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Review on heat transfer analysis of semi-elliptical notched rectangular fin array with area compensation at side, height and without area compensation.

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ABSTRACT

Fins are the extended surfaces which are used to dissipate heat from hot surfaces through natural convection without any external device. Geometry and orientation play a significant role in natural convection heat transfer. Fin arrays on horizontal and vertical surfaces are used in variety of engineering applications to dissipate heat to the Surrounding. For semi-elliptical notch fin array a chimney flow pattern is developed due to density difference. This flow pattern creates a stagnant zone near central bottom region. That portion does not contribute much towards heat dissipation. This area is removed from fins and this modified geometry reduces material cost, material weight without hampering heat transfer rate. The purpose of the present study is to investigate thoroughly the possibility of performance improvement of such arrays by providing a notch at the center and suggest for selection of optimum notch dimensions and spacing by analyzing variety of fin arrangements. The dimensions of fins are changed by maintaining constant spacing between the fins. Study is caried out by comparing results between experimental and CFD analysis. The effect on heat transfer coefficient of fin array with various geometries such as fins without notch, fins with notch, fins with compensation of notch area at sides along length and compensation of notch area at height is examined by experimentally and by CFD. The notches given in semi-elliptical shape. The paper is focusing on effect of semi-elliptical notch on heat transfer rate of horizontal rectangular fin array.

Keywords— Natural Convection, fin arrays, notches, area compensation.

1. Introduction

Heat transfer is a science that studies the energy transfer between two bodies due to temperature difference. This temperature difference is thought of as a driving force that causes heat to flow. Heat transfer occurs by three basic mechanisms or modes: conduction, convection, and radiation. In this paper we are mainly focusing on heat transfer due to natural convection through vertical fin array with horizontal base fins. In the study of heat transfer, a fin is an extended surface of an object which is used to increase the rate of heat transfer to or from the environment by increasing convection[1].

1.1 Convection

The effectiveness of heat transfer through convection based largely upon the mixing movement of the fluid. With respect to the origin, types of convection are distinguished, forced and natural convection[2]. Natural or free convection is observed because of the motion of the fluid due to density changes arising from the heating and cooling process[3]. The convection heat transfer mode is comprised of two mechanisms: random molecular motion (diffusion) and energy transferred by bulk or macroscopic motion of the fluid. The convection heat transfer occurs when a cool fluid flows past the warm body, The fluid adjacent to the body forms a thin slowed down region called the boundary layer. The velocity of the fluid at the surface of the body is reduced to zero due to the viscous action. Therefore, at this point, the heat is transferred only by conduction. The moving fluid then carries the heat away. The temperature gradient at the surface of the body depends on the rate at which the fluid carries the heat away. Therefore, for two surfaces at temperature T1 & T2 heat transfer rate is given according to Newton's Law of cooling is,[4]

$$Q = h A (T1 - T2)$$

Where,

h- Heat Transfer Coefficient,

A- Area,

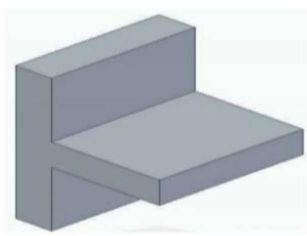
T1- Temperature of Bod,

T2-Surrounding Temperature.

1.2 Introduction to fins:

Fins are the extended surfaces which are used for heat transfer in many electronic applications. When available surface is found inadequate to transfer required quantity of heat with available temperature gradient, fins are used. Rate of heat dissipation from a fin configuration by convection heat transfer depends on the heat transfer coefficient and the surface area of the fins. Using fins is one of the cheapest and easiest ways to dissipate unwanted heat and it has been commonly used for many engineering applications successfully. Because of reduction surface area available for heat dissipation and low heat transfer coefficient optimization of fin geometry becomes very important in natural convection heat transfer Natural convection heat transfer is often increased by provision of rectangular fins on horizontal or vertical surfaces in many electronic applications such as motors and transformers, in thermoelectric refrigeration systems[5]. Rectangular fins are the most popular fin type becauseof their low production costs and high effectiveness. Natural convection heat transfer is augmented by provision of rectangular fins on horizontal or vertical surfaces in many electricaland electronic appliances[6]. In LED cooling fins are very important as they increase life span of LED[7]. Practically with electronic systems, for the thermal loading heat transfer enhancement, heat sink with fin array is often used with a typical fins arrangement and air flow direction through the channels[8]. Fins are also useful in cooling of IC engine and in hydrogen fueled vehicles[9].

Various geometries of fins-[10]



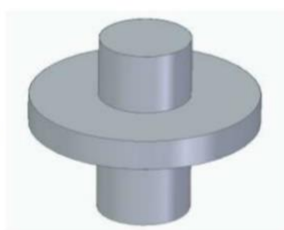


Fig 1.1: Rectangular fin   Fig. 1.2: Annular fin

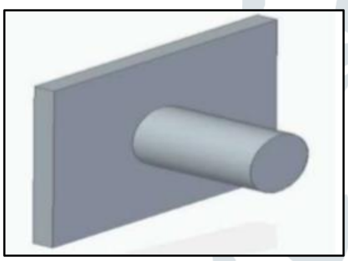
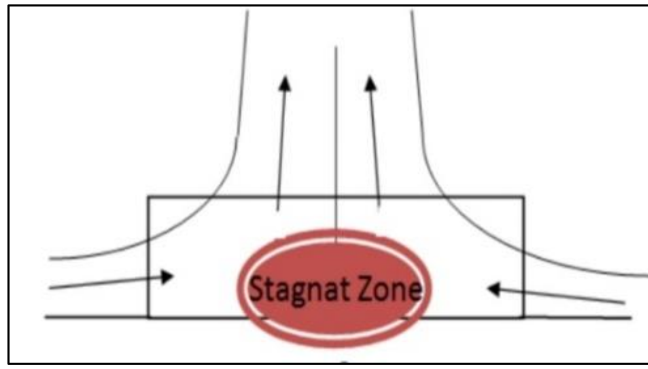


Fig. 1. 3: Pin fin

Several types of fins are as shown in above fig. 1.3 out of these fins rectangular fins transfers more amount of heat than annular fin and pin fin[11]. Rectangular fins are of four types: standard rectangular fins, inclined rectangular fins, perforated rectangular fin, interrupted rectangular fin[12]. This paper mainly focusing on standard rectangular fins with semi-elliptical notch.

1.3 Need of Investigation:

Fig. 1.4: Single Chimney Effect



Generally, in natural convection heat transfer with vertical fin array on horizontal fin base, it is observed that single chimney flow pattern is there[13] as shown in fig. 1.4. From the early research work and literature survey, there is establishment of single chimney pattern for fin with high aspect ratio (L/H~5)[14]. There is sidewise entry of air in case of natural convection cooling of vertical fin array. The air coming inwards gets heated as it moves towards the center of the fin, as well as it rises due to decrease in density. So, the central bottom portion of the fin becomes less effective or sometimes ineffective because hot airstream passes over that part and therefore it does not bring about large heat transfer through that portion. A Stagnant zone is created at the central bottom portion of fin array channel and hence it does not contribute much in heat dissipation. The area from the stagnant zone is removed in the form of notch and added equally on both sides of fin along the length to modify its geometry for enhancement of heat transfer. This is called **Area compensation**[13]**.** So, in this work we are going to remove the semi-elliptical shaped area from the stagnant zone and compensating this area once at side and once at height to enhance the heat transfer rate. Results are taken at various inputs- 50W, 75W, 100W[3].

2. Literature Survey

Table:1

Sr. No.	Title Of Research Paper	Author Name	Year	Remark
1	Convection heat transfer from horizontal rectangular fin array having triangular perforations.	S. Taji	2016	Triangular perforated fin arrays are 20% to 30% superior to un-perforated arrays, in terms of average heat transfer coefficient.
2	Analysis of heat transfer through fins of IC engine.	Sujan S.	2019	Temperature distribution of cylinder and fins, heat flux through walls was done with the help of ANSYS R19.2 and conclude that grey cast iron has low thermal conductivity hence the heat transfer rate is comparatively extremely low.
3	Experimental investigation of natural convection heat transfer from a blackened v-fin array.	S. Wani	2016	V-Fins with Apex facing downwards configuration, the temperature difference is in the range of 18.06 – 34.16ºC, which is the lowest as compared to any configuration that means this configuration gives the better performance.
4	Effects of corrugation profile on the heat transfer rate of fins.	Walid A.	2016	The corrugated profiled fins have an improved heat dissipation capacity than flat fin.
5	Study on performance of the thermoelectric cooling device with novel sub channel finned heat sink.	Gaoju X.	2022	COP of the thermoelectric refrigeration system under the novel sub channel fin can be increased by 22.8%.
6	A brief overview of application of extended surfaces (fins) for enhancement of heat transfer.	Pandya B.	2019	Performance of the fin is dependent on fin geometry, fin materials and other parameters like fin height, fin spacing, weight of fin.
7	Comparative analysis of integrated heat sink vapor chamber with conventional heat sink for LED cooling.	Chandrakishor L.	2022	Temperature distribution in IHSVC is uniform compared to the CHS.
8	Performance of rectangular pin-fin heat sink subject to an impinging air flow.	Adil M.	2021	The temperature drop along the extended surfaces is consistently higher as the base heat flux increasing.
9	Transient thermal analysis of different types of IC engine cylinder fins by varying thickness and introducing slots.	G. Harish	2021	Multiple slots on the fin profile enhance the overall heat transfer rate.

Table: 1 continued

Sr. No.	Title Of Research Paper	Author Name	Year	Remark
10	A review on parameters affecting the heat transfer rate of fin.	Vidyasri K.	2018	Slots or holes or gaps surface roughness in fins is used to improve heat transfer rate.
11	Experimental analysis of natural convection of heat transfer of Different types of notches in fins: Review.	Suvarna P.	2017	Heat transfer enhancement depends on number of perforations, size and shape of perforation, thickness of perforated fin and thermal conductivity of fin material.
12	Review of enhancement of heat transfer from rectangular fin arrays.	Ece A.	2018	Perforated fins have higher heat transfer coefficient than solid fins because number of perforations are directly proportional to Nusselt number.
13	Natural convection heat transfer by heated plate using different types of notched fin arrays–a review.	T. Ramsing	2015	Making notch is effective method for increasing heat transfer because the values of heat transfer coefficient are higher for notched fin arrays.
14	Impact of channels aspect ratio on the heat transfer in finned heat sinks with tip clearance.	Elena M.	2022	Nusselt number multiplied by a factor of 1.14 when aspect ratio lies between 0.25 and 1.75, so that Nusselt number value gets increased which will increases the heat transfer rate.
15	Finite Element Thermal Analysis of Electronic Heat Sinks of Convex and Concave Parabolic Porous Fins with Temperature-dependent Thermal Properties and Internal Heat Generation.	Sobamowo G.	2022	Copper porous fin has the highest values of temperature distribution while stainless steel has the least temperature distribution.
16	Experimental and computational analysis of various types of fins	N. Arul	2017	Rectangular fin transfers more amount of heat than circular fin and pin fin.
17	Heat transfer from different types of fins with notches with varying materials to enhance rate of heat transfer a Review.	Viveksheel Y.	2020	Implementation of notches in the design of fins leads to the dissipation of heat from surface.
18	Numerical design and optimization of a novel heat-sink using ANSYS steady-state thermal analysis.	Andre M.	2020	The novel heat-sink of multiple branches have higher thermal efficiency.

Table: 1 continued

Sr. No.	Title Of Research Paper	Author Name	Year	Remark
19	A Comparative Review of Thermocouple and Infrared Radiation Temperature Measurement Methods during the Machining of Metals.	Emilios L.	2022	Infrared-thermometer is more accurate than thermocouple, is not affected by heat conduction or heat convection and also provides rapid response for small change in temperature.
20	Comparison Between Numerical Study and Experimental Work on Heat Transfer from Heat Sink Under Transient Conditions.	Ehsan F.	2021	Investigated transient temperature distribution along constant rectangular fin by using COMSOL software and examined experimentally
21	Experimental Study of Natural Convection from an Array of Square Fins.	Mehdi. K.	2017	The optimum fin spacing for the three finned tubes examined in this study is 9 mm.
22	Experimental Investigation of Heat Transfer by Natural Convection with Perforated Pin Fin Array.	Shitole P.	2018	Average Nusselt number (Nu) increases gradually as the ratio of fin spacing to height (S/H) increases for fin array.
23	Experimental analysis of rectangular fin arrays with continuous fin and interrupted fins using natural and forced convection.	Vinaya K.	2016	Rectangular fins with 4 interrupts show higher heat transfer coefficient than 1 and 3 interrupted fin patterns.
24	Experimental study of free convection from rectangular fins array on a heated horizontal plate with notch effects.	Saad N.	2017	Average convective heat transfer coefficient of notched fin array is 28% to 45% higher than that for fins array without notches at the same conditions.
25	Experimental study for optimum fin spacing of rectangular fin arrangements under the influence of free convection.	Abbas J.	2020	The optimum fin spacing is (6 mm to 12 mm) S=12 mm to get maximum heat transfer coefficient, maximum Nusselt number, and heat transfer rate.
26	Thermal analysis on microelectronic heat-sink by CFD using rectangular and trapezoidal fin arrays.	B. Jayalakshmi	2017	Heat transfer rate of an array of rectangular heat sink 2% more than trapezoidal fin array.
27	Numerical analysis of the surface and geometry of plate fin heat exchangers for increasing heat transfer rate.	Farivar F.	2018	Perforated fins have higher convection heat transfer coefficient and Nusselt number than normal fin.

3. Problem Statement and Objectives

Problem Statement:

Only few shaped notches are used, as there are many other shapes like trapezoidal, elliptical, semi-elliptical and so on. Longitudinal rectangular fins have relatively low cost and ease of manufacturing[15], various works need to be focused on this shape of fin, also rectangular fins have higher heat transfer coefficient than circular fin and pin fin[16]. Many of the researchers used the rectangular notched fin array but it was not inverted so that the air does not get more contact surfaces to carry out the heat whereas in inverted rectangular notched fin array, the area removed is greater than the other shapes so that heat transfer through the conduction decreases. Most of the researchers made area compensation on the top of the fin i.e. at the tip of the fin and increasing the height of the fin due to which the aspect ratio will decreases and we will not get the perfect single chimney flow effect. No one compare the results of compensation of area at sides along the length with compensation of area at height and effect of % area removed on heat transfer coefficient of the fin array. Fins with various notches is as shown in fig.3.1.[17]

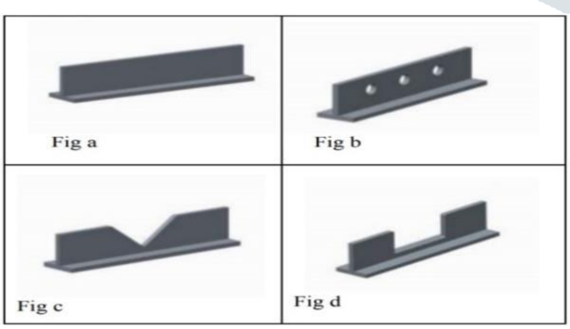


Fig. 3.1: Fin array without notch and fins with various notches.

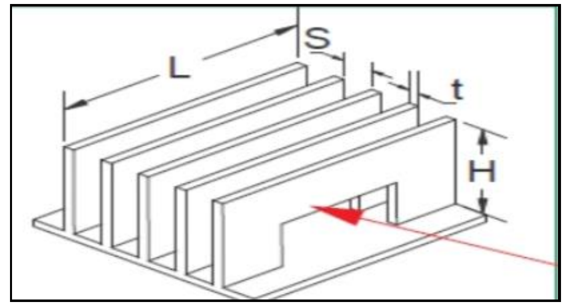


Fig. 3.2: Fin array with inverted rectangular notch[13].

Objectives:

Analysis will be done experimentally by using the semi-elliptical notch at some distance above base and area compensation of the notch at the entry side of air to the fin so that there will be creation of single chimney flow so that more air gets entered fin spacing area[13]. Comparison between effect of compensation of area at side, at height and without area compensation on heat transfer coefficient of fin array is carried out through experimentally by giving heat input such as 50w, 75w, 100w.

Following are the objectives:

1. To Study the effect of semi-elliptical notch at central base on convective heat transfer coefficient of fins.
2. To Study the effect of different heat input given on heat transfer coefficient of fins. (50w, 75W, 100W)
3. To Study the effect of notch area & compensation of that area on entry side on heat transfer coefficient.
4. To compare the results of experimentation and numerical.
5. To compare the results of compensation of area at sides along length with

compensation of area at height.

4. Methodology:

4.1 Design of Model

In the CPU heat sink rectangular fins of aluminium is used to transfer the heat to maintain the processor cool, so to increase the heat transfer rate from that type of fins the rectangular size of fin is decided. Notch shape selected as semi-ellipse slightly above the base as shown in below figure & Compensation of area removed is to be added at entry side of the air because L/H ratio increases.

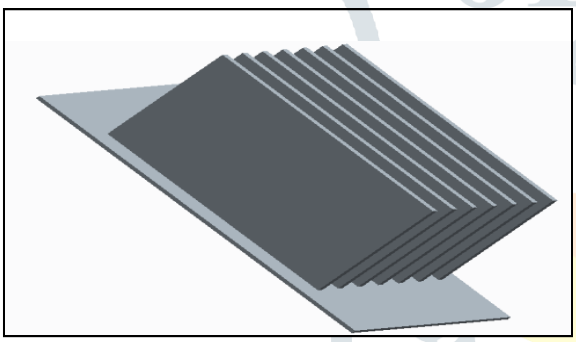


Fig. 4.1: Fin without notch.

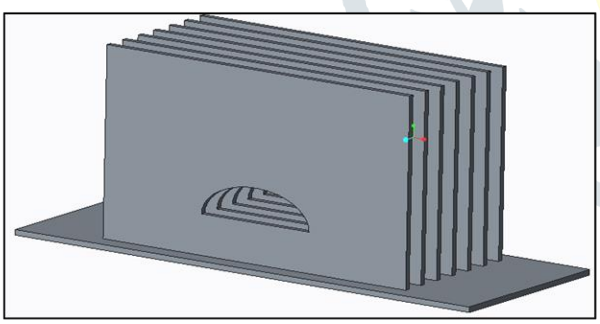


Fig.4.2: Fin with semi-elliptical notch

For experimentation fin arrays made up of aluminium are attached on the base plate which is which is also made up of aluminium[18]. Below base plate heater is placed for giving the heat input, with insulation so that heat should not have to be lost from other side of the base plate. Heat transfer should be from sides of fin only. Then this assembly should have to keep in wooden box to achieve natural convection cooling. By giving heat input to heater and by using industrial temperature gun, temperature at tip of each fin is recorded. Also, temperature at base plate is recorded by temperature gun (IR thermometer)[19]. Control panel is required for controlling the heat input.

4.2 Dimensions of fin array

Four types of fin arrays were used for analysis.

- Fin array without Notch,
- Fin with notch area removed and compensated along length,
- Fin with notch area removed and compensated at height,
- Fin with notch area removed but not compensated.

Dimensions:

1. Size of base plate = (70mm * 180mm)
2. Thickness of Fins & base plate = 2mm[20][21]
3. Number of fins = 7 [22], [23]
4. Fin spacing = 7mm[24]

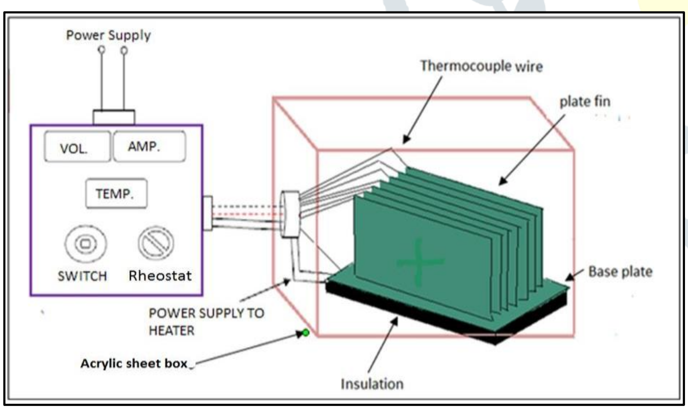
4.3 Experimental Setup

The experimental setup consists of rectangular fin array which is made up of aluminium[18] alloy-1050 placed on rectangular heater plate of size 70 mm x 180 mm. In order to reduce heat loss from other side of base plate an insulating box is provided which is made up of glass wool. This is then enclosed by rectangular enclosure made up of acrylic sheet. To measure temperature industrial temperature gun (IR sensor)[19] is used as there are 13 fin arrays. In many of the experiments k-type thermocouples are used but in this experimentation k-type thermocouples are replaced by industrial temperature gun because IR sensors are not affected by heat conduction or heat convection, and they also provide rapid response. The IR sensors have higher accuracy than thermocouples[19]. The base plate temperature is also recorded by gun (IR sensor). To measure the heat input given to the heater plate digital ammeter (0A to 5A) and voltmeter (0V to 750V) are used and to vary the heat input given to the heater plate a rotary type of dimmer-stat (0 to 230 V) is used.

Fig. 4.3: Experimental set-up.

Experimentation procedure

1. Place rectangular fin array which is without notch on the heater plate.
2. Connect heater wire to control panel and give power supply to control panel.



3. Put acrylic box around fins as shown in figure 4.3.
4. Give 50watt[25] input supply to heater with rheostat and measure with ammeter and voltmeter readings.
5. Take temperature readings after steady state is reached.
6. Then increase the heat input as 50 w, 75 w and100w.[25]
7. Follow same procedure for all types of fin array.
8. Cut off power from control panel.

Readings to be taken:

For Heater - Input given (50w, 75w, 100w)[25] to take the following readings:

- Temperatures of tip of fin array:

Each array has 7 fins -- T_1, T_2, T_3, T_4, T_5, T_6 and T_7.

- Temperature of base plate -- T_b
- Atmospheric temperature -- T_∞

4.4 Formulae to be Use for Calculation

The formulae that are used for calculating heat transfer coefficient are given below: [17]

1. To find average temperature of fins (T_f)

$$T_f = \frac{T_1+T_2+T_3+T_4+T_5+T_6+T_7}{7}$$

Where, T1, T2, T3, T4, T5, T6 and T7 are the temperatures of tip of fins in ° C.

2. To find temperature of whole body (T_{body})

$$T_{body} = \frac{T_f+T_b}{2}$$

Where, Tb is the temperature of base plate in °C.

3. To find temperature difference between body (Tsurr.) & surrounding temperature (Tsurr)

$$\delta T = (T_{body} - T_{surr.})\ °C$$

4. To find mean film temperature (Tm)

$$T_m = \frac{T_{body}+T_{surr}}{2} \circ C$$

From this temperature find out following properties of fluid,

υ = kinematic viscosity of the fluid, m2/s

Pr = Prandtl number

k = Thermal conductivity of fluid, W/mk

5. To find coefficient of volume expansion

$$\beta = \frac{1}{T_m+273} K^{-1}$$

6. To find Grashof number (Gr)

$$Gr = \frac{g\beta\delta T L_c^3}{\upsilon^2}$$

Where,

Lc= height of the fin, m

7. To find Rayleigh number (Ra)

$$Ra = Gr\times Pr$$

If $10^4 < Gr\times Pr < 10^9$ then, $Nu = 0.59\,(Gr\times Pr)^{1/4}$

If $10^9 < Gr\times Pr < 10^{12}$ then, $Nu = 0.59\,(Gr\times Pr)^{1/3}$

8. To find heat transfer coefficient (h)

$$Nu = \frac{hL_c}{k}$$

Where, h is Heat transfer coefficient, W/m^2k.

Using these formulae h is calculated.

5. Research gap

All authors mentioned in literature review have discussed several studies on fins regarding increment of heat transfer, they have studied fin arrays with different geometries like trapezoidal fin[26], triangular notch fin, rectangular notch fin, and many other types of fins and effect of fin parameters like fin spacing, length, height, material, perforations[27], slots and holes on heat transfer rate of fin. But here is no detailed study which shows the comparative results of effect on heat transfer rate of notched fin array with area compensation at height and area compensation along the length for rectangular fin array. As many other shapes are available to provide notch to the rectangular fin array to improve the heat transfer rate. Also, there is need to study on innovative structures such as wavy fins, coated fins.

6. Conclusion

After studying various literatures, I have decided to use the rectangular fin array with semi-elliptical notch at the central base of fin just above the base plate, to prevent conduction losses and the removed area is compensated at height of a fin for once and compensation of area along the length of fin to get better single flow chimney effect. Comparison between the numerical results and experimental analysis is carried out and this comparison is based on effect on heat transfer coefficient of fin without notch, fin with notch, fin with compensation of notch area along the length and fin with compensation of notch area at height.

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