CHAPTER 6

ALLOCATION OF CHIP MODULES BY SUPERPOSITION OF SELF-HEATING AND THERMAL WAKE EFFECTS FOR CONTROLLING MODULE TEMPERATURES

6.1 Introduction

From the previous chapters, there are two methods for predicting the module temperatures mounted on circuit board. The first one has used the heat transfer coefficient based on the temperature difference of the module and the ambient air over the module. The second approach has used a superposition technique that includes the convection from adiabatic heat transfer coefficient based on the temperature difference between the module and the entering air at the leading edge and the heat due to the heat generation from the upstream module.

The second method is more versatile to be used for predicting the module temperatures even each module generates different heat flux while the first one has to developed the related correlation case by case. In this part the second method is modified to adjusting the chip modules mounted on the circuit board for controlling the module temperature not to exceed the required limit.

6.2 Procedure for Module Adjustment

Figure 6.1 shows an example of air cooling in electronic modules mounted on a circuit board. The dimensions of the modules and their spacings are also given in the figure. The module temperature at any position could be calculated by (see Chapter 5)

$$T_k - T_0 = \left(\frac{q_k}{h_k A_k}\right) + \sum_{i=1}^{k-1} \theta_{k-i} \left(T_i - T_0\right), i < k \qquad (6.1)$$

q_k is the internal heat generation in the k^{th} chip, A_k is the heat transfer area and h_k is adiabatic heat transfer coefficient and θ_k is thermal wake function which is the fraction temperature increase of the k^{th} component due to heat release from the other elements.

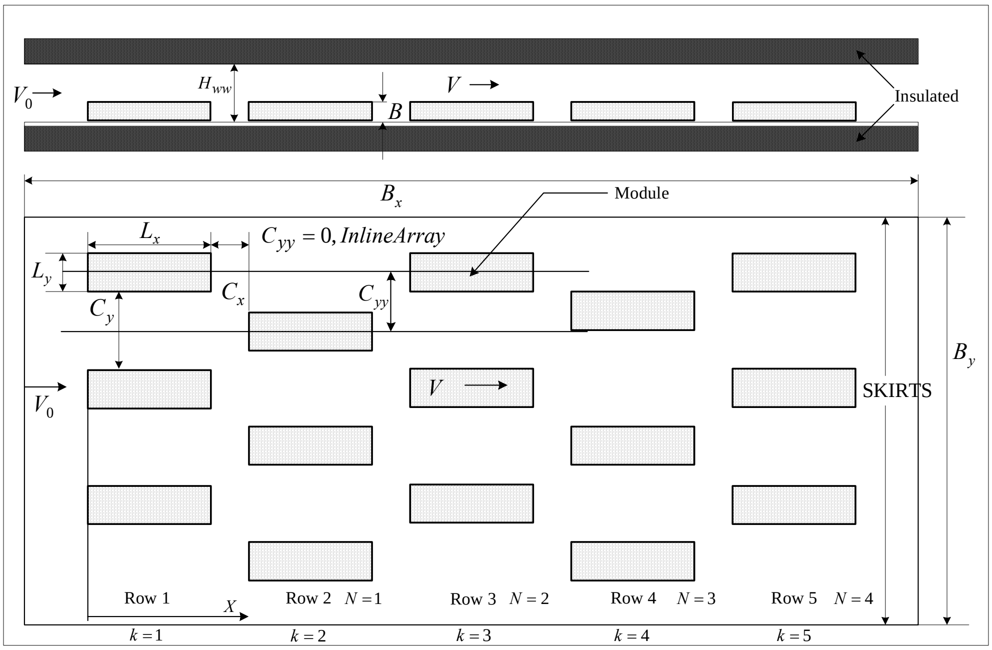
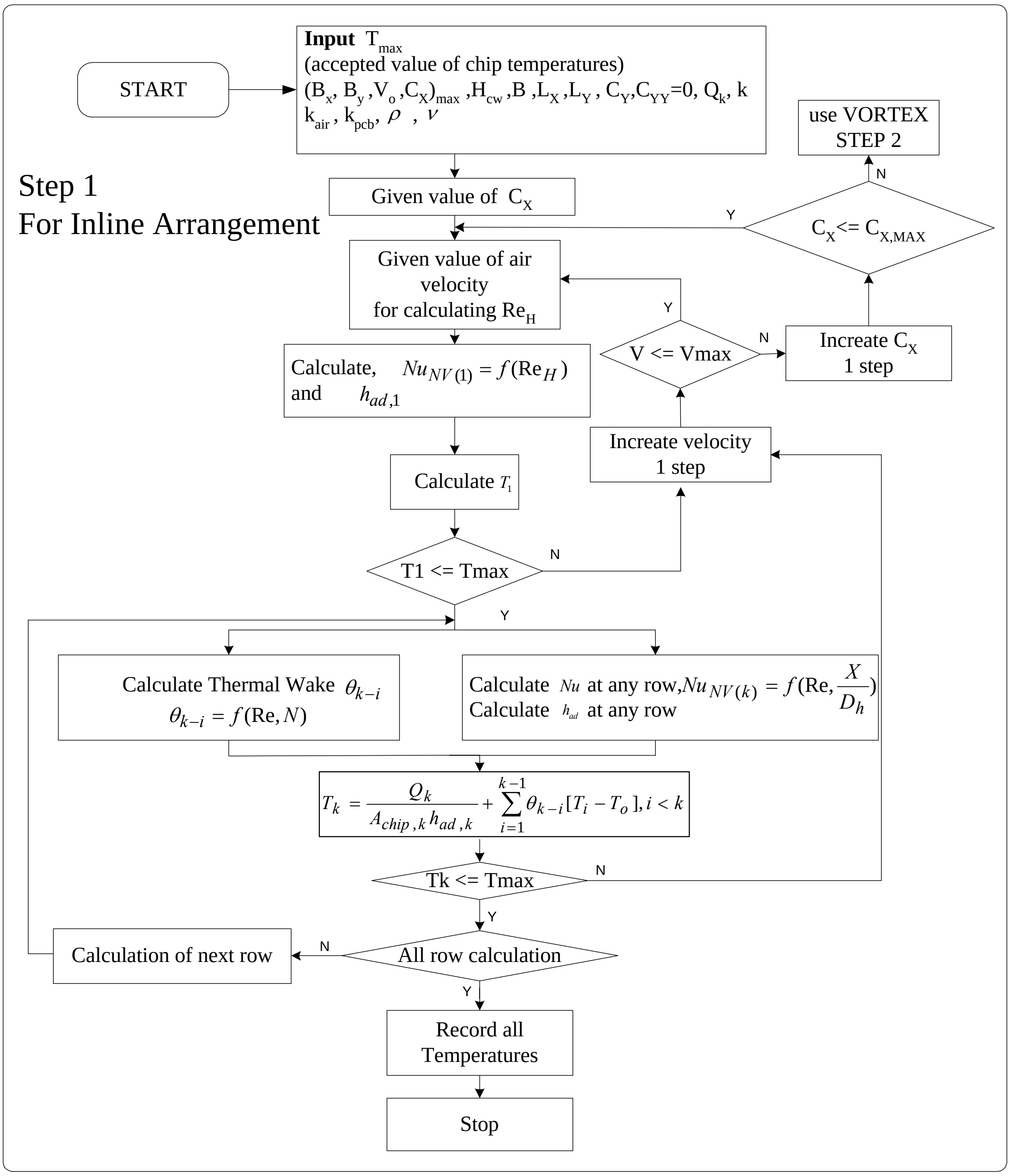


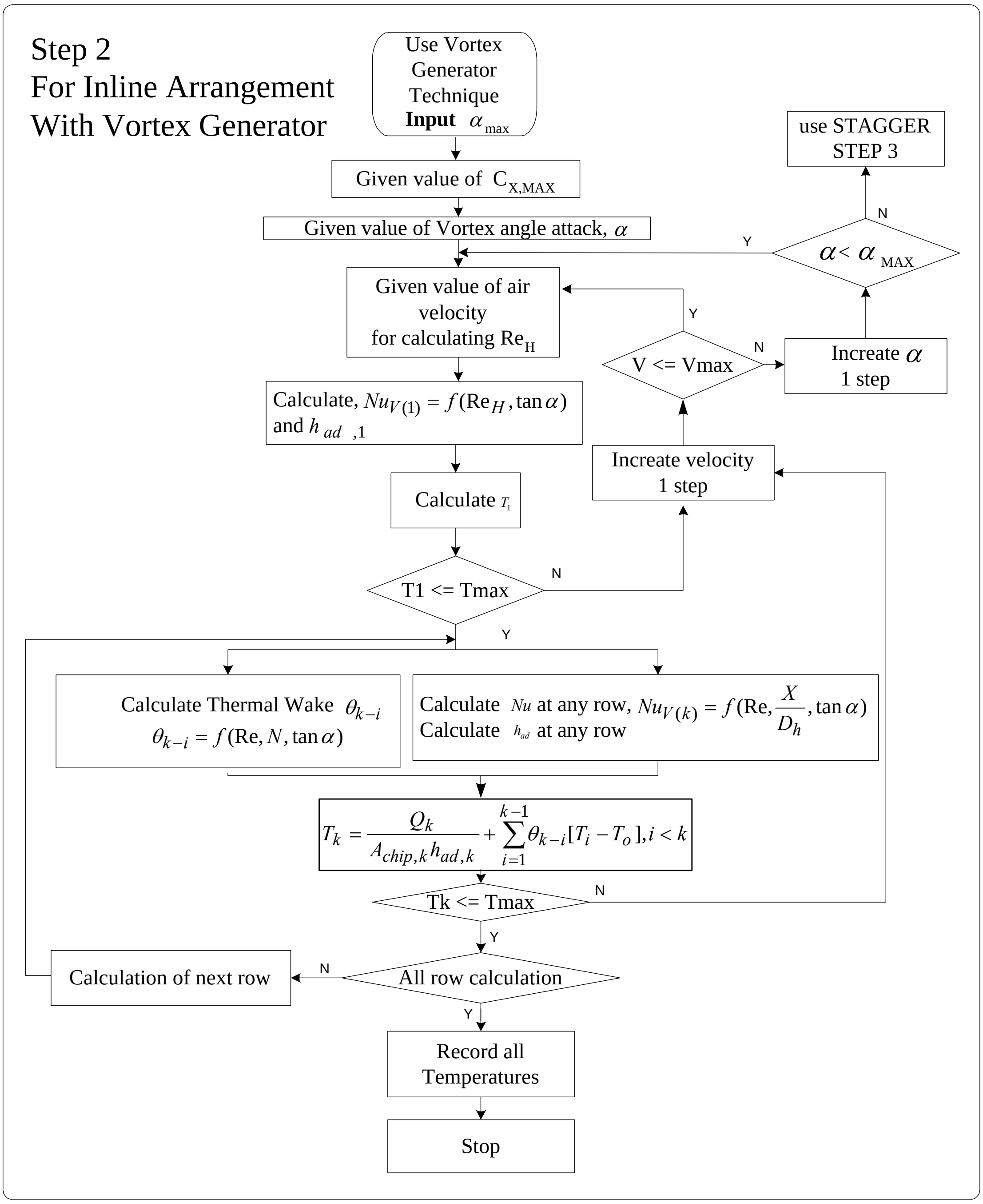
Figure 6.1 Air cooling in a circuit board.

Both h_k and θ_k depend on the module shape, module spacing, module position, inlet air temperature and inlet air Reynolds number. Chapter 5 has given the correlations for estimating the values in cases of in-line and staggered rectangular module arrangements with and without vortex generators. If the shape of the module is different from these, the experimental study will be carried out to find the new adiabatic heat transfer coefficient.

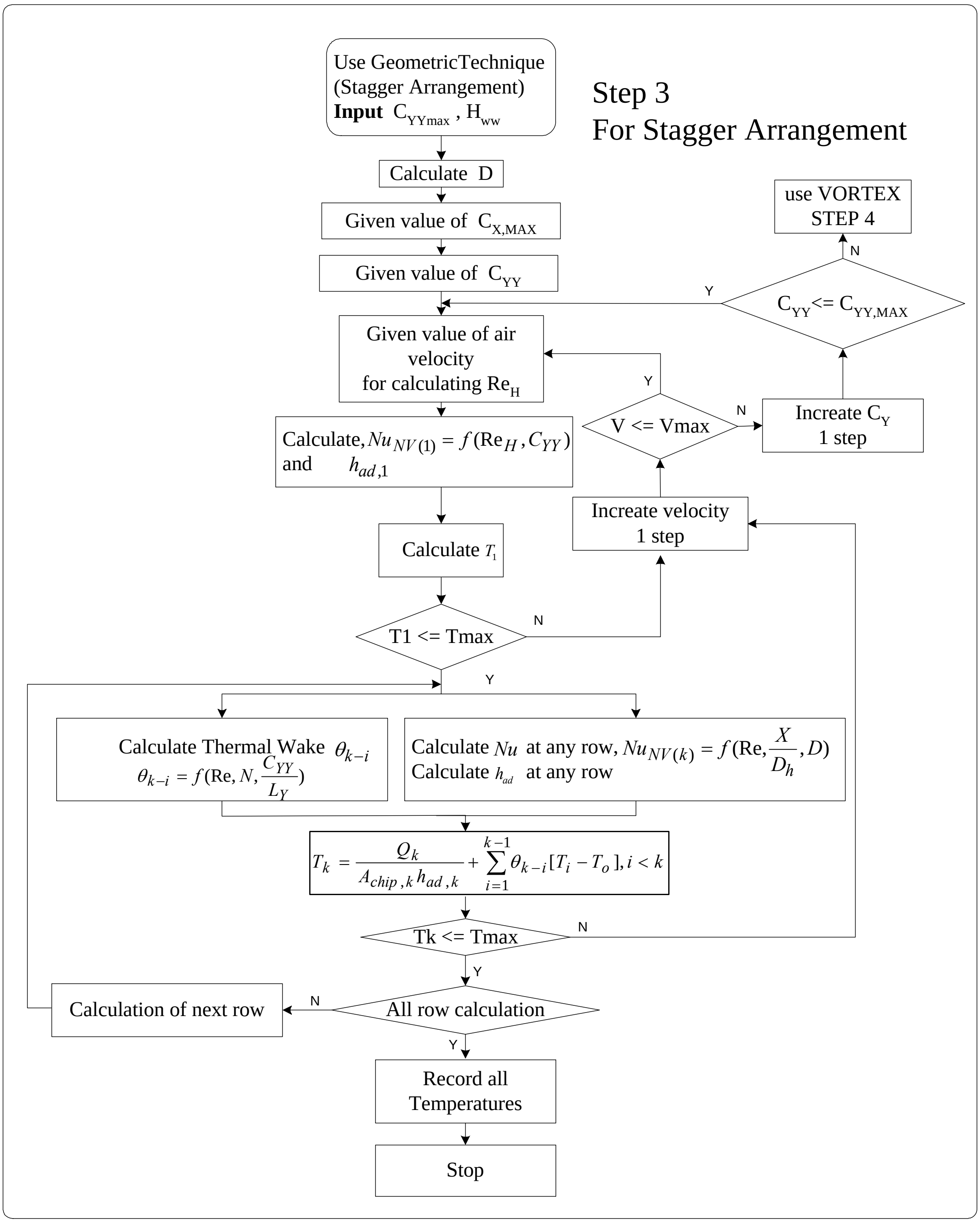
With the prescribed values of inlet air temperature and Reynolds number, the module dimensions and its heat generation, a trial of the module spacings, C_X and C_{YY} are performed to perform the module temperatures be lower the recommended values. Figure 6.2 shows the computational steps for the in-line and staggered modules with and without vortex generators.


START
Input T_{max}
(accepted value of chip temperatures)
$(B_x, B_y, V_o, C_X)_{max}, H_{cw}, B, L_X, L_Y, C_Y, C_{YY}=0, Q_k, k$
$k_{air}, k_{pcb}, \rho, \nu$
use VORTEX STEP 2
Step 1
For Inline Arrangement
Given value of C_X
$C_X <= C_{X,MAX}$
Given value of air velocity for calculating Re_H
V <= Vmax
Increate C_X 1 step
Calculate, $Nu_{NV(1)} = f(Re_H)$ and $h_{ad,1}$
Increate velocity 1 step
Calculate T_1
T1 <= Tmax
Calculate Thermal Wake θ_{k-i}
$\theta_{k-i} = f(Re, N)$
Calculate Nu at any row, $Nu_{NV(k)} = f(Re, \frac{X}{D_h})$
Calculate h_{ad} at any row
$T_k = \frac{Q_k}{A_{chip,k} h_{ad,k}} + \sum_{i=1}^{k-1} \theta_{k-i}[T_i - T_o], i < k$
Tk <= Tmax
Calculation of next row
All row calculation
Record all Temperatures
Stop
Y
N

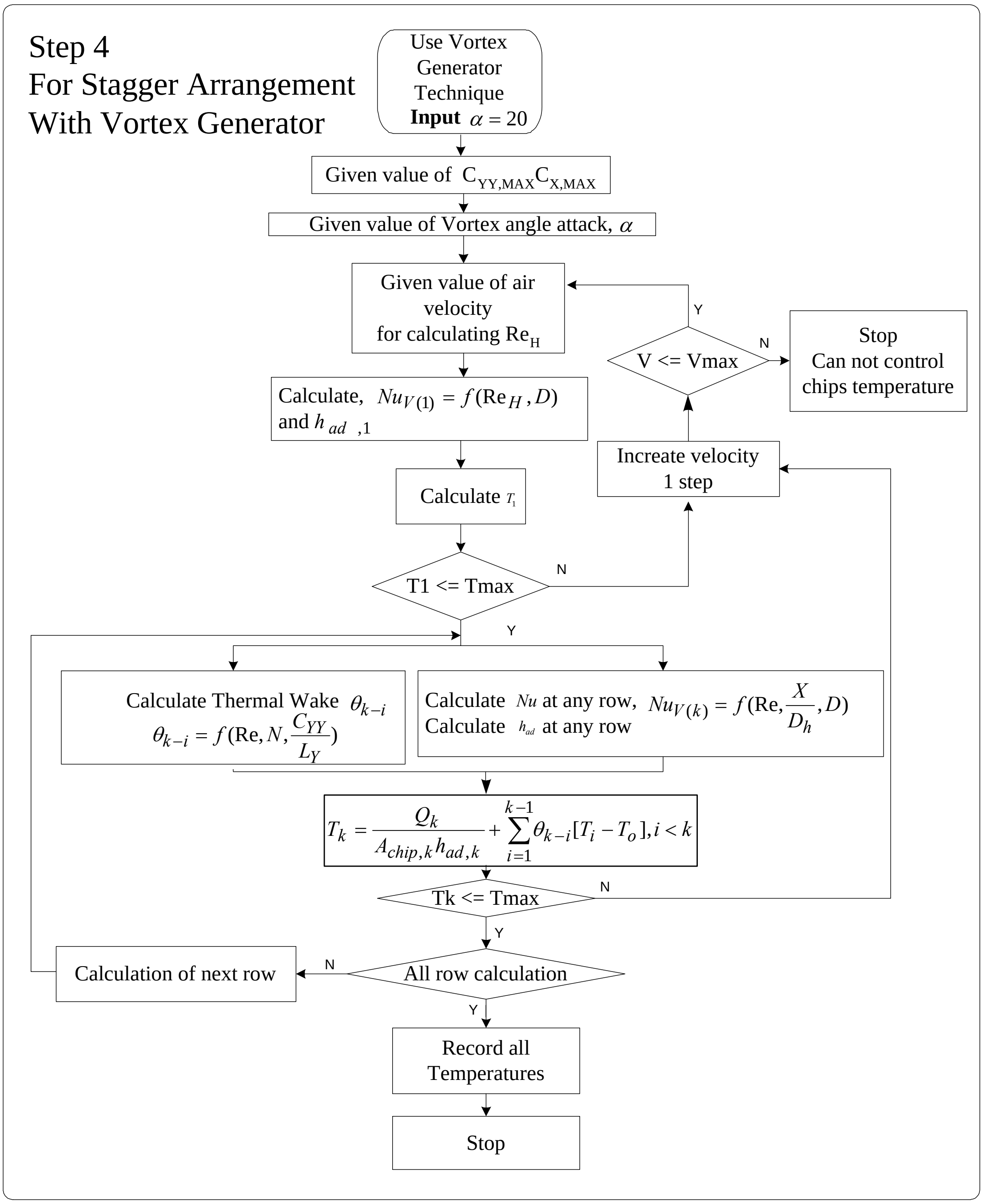
(a)


Step 2
For Inline Arrangement
With Vortex Generator
Use Vortex Generator Technique
Input α_{max}
Given value of $C_{X,MAX}$
Given value of Vortex angle attack, α
Given value of air velocity for calculating Re_H
Calculate, $Nu_{V(1)} = f(Re_H, \tan\alpha)$ and $h_{ad,1}$
Calculate T_1
T1 <= Tmax
Increate velocity 1 step
V <= Vmax
Increate α 1 step
$\alpha < \alpha_{MAX}$
use STAGGER STEP 3
Calculate Thermal Wake θ_{k-i}
$\theta_{k-i} = f(Re, N, \tan\alpha)$
Calculate Nu at any row, $Nu_{V(k)} = f(Re, \frac{X}{D_h}, \tan\alpha)$
Calculate h_{ad} at any row
$T_k = \frac{Q_k}{A_{chip,k} h_{ad,k}} + \sum_{i=1}^{k-1} \theta_{k-i}[T_i - T_o], i < k$
Tk <= Tmax
All row calculation
Calculation of next row
Record all Temperatures
Stop
Y
N

(b)


Use GeometricTechnique
(Stagger Arrangement)
Input C_{YYmax} , H_{ww}
Step 3
For Stagger Arrangement
Calculate D
use VORTEX STEP 4
Given value of $C_{X,MAX}$
Given value of C_{YY}
$C_{YY} <= C_{YY,MAX}$
Given value of air velocity for calculating Re_H
V <= Vmax
Increate C_Y 1 step
Calculate, $Nu_{NV(1)} = f(Re_H, C_{YY})$ and $h_{ad,1}$
Increate velocity 1 step
Calculate T_1
T1 <= Tmax
Calculate Thermal Wake θ_{k-i}
$\theta_{k-i} = f(\mathrm{Re}, N, \frac{C_{YY}}{L_Y})$
Calculate Nu at any row, $Nu_{NV(k)} = f(\mathrm{Re}, \frac{X}{D_h}, D)$
Calculate h_{ad} at any row
$T_k = \frac{Q_k}{A_{chip,k} h_{ad,k}} + \sum_{i=1}^{k-1} \theta_{k-i}[T_i - T_o], i < k$
Tk <= Tmax
Calculation of next row
All row calculation
Record all Temperatures
Stop
Y
N

(C)



(d)

Figure 6.2 The computational steps for the module adjustings.

6.3 Examples of the Calculation

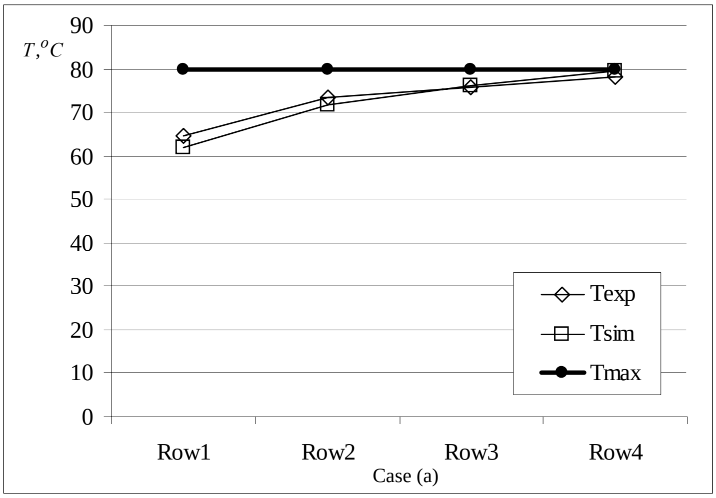
From Figure 6.2 when the maximum temperature of the module is prescribed, different techniques of air cooling (in-line and staggered module arrangements arrangements with and without vortex generator integrated in front of each module) will be used to estimate the module temperatures not to exceed the limit.

Table 6.1 gives the test conditions as the examples for the calculation of the module temperature. The maximum temperature is prescribed as 80^{o}C(a), 70^{o}C(b), 60^{o}C(c), 50^{o}C(d) and 45^{o}C(e).

Table 6.2 shows the technique including the appropriate module spacings to control the module temperatures not to exceed the limits. Experimental results are also carried out to verify the simulated conditions. The results are also shown in Figs. 6.3(a) – 6.3(e). For low prescribed maximum temperature, the vortex generators could control the module temperatures to be less than the limit value, effectively. It could be seen that the models developed are good enough to be used for adjusting the modules.

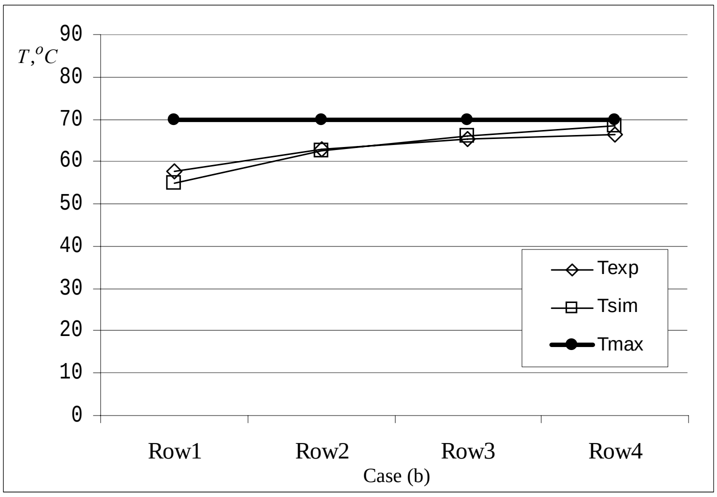
Table 6.1 The test conditions.

Parameters		Unit
To	27	C
Qk	2.5	Watt
Bx,max	0.4	m
By,max	0.2	m
Vo,max	3	m/s
Hcw	0.018	m
B	0.006	m
Lx	0.058	m
Ly	0.018	m
Achip	0.001956	m2
c	4	Coluum
k	4	Row
k,air	0.0263	W/mK



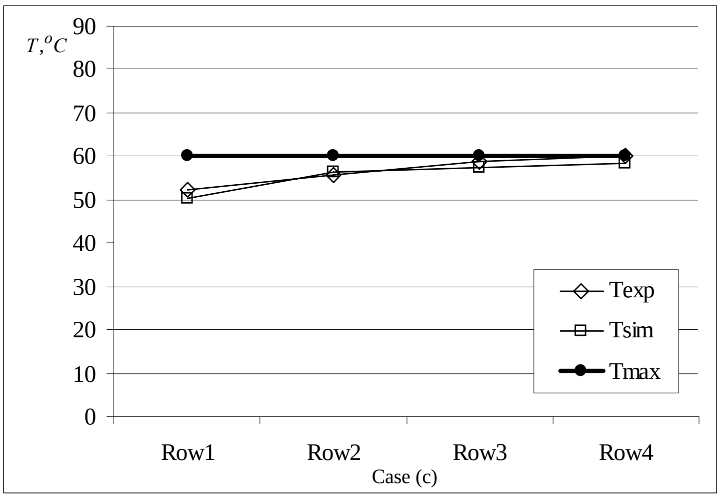
T,°C
90
80
70
60
50
40
30
20
10
0
Texp
Tsim
Tmax
Row1
Row2
Row3
Row4
Case (a)

(a)



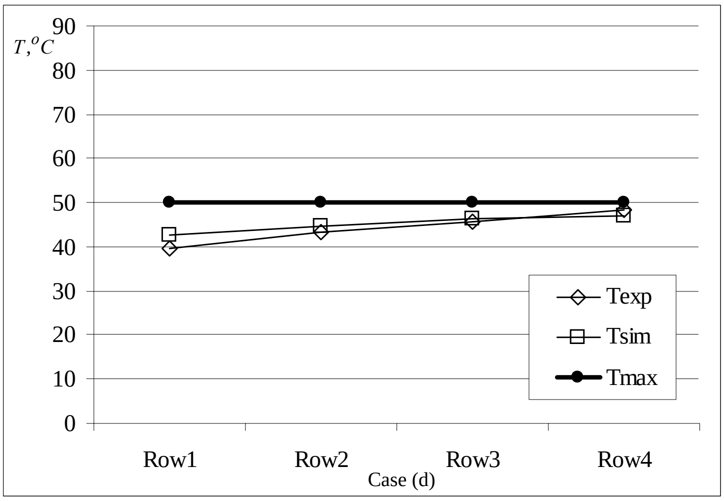
T,°C
90
80
70
60
50
40
30
20
10
0
Texp
Tsim
Tmax
Row1
Row2
Row3
Row4
Case (b)

(b)

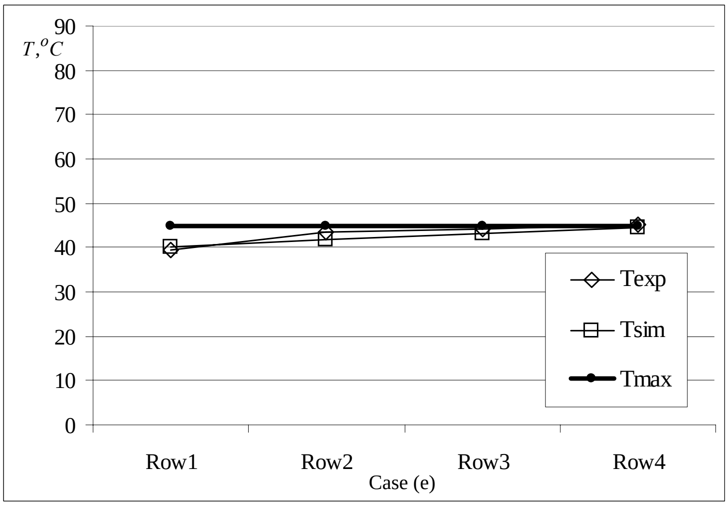


T,°C
90
80
70
60
50
40
30
20
10
0
Texp
Tsim
Tmax
Row1
Row2
Row3
Row4
Case (c)

(c)



(d)



(e)

Figure 6.3 The comparison of the simulated module temperatures with the experimental data with the conditions in Table 6.2.

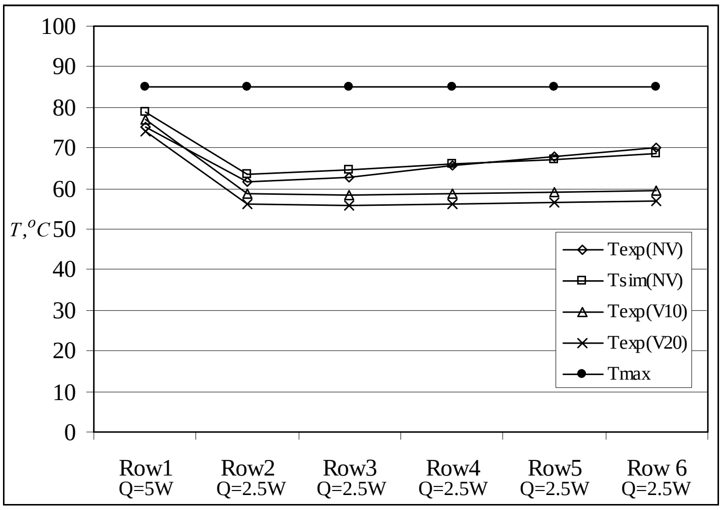
Table 6.2 The simulation results for the module adjustment.

Parameter		**CASE (a)**	**CASE (b)**	**CASE (c)**	**CASE (d)**	**CASE (e)**
T,max		80	70	60	50	45
Techniques		Inline	Inline + Re + Cx	Inline + Re + Cx +Vortex	Stagger + Cyy	Stagger + Cyy +Vortex
Vo,m/s	max = **3** m/s	2.4	**3**	**3**	**3**	**3**
Cx,m		0.017	0.023	0.035	0.035	0.035
Bx,m	max = **0.4** m	0.342	0.359	**0.4**	**0.4**	**0.4**
Cyy,m		-	-	-	0.015	0.021
By,m	max = **0.2** m	-	-	-	0.165	**0.2**
Vortex	max = **20** Degree	0	0	10	0	**20**
Error (+ -%)		4	5	4	6	4

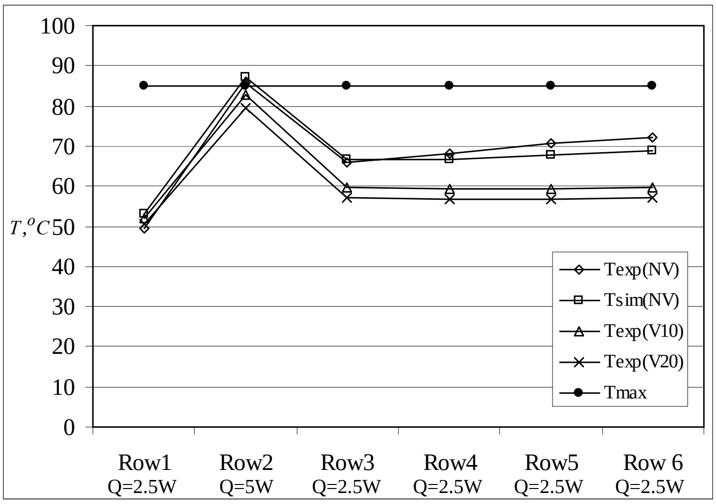
Table 6.3 shows the example data when one row(total 6 rows) has a high heat rate which is 5 W compared with 2.5 W of the others. The simulation have been trial for the case of in-line arrangements with and without vortex generators. The results are shown in Figure 6.4.

Table 6.3 The example data when the modules of one row generate high heat rate.

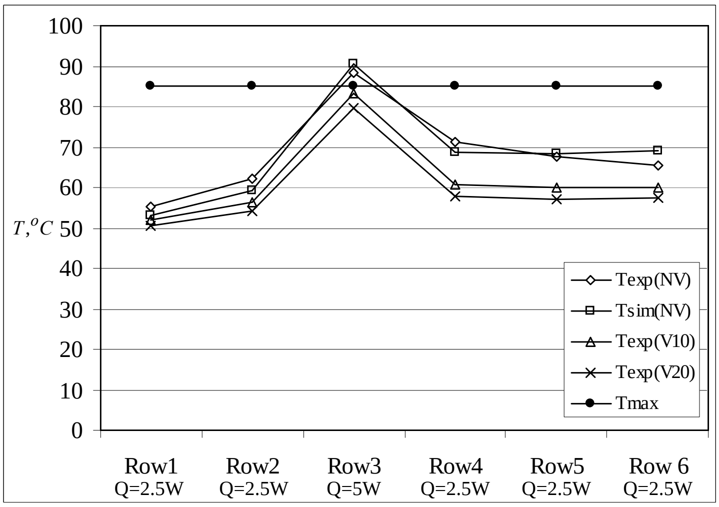
Parameters		**Unit**
To	27	C
Qk	2.5 / 5	Watt
Bx	0.5	m
By	0.09	m
Vo	4	m/s
Hcw	0.018	m
B	0.006	m
Lx	0.058	m
Ly	0.018	m
Achip	0.001956	m2
c	2	Column
k	6	Row
k,air	0.0263	W/mK



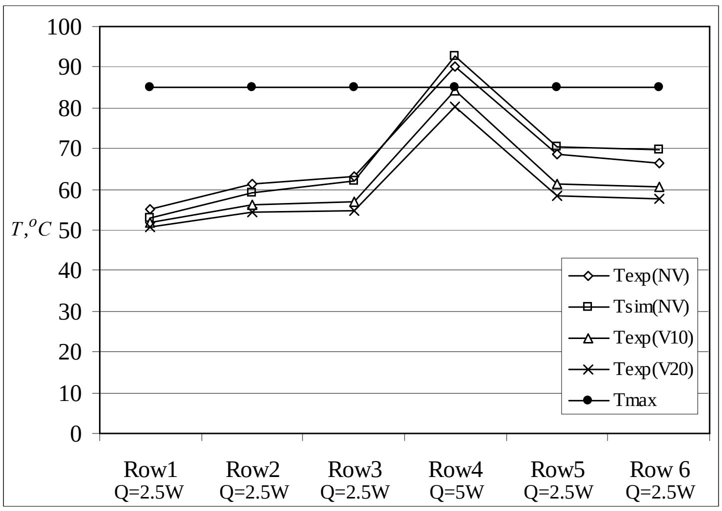
(a)


100
90
80
70
60
T,°C 50
40
30
20
10
0
Texp(NV)
Tsim(NV)
Texp(V10)
Texp(V20)
Tmax
Row1 Q=2.5W
Row2 Q=5W
Row3 Q=2.5W
Row4 Q=2.5W
Row5 Q=2.5W
Row 6 Q=2.5W

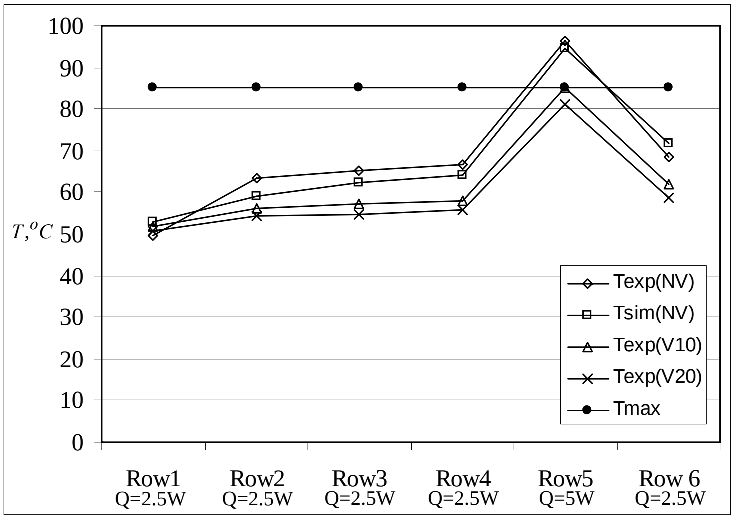
(b)


100
90
80
70
60
T,°C 50
40
30
20
10
0
Texp(NV)
Tsim(NV)
Texp(V10)
Texp(V20)
Tmax
Row1 Q=2.5W
Row2 Q=2.5W
Row3 Q=5W
Row4 Q=2.5W
Row5 Q=2.5W
Row 6 Q=2.5W

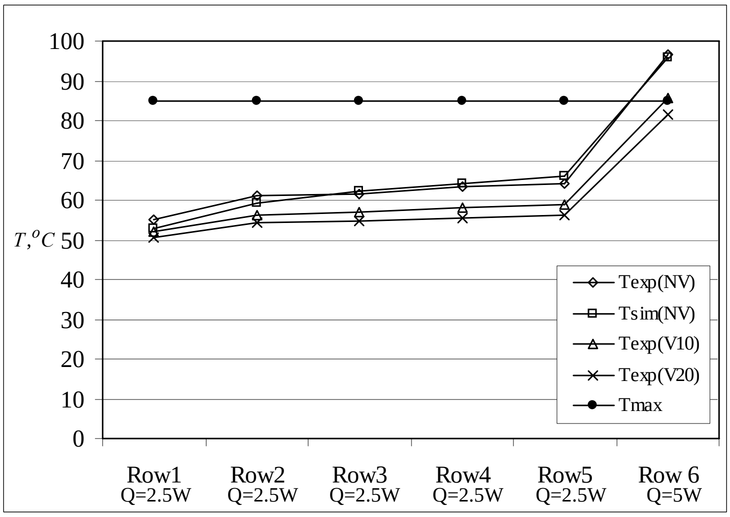
(c)


100
90
80
70
60
T,°C 50
40
30
20
10
0
Texp(NV)
Tsim(NV)
Texp(V10)
Texp(V20)
Tmax
Row1 Q=2.5W
Row2 Q=2.5W
Row3 Q=2.5W
Row4 Q=5W
Row5 Q=2.5W
Row 6 Q=2.5W

(d)



(e)



(f)

Figure 6.4 The results of the module temperatures for different allocation of the modules having the highest heat rate.

From the simulation results, when the set maximum temperature is 85 ^{o}C, it could be seen that the suitable allocation for the module having the highest heat rate should be installed at the first row while the for other row positions, the hot spot will be higher than that of the set value. However, when vortex generator are integrated the vortex generator also reduces the temperature of the hot spot around 8 ^{o}C. In these cases , the temperature of the hotspot could be controlled to be less than the set value for all positions.

6.4 Conclusion

The superposition method that includes the self-heating due to the heat generating within the module and the second heating effect due to the heat release from upstream components could be modified for adjusting the positions of the chip modules for controlling their temperatures. The procedure developed is very effective to allocate the modules both with and without vortex generators. For low temperature limit, the vortex generators have a high potential to control the hot spot.