full foam (case F0). The difference between mass flows measured and simulated is very low (few percentage only). In case of F0 there is not much flow of air. Therefore it could be stated that strong flows through perforated holes have the main effect in total mass flow balance and the flow through foam is negligible.

3- Influence of pressed foam layer has practically no influence on the total flow. According to previous points. The main part is flowing through "empty" holes practically without resistance (compared with reduced flow through the foam volume. due to the higher foam resistance after pressing).

The simulation can be used to test it with even more added layers and check the permeability of sandwich car seat covers.

10 Summary of the thesis

It can conclude from our research that:

Highly permeable top layers alone cannot improve the overall breathability of the car seat. The problem zone for the breathability will be always the PU-foam and the lamination. The focus should be to use the breathable layer with improvement to the lamination and the PU-foam for better permeability. The car seat comfort should be evaluated considering overall carseat, not just the top layer.

In this research 3D spacer fabric are compared with commonly used PU foams the non-woven materials, results shows that 3D spacer fabric shows a great improvement for the car seat thermal comfort. Use of 3D spacer fabric can reduce the number of layers of car seat cover, as more number of layer negatively affect the thermal comfort of the car seat. High variety of thickness of the 3D spacer fabrics gives opportunity to be used as car seat cover as well as cushion part of the car seat.

The classical PU-foam were replaced by the molded perforated foams for the cushion part and the Pu-foam for the interlining are perforated by LASER technology. Significant improvement in the breathability of the car seat was observed. The perforated foams can be future replacement for the classical foams. Different design of grooves and shapes of holes can also be introduced to increase the porosity of the foams.

The use of super absorbent polymers (SAP) for moisture absorption and comfort is studied. In this research the efficiency of different SAP fibrous webs are determined under different moisture percentage to examine the sorption and desorption efficiency. The SAP fibrous web with low thickness and high moisture absorption are tested with multilayer sandwich structure of car seat cover to determine the moisture absorption through cover material. It is observed that the SAP fibrous layers are very effective in absorbing and desorbing water vapour under high and low moisture percentages. The superabsorbent material are efficient to absorb and desorb water vapour and 50% and higher rate of absorption can be easily achieved under extreme humidity level. The fast sorption and desorption process can be repeated multiple times and make it potential use in the comfort of car seat. The research is initial work to see the utilization of superabsorbent in car seat. This is novel and initial work and further research will be done regarding the life time of the SAF in car seats.

To determine the compression results it was necessary to find the exact pressure inserted by the human on the car seat. This pressure value was obtained from the pressure distribution experiment by X-Sensor device as 13 kPa and this value was further used for the compressibility and life time testing of the carseat materials. It's necessary that the properties of the material does not change dramatically with time. Results shows that the 3D spacer fabric shoes is better in retaining its thickness even after multiple loadings.

The research work shows that there is significant improvement of the breathability of car seat's PU foam due to the perforation. The hole sizes effectively help in the transfer of air and moisture and shows a huge increase in permeability of the material. The effect of this perforation was also tested for the compressibility properties of the PU foam and it was observed that there is insignificant effect of perforation on the thickness of foam. The research work is unique for providing an alternative for better comfort of car seat with negligible effect on the usability or life time of car seat.

In this research multiple novel techniques/devices are made to test the comfort properties of the car seat. Firstly thermal camera is used to analyse the real time thermal field of the car seat and see performance of interface heating of the carseat. Secondly a sensor sheet is made to analyse the humidity and temperature field of the car seat during usage. Thirdly the classical Cup Method is modified to analyse the permeability of the material under different pressures. Lastly a unique portable device is made to measure the water vapour permeability of the real car seat.

The air permeability of different geometry of the perforated foams are tested for different pressure. The initial experimental results is used to develop a theoretical model to simulate the air permeability of perforated foams. The percentage difference of the experimental and the theoretical results shows less than 5%. This model can be used for predicting the air permeability of PU foam under different load and different geometry of perforation.

11 Future Work

The research is beneficial and shows significant improvement of the comfort of the car seat. The research can be continued to comprehensive investigation related to cost and life time benefit of using perforated foams and also the effect of forced ventilation with perforated foams. More advancement to the novel technique of measurement can be made and a complete theoretical model of moisture transport through car seat inside car cabin can be also considered for future work.

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APPENDIX

Funda Buyuk Mazari, Michal Chotebor, Jawad Naeem, *Adnan Mazari, Antonin Havelka

Effect of Perforated Polyurethane Foam on Moisture Permeability for Car Seat Comfort

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Abstract
Polyurethane (PU) foams are the most essential part of a car seat cushion. PU foams are durable and easily moldable according to the shape of the car seat, but they are poorly permeable to moisture. This impermeability of PU foam causes wetness of the microclimate between the person and car seat and makes it uncomfortable. In this research PU foams with two different thicknesses and three different hole sizes were obtained from industry by the moulding process. The foams were tested for moisture permeability by the standard cup method to determine the effect of the size of the hole on the overall moisture permeability. The foams were further tested with 11 of the most common top layer fabrics to check the effect of the top fabric layer on the overall moisture permeability of the car seat. All the top layers were first tested by means of a sweating guarded hot plate (SGHP) to measure the water vapour resistance (Ret) and then 4 materials with the minimum Ret values were tested with the most permeable foam. The results shows that the perforation of PU foam causes a significant increase in moisture permeability, whereas the top layer with the minimum Ret value decreases the overall moisture permeability and a maximum of 40g/m2 of moisture per hour is obtained with the most permeable foam with the least Ret value of the top layer. This research is an initial work on replacing the car seat with perforated PU-foams.

Key words: *car seat, comfort, poly-urethane, moisture permeability.*

Introduction

Comfort is the basic and universal necessity of the human being. However, it is very complicated and challenging to define. Slater [1] defined comfort as a pleasant state of psychological, neurophysiological and physical harmony between the environment and the human being. According to him, comfort can be defined in the following ways [2]:

1. Absence of discomfort or unpleasant feeling
2. Physiological response of the wearer
3. Temperature regulation of the human body
4. Pleasant physical, physiological and psychological conditions and harmony between the human being and the surrounding environment

The normal internal body temperature of human beings is 37 °C (98.6 °F), with a tolerance of ± 0.5 °C under different climatic conditions. Any variation from a body temperature of 37 °C may create changes in the rate of heat production or the rate of heat loss to bring the body temperature back to 37 °C. Metabolic activity or the oxidation of foods causes the production of heat and can be partially adjusted by controlling the metabolic rate [2 - 4].

Comfort has become the main quality standard of cars. Comfort in a car is complicated process and includes different features like driving, behaviour, noise and ease of handling [5]. Thermal comfort is the most significant factor affecting passenger suitability. Car seats are one of the main features of vehicle comfort. Seats not only have a striking design or meet specific design standards for safety reasons, they must also have optimal parameters of comfort. Apart from ergonomic considerations, thermophysiological comfort is of significant importance. At present, the thermophysiological comfort of car seats can be acquired by a set of laboratory test apparatus. It is now probable to improve and calculate thermophysiological characteristics of car seats at the development stage by using a skin model and seat comfort tester [6, 7].

It was initially observed that a strong discomfort sensation arise due to the small quantity of water in the microclimate between the person and the car seat [8]. It has been confirmed in numerous researches that either moisture from sweating or additional moisture creates clothing contact sensations. The method for these calculations highlighted that a little amount of moisture is required to instigate a discomfort sensation [9, 12 - 17].

There are four factors of car seats with respect to the physiological point of view as follows:

- The preliminary heat flow ensuing from the first contact with the seat. Especially a feeling of warmth or cold in the first few minutes or even seconds after entering the car.
- The dry heat flow on lengthy journeys, i.e. the quantity of heat transferred by the seat
- The capability termed as "breathability" to transfer any sweat away from the body. In so-called "normal sitting situations" there is no distinguishable sweating; however, the human body constantly discharges moisture (insensible perspiration), which has to be carried away from the body.
- Contingent on heavy sweating (a vehicle in summer heat and stressful traffic situations), the ability to absorb perspiration without a damp feeling of the seat.

Thermophysiological comfort is based on the fundamentals of energy conservation. ***Figure 1*** shows all the energy created has to be dissipated in precisely the same amount from the body [18]. The mathematical formula mentioned under this principle is:

$$M - P_{ex} = H_{res} + H_c + H_e + \Delta S/\Delta t \quad (1)$$

The energy of production is given by M, and in the case of cars the range of M is between 150 and 300 watts. P_{ex} is the exterior physical work, which in a car is primarily due to steering and shifting

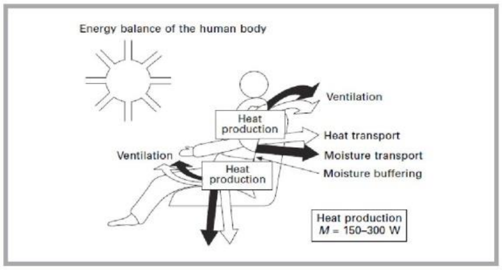

Figure 1. Energy balance between the heat produced and dissipated as a prerequisite for good thermal comfort [18].

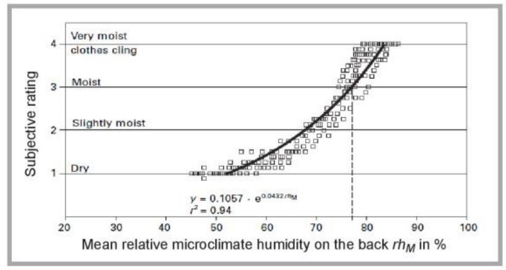

Figure 2. Subjective moisture sensation of human test subjects as a function of relative humidity in the microclimate between the skin and seat [18].

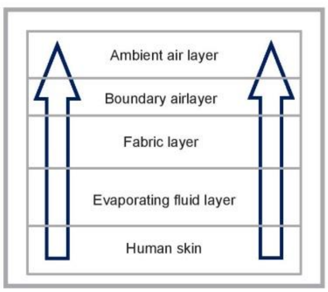

Figure 3. Transportation of moisture vapor through different layers [3].

gears, being much smaller than M. H_{res} is the respiratory heat loss due to breathing, which is approximately 10% of the metabolic rate M. H_c is the dry heat flux encompassing conduction, radiation, and convection. H_c is heavily dependent on the car seat, the passenger's clothing and cabin climate. The same applies for H_e; which is caused by perspiration.

If more energy is produced than discharged, then the body suffers from hyperthermia. However, too much heat loss causes hypothermia. Both these conditions lead to alteration of the body's energy content ΔS with time Δt. ΔS can be either positive (hyperthermia) or negative (hypothermia) and is zero for a steady state.

This steady state ($\Delta S = 0$) is necessary and has to be the goal of a car seat producer to acquire energy balance. M, P_{ex} and H_{res} cannot be affected by the car seat, however, H_c and H_e can be affected.

Water vapour transportation

The moisture sensation of a person is very significant for observation of the overall seat comfort. ***Figure 2*** reveals that a seated passenger can distinguish microclimate humidity between the skin and seat [18]

For achieving a dry microclimate, the breathability of the seat to transfer sweat produced away from the body is critical. The human body continually discharges moisture, called insensible sweating. The human body loses 30 grams of moisture per hour. As car seats cover a large area of the body, the seat has to accommodate a large part of perspiration produced and thus a substantial quantity of moisture per hour. In order to maintain thermoregulation, the human body does not only produce insensible sweating but also sensible perspiration to cool down the core temperature of the human body through the evaporation of sweat. Up to one liter/hour of moisture can be produced during sports activity or hot surroundings.

For sensible perspiration, moisture is actively produced by sweat glands inside the human skin. However, the desired cooling effect can be acquired only from the evaporation of this moisture. This is a direct requisite of the vehicle seat, which has to permit this evaporation. Besides thermoregulation, the human body sweats further due to mental stress. This stress driven sweating may be produced during car driving in tough traffic circumstances. Thus it is important that the seat delivers high vapour transport to permit the evaporation of perspiration for the majority of seating situations. The seats must have low water vapour resistance (i.e. high breathability). All the parts of the seats must be water vapour permeable as one single impermeable layer can obstruct transportation of water vapours.

In the case of fabrics, moisture vapour transmission is managed by the inter yarn or inter fibre gaps. Vapours are diffused through air gaps between fibrous materials. It can be observed from figure 3 that the resistance to moisture vapour diffusion comes in different layers during the diffusion of moisture vapours through textile materials. These different layers are

1. The evaporating fluid layer (which is full of water saturated vapor),
2. The confined air layer (sandwiched between the skin and fabric),
3. The boundary air layer,
4. The ambient air layer.

Moisture vapour is transmitted through fibrous materials by the following mechanisms:

1. Diffusion of water vapour through the air gaps between fibres,
2. Absorption, transmission and desorption of water vapour by fibres,
3. Adsorption and migration of water vapour along the surface of fibre,
4. Water vapour transportation by forced convection [3].

Investigation of scientific literature revealed the keen interest of researchers to solve the issue of reliable determination of the vapour permeability properties of textile materials [11, 12].

Upright cup method (***Figure 4***)

In this method, the fabric sample is positioned and sealed above a cup, 2/3rd of which is filled with water, and then it is placed in a wind tunnel in a standard atmosphere on a weighing balance and the variation in mass of the fabric at a time interval is calculated [10].

Sweating guarded hot plate

This method is also called a skin model and is utilized for evaluating the thermo-physiological comfort of clothing and work as per ISO 11092 standard [7]. This method simulates the transportation of moisture through textiles and clothing assemblies when they are worn next to the human body. Evaluation of the water vapour resistance of the fabric is made from the evaporative heat loss in the steady state condition by this method. The temperature of the guarded hot plate is maintained at 35 °C and the standard atmospheric condition for testing (65% R.H. and 20 °C) is utilised.

The water vapour resistance (R_{et}) of the fabric is calculated as follows:

$$R_{et} = \frac{A(P_m - P_a)}{H - \Delta H_c} - R_{et0}\left(\frac{m^2 Pa}{W}\right) \quad (2)$$

where, A is the test area, P_m the saturation water vapour partial pressure at the surface of the measuring unit, P_a the water vapour partial pressure of air in the test chamber, H the amount of heat supplied to the measuring unit, ΔH_c is the correction factor, and R_{et0} is the apparatus constant [3].

The evaluation of moisture vapour transmission through fabric is slow and sensitive but a very effective process. Different standard methods utilised for evaluating moisture vapour transmission properties of textile substrates are as follows:
1. The evaporative dish method or control dish method (BS 7209),
2. The upright cup method or gore cup method (ASTM E 96-66),
3. The inverted cup method and the desiccant inverted cup method (ASTM F 2298),
4. The dynamic moisture permeable cell (ASTM F 2298),
5. The sweating guarded hot plate method, skin model (ISO 11092).

Experimental part

There are two common thicknesses of car seat PU foams which are used according to the seat requirement. Each foam, with 3 different hole sizes, was obtained from industry, made by the molding process. The foams were not drilled or cut from the top or bottom in the laboratory so that the real surface property of the foams should be kept, as the molded surface is very different from that of cut foams.

The original foam was first observed under X-ray micro tomography, which is very beneficial to observe the internal structure of the material. ***Figure 5*** clearly shows that the air gaps inside the PU foam are not connected from the top to the bottom of the foam material. and

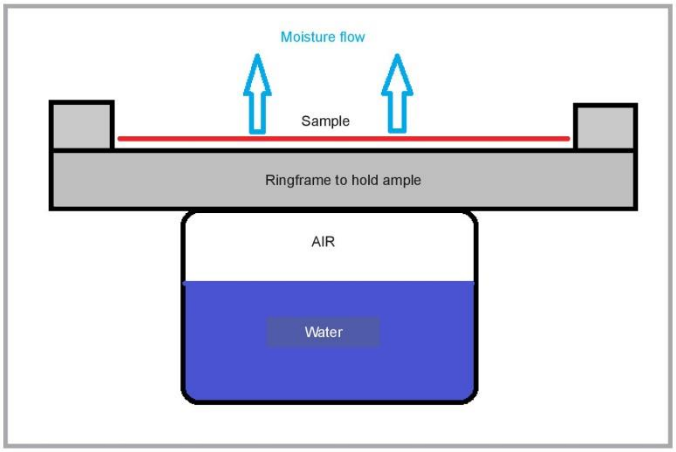

Figure 4. *Upright cup method [3].*

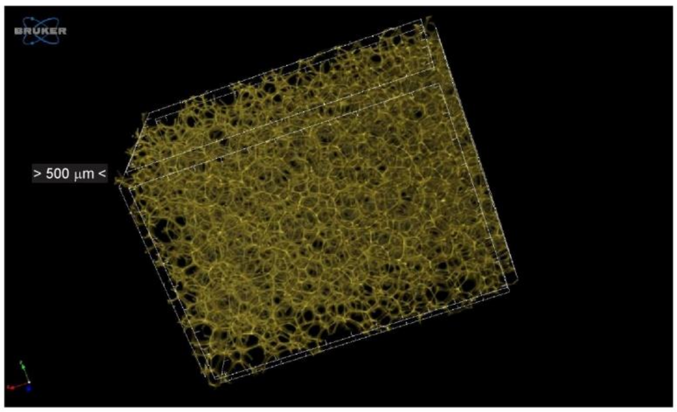

Figure 5. *X-ray micro tomographic image of PU-foam.*

Table 1. *Properties of PU foam used for the experiment.*

	Foam thickness, mm	Number of holes, -	Hole diameter, mm	Total area of foam sample, mm²	Area of holes, mm²	Area of solid foam, mm²
A	60	0	0	16505	0	16505
A1		7	10		550	15955
A2			15		1236	15268
A3			20		2198	14307
B	85	0	0	16505	0	16505
B1		7	10		550	15955
B2			15		1236	15268
B3			20		2198	14307

hence nthis material can never be breathable to air or moisture.

It is shown in ***Figure 5*** that the PU foam does not have open channel pores, which means that moisture cannot be transmitted from the top to the bottom surface. Consequently it was decided to replace the PU-foam with perforated foams to enhance the moisture permeability.

The original foams and perforated foam properties are shown in ***Table 1***.

Figure 6 shows a real picture of the perforated foams.

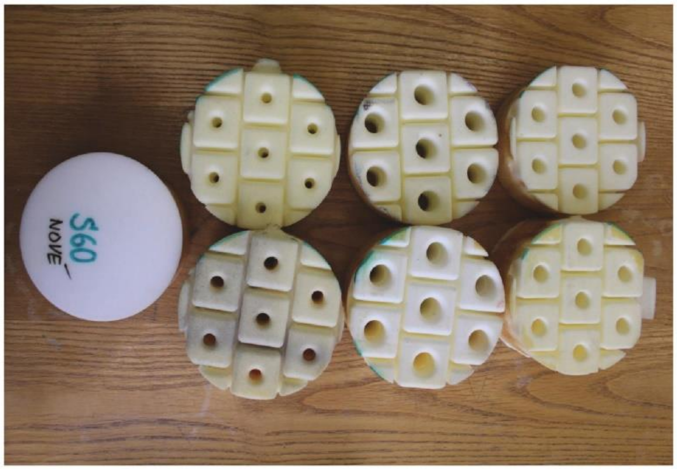

Figure 6. *PU foam samples.*

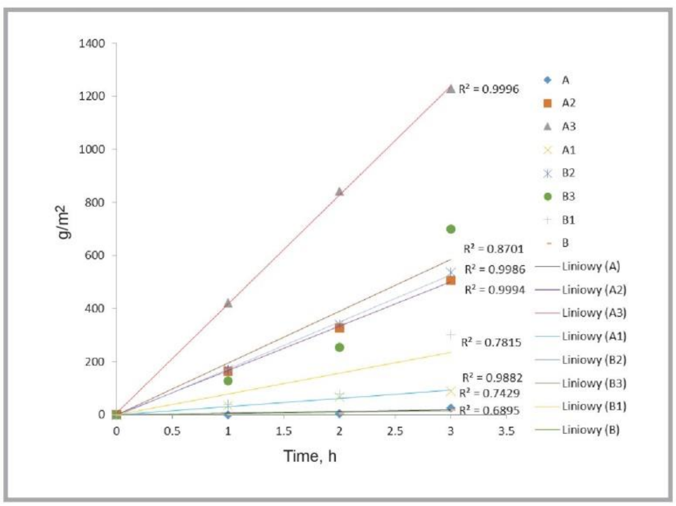

Figure 7. *Moisture permeability through PU-foam.*

All the foams were tested with the upright cup method (ASTM E 96-66) for water vapour permeability. Any other technique of moisture permeability measurement was not possible as the foams were thick, and it was not possible to use such thick samples. Testing was performed in a climate chamber with controlled conditions to avoid condensation of moisture in the sample. The testing was performed for 3 hours and measurements obtained after every hour.

Eleven of the most common top layer fabrics were obtained from the car industry and tested first for water vapour resistance (R_{et}) on a sweating guarded hot plate (SGHP). The 4 samples with the minimum Ret value were selected to test moisture permeability as a combined layer with perforated foams (***Table 2***).

Results and discussion

All the PU foams were tested for moisture permeability with the upright cup method (ASTM E 96-66) as well as for water vapour permeability; the test was performed for 3 hours and measurements obtained after every hour.

It is observed from ***Figure 7*** that non-perforated foams A and B are almost impermeable to moisture and the bigger size of the porosity causes higher breathability of the foam. Foams A3 and B3 have the maximum air area (area of the holes) in the sample and shows a significant increase in moisture permeability. The A3 sample shows more permeability than the B3, which is due to the thickness difference of the sample, and the moisture permeability is dependent on the thickness of the sample.

Table 2. *Properties of top layer of car seat cover.*

<table>
<tr><th rowspan="2">No.</th><th colspan="3">Fleece</th><th colspan="3">3D Spacer</th><th colspan="4">Face Fabric</th></tr>
<tr><th>Mass per unit area, g/m²</th><th>Thickness, mm</th><th>Material composition</th><th>Mass per unit area, g/m²</th><th>Thickness, mm</th><th>Material composition</th><th>Technology</th><th>Warp direction details</th><th>Weft direction details</th><th>Material composition</th></tr>
<tr><td>26989</td><td>100</td><td>2</td><td>100% PES</td><td>250</td><td>3</td><td>100% PES</td><td rowspan="3">warp knitted</td><td>14 wale/cm</td><td>29 course/cm</td><td rowspan="11">100% PES</td></tr>
<tr><td>25976</td><td rowspan="3">230</td><td rowspan="3">5</td><td rowspan="3">70% PES, 30%WO</td><td colspan="3"></td><td rowspan="2">13 wale/cm</td><td rowspan="2">24 course/cm</td></tr>
<tr><td>25979</td><td rowspan="2">335</td><td rowspan="2">5</td><td rowspan="7">100% PES</td></tr>
<tr><td>26728</td><td rowspan="2">woven</td><td>33 end/cm</td><td rowspan="2">18 pick/cm</td></tr>
<tr><td>26977</td><td>100</td><td>2</td><td>100% PES</td><td>250</td><td>3</td><td>32 end/cm</td></tr>
<tr><td>26200</td><td>230</td><td>5</td><td>70% PES, 30%WO</td><td>335</td><td>5</td><td rowspan="2">warp knitted</td><td rowspan="2">15 wale/cm</td><td rowspan="2">25 course/cm</td></tr>
<tr><td>26195</td><td rowspan="2">100</td><td rowspan="2">2</td><td rowspan="2">100% PES</td><td rowspan="2">250</td><td rowspan="2">3</td></tr>
<tr><td>25962</td><td rowspan="2">woven</td><td>34 end/cm</td><td>18 pick/cm</td></tr>
<tr><td>25967</td><td rowspan="3">230</td><td rowspan="3">5</td><td rowspan="3">70% PES, 30%WO</td><td>335</td><td>5</td><td>36 end/cm</td><td>16 pick/cm</td></tr>
<tr><td>29086</td><td colspan="3" rowspan="2"></td><td>warp knitted</td><td>14 wale/cm</td><td>28 course/cm</td></tr>
<tr><td>29084</td><td>woven</td><td>36 end/cm</td><td>16 pick/cm</td></tr>
</table>

***Table 3.** Air and moisture permeability of car seat's top layers.*

No.	R_{et}, m^2Pa/W	Air permeability DIN EN ISO 9237 in l/min/100 cm^2
26989	14.2318	500
25976	12.4050	275
25979	16.1789	263
26728	16.9876	195
26977	14.7294	150
26200	17.9185	140
26195	15.3477	98
25962	15.4576	98
25967	21.9974	98
29086	31.2510	93
29084	29.0179	75

As the results of the perforated foams were very reasonable regarding moisture permeability, hence different top layer combinations were used to test the overall permeability of the car seat sandwich structure. All the top layers were tested first for air permeability by ISO standard 9237, as shown in ***Table 3***, to determine that of the top layers. The air permeability and moisture permeability are not comparable when the material is thick, and there is a possibility of axial airflow. As a consequence, the top layers were also tested for moisture vapour resistance by standard ISO 11092. Four of the samples were chosen according to low resistance to moisture and better air permeability, and later sandwiched with the perforated foam.

As shown in ***Table 3***, the four top samples were sandwiched with the highest permeable foam A3 and again tested for moisture permeability with the upright cup method (ASTM E 96-66) for water vapour permeability.

Figure 8 shows the overall permeability of the car seat cover with foam A3, and it can be seen that there is nearly 20 - 30 g of moisture transfer each hour, which is almost equal to the average human perspiration during driving. The top layer with 3D spacer fabric and wool showed better transportation of moisture. In this research the most common top layers are taken from industry to simply investigate the effect of perforated PU-foam.

Conclusion

The breathability of a car seat is a serious issue and in this research a unique concept of perforated molded PU-foams was used instead of classical foams. The results shows that perforation plays a significant role in the moisture transfer. An average human perspires 20 - 40 g per hour while driving but classical foams are impermeable and cause discomfort for the driver, whereas perforated foam and a top layer work together efficiently to transfer nearly 40 g/hour of moisture. The top layers of the fabric also play an important role, and it was observed that the layers with 3d spacer fabric and wool percentage have better transportation of moisture from the PU-foam below. The top layer will be studied further in future research as different layers sandwiched together with flame or chemical adhesion, which further reduces breathability; whereas in this research some of the most common top layers were taken to simply investigate the overall performance with the perforated foams. The perforated foams can be a future replacement for classical foams. The different design of grooves and shapes of holes can also be introduced to increase the porosity of the foams. This is a novel and initial work and further research will be done regarding the lifetime of the perforated foams.

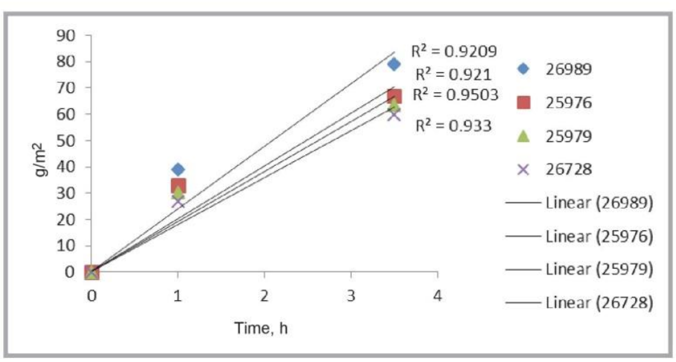

***Figure 8.** Water vapor permeability of sandwich car seat cushion.*

Acknowledgement

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Effect of a Superabsorbent for the Improvement of Car Seat Thermal Comfort

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Abstract
The use of super absorbent polymers (SAP) for moisture absorption and comfort is still unexplored. The aim of this work was to observe the application of SAF in car seats for comfort purposes. In this research the efficiency of different SAP fibrous webs were determined under different moisture percentages to examine the sorption and desorption efficiency. A SAP fibrous web with low thickness and high moisture absorption were tested with a multilayer sandwich structure of a car seat cover to determine moisture absorption through the cover material. The standard Cup method was used to determine the moisture permeability of different car seat covers with a superabsorbent layer closed with impermeable polyurethane foam. It was observed that the SAP fibrous layers are very effective in absorbing and desorbing water vapour under extremely high and low moisture percentages. In extreme humid conditions (95%RH), 20g of the SAP layer absorbs nearly 70% of its weight in water vapour, reaching the maximum absorption capacity in 6 hours.

Key words: *car seat, comfort, poly-urethane, moisture permeability, SAF.*

Introduction

Since yarns are assemblies of fibres, it becomes important to understand how the fibres are arranged in the yarn cross-section or,Hertzberg [1] describes comfort as the absence of discomfort. The term "seat comfort" is usually used to describe the temporary relief of the human body felt while sitting [2] Discomfort is primarily related to biomechanical factors (such as joint angles, muscle contractions, and pressure distribution) that produce feelings of pain, soreness, numbness, stiffness and so on [3, 4] Discomfort could easily come from the bad structural biomechanical design of the seat [5]. In this research our focus was only to remove excess perspiration moisture from a car seat. In this research a unique way is used to remove moisture by using a superabsorbent. Fibers absorb water vapour due to their internal chemical compositions and structure. Most textile fibers have a certain degree of moisture absorption capacity (called hygroscopicity). Moisture absorption influences heat and moisture transfer processes. For example, a wool fiber can take up 38% of moisture relative to its own weight [6]. The aims of this work were as follows

- Application of SAF in car seats for comfort purposes.
- Determining the efficiency of SAF in humid conditions.
- Measuring experimentally the absorption and desorption of moisture to SAF under humid and dry conditions, respectively.

Thermal comfort

Comfort has become the main quality standard of cars. Comfort in a car is complicated process and includes different features like driving, behaviour, noise and ease of handling [5]. Car seats are one of the main features of vehicle comfort. Seats not only have a striking design or meet specific design standards for safety reasons, they must also have optimal parameters of comfort. Apart from ergonomic considerations, thermophysiological comfort is of significant importance. At present, the thermophysiological comfort of car seats can be acquired by a set of laboratory test apparatus. It is now feasible to improve and calculate the thermophysiological characteristics of car seats at the development stage by using a skin model and seat comfort tester [6,7].

It is known that strong discomfort sensation arises due to a small quantity of water in the microclimate between the person and the car seat [8-12]. It has been confirmed in numerous researches that either moisture from sweating or additional moisture creates clothing contact sensations, where the wetness of the microclimate, for any reason, causes a discomfort sensation [13-17].

There are four factors of car seats from a physiological point of view:

- The preliminary heat flow on first contact with the seat. Especially the feeling of warmth or cold in the first few minutes or even seconds after entering the car.
- The dry heat flow on lengthy journeys, i.e. the quantity of heat transferred by the seat
- The capability, termed "breathability", to transfer any sweat away from the body. In so-called "normal sitting situations" there is no distinguishable sweating, however the human body constantly discharges moisture (insensible perspiration), which has to be carried away from the body.
- Contingent on heavy sweating (a vehicle in summer heat and stressful traffic situations), the ability to absorb perspiration without a damp feeling of the seat.

Super absorbent fibers (SAF)

Super absorbent fibers (SAF) or super absorbent fibrous material have been popular since the last decade to absorb and retain a high amount of liquids (nearly 300 times its own weight). The SAF used in this study was prepared from a cross-linked polymer consisting of three different monomers – acrylic acid (AA), methylacrylate (MA) and a small quantity of special acrylate/methylacrylate monomer (SAMM) – in which the acrylic acid is partially neutralised to the sodium salt of acrylic acid (AANa). The cross-links between polymer chains are formed as ester groups by a reaction between the acid groups in acrylic acid and the SAMM. The chemical structure of SAF is shown in ***Figure 1***.

Moisture sensaton

Water vapor transportation

The moisture sensation of a person is very significant for the observation of overall seat comfort. ***Figure 2*** reveals that a seated passenger can distinguish

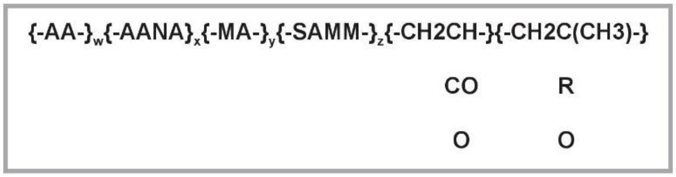

Figure 1. *Chemical structure of SAF. Where: -AA- = {CH2CH(COOH)-} from acrylic acid -MA- = {CH2CH(COOCH3)-} from methyl acrylate, -AANa = {-CH2CH(COONa)-} from acrylic acid and caustic soda, R= -COOCH2CH(CH3)-. The values of w, x, y and z depend on the amount of heat treatment received.*

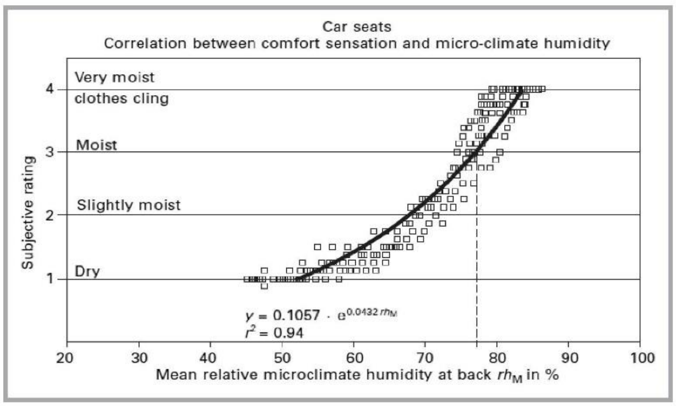

Figure 2. *Subjective moisture sensation of human test subjects as a function of relative humidity in the microclimate between the skin and seat [10].*

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To achieve a dry microclimate, the breathability of the seat for transferring sweat produced away from the body is critical. The human body continually discharges moisture called insensible sweating. Human body loses 30 grams of moisture per hour. As car seats cover a large area of the body, the seat has to accommodate a large part of perspiration produced, and thus a substantial quantity of moisture per hour. In order to maintain thermoregulation, the human body does not only produce insensible sweating but also sensible perspiration, as well as to cool down the core temperature of the human body through evaporation of sweat. Up to one liter/ hour of moisture can be produced during sports activity or hot surroundings [12].

For sensible perspiration, moisture is actively produced by sweat glands inside the human skin. However, the cooling effect desired can be acquired only from the evaporation of this moisture. This is the direct requirement from a vehicle seat, which has to permit this evaporation. Besides thermoregulation, the human body sweats further due to mental stress. This stress driven sweating may be produced during car driving in tough traffic circumstances. Thus it is important that the seat delivers high vapour transport to permit the evaporation of perspiration for the majority of seating situations. The seats must have low water vapour resistance (i.e. high breathability). All parts of seats must be water vapour permeable as one single permeable layer may obstruct the transportation of water vapours [12].

Sweat Buffering

Entering a hot car in summer, the human body starts to perspire excessively. This additional quantity of sweat has to be buffered to maintain a dry microclimate. The dominant components for the buffering capacity are linings and seat covers. For an adequate buffering capacity, both water vapour transportation and absorbency of water vapours are very pertinent. As revealed by researcher [17], water vapour transportation is of significant importance for a seat cover.

The impact of water vapour transportation on water vapor buffering becomes smaller when studying whole car seats. The thickness of car seats serves as barrier against diffusion because of their thickness. Consequently water vapour absorbency evaluates the water vapor buffering capacity for whole car seats. The underneath covering and lining material must be hygroscopic for acquiring swift absorption.

Fundamentals of moisture vapour transmission

Moisture vapour transmits through fibrous materials by the following mechanisms:

1. Diffusion of water vapour through the air gaps between fibers
2. Absorption, transmission and desorption of water vapour by fibers
3. Adsorption and migration of water vapor along the surface of fiber
4. Water vapour transportation by forced convection

Investigation of scientific literature revealed the keen interest of researchers to solve the issue of reliable determination of vapour permeability properties of textile materials. It is pertinent to design fabric with the moisture transmission properties required. The selection of the experimental procedure is the most important concern monitored during the evaluation of moisture transmission properties of a fabric or clothing system.

Heat and moisture transfer through fabric is evaluated in two conditions:

1. Steady state
2. Transient state

Steady state experiments deliver reliable heat and mass transfer data for non-active cases, but they are unable to demonstrate heat and moisture transfer mechanisms in actual wearing situations [18]. A number of test conditions, designs of devices and approaches facilitate the fundamental understanding and comprehensive learning of the vapour permeability process [11].

The evaluation of moisture vapour transmission through fabric is slow and sensitive but a very effective process. Different standard methods utilised for evaluating the moisture vapour transmission properties of textile substrates are:

1. Evaporative dish method or control dish method (BS 7209)
2. Upright cup method or Gore cup method (ASTM E 96-66)

3. Inverted cup method and desiccant inverted cup method (ASTM F 2298)
4. Dynamic moisture permeable cell (ASTM F 2298)
5. Sweating guarded hot plate method, skin model (ISO 11092)
6. Sweating manikins

Experimental part

In this research, different compositions of Super absorbent fiber (SAF) and car seat covers (from Company Martur/Turkey) were obtained.

The 3 SAF compositions used in this research are shown in ***Table 1***.

The car seat covers obtained from the Company Martur were made of different layers as shown in ***Figure 3***.

Properties of the X layer is shown in ***Table 2***.

Whereas Layer Y is a thin PU-foam layer with a thickness of 6mm and density of 300 g/m^2, Layer Z is a thin mesh of polyester with a thickness of 1mm and density of 50 g/m^2: this layer is used to make the sewing process easier as PU-foam is rough, compressible and causes stoppage of the sewing machine.

Methodology

SAF is famous for absorbing and retaining a huge amount of liquid, but moisture absorption and desorption is still an undiscovered property of SAF. In this research, firstly the absorption and desorption properties of the SAF layers were measured. Then the most efficient SAF was used in between rea carseat layers to observe the effect of superabsorbence in the carseat assembly. The measurement was performed by the Cup Method (ASTM E 96-66) for moisture permeability.

Absorption desorption isotherm

Isotherm was obtained by the desiccator method, where the specimen was put in a sealed container with different amounts of various saturated salt solutions until weight equilibrium could be assumed. Different salts were used to obtain the humidity level required in the sealed containers. Table III shows the relative humidity (RH%) obtained in different sealed containers at 20°C.

The specimens were pre dried at 7% RH prior to the absorption/desorption isotherm experiment. The specimens were weighed after every 4 days to a maximum of 12 days. Each container contained 4 samples: A, B, C and P (PU-foam). Each set of containers (5 containers with different percentages of the humidity level) were opened after 4, 8 and 12 days, respectively; a total of 15 containers were used in lab conditions of temperature 20°C. Weighing the samples after different days gave us information whether the material was still absorbing moisture, and if there was no difference in moisture gain from the last set of measurements (4 days and 8 days), then it was considered as the maximum moisture absorbed by the sample.

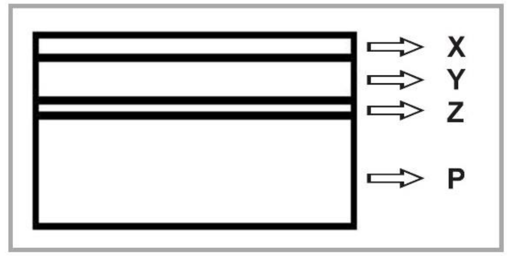

Figure 3. *Layers of carseat. Where: X is the top fabric layer which touches the person/driver, Y is the second layer made of thin polyurethane foam, Z is thin porous polyester mesh, P is 5 cm thick PU-foam.*

Climate chamber measurement

The absorption and desorption of samples were also tested in a climate chamber where the temperature was set as 20°C and the RH changed from 7% to 95%. The absorption and desorption of the specimen are calculated by the following formula ***Equation (1).***

Each sample was weighed inside the chamber after every 1 hour. This experiment gave valuable information regarding the time and efficiency of absorption and desorption of specimens. The experiment was repeated 3 times.

Standard Upright cup method

The standard Upright cup method or Gore cup method (ASTM E 96-66) was used to analyse the overall loss of water from the reservoir. A car seat cover material with a classic layer structure of X,Y, Z and P was first analysed and then an SAF layer was inserted between layers X and Y to determine the effect of the SAF layer on the moisture resistance of the complete sandwich material. Layer P was a thick PU-foam and is well-known for being impermeable and acts as a moisture barrier from the reverse side of the sandwich material. The PU-foam protects the SAF so as not to absorb moisture from the chamber environment; hence the results of the Cup method were precise as the flow of moisture was only from the top Layer "X". A visual illustration of the samples is shown in ***Figure 4***.

Reasons for methodology used

The absorption isotherm technique using

Table 1. *Saf properties.*

	Composition	Structure	Areal weight, g/m^2	Thickness, mm
A	Polyester staple fiber	Needle felt, non-woven	570	5.4
B	Fluff pulp	Bi component fiber	130	1.6
C	Polyester staple fiber	Super absorbent yarn netting, laminated with PES weave	115	1

Table 2. *Top woven layer of car seat.*

Woven pattern	Raw material	Warp density	Weft density	Cross section	Density, g/m^2	Yarn number	Filament number	Texture type
1x1 plain weave	100% Polyester	24	17	round	160	300	96	Air twisted yarn

$$\text{Moisture amount change } \% = \frac{(Newweig\ htofsample\ - originalsampleweig\ \ ht)}{originalsampleweig\ \ ht} * 100$$

Equation (1).

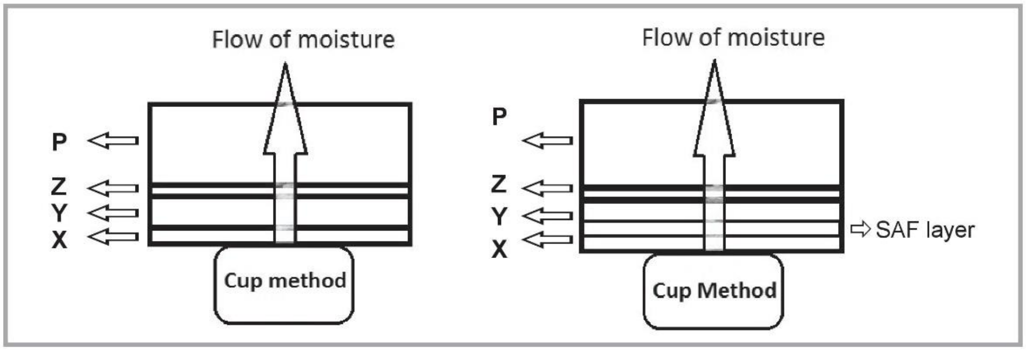

Figure 4. Visual illustration of specimen layers during testing.

salt is a very common method to measure the amount of moisture absorbed by the material over a long time. The experiment time is relatively high and human touch during measurement of the weight can cause error. To compensate for this, a climate chamber was used to compare the results of absorption and desorption. Finally the sandwich layers were tested using the Cup-method to avoid any external load on the sample, and finally the moisture permitted through the complete sandwich layers could be obtained.

Results and discussion

The specimen was put in a sealed container with different amounts of various saturated salt solutions until weight equilibrium could be assumed. 4 samples were placed in each container with 5 different salt solutions and tested after 4, 8 and 12 days; therefore a total of 15 containers were used for this experiment. Different salts, as shown in ***Table 3***, were used to obtain the humidity level required in the sealed containers. ***Figure 5*** shows the percentage gain of moisture with respect to time.

It is observed that the SAF's absorbed nearly 70% moisture in relation to their weight at 100% RH. Specimen "A" showed the highest rate of moisture gain measured after 12 days. There was no difference between the measurement taken after 8 days and 12 days of testing, and results observed after 12 days can be considered as the maximum moisture absorbed by the sample. The process of testing the samples with different salts providing different humidity levels is quite slow but provides accurate results.

Table 3. Salt solution and RH% in closed containers.

	Salt solution	RH%
1	Distilled water	100
2	Pottasium chloride	85.1
3	Sodium bromide	59.1
4	Pottasium carbonate	43.2
5	Lithium chloride	11.3

The PU-foam sample gained less than 2% moisture after 12 days.

The absorption and desorption of samples were also tested in the climate chamber, where the temperature was set as 20°C and the RH varied from 7% to 95%. The experiment was repeated 3 times, with the average value shown in the figure below. ***Figure 6*** shows the rate of absorption and desorption of samples.

Specimen A was inserted in between the car seat sandwich layers, as shown in ***Figure 3***, to test the water vapour permeability cup method (ASTM E 96-66). The car seat was covered by PU-foam, which is impermeable to moisture. The presence of the superabsorbent helped in the absorption of moisture though the top layer of the fabric and caused a decrease in the water level in the cup.

The superabsorbent layer was pre-dried at 35% RH, which is the average ambient humidity inside a car. The layer is then inserted in between the car seat layer, as shown in ***Figure 3***.

As shown in ***Figure*** *7*, it was observed that the material became highly breathable for the first 4 hours of testing, and after that it was still much better than the original sample's breathability. The experiment was repeated 3 times, with average values shown in the graph. The results show a significant difference in moisture transport when a superabsorbent is used.

Conclusion

The following is concluded from this research

- The superabsorbent material is efficient to absorb and desorb water vapour, and a 50% and higher rate of absorption can be easily achieved under extreme humidity .
- The fast sorption and desorption process can be repeated multiple times, showing potential use for the comfort of car seat covering.
- The use of superabsorbent causes a significant change in the moisture permeability from the top layer of the original seat cover.
- The use of a superabsorbent can be a cheap method in future to increase the comfort of car seats without the use of expensive ventilation systems.
- The research was an initial work to observe the utilization of an superabsorbent in carseat. This is a novel work and further research will be done regarding the life time of the SAF in carseats.

Acknowledgement

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Future works

The use of SAF is still unexplored for the carseat, and the future testing of SAF with different assemblies of carseats will be undertaken as well as the performance under load examined. The life time study of SAF is also an interesting research area to explore.

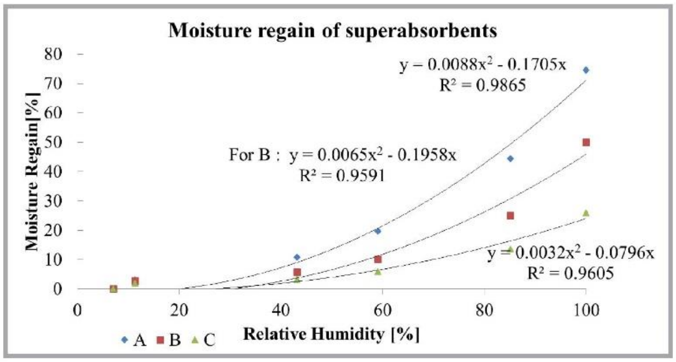

Figure 5. *Moisture absorption with respect to time.*

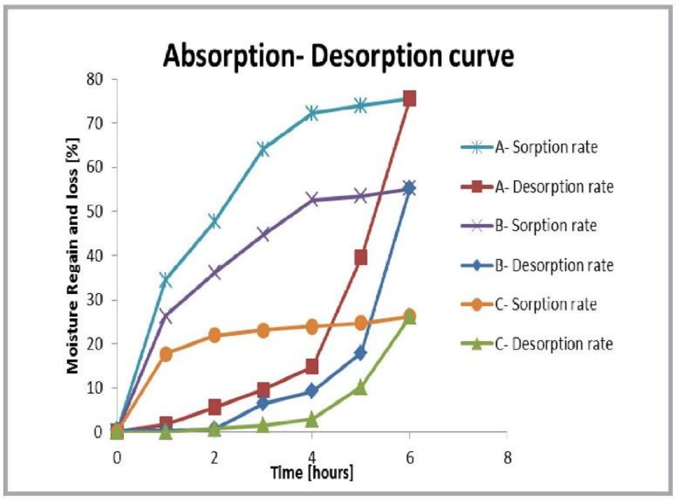

Figure 6. *Rate of absorption and desorption.*

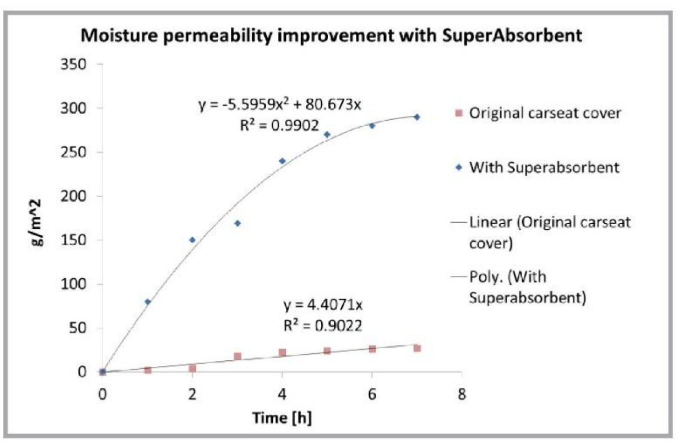

Figure 7. *Effect of superabsorbent on water vapor permeability.*

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