CHAPTER 4

INFLUENCE OF DERIVATIVES OF BI-LAYER KNITTED STRUCTURES ON THERMAL COMFORT CHARACTERISTICS OF LAYERED KNITTED FABRICS

4.1 INTRODUCTION

This chapter discusses the effect of derivatives of bi-layer knitted structures on thermal comfort characteristics of sportswear. The derivatives of bi-layer knitted structures were developed with micro-fibre polyester yarn as inner layer and modal yarn as outer layer. The layer which touches the skin is inner layer and facing the outer environment is outer layer. The thermal comfort characteristics such as air, heat and moisture transfer have been studied. The subjective evaluation by wear trial method has been carried out to find the suitable bi-layer knitted fabric for shuttle badminton sportswear.

4.2 MATERIALS AND METHODS

Four bi-layer knitted fabric derivatives were developed in which inner layer is made-up of micro-fibre polyester yarn (150Denier) and outer layer is made-up of modal yarn (132 Denier). The derivatives of bi-layer knitted fabric were developed by changing cam track, needle order and number of course repeat. The fabrics were developed in circular rib knitting machine and the machine specification is shown in Table 4.1.
Table 4.1 Specifications of circular rib knitting machine

<table>
<thead>
<tr>
<th>Machine particulars</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine make</td>
<td>Kemyoung-KILM-72AV</td>
</tr>
<tr>
<td>No. of feeders</td>
<td>68</td>
</tr>
<tr>
<td>Gauge</td>
<td>18</td>
</tr>
<tr>
<td>Cylinder diameter</td>
<td>28 inch</td>
</tr>
<tr>
<td>No. of needles</td>
<td>3168</td>
</tr>
</tbody>
</table>

The yarn which has to form the inner layer is fed into dial needle and the outer layer is fed into cylinder needle is shown in Figure 4.1. Four bi-layer derivatives were produced in circular rib knitting machine. Type 1 knitted fabric was produced with 12 course repeat. Dial needles knit on all odd feeders and cylinder needles knit on all even feeders. Cylinder needles form tuck stitch in 1st, 4th, 8th, 12th, 16th, 20th and 24th feeder with respect to needle order. Type 2 knitted fabric was produced with 14 course repeat and dial needle knit on all odd feeders and cylinder needle knit on all even feeders. Cylinder needles form tuck stitch in 1st, 4th, 6th, 10th, 12th, 18th, 20th, 24th and 26th feeder with respect to needle order set in the cam track. Type 3 knitted fabric was produced with 4 course repeat and dial needle knit on all odd feeders and cylinder needle knit on all even feeders.
Cylinder needles form tuck stitch in all odd feeders as per the needle order set in the cam track. Type 4 fabric was produced with 18 course repeat. Dial needles knit on all odd feeders and cylinder needles knit on all even feeders. Tuck stitch is introduced in every 18 course repeat to join inner and outer layer formed by dial and cylinder needles respectively. Cylinder needle forms tuck stitch in 1\textsuperscript{st} and 37\textsuperscript{th} feeder and tuck stitch is placed on every 12\textsuperscript{th} wale and 18\textsuperscript{th} course. The graphical representation of derivatives of bi-layer knitted fabric is shown in Table 4.2. The fabric details and bi-layer knitted fabric derivatives photograph is shown in Table 4.3.
Table 4.2 Graphical representation of bi-layer knitted fabric derivatives

**Type 1**
Cam set out:

| Feeders | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Dial     | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Cylinder | X | X | X | X | O | X | X | X | X | X | X | X | X | X | X | X | O | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

Needle set out:
Dial needle: ABABABABAC...
Cylinder needle: ABABABABABAC...
X-Knit; O-Tuck; -Miss

**Type 2**
Cam set out:

| Feeders | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Dial     | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Cylinder | X | X | O | O | O | O | X | X | X | X | X | X | X | X | X | O | O | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

Needle set out:
Dial needle: ABABABABAC...
Cylinder needle: ABABABABABAC...
X-Knit; O-Tuck; -Miss

**Type 3**
Cam set out:

<table>
<thead>
<tr>
<th>Feeders</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dial</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cylinder</td>
<td>X</td>
<td>X</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>O</td>
<td>O</td>
<td>X</td>
</tr>
</tbody>
</table>

Needle set out:
Dial needle: ABABABABAC...
Cylinder needle: ABABABABAC...
X-Knit; O-Tuck; -Miss

**Type 4**
Cam set out:

<table>
<thead>
<tr>
<th>Feeders</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dial</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cylinder</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Needle set out:
Dial needle: ABABABABAC...
Cylinder needle: ABABABABABAC...
X-Knit; O-Tuck; -Miss
Table 4.3 Photographs of bi-layer knitted fabric derivatives

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Fabric composition</th>
<th>Face view (Outer layer)</th>
<th>Back view (Inner layer)</th>
</tr>
</thead>
</table>
| Type 1      | Inner layer: Micro-fibre polyester  
Outer layer: Modal | ![Face view](image1) | ![Back view](image2) |
| Type 2      | Inner layer: Micro-fibre polyester  
Outer layer: Modal | ![Face view](image3) | ![Back view](image4) |
| Type 3      | Inner layer: Micro-fibre polyester  
Outer layer: Modal | ![Face view](image5) | ![Back view](image6) |
| Type 4      | Inner layer: Micro-fibre polyester  
Outer layer: Modal | ![Face view](image7) | ![Back view](image8) |
The methods adopted for evaluating the thermal comfort characteristics of bi-layer knitted fabric derivatives both objectively and subjectively were discussed in chapter 3.

4.3 RESULTS AND DISCUSSION

The geometrical properties of bi-layer knitted fabric derivatives are shown in Table 4.4.

**Table 4.4 Geometrical properties of bi-layer knitted fabric derivatives**

<table>
<thead>
<tr>
<th>Geometrical properties</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stitch density, loops/cm²</td>
<td>206</td>
<td>226</td>
<td>218</td>
<td>197</td>
</tr>
<tr>
<td>Weight, g/m²</td>
<td>196</td>
<td>213</td>
<td>201</td>
<td>182</td>
</tr>
<tr>
<td>Thickness, mm</td>
<td>0.62</td>
<td>0.69</td>
<td>0.65</td>
<td>0.58</td>
</tr>
<tr>
<td>Loop length, cm</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Porosity %</td>
<td>77.64</td>
<td>74.19</td>
<td>76.44</td>
<td>80.12</td>
</tr>
<tr>
<td>Tightness factor</td>
<td>12.77</td>
<td>12.77</td>
<td>12.77</td>
<td>12.77</td>
</tr>
</tbody>
</table>

4.3.1 Thermal Conductivity

Thermal conductivity is the intrinsic property of sportswear that indicates the ability to conduct heat. Due to the heat dissipation, heavy sweat is formed in the body that leads to accumulation of lot of moisture on the skin. It is the capability of the material to conduct heat from one location to another location (Sampath et al. 2011). Figures 4.2 and 4.4 show that among bi-layer knitted derivatives Type 4 shows lower Clo value than other derivatives. The reason is lower stitch density and thickness which entraps less air between the pores of bi-layer fabric and thereby increases the thermal conductivity. From the Figure 4.5, it is clear that due to lower stitch density; porosity is higher for Type 4 than other bi-layer derivatives and exhibits higher thermal
conductivity. In the next case, thermal conductivity is high for Type 1 followed by Type 3 and Type 2 fabrics. The amount of volume of dead air in the textile fabrics increases with the increase of thickness of fabric. Higher the volume of dead air within a textile structure, lower will be the thermal conductivity of bi-layer knitted fabrics. The thickness of bi-layer knitted derivatives is mainly influenced by the fabric structure with tuck loop placement in course and wale. The more number of tuck stitches formed between the layer bindings leads to accumulation of knit and tuck loops in Type 2 bi-layer fabric than Type 1 and Type 3 bi-layer fabrics. This causes higher thickness and mass per unit area for Type 2 fabric than other bi-layer knitted derivatives as shown in Figures 4.2 and 4.3 respectively and therefore volume of dead air present in the structure will also be high and exhibits lower thermal conductivity.

Type 1 shows good thermal conductivity than Type 2 and Type 3. Because, the tuck loop accumulation is lower than Type 2 and Type 3 and hence the less air is entrapped. This ensures higher thermal conductivity for Type 1 followed by Type 3 and Type 2 bi-layer knitted fabrics. Type 3 bi-layer knitted fabric shows good thermal conductivity than Type 2 due to the presence of tuck loop in every course formed by cylinder needles in odd feeder. This ensures lower thickness and mass per unit area than Type 2 fabric. Type 2 bi-layer knitted fabric, which is 14 course repeat forms more tuck loops per repeat than the other three bi-layer knitted derivatives. Hence, the higher thickness of Type 2 bi-layer fabric is due to the placement of more tuck stitches in a repeat. In two-layer fabric assembles, fabric thickness turned out to be a significant factor in determining the thermal conductivity (Jianhua Huang 2015). By comparing all the four derivatives, Type 4 possesses higher tendency for heat dissipation and it is clear that, thermal conductivity of bi-layer knitted fabrics mainly depends upon the geometrical properties such as thickness and mass per unit area of the structure and placement of tuck loops.
per repeat (AstaBivainyte 2012). Table A1.1 shows the ANOVA statistical analysis results at 5% significance level. The significant difference was found between the bi-layer knitted derivatives using one-way ANOVA (F_{actual} = 943 in comparison with F_{critical} = 3.24) at degree of freedom 3, 16. Error bars are used in the Figure 4.2 to indicate the estimated errors in the measurement.

**Figure 4.2** Relationship between stitch density and thermal insulation of bi-layer knitted fabric derivatives

**Figure 4.3** Relationship between weight and thermal insulation of bi-layer knitted fabric derivatives
4.3.2 Air Permeability

Figures 4.6, 4.7, 4.8 and 4.9 show that for all the samples, air permeability of dry state is higher than wet state. Modal yarn in the outer layer swells and its size is increased as they absorbed water by leaving narrow
gaps between the fibres and yarns and causes less air flow in wet state than dry state (Cil et al. 2009). Figures 4.7 and 4.8 show that air permeability is found high for Type 4 bi-layer knitted fabric followed by Type 1, Type 3 and Type 2 bi-layer knitted fabrics in both dry and wet state. The reason is mass per unit area and thickness of Type 4 bi-layer structure is found lower than other three bi-layer derivatives. Type 4 bi-layer structure is a 18 course repeat fabric in which tuck stitches are present on every consecutive 12\textsuperscript{th} wale. Due to less number of tuck stitches, the force exertion between the loops is lower and causes lower thickness and mass per unit area. This leads to the more numbers of pores in the bi-layer fabric surface that allows free air movement from inner layer to outer layer. Type 1 fabric shows high air permeability than Type 2 and Type 3 fabrics. Because in Type 1 fabric; the tuck stitch is located in every 12\textsuperscript{th} wale and 13\textsuperscript{th} course and forms a 12 course repeat structure. This leads to lower thickness, mass per unit area and higher porosity than Type 2 and Type 3 knitted fabrics. Type 3 bi-layer knitted structure is formed with 4 course repeat; the tuck loop formation by cylinder needle in every odd feeder leads to comparatively high thickness and mass per unit area and shows lower air permeability than Type 1 and Type 4 bi-layer knitted derivatives.

Air permeability of Type 2 is found lower than all other bi-layer knitted derivatives. Type 2 fabric is 14 course repeat and the layer binding is done at every 15\textsuperscript{th} course and 12\textsuperscript{th} wale. In addition to that, the structural formation in the inner layer is with more tuck stitches than Type 2, Type 3 and Type 4 fabrics. This leads to lower porosity, higher thickness and mass per unit area than other fabrics, which shows lower air permeability (Ali et al. 2015). With the same loop length and variations in course repeat, the tuck stitch used for joining two layers influences the air passage in derivatives of bi-layer knitted fabrics. The bi-layer knitted fabric Type 4 which exhibited higher air permeability entraps less air due to the placement of tuck stitch in every 12\textsuperscript{th} wale in a 18 course repeat. Figure 4.6 shows that decrease in stitch...
density increases the air passage through the bi-layer knitted fabric. Therefore, porosity is higher for Type 4 fabric which increases the air flow through it as shown in Figure 4.9. The porosity of bi-layer derivatives increases with decrease in stitch density, thickness and mass per unit area.

As a sportswear, the garment worn by the sports person should allow free movement of air from inner side of the fabric to the outer environment. In this case, porosity, thickness and mass per unit area primarily influence the air passage through the fabric and secondarily by the stitch density of bi-layer knitted fabric. Because, based on the structure type, stitch density varies between bi-layer knitted derivatives. Table A1.1 shows the ANOVA statistical analysis results at 5% significance level. The significant difference was found between the air permeability of bi-layer knitted derivatives in both wet and dry state using one-way ANOVA (Dry: $F_{\text{actual}} = 7124.345$ in comparison with $F_{\text{critical}} = 3.24$; Wet: $F_{\text{actual}} = 3684.771$ in comparison with $F_{\text{critical}} = 3.24$) at degree of freedom 3, 16.

![Figure 4.6 Relationship between stitch density and air permeability of bi-layer knitted fabric derivatives](image-url)
Figure 4.7  Relationship between weight and air permeability of bi-layer knitted fabric derivatives

Figure 4.8  Relationship between thickness and air permeability of bi-layer knitted fabric derivatives
4.3.3 Water Vapour Permeability

Water vapour permeability is one of the most important factors to determine the velocity of water vapour through the textile material. Moisture vapour transmission through the bi-layer knitted fabric is predominantly controlled by fabric geometric properties such as thickness and porosity. From Figures 4.10, 4.11, 4.12 and 4.13, it is noted that among four bi-layer knitted derivatives, Type 4 bi-layer fabric exhibits higher water vapour permeability than other bi-layer derivatives. Type 1 exhibited good water vapour permeability followed by Type 3 and Type 2 knitted fabrics. Figures 4.12 and 4.13 show that Type 4 bi-layer knitted fabric exhibited higher water vapour permeability due to lower thickness and higher porosity. Here the thickness plays a vital role; because it ensures the distance through which the liquid moisture has to transfer from inner layer to outer layer. Figures 4.10 and 4.11 respectively shows that lower stitch density and mass per unit area facilitates the easy passage of water vapour through the layered fabrics.
The fabric construction plays a major role for vapour permeability. Type 4 bi-layer knitted fabric is a 18 course repeat structure in which tuck stitch is present at every 12\textsuperscript{th} wale. The structure seems single jersey appearance on inner and outer layer and possesses greater water vapour permeability.

Type 1 fabric comparatively shows higher water vapour permeability than other bi-layer fabrics Type 3 and Type 2. This is due to lower thickness and less number of tuck stitches in the wale and course per 12 course repeat than Type 3 and Type 2 fabrics. Type 3 bi-layer fabric shows comparatively high water vapour permeability than Type 2 bi-layer fabric because of the presence of tuck stitch in each course of 4 course repeat. Type 2 bi-layer fabric possess lowest water vapour permeability than other bi-layer derivatives because it is closely packed due to the presence of more number of tuck stitches in wale and course per 14 course repeat. In case of Type 1, Type 2 and Type 4, being the binding of layer is done at 12\textsuperscript{th} wale by tuck stitch; due to difference in cam setting and course repeat showed greatest difference in thickness and mass per unit area and thereby water vapour permeability.

Micro-fibre polyester fabric as an inner layer exhibited comparatively good water vapour permeability due to the presence of channelled fibre structure and larger surface area. This channelled structure form a transporting system which pulls away the moisture from the skin to the outer surface (Sampath et al. 2011). Due to lower thickness and mass per unit area of Type 4 bi-layer fabric, the water vapour permeability is higher than Type 1, Type 3 and Type 2 bi-layer knitted fabrics. The bi-layer knitted fabric having low moisture vapour permeability is unable to pass sufficient perspiration and this leads to sweat accumulation in the clothing ensemble and causes discomfort. It was found from Table A 1.1, ANOVA results shows
that there is a significant difference between bi-layer knitted derivatives \( F_{\text{actual}}=919.362 > F_{\text{critical}}=3.24 \) (p<0.05).

**Figure 4.10 Relationship between stitch density and water vapour permeability of bi-layer knitted fabric derivatives**

**Figure 4.11 Relationship between weight and water vapour permeability of bi-layer knitted fabric derivatives**
Figure 4.12 Relationship between thickness and water vapour permeability of bi-layer knitted fabric derivatives

Figure 4.13 Relationship between porosity and water vapour permeability of bi-layer knitted fabric derivatives
4.3.4 Wicking

4.3.4.1 Vertical wicking

Wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. The capillary force caused by wetting is wicking. Longitudinal wicking height determines the liquid transporting ability and faster the rate of wicking better will be the sweat transporting ability and the fabric feels more comfortable to wear (Meltem & Fatma 2012). Longitudinal wicking was observed higher in inner layer side since it is well known that the wicking of modal is very low as compared to micro-fibre polyester. The longitudinal wicking height was increased for all the bi-layer derivatives for a given period of 30 minutes. When the material and liquid are unchanged at particular atmospheric conditions, the capillary height depends upon the fabric governing the shape of the capillary. Figures 4.14 and 4.15 show the vertical wicking height in wale and course direction respectively.

Figure 4.18 shows that among bi-layer knitted derivatives, Type 4 shows highest wicking height in both wale and course wise followed by Type 1, Type 3 and Type 2 bi-layer knitted fabrics. The reason is thickness of fabric is lower than other bi-layer knitted derivatives. In Type 4 bi-layer structure, the two layers are joined by the tuck stitch on every 12th wale in 18 course repeat. This facilitates lower thickness and higher vertical wicking in wale and course direction. Figures 4.16 and 4.17 show that decrease in stitch density and mass per unit area increases the wicking height in both wale and course direction. The initial rate of water take-up in vertical wicking was higher for knitted fabric which has good capillary action. Type 4 showed higher water take-up in wale and course direction initially itself for 5 minutes. After every 5 minutes of duration for 30 minutes, all the bi-layer derivatives shows increasing trend in water take-up in both wale and course direction. The wicking height of Type 4 bi-layer fabric in wale and course direction
almost reached the same distance. In Type 1, Type 2 and Type 3 bi-layer fabrics, the wicking height in wale-wise manner was higher than wicking height in course direction. This is due to better capillary action in wale-wise than course-wise manner. The presence of more number of tuck stitches in different places per repeat affects the water take-up in course direction. Increase in porosity of bi-layer knitted fabric tends to increase the wicking height as shown in Figure 4.19. The factors influencing porosity of bi-layer knitted fabric are stitch density, thickness and mass per unit area.

Type 1 possesses higher vertical wicking than Type 3 and Type 2 fabrics due to structural formation in such a manner which exhibits better capillary action. Type 3 fabric showed better vertical wicking in wale and course direction than Type 2 bi-layer fabric. This is due the placement of tuck stitch in every course of 4 course repeat. Whereas in Type 2 bi-layer knitted fabric, the placement of tuck stitch is formed by cylinder needles in even feeders and joining of layer was done by cylinder needles tuck at odd feeders such as 1st, 29th and 57th feeders. In Type 2 fabric, while forming each course itself binding was done by cylinder needle tuck and knit on both even and odd feeders. This ensures lower wicking than other bi-layer knitted derivatives which seems bulky. Therefore, the thickness of Type 2 is higher than all other bi-layer derivatives and shows lower wicking height in wale and course direction. The vertical wicking value of bi-layer knitted derivatives has significant difference between the structures \[F_{\text{actual}}=855.0456>F_{\text{critical}}=3.24\] in walewise; \[F_{\text{actual}}=1478.439>F_{\text{critical}}=3.24\] in coursewise] is shown in Table A1.1.
Figure 4.14  Vertical wicking in wale direction of bi-layer knitted fabric derivatives

Figure 4.15  Vertical wicking in course direction of bi-layer knitted fabric derivatives
Figure 4.16  Relationship between stitch density and vertical wicking of bi-layer knitted fabric derivatives

Figure 4.17  Relationship between weight and vertical wicking of bi-layer knitted fabric derivatives
Figure 4.18 Relationship between thickness and vertical wicking of bi-layer knitted fabric derivatives

\[ y = -42.92x + 42.10 \quad R^2 = 0.995 \]
\[ y = -51.61x + 46.20 \quad R^2 = 0.944 \]

Figure 4.19 Relationship between porosity and vertical wicking of bi-layer knitted fabric derivatives

\[ y = 0.810x - 47.63 \quad R^2 = 1 \]
\[ y = 0.980x - 62.20 \quad R^2 = 0.961 \]
4.3.4.2 Transverse wicking

Analysis of transverse wicking characteristics of bi-layer knitted fabric is more important than longitudinal wicking because perspiration transfer from the skin involves its movement through the lateral direction of fabric. Figures 4.20, 4.21, 4.22 and 4.23 show the transverse wicking rate of bi-layer knitted fabrics. The wicking rate was higher for Type 4 bi-layer knitted fabric compared to Type 1, Type 3 and Type 2 fabrics. This behaviour is most probably due to the presence of a tuck stitch in 18 course repeat in the structure which has the ability to transport water through it. The transverse wicking of the bi-layer knitted fabric were mainly governed by the thickness of the fabric. The presence of less number of tuck stitches leads to lower stitch density, mass per unit area and thickness in Type 4 fabric and thereby exhibited good wicking rate as shown in Figures 4.20, 4.21 and 4.22. The bi-layer knitted structure with 12 course repeat, Type 1 exhibited good wicking rate than Type 3 and Type 2. The faster wicking rate is due to the lower thickness and stitch density than Type 3 and Type 2 bi-layer knitted fabrics. Type 3 bi-layer fabric showed comparatively better wicking rate than Type 2 bi-layer fabric. Higher the thickness and stitch density; lower will be the wicking rate.

Type 2 fabric exhibited lowest wicking rate on the surface of fabric than all other bi-layer knitted derivatives. In fabric, the sweat from the inner layer is transferred slowly to the outer layer and gets evaporated to the outer environment. Figure 4.23 shows that presence of more pores in Type 4 bi-layer fabric facilitates good wicking rate due to less number of tuck stitches per repeat. Reducing the capillary size of the fabric, such as through the introduction of micro-fibres in the bi-layer knitted fabric can also improves the wicking performance of fabrics. It is also found from Table A 1.1 that
there is a significant difference between the transverse wicking of bi-layer knitted derivatives [\( F_{\text{actual}} = 573.259 > F_{\text{critical}} = 3.24 \) (\( p<0.05 \))].

**Figure 4.20** Relationship between stitch density and transverse wicking of bi-layer knitted fabric derivatives

**Figure 4.21** Relationship between weight and transverse wicking of bi-layer knitted fabric derivatives
Figure 4.22  Relationship between thickness and transverse wicking of bi-layer knitted fabric derivatives

\[ y = -28.84x + 25.34 \]
\[ R^2 = 0.816 \]

Figure 4.23  Relationship between porosity and transverse wicking of bi-layer knitted fabric derivatives

\[ y = 0.557x - 35.98 \]
\[ R^2 = 0.839 \]
4.3.5 Moisture Absorbency

When the fabric is subjected to heavy sweating conditions, the sweat absorbed by the fabric cannot be given off to the atmosphere instantaneously. So, to prevent the wearer from feeling wet and clammy, the moisture should be stored in the fabric (Behera et al. 2002). The moisture absorbency is found high for Type 2 fabric due to the more number of tuck stitches present in a repeat and causes higher stitch density as shown in Figure 4.24. In addition to that, tuck stitches leads to higher mass per unit area and thickness and exhibits greater moisture absorbency than other bi-layer knitted fabrics as shown in Figures 4.25 and 4.26. Next to Type 2, the maximum absorbency was found in Type 3 followed by Type 1 and Type 4 fabrics. Higher the stitch density of Type 2 and Type 3 bi-layer knitted fabrics, more the amount of moisture can be stored by a fabric and better would be the performance of the fabric under moderate sweating conditions. Type 4 bi-layer knitted fabric exhibited lower absorbency due to lower stitch density and thickness. From Figure 4.27, it is inferred that the increase in porosity decreases the moisture absorbency of bi-layer knitted fabrics. With the same yarn type, the structure of bi-layer knitted fabric majorly influences the absorbency of fabric. The geometric properties such as stitch density, thickness and mass per unit area were also the contributing factors for moisture absorbency. The moisture absorbency of bi-layer knitted derivatives shows significant difference between them ($F_{\text{actual}} = 39.2193 > F_{\text{critical}} = 3.24$) at degree of freedom 3, 16 is shown in Table A 1.1.
Figure 4.24 Relationship between stitch density and moisture absorbency of bi-layer knitted fabric derivatives

![Graph showing relationship between stitch density and moisture absorbency](image)

\[y = 1.103x + 37.91\]
\[R^2 = 0.941\]

Figure 4.25 Relationship between weight and moisture absorbency of bi-layer knitted fabric derivatives

![Graph showing relationship between weight and moisture absorbency](image)

\[y = 1.100x + 53.54\]
\[R^2 = 0.940\]
Figure 4.26  Relationship between thickness and moisture absorbency of bi-layer knitted fabric derivatives

\[ y = 303.1x + 79.00 \]
\[ R^2 = 0.938 \]

Figure 4.27  Relationship between porosity and moisture absorbency of bi-layer knitted fabric derivatives

\[ y = -5.722x + 712.6 \]
\[ R^2 = 0.941 \]
4.3.6 Drying Behaviour

Moisture transfer is a critical factor for thermoregulation of the body heat. Moisture on the skin or clothing increases the heat loss of the body and also affects the overall performance and endurance of the body. So, the clothing should have quick drying ability property (Meltem & Fatma 2012). Among four bi-layer knitted derivatives with micro-fibre polyester as an inner layer and modal as an outer layer, Type 4 bi-layer knitted fabric possess good drying rate than Type 1, Type 2 and Type 3 fabrics. Figures 4.28, 4.29, 4.30 and 4.31 show the drying rate and its relationship with geometrical properties of bi-layer knitted derivatives. Type 4 bi-layer knitted fabric requires less time to dry or to reach the initial dry mass of fabric. This is due to lower stitch density, mass per unit area and thickness as shown in Figures 4.28, 4.29 and 4.30. The high moisture vapour transmission is achieved by higher porosity and it increases the drying rate of Type 4 fabric as shown in Figure 4.31. It is observed that drying rate is lower for Type 2 fabric, denoting that it requires more time to reach initial dry mass comparatively. The reason was higher mass per unit area and thickness than Type 3, Type 1 and Type 4 fabrics as shown in Figures 4.29 and 4.30.

With the same fibre type, the changes in geometrical properties such as stitch density, thickness and mass per unit area were due to knitted structure variation. The more number of tuck stitches in Type 2, showed higher thickness. In Type 1 fabric, the number of tuck points is lesser and exhibited good drying than Type 3 and Type 2 knitted fabrics. Type 3 fabric exhibited higher and lower water vapour permeability than Type 2 and Type 4 bi-layer knitted fabrics respectively. This facilitates good drying rate than Type 2 and poor drying rate than Type 4 fabric. Lower the thickness and mass per unit area, higher the porosity better will be the fast drying ability. The
drying ability of bi-layer knitted fabrics was primarily affected by the knitted structure, mass per unit area and thickness.

**Figure 4.28** Relationship between stitch density and drying rate of bi-layer knitted fabric derivatives

**Figure 4.29** Relationship between weight and drying rate of bi-layer knitted fabric derivatives
Figure 4.30  Relationship between thickness and drying rate of bi-layer knitted fabric derivatives

Figure 4.31  Relationship between porosity and drying rate of bi-layer knitted fabric derivatives

The garment worn should dry up as soon as possible because the sportsman’s body is constantly producing sweat and this has to dissipated as
quick as possible so that the wearer does not feel clammy. It is also found that there is a significant difference between the drying rate of bi-layer knitted derivatives \[F_{\text{actual}}=485.4869>F_{\text{critical}}=3.24 \text{ (p<0.05)}\] is shown in Table A 1.1.

4.3.7 **Moisture Management Properties**

4.3.7.1 **Wetting time**

The wetting time of top surface (WTT) and bottom surface (WTB) are the time period in seconds, in which the top and bottom surfaces of the fabric just start to get wetted respectively, after the test is started (Hu et al.2005). The fabric worn next to skin is considered as top surface (inner layer) and the fabric facing the outer environment (outer layer) is considered as bottom surface. It can be observed from the Figure 4.32, the wetting time of bi-layer knitted fabric was different for each type of fabric. The top wetting time is lower for Type 4 and Type 1 bi-layer knitted fabric derivatives than other bi-layer knitted derivatives. This is due to placement of tuck stitch in the fabric structure which greatly influences the thickness of the bi-layer knitted fabric. The top wetting time is higher than bottom wetting time for all bi-layer knitted derivatives expect for Type 2 fabric.

Type 2 fabric possesses lower top wetting time and higher bottom wetting time due to the placement of tuck stitch in different positions. This leads to higher thickness and stitch density than Type 4, Type 1 and Type 3 structure and shows longer wetting time in the bottom surface than other bi-layer knitted fabrics. When the liquid is dropped on the top surface of the Type 4 and Type 1 fabric, it is directly transferred to the bottom surface and absorbed by the modal yarn. Compared to Type 1, Type 3 fabric has taken longer time to wet on the top surface and bottom surface. In this case, the construction factors have a more marked effect because they affect the capillary spaces (Esra et al. 2015). In Type 4 fabric, the liquid can easily be
transferred to the bottom surfaces because of decrease of fabric thickness and mass per unit area. Hence, the wetting time on the top and bottom surface of Type 4 fabric is comparatively lower than other bi-layer knitted derivatives. When the liquid drops on the top surface of the bi-layer knitted fabric, Type 4 followed by Type 1 and Type 3 fabric required faster time to wet on the bottom surface of the fabric. Table A1.1 shows the ANOVA statistical analysis results at 5% significance level. WTT and WTB of all the bi-layer knitted derivatives shows significant difference between them (WTT: $F_{\text{actual}}=1061.740$ and WTB: $F_{\text{actual}}=564.710$ in comparison with $F_{\text{critical}}=3.24$) at degree of freedom 3, 16.

![Figure 4.32 Wetting time of bi-layer knitted fabric derivatives](image)

4.3.7.2 Absorption rate

Absorption rates on the top (TAR) and bottom surfaces (BAR) are the average speed of liquid moisture absorption ability of the specimen, in the pump time (Hu et al.2005). It is clearly shown in Figure 4.33, that the top absorption rate is indirectly proportional to wetting time of bi-layer knitted fabric (Esra et al. 2015). The bottom absorption rate is higher than top
absorption rate for all bi-layer knitted fabrics, except for Type 2 bi-layer fabric. The increase of porosity in bi-layer knitted structure contributes to the fabric ability in the top surface to transport moisture quickly to the bottom surface. The bottom absorption rate is higher for Type 4 fabric due to lower thickness than other bi-layer knitted fabrics. The reason is also due to the structural variation with less number of tuck points in the structure decreases the thickness of fabric. The accumulation of tuck stitch in the Type 3 bi-layer knitted derivative leads to less absorption of moisture in the bottom surface of fabric. In Type 2 bi-layer fabric, more water is absorbed in the top surface and lesser amount of water is absorbed by the bottom surface. The greatest variation in Type 2 among all bi-layer knitted derivatives is the placement of more number of tuck stitches in wale and course per 14 course repeat.

The wetting time is also lower for top surface and higher for bottom surface. In this case, the sweat is quickly absorbed by the top surface and transmitted less to the bottom surface. Whereas in Type 4, Type 1 and Type 3 bi-layer knitted derivatives, moisture is not readily absorbed by the top surface and transmitted more through the top surface and absorbed by the bottom surface. These bi-layer knitted derivatives transmit the sweat quickly through the top surface by micro-fibre polyester yarn where it is in contact with the skin and transmitted to the bottom surface by diffusion where it is exposed to the outer environment. When a person is engaged in any strenuous physical activity may sweat as much as a quart (1/4 gallon) of fluid in an hour (Song 2011). The amount of heat loss is equal to the latent heat of vapourization of the moisture evaporated. Type 4 bi-layer knitted fabric due to lower stitch density and thickness, the water vapour can be easily replaced by the movement of air. It improves the comfort of the wearer during physical activity. It was found from Table A 1.1, ANOVA results shows that with respect to TAR there is a significant difference between the bi-layer knitted derivatives at degreeof freedom 3, 16 [F_{actual}=228.411>F_{critical}=3.24 (p<0.05)]
and for BAR, there is a significant difference between the structures \( F_{\text{actual}} = 2538.517 > F_{\text{critical}} = 3.24 \) \((p<0.05)\).

**Figure 4.33 Absorption rate of bi-layer knitted fabric derivatives**

### 4.3.7.3 Maximum wetted radius

MWRT and MWRB are defined as the greatest or maximum wetted radius at the top and bottom surfaces, respectively (Hu et al. 2005). The maximum wetted radius indicates the ability of the liquid spreading and evaporation over larger area. Figure 4.34 shows the top and bottom maximum wetted radius of all bi-layer knitted fabric derivatives. The maximum wetted radius in the bottom surface was found high for Type 1, Type 3 and Type 4 bi-layer knitted fabrics. The maximum wetted radius in the top surface was found high for Type 1 and Type 4 bi-layer knitted derivatives. It can be seen that, Type 2 fabric had both lowest top and bottom wetted radius. Type 1 and Type 4 had taken lesser time to wet on top and bottom surface and more liquid moisture was distributed on the top and bottom surface of the fabric. The water content of the bi-layer fabric plays a major role in determining the maximum wetted radius. The wetting time is shorter for Type 4 and Type 1 and hence the
maximum wetted radius is high for those bi-layer derivatives. The fabric with relatively large wetted radius on the bottom surface indicates that the liquid can be spread and evaporated from the bottom surface more quickly (Zhou et al. 2007).

For Type 3 fabric, bottom maximum wetted radius was higher than top maximum wetted radius. This is due to more tuck points in the fabric structure compared to Type 1 and Type 4 fabrics. In Type 2 fabric, the formation of knit, tuck and miss loops in the structure per 14 course repeat causes minimum distribution of water on top and bottom surface of fabric. The reason being would probably due to higher thickness and mass per unit area. In general, the increase of maximum wetted radius decreases the drying time of the layered knitted fabric. In Type 4 and Type 1 bi-layer knitted derivatives, the sweat is quickly transferred to the top surface and spread on the bottom surface with same radius. These types of fabrics exhibit quick absorbing and drying of fabrics which makes the wearer to feel comfortable.

![Graph showing maximum wetted radius of bi-layer knitted fabric derivatives](image)

**Figure 4.34** Maximum wetted radius of bi-layer knitted fabric derivatives
4.3.7.4 Spreading speed

Top surface spreading speed (TSS) and the bottom surface spreading speed (BSS) is the accumulated rate of surface wetting from the centre of the specimen where the test solution is dropped to the maximum wetted radius (Hu et al. 2005). Maximum wetted radius and spreading speed indicates the ability of liquid moisture spreading and its evaporation over larger surface area of fabric. Among all bi-layer knitted derivatives, Type 4 rated good maximum wetted radius and spreading speed is shown in Figure 4.35. This is due to the bi-layer structure’s ability to act like a capillary system and transport the water to the outer layer. Lower the thickness of Type 4 fabric than other bi-layer derivatives, easier for liquid moisture to diffuse through the fabric. It can also be observed that, bottom spreading speed is higher than top spreading speed for Type 1, Type 3 and Type 4 bi-layer knitted derivatives. But for Type 2 fabric, bottom spreading speed is lower than top spreading speed. TSS and BSS are the speeds of the liquid moisture on the top and bottom fabric surface to reach the maximum wetted radius (Zhou et al. 2007). Type 2 exhibited the smallest TSS and BSS among all the bi-layer knitted derivatives, indicates that the liquid moisture was assembled on the top surface and was not absorbed quickly by the bottom surface.

Type 4 bi-layer knitted derivative exhibited the higher BSS than its TSS, indicates faster transfer of liquid on the bottom surface of the fabric. Next to Type 4, Type 1 fabric possesses high BSS than its TSS followed by the Type 3 bi-layer knitted derivative. It can be concluded that the more the amount of water absorbed and spread on the bottom surface easier for the bi-layer knitted fabric to get dry soon. In Type 2, even though maximum wetted radius is attained, but it possesses lower spreading speed in the bottom surface. Lower bottom wetted radius and lower bottom spreading speed ensures slow transfer of liquid moisture and evaporation to the environment.
For a sports person, the generated sweat should be transmitted to the environment through the bi-layer knitted fabrics. This can be achieved by the larger spreading speed of sweat in the bottom surface than its top surface (Type 4). This reduces the drying time of fabric and is one of the most important physiological parameters for sportswear comfort. It was found from Table A1.1, ANOVA results shows that there is a significant difference between the TSS value of all bi-layer knitted derivatives \( [F_{\text{actual}}=2336.991>F_{\text{critical}}=3.24 \ (p<0.05)] \). Also it is noticed that there is a significant difference in BSS between the bi-layer knitted derivatives \( [F_{\text{actual}}=1903.225>F_{\text{critical}}= 3.24 \ (p<0.05)] \).

![Figure 4.35 Spreading speed of bi-layer knitted fabric derivatives](image)

**Figure 4.35 Spreading speed of bi-layer knitted fabric derivatives**

### 4.3.7.5 Overall moisture management capacity

The overall moisture management capacity (OMMC) is an index to indicate the overall capability of the fabric to manage the transport of liquid moisture, which includes three aspects of performance: moisture absorption rate of the bottom side (BAR), one-way liquid transport capacity (OWTC); the difference of the cumulative moisture content between the two surfaces of
the fabric, and the spreading/drying rate of the bottom side (BSS), which is represented by the maximum spreading speed (Hu et al. 2005).

\[
\text{OMMC} = 0.25 \text{BAR} + 0.5 \text{OWTC} + 0.25 \text{BSS} \tag{4.1}
\]

The OMMC is an idea to indicate the overall capability of the fabric to manage the transport of liquid moisture. Figures 4.36 and 4.37 show the value of OWTC and OMMC of bi-layer knitted derivatives respectively. The one-way transport capacity was higher for Type 4 followed by Type 1, Type 3 and Type 2 bi-layer knitted derivatives. Type 2 bi-layer knitted fabric exhibited lower liquid moisture management properties than other bi-layer knitted derivatives. The reason is low wetted radius and spreading rate on the bottom surface. It indicates that, the liquid (sweat) can diffuse slowly from the next to skin surface to the opposite side than other bi-layer knitted derivatives and liquid will accumulate on the top surface of the fabric (Junyan et al. 2005). Type 4, followed by Type 1 and Type 3 derivatives were classified as excellent grade for overall moisture management capacity.

Type 4 bi-layer knitted fabric would dry quickly due to high maximum wetted radius and spreading speed in bottom surface. The fabric structure plays a major role in contributing OMMC of bi-layer knitted fabric. The changes in structure type, greatly influences the geometrical properties such as stitch density, thickness and mass per unit area. The above said properties are the contributing factors of OMMC of bi-layer knitted derivative. Lower the mass per unit area and thickness of bi-layer knitted structure better will be the OMMC of the bi-layer fabricas shown in Figures 4.39 and 4.40. Lower the stitch density higher will be the porosity and better will be the OMMC of bi-layer knitted fabric and its relationship is shown in Figures 4.38 and 4.41. Figure 4.42 shows the finger print of Type 4 bi-layer knitted derivative. It is also found that there is a significant difference between the OWTC of bi-layer knitted derivatives.
\[ F_{\text{actual}} = 1537.804 > F_{\text{critical}} = 3.24 \text{ (p<0.05)} \] is shown in Table A 1.1. The OMMC of bi-layer knitted fabrics shows significant difference between them \( (F_{\text{actual}} = 38.659 > F_{\text{critical}} = 3.24) \) at degree of freedom 3, 16 is shown in Table A 1.1.

**Figure 4.36** One-way transport capacity of bi-layer knitted fabric derivatives

**Figure 4.37** Overall moisture management capacity of bi-layer knitted fabric derivatives
Figure 4.38  Relationship between stitch density and OMMC of bi-layer knitted fabric derivatives

\[ y = -0.005x + 1.913 \]
\[ R^2 = 0.847 \]

Figure 4.39  Relationship between weight and OMMC of bi-layer knitted fabric derivatives

\[ y = -0.006x + 1.876 \]
\[ R^2 = 0.915 \]
Figure 4.40 Relationship between thickness and OMMC of bi-layer knitted fabric derivatives

\[ y = -1.653x + 1.712 \]
\[ R^2 = 0.875 \]

Figure 4.41 Relationship between porosity and OMMC of bi-layer knitted fabric derivatives

\[ y = 0.031x - 1.775 \]
\[ R^2 = 0.902 \]
4.3.8 Subjective Analysis by Wear Trial

Figure 4.43 shows the assessment of the influence of the thermal environment using subjective judgment scales. All the bi-layer knitted fabric derivatives were rated by the shuttle badminton players on thermal environment subjective rating scale. Ergonomics of thermal environment using subjective judgment scales consists of five scales such as thermal perception, affective assessment, thermal preference, personal acceptability statement and personal tolerance. By wear trial method, Type 4 bi-layer knitted derivative showed good rating on judgment scales. It was rated as cool on 9-point thermal perception scale, comfortable on 4-point affective assessment scale, slightly cooler on 7-point thermal preference scale, acceptable on two category statement of personal acceptability and perfectly tolerable on 5-point personal tolerance scale. In the next case, Type 1 bi-layer knitted derivative showed good rating on subjective judgment scale. It
was rated as neutral on thermal perception scale, slightly uncomfortable on affective assessment scale, no change on thermal preference scale, not acceptable on personal acceptability statement and slightly difficult to tolerate on personal tolerance scale.

Type 2 bi-layer knitted derivative showed least rating on judgment scale; rated as warm on thermal perception scale, very uncomfortable on affective assessment scale, warmer on thermal preference scale, not acceptable on personal acceptability statement and very difficult to tolerate on personal tolerance scale. Type 4 bi-layer knitted derivatives with tuck stitch on 12th wale and 18th course showed good rating on thermal environment subjective judgment scale. This is due to the position of tuck stitch for joining inner and outer layer and lower thickness and mass per unit area, leads to good comfort for the shuttle badminton players. The Friedman one-way analysis of variance by rank was used to find out the significant difference between bi-layer knitted derivatives on ratings of thermal environment subjective judgment scales. The number of subjects used for wear trial was 15 and hence chi-square was used for the analysis. The selected confidence level was 95%, degree of freedom is 3 and the F value is 7.8. The critical F value is less than the obtained value of chi-square, which proves that there is a significant difference between the rankings was found between the bi-layer knitted derivatives. The results of Friedman one-way analysis of variance by rank is given in Table A 1.2.
Among four bi-layer knitted fabric derivatives, Type 4 showed good ranking by wear trial method and good results by objective evaluation. An attempt has been made to find out the rank correlation between objective and subjective evaluation in the last part of the study. The thermal comfort characteristics such as thermal insulation, air permeability, water vapour permeability, vertical wicking, transverse wicking, moisture absorbency, drying rate and overall moisture management capacity is correlated with subjective judgment scales such as thermal perception, affective assessment, thermal preference, personal acceptability statement and tolerance. The result shows that there is a good rank correlation found between objective and subjective thermal comfort test results. The Spearman’s rank correlation coefficient between objective and subjective test results is shown in Table A 1.3. All the subjective judgement scales are positively correlated with thermal insulation and moisture absorbency and negatively correlated with other
thermal comfort characteristics (Thermal perception with objective test results: $r = -1$ & $r = 1$; Affective assessment: $r = -0.95$ & $r = 0.95$; Thermal preference: $r = -0.95$ & $r = 0.95$; Personal acceptability: $r = -0.77$ & $r = 0.77$; Personal tolerance: $r = -1$ & $r = 1$)

4.4 CONCLUSION

Following conclusions are drawn from the studies conducted on thermal comfort characteristics of bi-layer knitted fabric derivatives:

- Bi-layer knitted fabric derivative with tuck stitch on 12\textsuperscript{th} wale and 18\textsuperscript{th} course in which inner layer is made up of micro-fibre polyester yarn and outer layer is made up of modal yarn exhibited good thermal conductivity when compared to other bi-layer knitted derivatives due to lower thickness and mass per unit area.

- Air permeability and water vapour permeability of bi-layer knitted fabric with tuck stitch on 12\textsuperscript{th} and 18\textsuperscript{th} wale gives better results when compared to other fabrics due to lower thickness, mass per unit area, higher porosity and less number of tuck stitches. The lower thickness, mass per unit area and higher porosity facilitates the easy passage of water vapour and liquid moisture transfer through the bi-layer knitted fabric derivatives. The fabric construction plays a major role in air and water vapour permeability.

- The lower thickness and less tuck stitches used for layer joining exhibited good wicking ability in bi-layer knitted derivatives with tuck on 12\textsuperscript{th} wale and 18\textsuperscript{th} course.

- The drying behaviour of fabric depends upon the fabric structure and geometric properties of bi-layer knitted fabric.
The high vapour transmission, lower thickness and mass per unit area exhibited good drying ability. It has the ability to transfer perspiration from the inner layer of fabric to the outer layer and it easily gets evaporated and dried.

- Bi-layer knitted derivative with tuck on 12<sup>th</sup> wale and 18<sup>th</sup> course exhibited good overall moisture management properties when compared to other bi-layer knitted derivatives due to higher bottom wetted radius and spreading speed and higher top wetting time.

- From the subjective evaluation of shuttle badminton players, it is concluded that the bi-layer knitted derivatives with tuck stitch on 12<sup>th</sup> wale and 18 course repeat shows good rating on thermal environment subjective judgment scales. The good rank correlation was obtained between the subjective and objective test results of thermal comfort characteristics.

- In bi-layer knitted fabric derivative with the same fibre type, the fabric structure and the number of tuck stitch present in the course and wale plays a vital role in determining the thermal comfort characteristics of fabric. Bi-layer knitted fabric derivative with tuck on 12<sup>th</sup> wale and 18<sup>th</sup> course can be preferred as sportswear for shuttle badminton players.