

Thermal Release Ice Maker

Engineering Design II – Carnegie Mellon University
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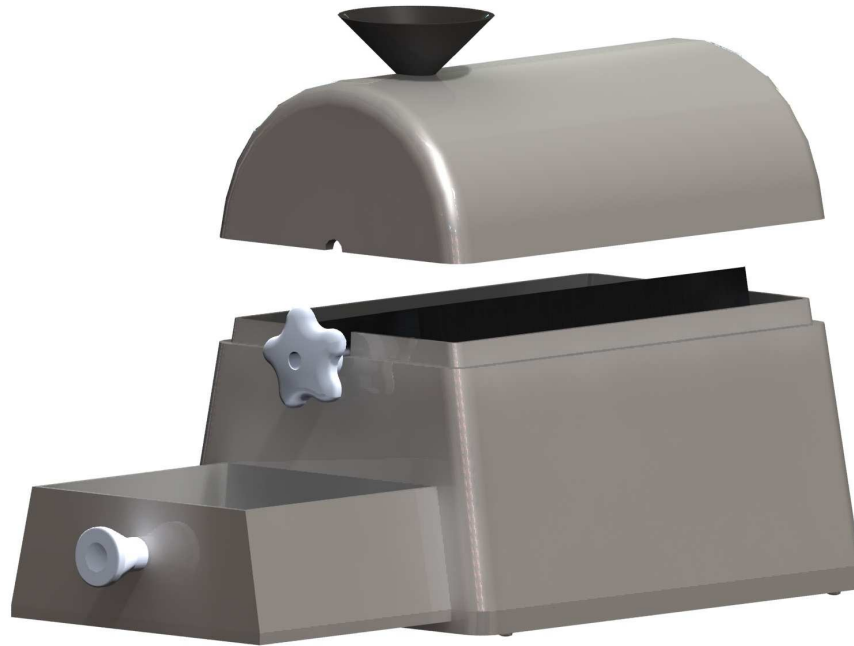


Figure 1 - Final Design Model

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Executive Summary

Our design process began with a very open-ended topic: “kitchen appliance. ” After much brainstorming, we decided to dissect an automatic ice maker because it was a mysterious device that lived (unused) in our freezers and we wanted to know how it worked. We wanted to focus on green design and eliminating the need for external power or plumbing connections.

When we began to think of new designs, we brainstormed well over 100 ideas of how to make ice cubes, ice shapes in general, or all other sorts of methods for cooling drinks. Our first design review, we examined multiple ways we could adapt an existing ice maker to require less power, but eventually concluded that it might be more worth it to start over with an entirely new device.

The final design, the thermal ice maker, addresses a great majority of the concerns we discovered during our user testing, particularly in that it requires no external power or water lines and very little user interaction (especially compared to a typical single ice tray.) Though it requires more interaction than an automatic ice maker, it makes the user feel more in control because whenever they want ice, they immediately can get a tray full, and every time they get ice, they automatically make more for the next time. Also, the ice stays tasting fresh because our plastic housing closes the ice off from the freezer environment.

The most novel part of the design is our ice tray. Made of aluminum for its low weight, low price, and high conductivity, it features notches and staggered wells so that the water flows evenly throughout the tray and automatically fills each well to the same height (with built-in features for overflow.) It is double-sided, one side for each batch of ice. Each well is a triangular prism that nests into two on the other side so that each “cube” has the maximum shared surface area. To use, first fill one side with water and leaving it in your freezer to solidify. Then turn it over on its axis and add water to the other side. The warmth of the water transfers conductively, melting a thin layer of ice along the tray. When the ice’s weight overcomes the forces of adhesion, the ice cube separates and falls into a bin with no need for heating coils or motors. According to our analysis, the tray can work with water as cold as 3 degrees Celsius.

Outside of the tray, we designed an injection-molded plastic shell and axis-support to protect the flavor of the ice and give the device a more pleasing appearance. It comes with a plastic cup pre-measured for the appropriate amount of water and a bin to catch the ice when it separates from the tray. It is cheap to make and assemble, leading us to believe we could market the entire device for under fifty dollars, and the tray alone for under twenty. Considering an automatic ice maker would cost you at least two hundred dollars in initial and installation costs as well as the extra users pay each month to have a heating coil heating their freezer, we are confident that our design is, in fact, a marketable invention.

Design Process

For our idea-generation process we began with user research and contacted friends and family members of various ages and locations. We met as a group and began brainstorming in the “round robin” method. After generating the initial 75 ideas we began a Gantt chart, Table 1, to begin planning. Before our next meeting we conducted some market research and individually thought of a concept that uses one or more of the 75 original ideas. We began our next brainstorming session by going over what’s available on the market and reviewing our old list of ideas. After presenting the ideas produced individually, we narrowed the list of ideas down to what we thought was the most important and feasible and then began brainstorming again. Before our next meeting we researched ice maker patents. At our final meeting we narrowed down the list to the top 4 listed in the report and then created the Pugh charts to benchmark them against what had already been created. We then chose the Manual Ice Maker as our design concept.

After presenting our idea, we began the conceptual design of our Manual Ice Cube Maker. We met as a group to brainstorm ideas for the release mechanism for the ice cubes, conducted in a similar manner to idea generation period. We considered many approaches, but decided that the simplest would be the chosen release method. The ice tray is identical on both sides and when the water is poured in for a new batch of ice cubes; heat is transferred across the thin metal tray, melting enough of the ice for the cubes to fall into the tray. We researched possible shapes for the ice cubes and created a small prototype to test our shape and theory. The ice cubes are triangular prisms, because the shape nests well in space and allows for the highest heat transfer surface.

We did a thermal analysis of the heat transfer across the metal. We found that as we suspected, the temperature of the water could be very low (the temperature of the average fridge) and still release the ice cubes. After our analysis, we continued the detail design of the ice cube maker. We built several prototypes to test the design of release and overall mechanism.

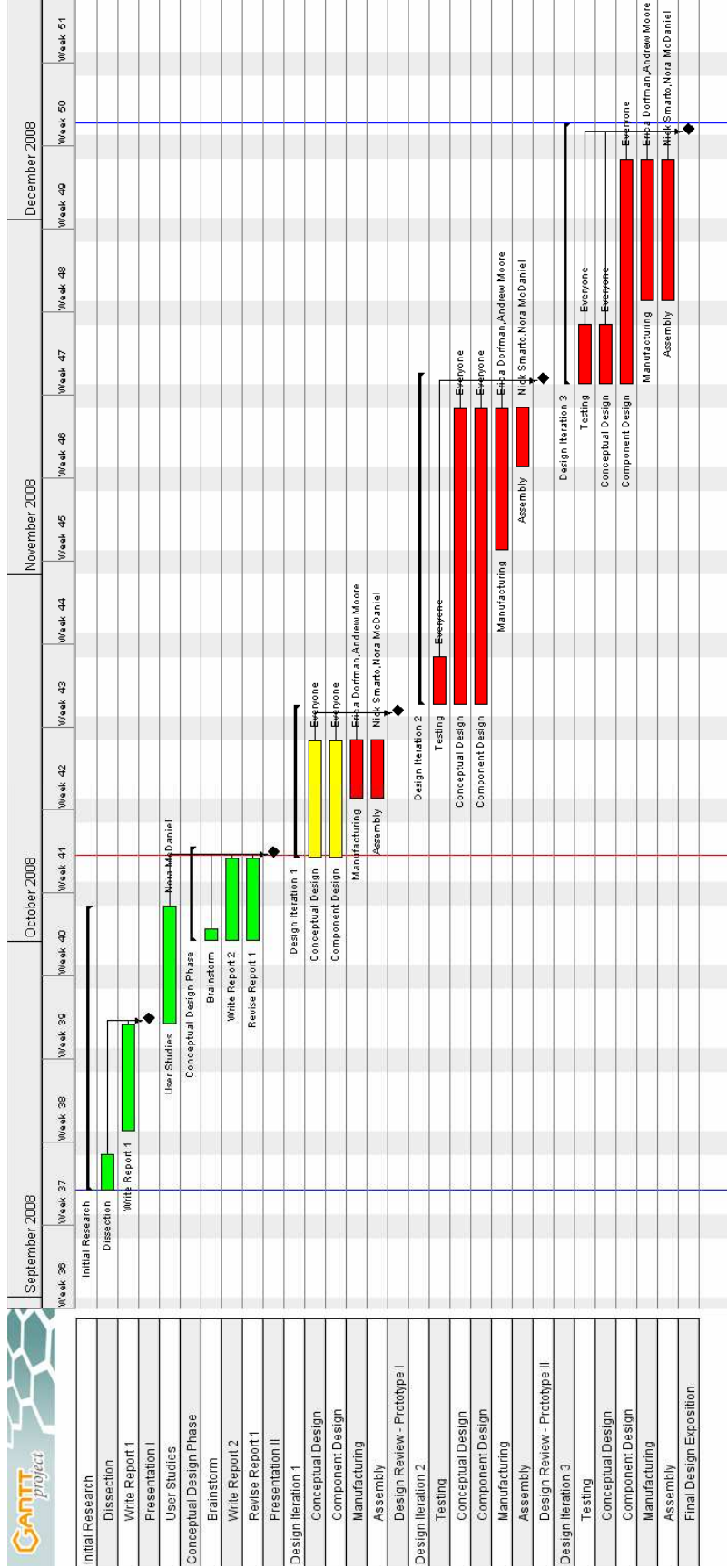
The first prototype was manufactured out of aluminum strips and silicone caulk to test the cases with the lowest heat transfer surface area (occurring in the cases of the ice cubes on the end of a row). After testing our first prototype to show that the ice cubes will still release in the edge cases, we continued to make a prototype with multiple rows and a water cascading system with a setup similar to the final design.

The newest prototype has a CNC milled tray that is the same as the final design, showing the superiority of a tray made of one piece of metal instead of a composite of sheet metal and silicone caulk. The size of our final prototype is significantly smaller than the previous prototype. We engineered the space efficiently and found that we could decrease the volume of the prototype to be half that of the earlier. The final prototype has a complete water input system for the user to easily input the water into the system. The water is poured through a funnel and flows through a tube that slowly opens for it to flow into the tray. We included an overflow bin to catch any extra water that the user might input. This prototype works well and is similar to the final design.

We then designed the final design to eliminate unused freezer space and use more efficient manufacturing methods than those of the prototype. We designed for this because the final design will be mass-produced, and so the parts will be manufactured and assembled using different techniques. Many of the parts for the final design will be manufactured using injection molding. The outer casing, ice bin, and filling mechanisms will be made out of ABS plastic allowing the final design to be more attractive and compact. These parts are made out of corrugated plastic and aluminum L-brackets for the prototype because injection molding is expensive on a small scale. The aluminum ice tray will be cast for the final design while the prototype has been machined using a CNC mill. CNC milling is expensive and time consuming and only affordable for the small scale prototype. In the final design the water funnel is placed on top of the ice maker instead of on the front face because this eliminates extraneous parts necessary for the water input since the water flows directly from the funnel into the tray. The overall part count is much smaller for the final design by consolidating components that needed to be made of many corrugated plastic sheets and aluminum L-brackets. We expect a high production volume for the final design and have adjusted our components to reduce cost and increase user appeal for larger scale production.

There are some items to consider when using this idea. We suggest looking into an LED attached to a thermocouple that detects when the ice is frozen and lights up. This would aid the user in knowing when to rotate the ice tray. A Teflon coating such as that used on the automatic ice maker's tray might improve the thermal properties and ability of the ice to separate cleanly from the tray. We also suggest looking into the potential in marketing just the tray with a rack it could sit on over an ice bin.

Table 1: Gantt Chart for Planning



Bill of Materials

In our design there are a few main subassemblies: the ice tray which rotates, a funnel to input water, a housing that supports and protects the ice tray and bin from the freezer, an ice bin to hold ice, and a magnetic stopping system.

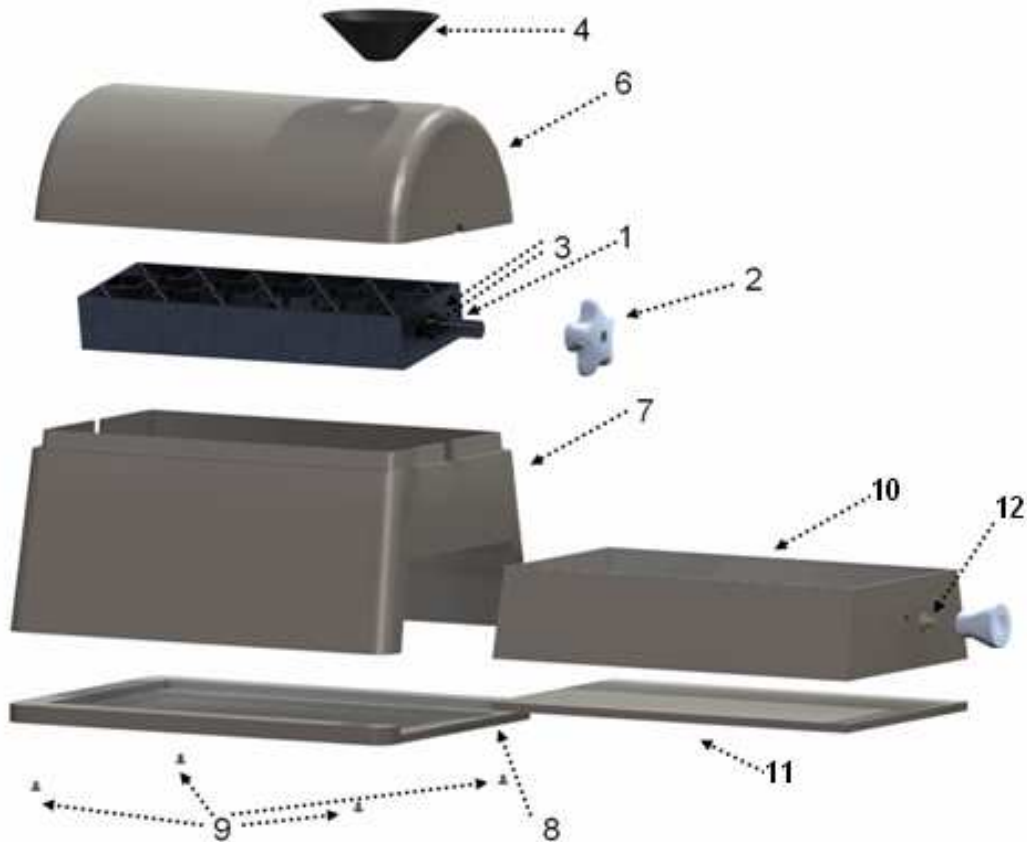


Figure 2: Exploded View of Design

Figure 2 (above) shows an exploded view of the design with the part numbers labeled for reference.

Table 2 (below) shows an itemized list of the parts of the ice cube maker. Several of the components, including the screws, handle and rare earth magnets were purchased for the product.

Table 2: Bill of Materials

Part #	Part Name	Qty	Function	Weight (oz)	Material	Price (\$)	Manufacturing Process
1	Ice Tray	1	Hold water that freezes to become ice, and rotate for release	26.4	Aluminum	5.75	Metal Casting
2	Handle	1	Facilitate rotation of tray	14.4	Zinc	4.36	Purchased, McMaster Carr # 6048K32
3	Rare Earth Magnets	3	Stop rotation of tray at 180 degrees	<1oz	Neodymium-iron-boron (metal)	1.75 (5.25)	Purchased, McMaster Carr # 590K55
4	Funnel	1	Guide water input to ice tray	<1 oz	ABS	0.60	Injection Molding
5	Water Cup	1	Hold the correct amount of water for the user to pour into the tray	2 oz	ABS	0.71	Injection Molding
6	Outer housing - top	1	Hold the funnel and protect the ice tray	21.28	ABS	4.19	Injection Molding
7	Outer housing - middle	1	Support and protect the ice tray, hold the ice bin	40.16	ABS	6.16	Injection Molding
8	Outer housing - bottom	1	Support and protect the ice tray and ice bin	20	ABS	3.27	Injection Molding
9	Screws	4	Connect parts and balance the ice cube maker	<1 oz	Steel	0.12 (0.48)	Purchased, Phillips, .138 in long with 32 pitch

10	Ice bin – top	1	Collect and store ice cubes	6.24	ABS	2.42	Injection Molding
11	Ice bin – bottom	1	Support the top of the ice bin and hold the ice cubes	11.84	ABS	2.85	Injection Molding
12	Glue	n/a	Connect the ice bin together, the funnel and the outer housing - top, and the rare earth magnets to the housing and tray	<1 oz	Plastic	.25	Purchased, 3M™ Scotch-Weld™ Hot Melt Adhesive 3747

Design for Environment

The Economic Input-Output Life Cycle Assessment (EIO-LCA) website, www.eiolca.net, contains data on the most common contributors to greenhouse gases, toxic releases, and energy usage from industries and sections of those industries. Although there was not a category that specifically fit our product, our ice maker fit best in the category of “Household refrigerator and home freezer manufacturing.” The simulation pretended that an additional \$1 million had been spent in this industry; we then examined the how many extra greenhouse gases would be released into the atmosphere. If the product were typical for its sector, the following table displays how many greenhouse gases would be emitted in to the atmosphere by spending an extra \$1 million:

Table 3: Design for Environment

Sector	GWP MTCO2E	CO2 MTCO2E	CH4 MTCO2E	N2O MTCO2E	CFCs MTCO2E
Total for all sectors	881.	671.	62.0	12.7	136.
Power generation and supply	231	228	0	0	2.
Industrial gas manufacturing	161.	46.1	0	0	115
Truck transportation	54.3	53.5	0.083	0.746	0
Household refrigerator and home freezer manufacturing	36.3	36.3	0	0	0
Waste management and remediation services	27.2	4.30	22.9	0.033	0
Plastics material and resin manufacturing	18.8	18.8	0	0	0
Oil and gas extraction	18.1	3.04	15.1	0	0

In manufacturing an ice maker, about a third of the greenhouse gasses emitted come from the creating the power necessary to create it. The metal necessary to create a freezer or refrigerator explain why Iron and steel mills are the next highest sector to output greenhouse gases. Our product, the manual Ice Cube Maker has a very lower metal content, so this does not make much sense in the context of our specific product. Transportation of materials and finished product requires a significant amount of energy. The sector in which our product appears contributes a smaller amount of greenhouse gases, but the waste from the process contributes and even smaller amount. After these sectors we find that manufacturing the plastic components contributes as well as the process of extracting oil and gas (used in both the power generation and the creation of the plastics).

The cost of a standard automatic ice maker is about 100 dollars and so with an economic input of one million dollars to the sector this accounts for about 10000 ice makers. The Global Warming

Potential for the input of \$1,000,000 is 881 MTCO₂. Therefore in manufacturing one standard ice maker the total greenhouses gases emitted is approximately 0.0881 MTCO₂.

In an earlier report we found that a standard automatic ice maker requires 556.20kW per year for the heater and motor in addition to the extra 5023.8kW required to freeze the ice. This is with a cycle time of about five hours. The EIO-LCA for the power generation and supply shows that 10500 MTCO₂ are emitted per \$1 million. With the average price of power at \$0.10 this is 0.00105 MTCO₂ emitted per kWh. The automatic ice cube maker requires additional energy which was calculated to be 5580 kWh per year or 122760 kWh over an expected lifetime of 22 years. Over the lifetime of the product 128.898 MTCO₂ are emitted.

Our previous analysis shows that the most effective way to make an ice maker more environmentally friendly would be in reducing the amount of energy required to make the ice. Unfortunately, most of the additional energy require in using the ice maker to make ice comes from the additional energy the refrigerator must supply to the freezer to freeze the ice.

To make the same amount of ice with the same cycle time schedule, the manual ice maker, however, would only require the 5032.8kW/h required to freeze the ice every five hours, as opposed to the 5580 kW/h required by the automatic, to create the same volume of ice. The manual ice maker, however, has a different average cycle time and volume of ice created.

Per cycle the manual ice maker creates 15 ice cubes, each ice cube of a mass of about 16 grams. As the 0.246 kg of water freezes into ice the temperature must change from the input of about 20 degrees Celsius to its freezing point of 0 degrees Celsius. As the specific heat capacity of water is 4.187 kJ/kgK, this requires 20.598 kJ. The phase change from liquid to solid requires additional energy, 0.0822 kJ, which is calculated using the latent heat of melting of 334kJ/kg. Overall the freezer must compensate for the energy necessary for freezing the ice, 20.680 kJ per cycle or 4.136 kWh per cycle. With an average of 2.25 cycles per day, this is 3396.7 kWh per year.

The manual ice cube maker will use about 3400 kWh per year in contrast to the 5600 kWh per year required by the automatic ice maker. The new product is much greener than the automatic design that it replaces. Over its lifetime, the manual ice maker produces about 80 MTCO₂, about $\frac{3}{4}$ of the amount produced by a standard automatic ice maker.

Design for Manufacturing and Assembly

Parts for the ice maker will be made using casting and injection molding processes. Because of the high volume expected for this kitchen appliance the design can be made for less cost using these processes. The outer casing, bin, and funnel are designed to be made out of injection molded ABS plastic. These parts utilize draft angles to make the injection release from its mold more easily. The ice tray will be cast from aluminum in one piece. By casting the part we are able to consolidate the bushings, tray, and axle into one component. The part is made to simplify the mold by using draft angles.

Individual components are made to nest onto each other using flanges. This makes the product easy to assemble and package. To assemble the ice maker, the user or manufacturer can simply stack the parts.

Injection molding and casting are more However, we expect a high volume that justifies the use of both of these techniques and will actually drive down the cost by reducing the cost for individual parts.

Failure Mode and Effects Analysis

The Failure Mode and Effects Analysis (FMEA) for our design yielded several key danger areas. The worst failure would be for the user to forget to turn the ice tray over before inputting the new water. This would lead to a failure of the mechanism because a large amount of water would spill all over the freezer and overflow the runoff bin. It would also ruin the ice already made in the bin by soaking it with water and causing it to be un-cubed. Other possible failures that could be caused by the user include getting ice in the handle connection so that it can no longer turn (considering that the mechanism requires the ability to turn to function.) If the relatively few parts of the mechanism are not assembled correctly (screws loose, tray not in groove of casing, casing not attached correctly to base) then the mechanism would be unbalanced and not fill correctly, and would likely spill water. If the user breaks or bends the shafts allowing the tray to rotate, then again the mechanism would be unable to function, so this is a severe failure mode.

Many of the possible failure modes stem from the fact that most of the housing is made out of plastic. Thin plastic has the possibility of fracturing in the cold of the freezer. To control this, the Materials Engineer should select a plastic with acceptable thermal properties. Because several of the components are attached with glue, which is somewhat unpredictable, the engineers in charge of choosing materials are charged with the necessity for glue with good thermal properties, as well. It should not become brittle in the cold so that it should not allow the glued parts to become unattached. This would lead to cubes not being able to stay in the bin and to the magnets not being there to hold the tray horizontal.

An unexpected failure mode discovered through user testing was that water at too high a temperature melted the ice cubes before they were able to fall out of the tray. This turned out to be a very severe failure, and fairly undetectable. We would like to make it very clear to the user what the proper operating temperature range would be for input water.

Because of the relatively few parts required for this design, many of the failure modes are serious failures that would cause the mechanism not to function. Our hope is that such failures would occur during normal usage of the product so that a user would want to buy a new one every few years if it should break seriously.

Table 4: Failure Modes and Effects Analysis

Part	Function	Failure Mode	Effects of Failure	S	Cause of Failure	O	Design Controls	D	RPN	Recommended Actions	Responsibility
1	Ice Tray	Not turned over	Water runs over ice already in tray and overflows	10	User forgets to turn tray	9	Printed reminders	5	450	Purse indicator subotions	Mechanical Engineer
		Is not placed back into groove in Part 7	Tray is uneven	6	User error	7	Smug groove for shaft width	4	168	Closely designed fit	Mechanical Engineer
		Shafts bent	Rotation is difficult	7	Overzealous user	2	Well-supported strong shaft material	6	84	Fatigue Testing	Materials Engineer
2	Handle	Broken Shaft	Rotation is impossible, tray falls down	10	Overzealous user	1	Well-supported strong shaft material	2	20	Fatigue Testing	Materials Engineer
		Water input too hot	Ice cubes melt before falling out of tray	10	Confused user	5	Clear recommendations	8	400	Thermal calculations	Mechanical Engineer
3	Rare Earth Magnets	Ice in connection	Handle difficult to turn	3	Water Spillage	3	Use good strength plastic	7	63	Minimize possibility for spillage	Mechanical Engineer
		None	None	0	None	0	None	0	0	None	None
4	Funnel	Broken off	Difficult to input water to tray	6	Brittle from cold temperature	7	Use good strength plastic	2	84	Fatigue Testing	Materials Engineer
		Overflows	Spillage and unwanted ice	3	User ignores cup indicator line	8	Very clear indicator line, runoff catch	1	24	Accurate water level calculated	Mechanical Engineer
5	Water Cup	Fractures	Cup does not hold water	6	Brittle from cold temperature	3	Use good strength plastic	3	54	Fatigue Testing	Materials Engineer
		Fractures	Low Ice Quality	2	Brittle from cold temperature	3	Use good strength plastic	3	18	Fatigue Testing	Materials Engineer
7	Outer housing - middle	Fractures	Low Ice Quality	5	Brittle from cold temperature	2	Use good strength plastic	3	30	Fatigue Testing	Materials Engineer
		Is not placed well onto Part 9	Tray is uneven	6	User error	7	Guided interlocks for parts	4	168	Closely designed fit	Mechanical Engineer
8	Outer housing - bottom	Fractures	Ice bin falls out	7	Brittle from cold temperature	3	Use good strength plastic	3	63	Fatigue Testing	Materials Engineer
		Loosen	Casing is uneven	5	Manufacturer error	8	Correct length of hole	6	240	Stress Testing	Mechanical Engineer
10	Ice bin - top	Fractures	Bin cannot contain ice	5	Brittle from cold temperature	4	Use good strength plastic	3	60	Fatigue Testing	Materials Engineer
		Bin Fractures	Bin cannot contain ice	7	Brittle from cold temperature	3	Use good strength plastic	3	63	Fatigue Testing	Materials Engineer
11	Ice bin - bottom	Handle Fractures	Bin cannot be opened	2	Brittle from cold temperature	2	Use good strength plastic	3	12	Fatigue Testing	Materials Engineer
			Bin cannot contain ice	4	Ghee loses adhesion qualities in cold	2	Use ghee with desired thermal properties	8	64	Research thermal properties	Materials Engineer
12	Ghee	Does not adhere	Magnets fall out and tray does not stay horizontal	7	Ghee loses adhesion qualities in cold	2	Use ghee with desired thermal properties	8	112	Research thermal properties	Materials Engineer

User Research

Users and Ice:

We conducted user research by contacting individuals of different ages and geographical regions with ice makers. We found that in comparison with the North people fewer people in the South don't have an ice maker. One of the most common comments from Northerners without ice makers was that they "didn't like ice trays, but couldn't justify buying an expensive ice maker." The estimated average ice consumption per person during the summer is 20-40 ice cubes a day in the South and 5-20 ice cubes per day in the North.

The most common comments about ice trays concerned the actual ice making process. Within the ice making process the user controls and does every step. Some users expressed difficulties in the process of filling the trays: it can be difficult to get the trays from the sink to the freezer without spilling them and additionally, especially in group settings, many people believe that it is too much work to fill the ice trays. Other complaints about the process include trays that don't stack well and the ice cube removal process. Although some users found that the ice cubes from their standalone trays were too tiny, there are many ice trays available with a variety of shapes and sizes. The main things that users loved about ice trays were that they are inexpensive, have a variety of different shapes available so that they can have fun shapes or even ice cubes that fit easily in their water bottles, and their control over the shape and quantity that are made. One user even expressed theories about how to ideally freeze ice cubes with more convection because of the manner in which he found that the ice cubes commonly froze.

The most common comments about ice makers concerned the taste of the ice cubes. Some users commented that the ice had a metallic taste and other said that their ice cubes would pick up all the flavors of the freezer because the ice maker made more than they could use and the ice sat in the bottom of the tray. Not all users had problems with too much ice. Users also commented that they would love it if their ice maker made more ice, especially on short term notice for a party or large family function. One user commented that she couldn't ever get just one ice cube out at a time because they always fell out of her hands due to the awkward crescent shape. Another user commented that he felt that the shape of the ice cubes "wasn't sexy". Some users expressed concerns about the noise due to the ice cubes falling. The placement in the freezer posed problems for some users as the placement was near the hinge instead of the opposite side, making it hard to access. Some users were worried about installing them in vacation homes because they were worried about what would happen while they were not there: something could potentially go wrong with the water connection and additionally the ice maker might continuously make cubes. All of the users of ice makers interviewed expressed that they were generally satisfied with the ice maker because of the convenience of this product. One user was so pleased that she declared it "the greatest invention of the 20th century!"

Complaints common to both the ice maker and ice trays were varied. Some of these complaints concerned the freshness of the ice. Users expressed concerns about the odors the ice picked up from other food in the freezer as well as freezer burn. Taste was important to all users. Both sets of users expressed concerns about the amount of ice necessary for a party or large group setting. Due to the freezers cyclic manner, the ice will often clump together which posed a problem for most users.

Overall people were satisfied with ice cube makers and one user even expressed that she “wouldn’t consider buying a fridge without one”. From our research it is evident that users highly value their freezer space and would not be interested in a larger ice maker unless it gave them significant improvements. We did find a potential market of users who are very interested in ice makers, but can not justify paying for the expensive installation to hook their ice maker up to a water line.

Users and the Ice Cube Maker:

We conducted user research with our prototype to find how users would interact with our product. All of the users enjoyed their experience with the prototype. Most commented on how they thought it was a novel idea and thought that it was “cool”. Many users liked the concept (and ice) enough to suggest that they would buy it if it were on the market. Some of these people are in our perceived market of those who “don’t like ice trays, but can’t justify buying an expensive ice maker” in addition to those who just love the “science” aspect of the product.

Many users showed great pleasure and fascination while watching the ice tray fill by the cascading water and expressed an interest in filling it again. Another favorite feature was the rotation and the accompanying stopping mechanism, some played with it for long periods of time. Most users commented on the shape and wanted to use the ice cubes immediately. One user was especially happy with the idea that “you get all the ice cubes at one time” and that she would not need to have problems with ice falling out of the tray on the floor when she wanted ice. The fact that it was an environmentally green product also appealed to users.

Some were slightly concerned about all the metal and how they would feel about touching it. They were pleased to hear that they would not need to touch the tray, eliminating this concern. They were also pleased with the idea of the enclosed ice, protected from the freezer, so that it would not pick up the odors of the freezer.

We also discovered an unforeseen failure mode through our user testing: hot water is undesirable for making ice cubes in the tray because it melts the ice cubes non-uniformly and too fast for them to drop into the tray. In this failure mode the ice cubes enter the tray as liquid instead of solid. We also discovered through user testing that for release of the ice cubes the ideal temperature of water is tepid (about room temperature) to cold (from a refrigerator).

Overall people were pleased with the prototype and final design. Many asked when they could buy one because they wanted to use it. The simplicity of our product appeals to users, even those who professed to already having an ice maker.

Market Analysis

The main consumer devices currently on the market for in-home ice production are the standard ice tray (with no moving parts) and the automatic ice maker. Both strongly address particular niches in the market, but we discovered from our user studies that there were many unsatisfied consumer needs.

The ice tray is a popular design choice because it is very cheap (usually less than five dollars.) It was first invented in the 1920's and has had many different innovations. Early metal models had mechanical parts that would shift the ice to loosen it from the tray. Later, with plastic technology, trays were made extremely cheaply and were able to twist to release the ice cubes. Plastics also made it easier to handle the trays because they were not cold to the touch. Today, trays are often made from silicone to be able to twist the maximum amount. Silicone is also very unlikely to fracture in the cold temperatures of a freezer. Today, users have become frustrated with ice trays because nothing can be stacked on top of them and they always need to sit on perfectly level surfaces. The ice is very hard to remove from the tray and there is no place to put the ice once it has been removed. Users also reported that the ice had a "freezer taste."

The automatic ice maker is an invention that commonly comes built-in to modern freezers. By itself, it costs upwards of \$100. Even though it automatically makes ice and ejects it from the tray, its heating coil requires extra energy and a power connection, and its automatic water-filling requires a plumbing connection. Both of these extra connections require the average user to call in professionals and incur more costs up an additional \$100. Many users we consulted reported that they never have had their ice makers fully installed and that it just takes up room in their freezer. Users also reported the same "freezer taste" as an ice tray because once the cubes are ejected, they are left to sit in a bin open to the freezer environment.




Our thermal ice maker uses heat transfer to release the cubes from the tray and remove heat from the inputted water. It requires no plumbing or electrical connections and therefore has no extra installation beyond being placed in the fridge. It has an exterior housing with a removable bin inside so that the cubes stay fresh but are easy to access. Our target market is any user who wants a simple, cheap way to get ice with low physical force required and high capacity. As ice takes a very long time to freeze, it also helps that our ice freezes faster as the heat is removed from the input water. With the materials used (injection molded plastic and cast aluminum, mostly) and a large enough production volume, the product could be sold for a target range of \$20-\$40. Also, the easy-removal ice tray portion of the overall design could be simplified and sold individually for \$10-\$15.

The cost to manufacture our product is estimated at \$39.00 (See Bill of Material) for a production volume of 100,000 ice makers. This estimate is an upper bound and can likely be reduced nearer to \$30 since each part was accounted for individually. If the same manufacturer builds all of the parts the price per part can likely be lowered since upfront costs for tools can be reduced.

Our product operates between the two standard models of ice creation and our comparisons are easily summed up within our Pugh chart (Table 5). The Pugh chart indicates that the ice tray is better than the automatic ice maker because of its extremely low cost and small freezer volume

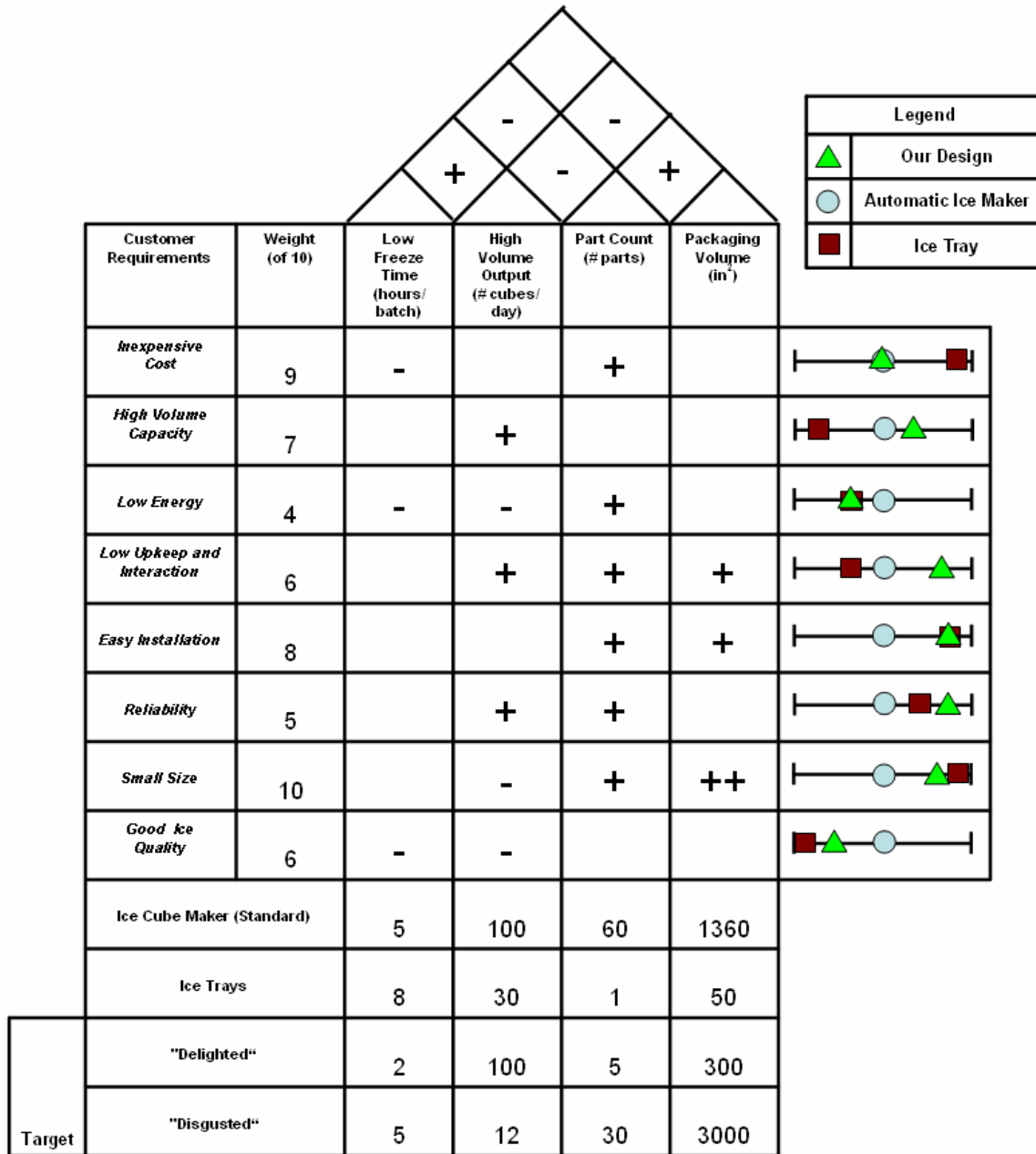
required, even though the automatic ice maker is very strong in terms of user interaction. However, compared with our thermal ice maker, the ice tray scores very low on user interaction, and the automatic ice maker scores very low on cost, installation, and energy usage. Since these are all important considerations for the client, according to the weighting, the thermal ice maker is a more desirable option.

Table 5: Pugh Chart Comparison of State of the Art with New Design

				
User Needs	Weight	Thermal Ice Maker	Ice Tray	Automatic Ice Maker
Cost	7	=	++	--
Installation	9	=	=	--
Capacity	6	=	-	-
Individual Cycle Time	5	=	-	-
Energy Usage	3	=	=	--
Freezer Space	7	=	+	=
User Interaction	8	=	--	++
Evaluation:		=	-	--

Our House of Quality (Table 6) indicates again that, as compared with the automatic ice maker (a very popular freezer option, and the invention that we originally sought to improve), our design is an improvement in a majority of the customer requirements.

Table 6: House of Quality Comparison of State of the Art with New Design



Thermal Analysis

In order for ice to be released within twenty seconds water above 3.3 °C (38 °F) must be poured into the top section. We have calculated this value using a one-dimensional transient analysis. We can calculate the power per area using the following equation

$$\frac{q}{a} = \frac{T_1 - T_3}{\frac{\Delta x_1}{k_1} + \frac{\Delta x_2}{k_2}} \quad (1)$$

We can find the thickness of melted ice using the known latent heat of ice.

$$\Delta x_{melted} = \left(\frac{q}{a} \right) \left(\frac{t}{\rho L} \right) \quad (2)$$

Using a numerical iterative approach we obtain the thickness of the melted ice over time. The following figure (Figure 3) shows the coldest water that will successfully allow the ice to release is 3.3 °C.

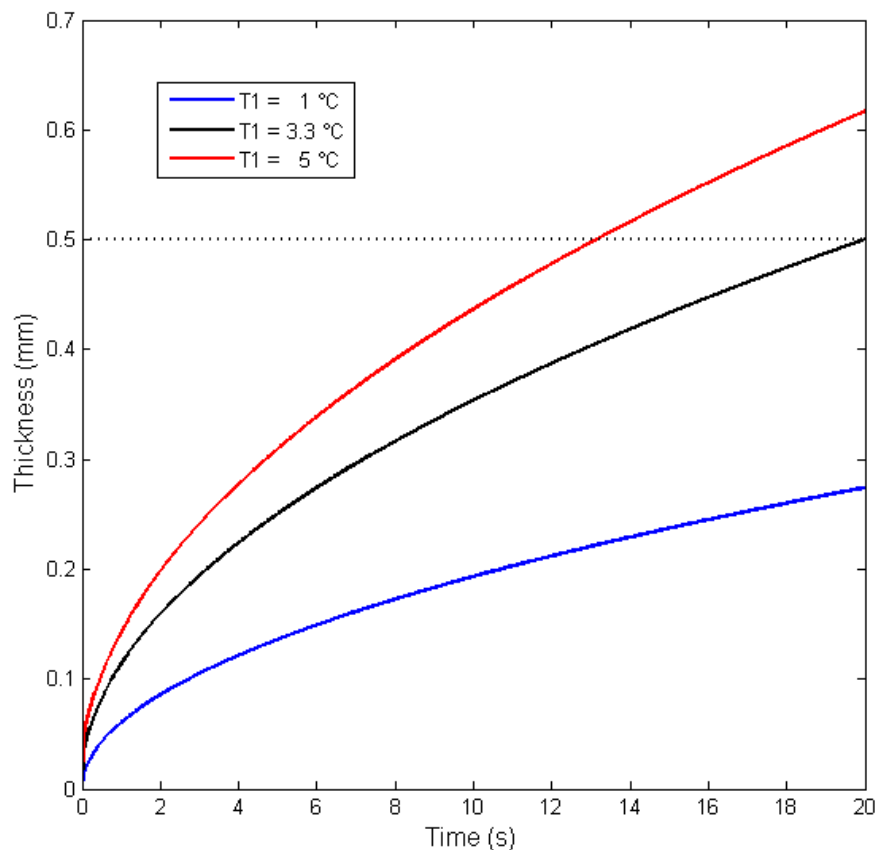


Figure 3: Thermal Analysis of Melted Ice Thickness versus Time

The figure below (Figure 4) illustrates the temperature distribution of the system.

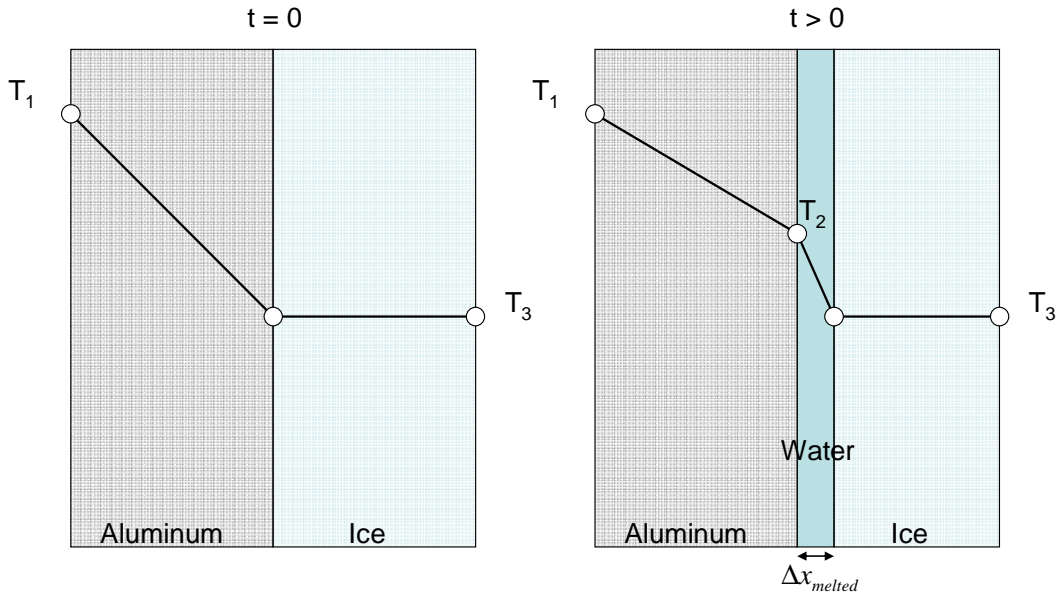


Figure 4 Figure 3: Thermal Analysis of Temperature Distribution

Matlab Code

```

clear all
close all

% Set system and thermal properties
T3 = 0; %C
rho = 910; %kg/m^3
dxice = 0; %m
dxal = 0.00079375; %m
L = 334000; %J/kg
kal = 204; %W/mC
kwater = 0.58; %W/mC

% Set the solving conditions
tStep = 0.01;
tMax = 20;
tNum = tMax/tStep;
dxice(1) = 0;

% Test different temperatures
for T1 = [1,3.3,5]
    % Iterate through time
    for t = 1:(tMax/tStep)
        qa = (T1 - T3)/(dxal/kal + dxice(t)/kwater);
        dxice(t+1) = dxice(t) + qa*(tStep/(rho*L));
    end
    hold on
    plot(0:tStep:tMax,dxice*1000);
end

```

Provisional Patent Application

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Thermal Release Ice Tray

ABSTRACT

A double-sided aluminum ice tray having nested triangular-prism wells and a rotating mechanism for refilling. After an initial batch of ice is frozen in the user's freezer, the tray is turned over 180 degrees. Water is poured into the tray and automatically spreads evenly into each well by flowing through notches in the tray inside walls. When the tray is held above a collecting bin, the triangular-prism ice cubes are released by being warmed by the heat of the water for the second batch. The ice is therefore effortless to release, and by removing the heat from the water to release the cubes, the water is colder to start and freezes faster.

BACKGROUND OF INVENTION

In 1914, the first freezer was invented. In the following decades, it became common for freezers to come with a removable portion with wells for ice cubes. In 1933, the first flexible steel tray was invented and required a 5 degree manual twist to eject the ice cubes. In the 1950's a tray was invented that used a shifting steel insert to jolt the cubes free from being frozen to the tray. Modern freezers come with built-in automatic ice makers that require external energy sources and installation requirements including a water line hookup.

DESCRIPTION OF PRIOR ART

Previous ice cube trays have included manual self-ejecting models and automatic built-in ice cube makers. Automatic ice cube makers have a built-in heating coil that warms the ice so it can be easily released and a required connection to water line so that after each batch the tray is automatically refilled. The ice trays are very inexpensive (\$3) but the automatic ice cube makers are very expensive (\$100) and require more installation abilities than are possessed by the average user. Often an electrician and a plumber are required to set-up the automatic models for use.

SUMMARY OF INVENTION

The design is an aluminum tray made by casting. It is double-sided and has three rows of 5 wells each. Each well is shaped like a triangular prism with the point down, and the two sides interlock so that each well has the maximum surface area in common with the wells of the opposite side. The rows on each side are staggered and notches are cut in the sides so that if

water is poured in any part of the tray, it will spread through and fill the side evenly. When a side is filled, the ice tray is placed in the freezer until the ice cubes freeze. When the ice is frozen, the tray is turned over 180 degrees and the tray is held above a collecting receptacle. With aluminum of a thickness of 0.1 cm, water of any temperature greater than 3.3 degrees Celsius is then poured in the empty, now-upper side and fills up the side. The heat energy from the water then flows through the highly conductive ice tray into the ice and melts a thin layer along the contacting surfaces that hold the cube to the tray. The gravity of the cube then overcomes the adhesion of the melted ice cube to the aluminum tray and the ice cubes fall into the receptacle. Thus, the cubes are effortless to retrieve from the tray because the mere action of refilling the tray releases ice cubes. Also, if quickly placed back into the freezer, the water will have lost heat energy to melt the ice cubes and will therefore freeze the new batch of ice faster.

CLAIMS

What is claimed is:

- (1) An double-sided ice cube tray that uses the thermal energy of inputted water in one side to release ice cubes from the other side.
- (2) An ice cube tray where, when a thin surface of the cube touching the aluminum tray is melted, the weight of the ice cube overcomes the adhesion of ice to aluminum to allow the ice cube to fall out with no manual force required.
- (3) A double-sided ice cube tray design that uses nested triangular prism-shaped wells (point-edge down) to give each well the maximum shared surface area with the wells it interlocks with.
- (4) An ice cube tray design that uses staggered wells with notches in the walls to allow automatic even water distribution throughout.